RPH3

Point-on-Wave controller

Service manual

Volume 1
Description

D1620 EN 03

Grid Solutions
a GE and Alstom joint venture

REVISION HISTORY

REV	ESTABLISHED	CHECKED	APPROVED	DATE	MODIFICATIONS
04	J. Soubies-Camy	JL. Rayon	JL. Rayon	01/10/2019	GE logo
03	J. Soubies-Camy	A. Fanget	D. Lequeux	17/12/2012	Fix by-passing diagrams, considering the contact M4-J4:2 & 3 as normally OPEN
02	J. Soubies-Camy	A. Fanget	D. Lequeux	30/11/2012	update typical by-passing diagrams Pinout corrections
01	J. Soubies-Camy	A. Fanget	D. Lequeux	04/06/2012	First issue

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PURPOSE OF THIS DOCUMENT

This document is a service manual, providing the reader with information on the RPH3 device, GE's solution for "Point-on-Wave" switching of High Voltage Switchgears. This manual aims to support RPH3 end users for the understanding, installation, use and maintenance of the RPH3.

STATEMENT OF LEGAL AUTHORITY

REFERENCES

GE GRID SOLUTIONS reference documents

The following documents issued by GE GRID SOLUTIONS shall be referred to as complements of the present handbook :

[1] **D1621EN**
RPH3 USER'S MANUAL – Volume 2 – RPH3 Control interface
➔ detailed description and user manual of the RPH3 embedded Man-Machine Interface (web-based)

[2] **D1622EN**
RPH3 USER'S MANUAL – Volume 3 – RPH manager
➔ detailed description and user manual of the PC based software tool "RPH Manager", to be used as a viewer of RPH3 event records.

[3] **NOT 200.8550A**
RPH3 USER'S MANUAL – Volume 1 – RPH3 for switching transmission lines
➔ RPH3 controller handbook for transmission lines switching applications.

International standard reference

Switchgears that are used with Point-on-Wave switching must have their individual poles closed at the correct point on the voltage waveform of each phase. The individual poles must operate at times that account for the 120 degrees rotational shift of three-phase voltages. Such switchgears must be designed and manufactured in accordance to the standard IEC 62271-302 TR Ed.1: (Technical Report) "High-voltage switchgear and control gear – Part 302: Alternating current switchgears with intentionally non-simultaneous pole operation". [1]

Additional References

CIGRÉ Publication 262, "Controlled Switching of HVAC Switchgears - Benefits & Economic Aspects", CIGRÉ Working Group A3.07, December 2004. [2]

CIGRÉ Publication 263, "Controlled Switching of HVAC Switchgears - Guidance for Further Applications Including Unloaded Transformer Switching, Load and Fault Interruption and Switchgear Uprating", CIGRÉ Working Group A3.07, December 2004.

CIGRÉ Publication 264, "Controlled Switching of HVAC Switchgears - Planning, Specification and Testing of Controlled Switching Systems", CIGRÉ Working Group A3.07, December 2004.

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[1] IEC publications are available at IEC Publications are available International Electrotechnical Commission (IEC), 3, rue de Varembé, Geneva, Switzerland http://www.iec.ch

[2] CIGRÉ publications are available from CIGRÉ (Conférence Internationale des Grands Réseaux Électriques Haute Tension) (International Conference on High Voltage Systems), 21, rue d'Artois, F 75008 Paris, France http://www.cigre.org

SAFETY AND WARNING INSTRUCTIONS

NOTE : Electrostatic discharges (ESD) may cause unrecoverable damage on the RPH3 device. Observe the necessary safety precautions when handling components that are vulnerable to electrostatic discharge (EN 61340-5-1 and EN-61340-5-2 as much as IEC 61340-5-1 and IEC 61340-5-2).

NOTE : Prior to any power appliance, check that connecting cables are securely locked into connector terminals using the integrated screws.

HAZARD OF ELECTRIC SHOCK, EXPLOSION OR ARC FLASH

- Turn power off before installing, removing, wiring or maintaining.
- Confirm that the product power supply voltage and its tolerances are compatible with those of the network.
- The installation, use and maintenance of RPH3 and related products described in this manual must be restricted exclusively to qualified engineers or persons instructed by them since RPH3 users must also be qualified to operate High Voltage switching systems.
- No responsibility can be assumed by GE GRID SOLUTIONS for any consequences arising out of the use of this product.

FAILURE APPLYING THESE INSTRUCTIONS MAY RESULT WITH DEATH OR SERIOUS INJURIES

Handling the RPH3 as an electronic equipment

The RPH3 device contains electrical and electronic components that may still be charged after disconnection. The user may suffer electrical shock if precautions and instructions are not followed before handling or opening the device case.

– **Before any use of the RPH3 device, it must be grounded via the functional ground connection and the housing grounding terminal / lug.**

– Before use, check that all plug-in cable connectors are securely locked to the RPH3.

- On the RPH3, the continuity of secondary wiring of the current transformers is assumed by an internal connection inside the connector ("make before brake" connection). Before removing these connectors, make sure to avoid any damage on the personal safety and on the current transformers devices.

Unpacking

Despite the general robust construction of the RPH3, it shall be handled with care before installation. Before accepting the RPH3 it should be checked for damage which could have originated during transportation. If you have cause for complaint, please refer to the transport company and notify your usual contact person within GE Grid Solutions.

Storage

If the RPH3 is not to be installed immediately upon receipt, it should be stored in a place which is free of dust and moisture, in its original packaging. If a moisture-absorption bag is in the packaging, keep it as it is. The efficiency of the drying agent is impaired if the unprotected bag is exposed to the surrounding conditions.
Before the Point-on-Wave Controller is placed in the box again, warm the drying bag slightly in order to regenerate the drying agent.

Storage temperature range: -40 °C to +70 °C.

Installation

The RPH3 shall be installed in the control room or the relay room of the substation. Its position should be chosen for easy inspection, which implies an easy access to the RPH3 rear connections in case of need.

The RPH3 shall be well lit and properly locked to its housing location, taking its weight into account (care shall be taken to weight distribution issues, especially in case of an installation in a location exposed to large vibrations.

The RPH3 Point-on-Wave Controller can either be installed in a switchboard or a suitable frame with the provided material, or a special fitting is available for 19" rack integration in case of seismic withstands requirements.
As the RPH3 can be located up to several hundreds of metres away from the switchgear (e.g. in the control room), please check that the requirements noted on the HV diagram as provided by GE Grid Solutions are respected, and especially that there is no injections of current (even some milliamps like a coil supervision device) on the outputs of the RPH3.

Whatever its location, the RPH3 housing shall be appropriately grounded prior to be supplied.

1 PREAMBLE

1-1 Using this handbook

This manual intends to provide the reader with information on Point-on-Wave switching in general and the way the RPH3 device operates. It shall be used as a guide for understanding, installing and using the RPH3, but it does not provide detailed information on the RPH3 man-machine interface, which is described in separate dedicated handbooks. Please refer to documents **[1]** and **[2]**.

This service manual describes functions and features as assumed by the RPH3, introduces typical application notes, lists available product variants and all required data (related to both the switchgear itself and associated environment) for a proper usage of the device.

1-2 Glossary of terms

The following terms and acronyms are used in this manual :

acronym	meaning
HV	High Voltage
CB, CBR	HV Circuit Breaker (or switchgear)
SG	HV Switchgear (or Circuit Breaker)
PoW	Point-on-Wave : ability of a unit to control a CB drive mechanism in such a manner that HV contacts inside each CB interrupting chamber separate or touch at a date which is chosen synchronous to a target point on the corresponding HV signal wave.
S/S	HV Substation : node site of an energy transmission network.
AIS	Initially “Air Insulated Switchgear”. Generic acronym for CBR whose base technology is designed on interrupting chambers filled with a special gas (SF_6) so that arc extinguishing between HV contacts of the CBR is optimized in applications rating up to 800 kV / 80 kA.
GCB	Generator Circuit Breaker : range of CBR specifically designed for HV switching just in rear of energy generators (power plants).
VT	Voltage transformer

acronym	meaning
Pre-arc, Prestrike	Current flowing between the contacts during a closing operation before the contacts have mechanically touched (IEEE C37.100)
Prearcing time	Duration of the pre-arc in a given CBR pole during a closing operation.
Closing duration IEEEC37.100	Duration of the mechanical move of CBR contacts from their fully opened position to their fully closed position.
Closing time IEEEC37.100	CBR initially in fully opened position, amount of time between the initiation of the closing operation (date when the closing input command is triggered), and the date when a metallic continuity is established in : - all CBR poles (<u>switchgear</u> closing time) - or in the concerned pole (<u>pole</u> closing time).
<u>**NOTE :**</u> any delay introduced by equipments that are not part of the closing circuit is excluded from the closing time. Typically the operating time of a PoW controller channel is NOT included into the closing time.	

acronym	meaning
Make time IEC62271-302	CBR initially opened, amount of time between the triggering date of the closing command, and the date when current starts flowing through the concerned pole (make time of the <u>pole</u>) or through the first pole (make time of the <u>switchgear</u>). This make time may typically includes the pre-arcing time.
<u>**NOTE :**</u> any delay introduced by equipments that are not part of the closing circuit is excluded from the make times. Typically the operating time of a PoW controller channel is NOT included into the make times.	
Arc IEEE C37.100	Current continuation between CBR contacts during an opening operation after the contacts have been mechanically separated
Opening (Tripping) duration IEEE C37.100	Duration of the mechanical move of CBR contacts from their fully closed position to their fully opened position.
Opening (Tripping) time IEC62271-302	CBR initially in fully closed position, amount of time between the initiation of the opening operation (tripping input command is triggered), and the date when arcing contacts have separated in : - all poles (<u>switchgear</u> tripping time). - or the concerned pole (<u>pole</u> tripping time) May vary with the breaking current.
<u>**NOTE 1:**</u> any delay introduced by equipments that are not part of the tripping circuit is excluded from the tripping time. Typically the operating time of a PoW controller channel is NOT included into the tripping time.	
<u>**NOTE 2:**</u> self-tripping switchgears do not have tripping inputs; in that case the tripping time starts when, the switchgear being in the closed position, the current in the main circuit reaches the operating value of the overcurrent release.	

acronym	meaning
Idle time	amount of time between two consecutive CBR operations, during which the CBR position remains unchanged.
Adaptive control	Adjustment of CBR control timings based on past operating patterns (measurements of CBR previous operating times) and CBR idle time.
Compensation	Predictive adjustment of CBR control timings based on outside temperature, driving mechanism characteristics (e.g. hydraulic pressure if applicable) and operating circuit power supply conditions at the time a CBR operation is initiated (IEC62271-302).
<u>**NOTE :**</u> the adaptive control is excluded from compensation.	
RDDS IEC62271-302	"Rate of Decay of Dielectric Strength" of an interruptor. This is the rate that the dielectric strength across the closing contacts is decreased as the contacts come together during a closing operation. This characteristic is important in assessing the pre-arc prior to the mechanical touch of the contacts. (CIGRÉ Publication 262 to 264). In other words the RDDS is the voltage withstand reduction as a function of time or contact gap during closing of a switchgear.
RRDS IEC62271-302	"Rate of Rise of Dielectric Strength" voltage withstand increase as a function of time or contact gap during opening of a switchgear
Synchronous operation IEEE C37.100	Operation of a switching device in such a manner that the contacts are closed or opened at a predetermined point on a reference voltage or current wave
Target point for closing	Prospective instant for the HV contacts to touch during a closing operation.
Target point for making	Prospective instant of current initiation during a closing operation
Target point for tripping	Prospective instant for the HV contacts to separate during a tripping operation.

2 INTRODUCING POINT-ON-WAVE SWITCHING

2-1 Random switching versus PoW switching

HV switchgears may be controlled by several protection and control devices that have wired connections to their closing and tripping coils. Among these devices, “Point-on-Wave” controllers may be used to energize the switchgear coils in a way that single operations are optimized.

PoW controllers were introduced in 2000’s as an alternative to costly pre-insertion resistors, surge arresters and fixed reactors, which main function was to limit inrush currents and clamp voltage surges on the network and the switched load, that may occur during random switching operations (and persist after in some cases). There are many technical and economical reasons to avoid or limit these phenomena, and thus to use PoW controllers acting on their root cause instead of applying damping strategies like with passive equipments.

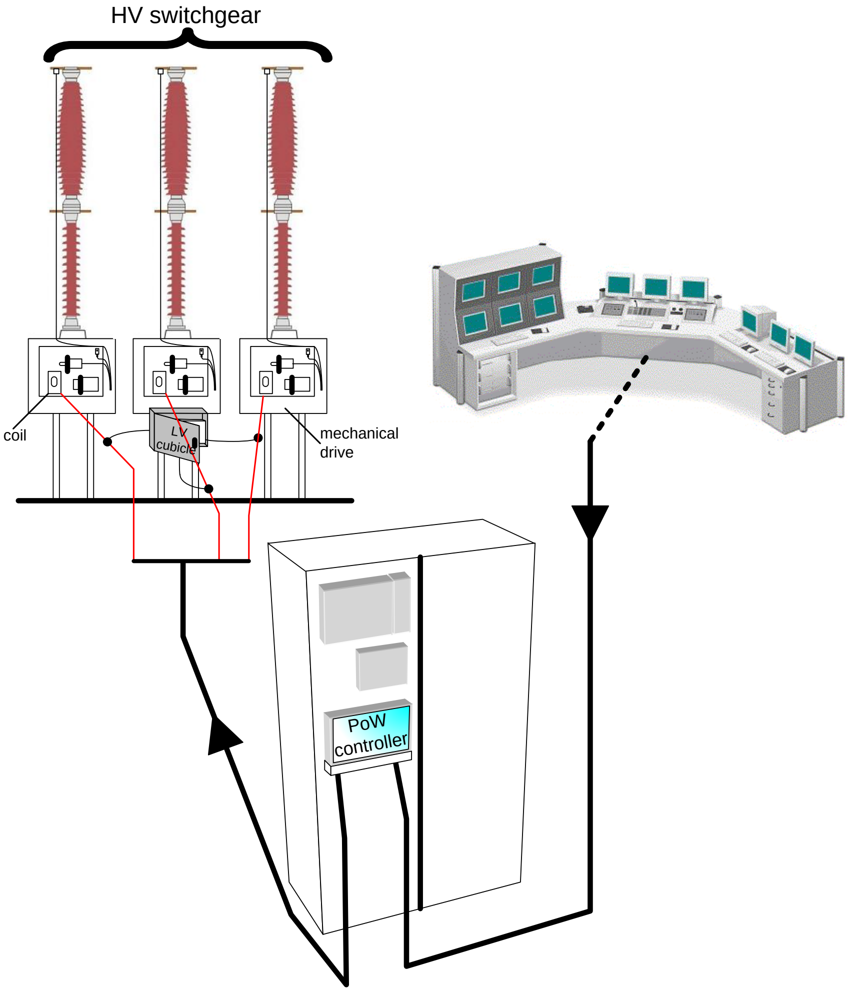


Figure 1 : the PoW controller acts as a switchgear command device

High inrush currents may lead electrodynamical efforts and unexpected protection trippings, whereas overvoltages may lead to restrikings, aging of surge arresters and decrease of the switchgear dielectric withstand performances.

The Figure 2 below illustrates the main benefits of “synchronous switching” (i.e. PoW controlled switching), compared to “random switching” (i.e. where all switchgear coils are energized at the same instant) during a closing operation :

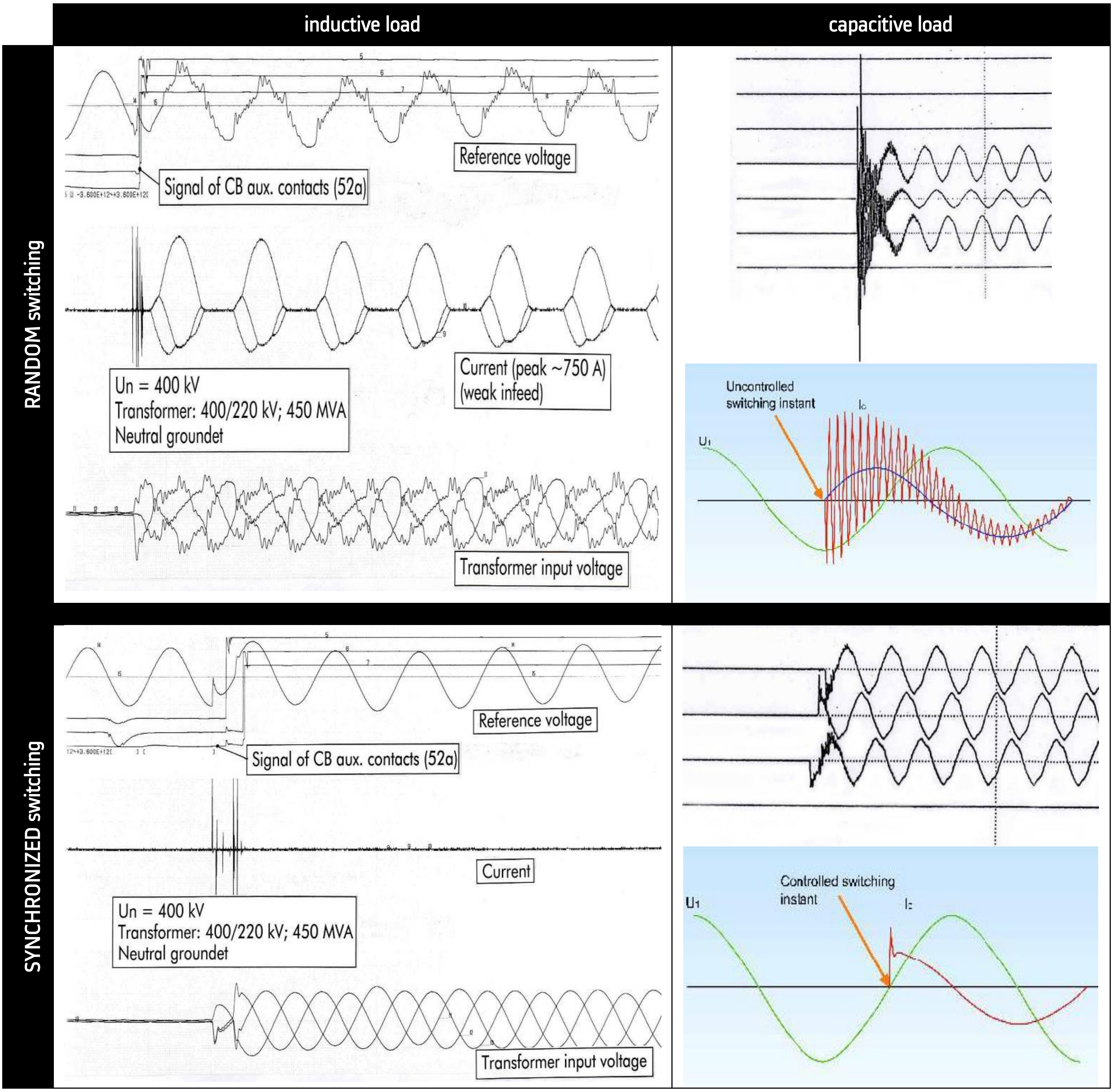


Figure 2 : synchronized switching versus random switching on different loads

In order to assume synchronous switching, the main feature of a PoW controller consists in introducing a suitable delay between the instant it receives an input command for operating the switchgear (either closing or tripping command) and the instant it actually starts energizing the switchgear coils, in such a manner that HV current is established or interrupted on each HV phase at chosen target points on associated phase voltage waveforms. This target point for the initiation / interruption of the HV current in each pole may vary from one application to an other, mainly depending on the type of load being switched (reactor, capacitors…) and associated neutral mode (grounded, isolated).
The Figure 3 below illustrates this feature for a closing operation (example on an inductive load) :

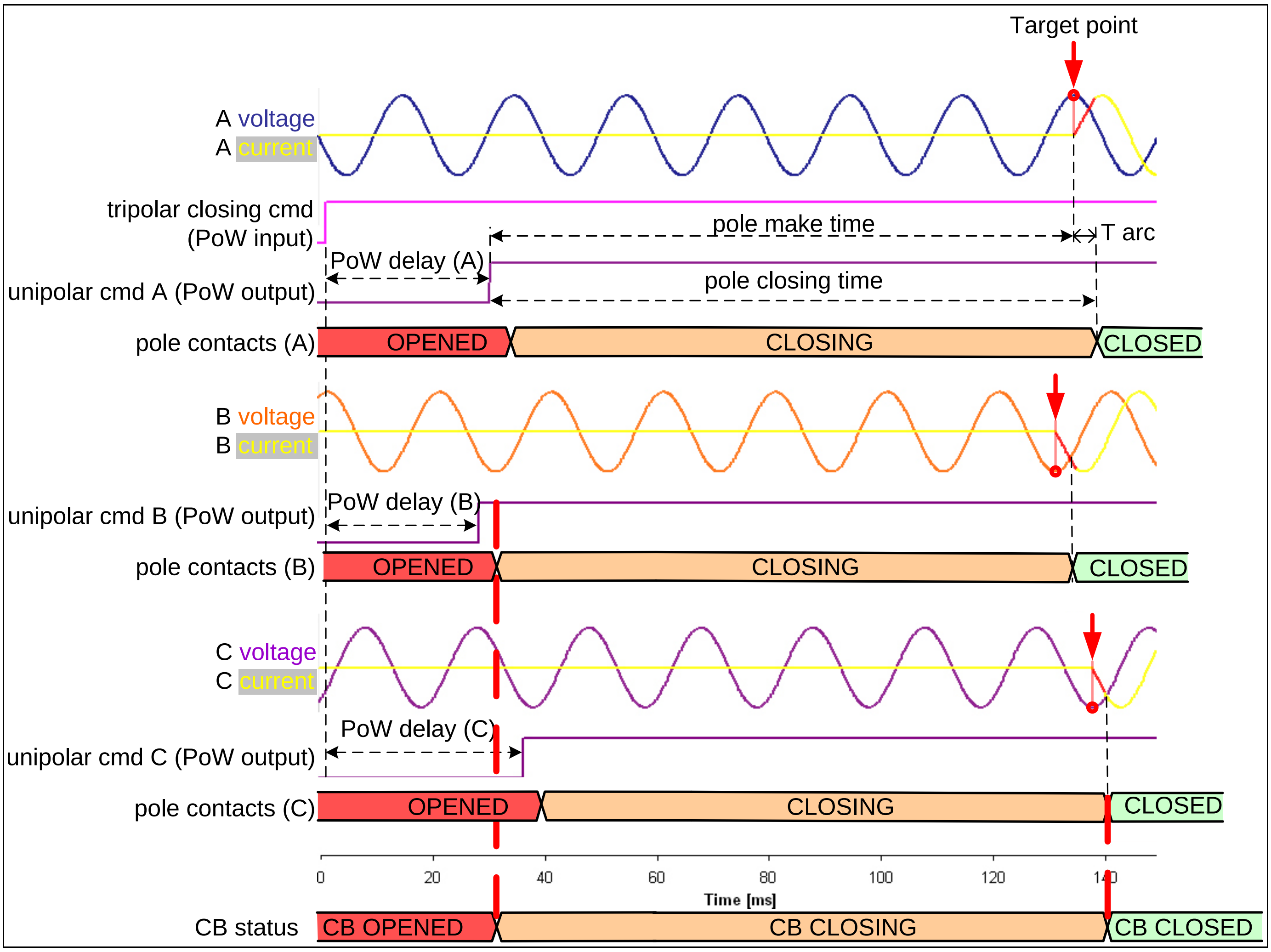


Figure 3 : PoW closing operation / example on a group of reactors

Once it received the tripolar input command, the PoW controller has to forecast the closing or opening time on each pole in order to introduce the best suitable delay between the tripolar input command and each unipolar output command (energizing the CBR coils), so that transient phenomena that may occur are as limited as possible (voltage surges, inrush currents, risk of re-striking or current chopping…).

These closing and opening times may significantly be impacted by the variation of several parameters, among which :

Environment related parameters :

- actual ambient temperature
- supply voltage of the CBR coils
- ...

Switchgear related parameters :

- dynamic perfos (operating durations, aging drifts, mechanical dispersions, hydraulic pressure, etc.)
- initial status (open, closed, undetermined) and idle time
- dielectric strength (RDDS, RRDS)
- ...

Electrical network related parameters :

- load impedance (transformer, bank of capacitors, shunt reactors, transmission lines, etc.) and neutral mode
- presence or not of grading capacitors
- actual network frequency, voltage level, current level
- slew rate of the voltage across the contact gap
- ...

Depending on the application, some of these parameters may be static (e.g. mechanical dispersions) or variable along different laws (fully random, linear...) from one CBR operation to an other.

An optimal interaction between the Point-on-Wave controller and the switchgear is thus the key feature to obtain expected results for controlled Point-on-Wave switching applications.

IMPORTANT NOTE : synchronous switching is not applicable for fast combined cycles of operations : O-C, O-C-O, etc. since these cycles are dedicated to emergency situations, for which the switchgear shall open or close as soon as possible under no condition.

2-2 Synchronous closing operations

Defining the optimal target point on each phase voltage wave for a synchronous closing operation requires to take the following into account :

- The equivalent impedance (type of load + neutral mode) of the circuit elements to be energized.
- The actual voltage across the switchgear terminals i.e. between the line (providing the energy) and the circuit elements to be energized.

The optimal target point for current establishment on the phase voltage wave is defined by a date when both the phase voltage and the circuit voltage are at the same level.

<u>**Example**</u> : the most suitable target point for energizing a capacitor is when the phase voltage reaches the value of the steady voltage across the capacitor (0 V in case it is initially discharged).

In any case the voltage conditions shall be considered on each phase separately, assuming that they are 120 electrical degrees phase shifted.

The Figure 4 below provides a detailed illustration of involved timings on 1 CBR pole during a synchronous closing operation (example of energizing a shunt reactor).

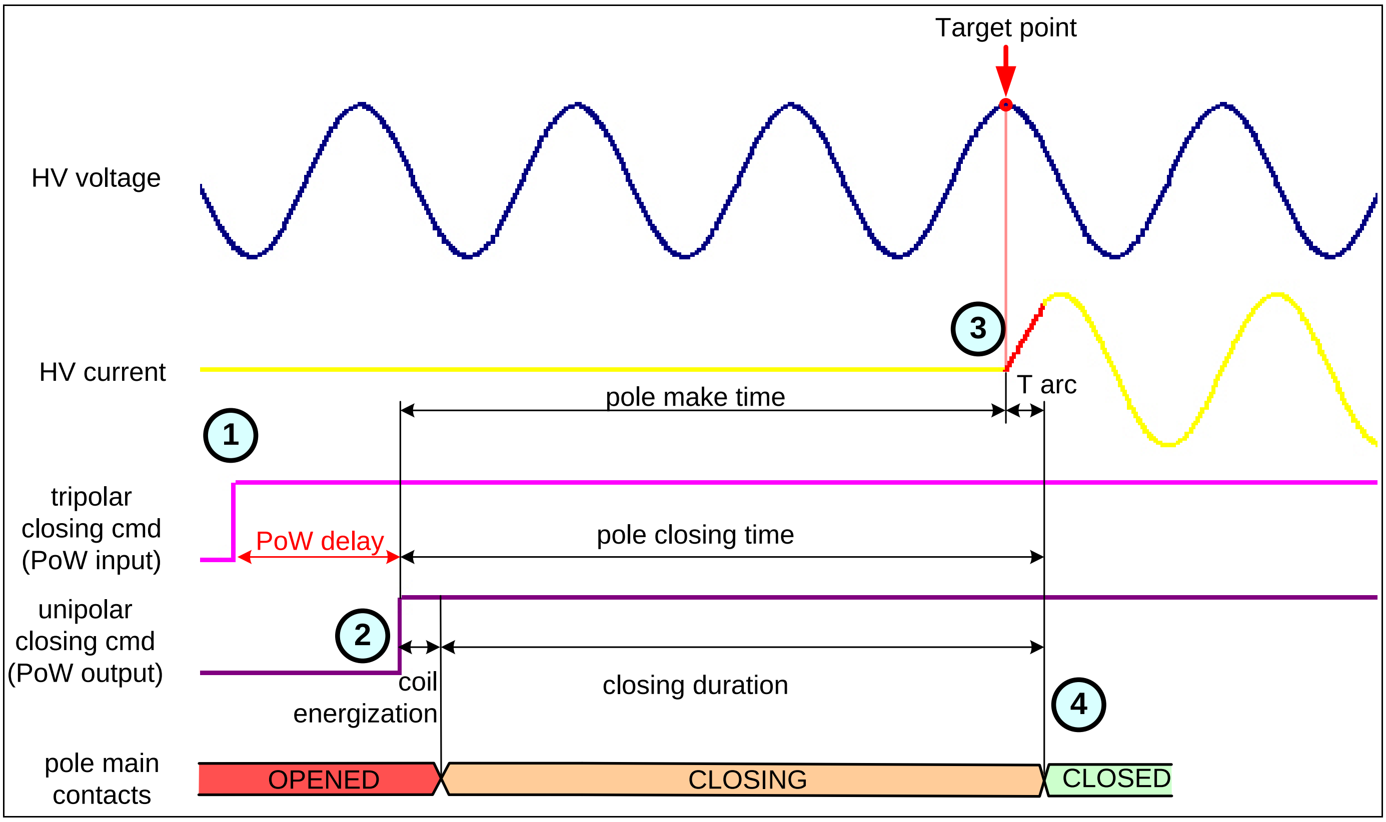


Figure 4 : synchronous energization of a shunt reactor (timings on 1 pole)

Once it received a valid impulse on its closing command input (1), the PoW controller is able to select by itself on the phase voltage wave the optimal target point for current initiation (3), knowing the type of load to be energized (and associated neutral mode) as well as the pole closing time.

Then it computes the suitable delay to be introduced between the input impulse (tripolar command) and the start of coil energization (2), taking into account other factors of influence like ambient temperature or actual coil supply voltage level, so that the current actually starts flowing at the desired instant (date of the target point).

Since the dielectric withstand capability of the interruptor (RDDS) is decreasing with the distance between its contacts, the current may start flowing slightly before the contacts mechanically touch (the electrical circuit is closed through a “pre-arc”).

Care must be taken of this phenomenon when energizing a circuit, especially in case the target point is located on the zero-crossing of the voltage across the interruptor (like on capacitive loads), as illustrated on the Figure 5 below :

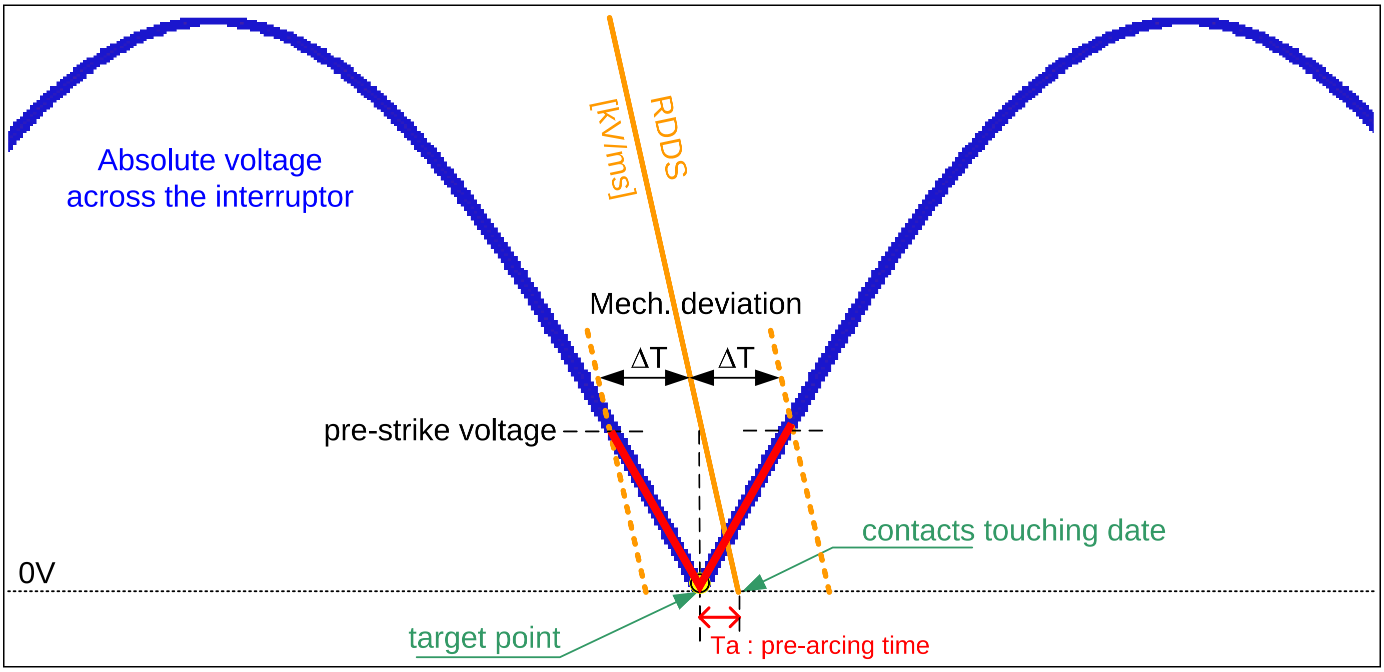


Figure 5 : CBR closing on voltage zero : pre-arcing time as a function of RDDS and mechanical deviation of the CBR interruptor

As observed on the Figure 5 above, the voltage slopes on both sides of the target point are the highest, as opposite to when it is located close to a voltage peak (e.g. for transformers or common core reactors).

Due to the non-ideal RDDS of the CBR interruptors and the deviation of their mechanical dynamic performances from one closing operation to an other (unavoidable tolerance on the closing duration), it is important to balance the risk of transients along both sides of the target point, so that the pre-strike voltage $U_p = \hat{U}.\sin(\omega.\Delta T)$ is the same on both sides of this target point.

This can be assumed by the PoW controller by applying a pre-arcing time of $Ta = \frac{\hat{U}.\sin(\omega.\Delta T)}{RDDS}$

NOTE : the magnitude of the voltage across the interruptor terminals may vary with the neutral mode (grounded or isolated) and the closing sequence between poles (like on capacitor banks).

As illustrated on the Figure 6 below the accuracy of the pre-arcing time definition is less sensitive when energizing close to a voltage peak : initiating the current 1 ms before or after the actual peak leads the pre-arc to start under 95 % of the peak voltage, (81% at 2 ms) : associated overvoltages are not significantly energetic.

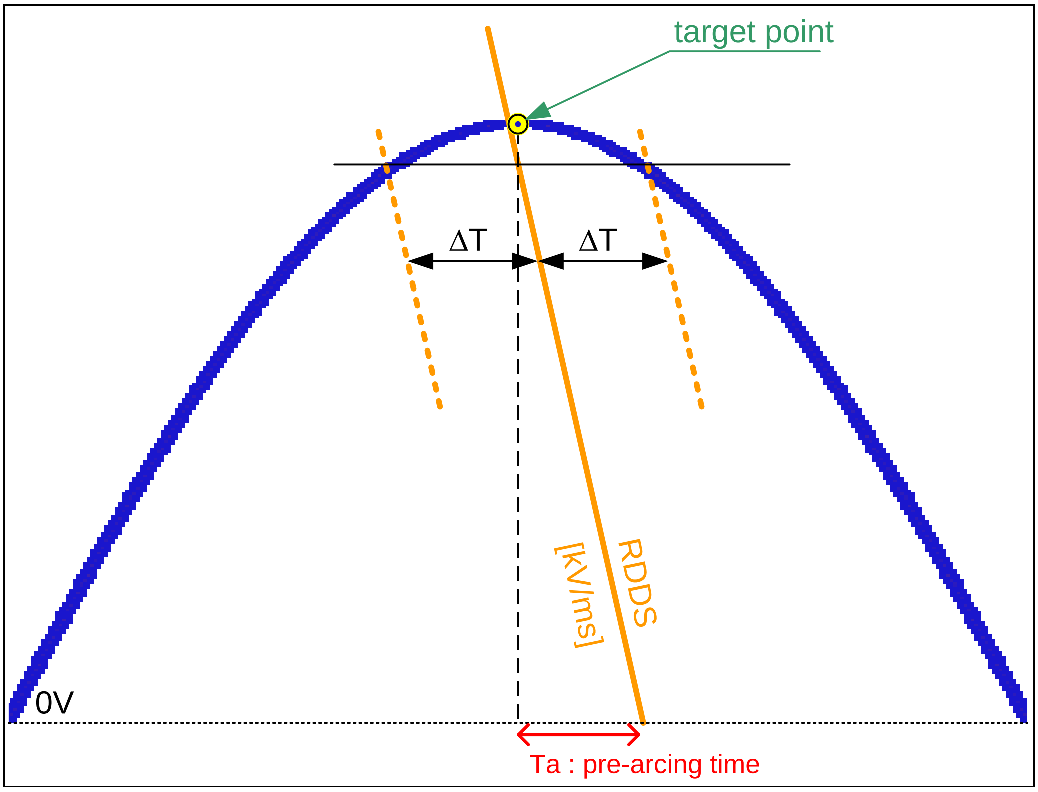


Figure 6 : CBR closing on voltage peak : pre-arcing time as a function of RDDS and mechanical deviation of the CBR interruptor

The pre-arcing time as applied by the PoW controller shall be $\mathbf{Ta} = \dfrac{\hat{U}.\cos(\omega.\Delta T)}{RDDS}$

2-3 Synchronous tripping operations

Choosing the target point for a synchronous opening operation on each phase voltage wave only depends on the type of load and neutral mode of the circuit elements to be energized.

The optimal target point on the voltage wave for current interruption is defined by a contact separation date located a sufficient amount of time before the zero crossing point of the HV current wave, so that the contact gap at the end of the arc is large enough to withstand the recovery voltage and thus avoid re-striking. But the target date shall also not be chosen too early in order to avoid current chopping (heavy effort for arc blasting, high arcing voltage ➔ high di/dt ➔ overvoltages).

<u>Example</u> : the most suitable target point for de-energizing a shunt reactor is when the phase voltage reaches its sine peak (either positive or negative), which corresponds to a current zero (90° el. phase shift).

In any case the voltage conditions shall be considered on each phase separately, assuming that they are 120 electrical degrees phase shifted.

The Figure 7 below provides a detailed illustration of involved timings on 1 CBR pole during a synchronous tripping operation (example of current interruption on a shunt reactor) :

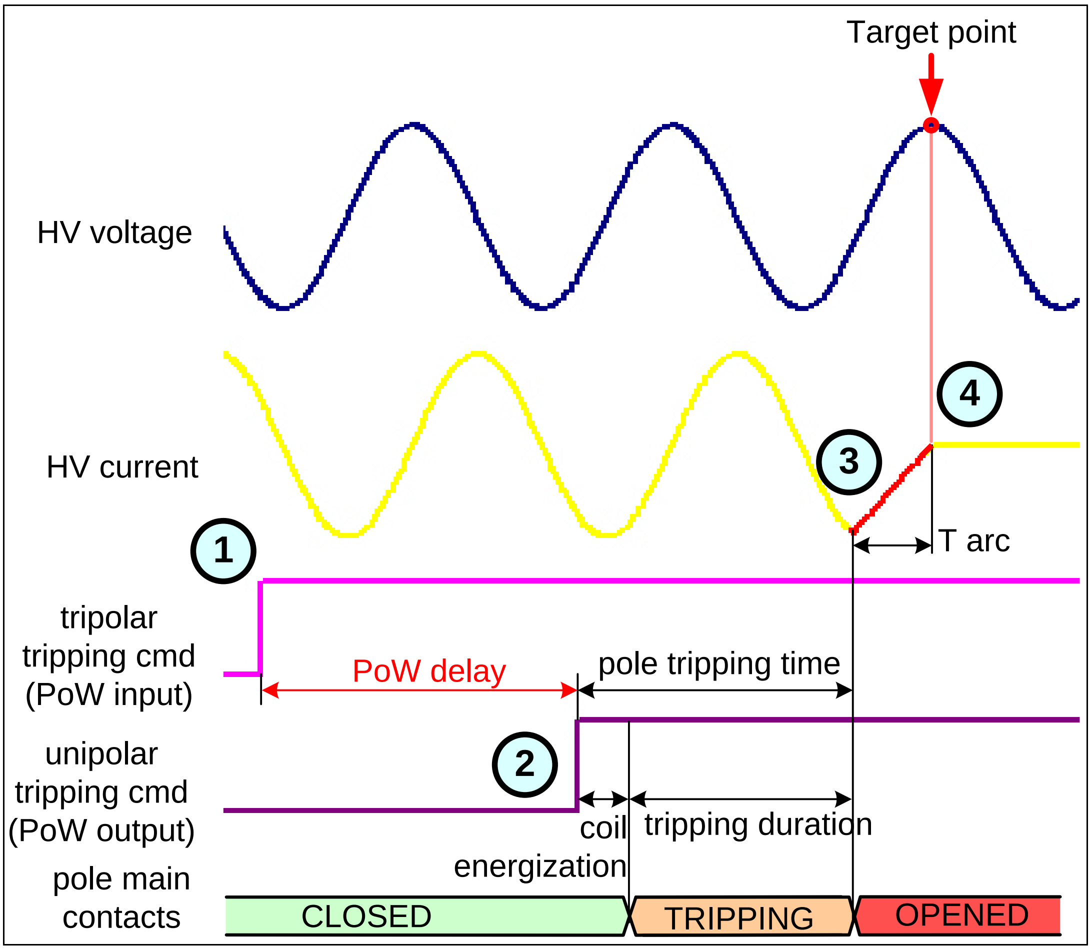


Figure 7 : current synchronous interruption on a shunt reactor (timings on 1 pole)

Once it received a valid impulse on its tripping command input (1), the PoW controller is able to select by itself the optimal target point on the phase voltage wave for current interruption (4), knowing the type of driven load (and associated neutral mode) as well as the pole opening time.

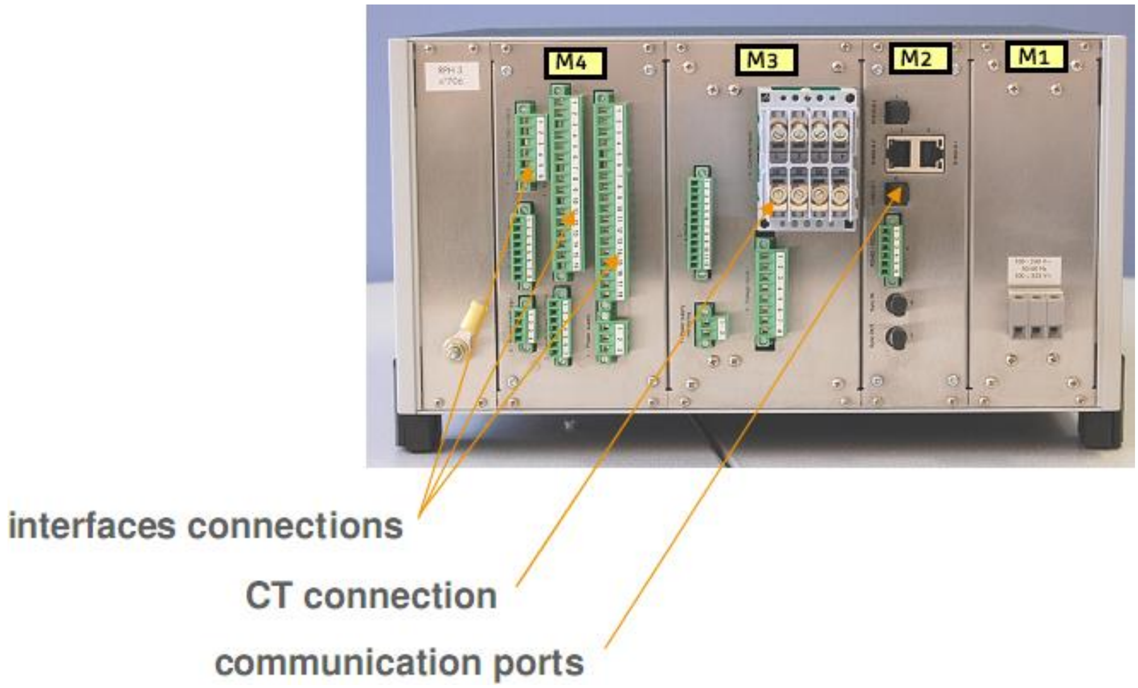
Then it computes the suitable delay to be introduced between the input impulse (tripolar command) and the start of coil energization (2), taking into account other factors of influence like CBR idle time or actual coil supply voltage level, so that the current actually ends flowing at the desired instant (date of the target point).

3 PoW SWITCHING SOLUTION FROM GE : RPH3 TCR

3-1 Introduction

The RPH3 is a standalone PoW controller implemented as a standalone device composed of 5 electronic modules assembled into a metallic case as illustrated on Figure 8 and **Erreur ! Source du renvoi introuvable.** below :

Figure 8 : RPH3 3/4 & front views



: RPH3 rear view

Note : the M5 module is located behind the front panel of the RPH3; it includes the 4 front LEDs and COM1 connector.

The RPH3 controller was designed to be used in 2 different scopes of applications :

- **TCR** : PoW switching on conventional loads : Transformers, Capacitors, Reactors (and combinations)
- **Lines** : PoW switching on transmission lines, which loading behaviour is much more complex since it deeply depends on “real-time” network conditions and complex feeding / consuming installations characteristics (wind generators, transformers with sensible residual flux…)

The hardware platform of the RPH3 being unique[3], the firmware version to be embedded into this platform shall be selected according to the switching end application (refer to section 4 Application Notes, page 107).

This section is dedicated to TCR scope of applications only.

For details on lines switching applications, refer to document **[3]**.

3-2 Outline dimensions

The RPH3 controller housing was designed for an easy wall mounting.
It is delivered with removable handles that allow mounting into a standard 19” rack.

Quotations given on Figure 9 below are in mm :

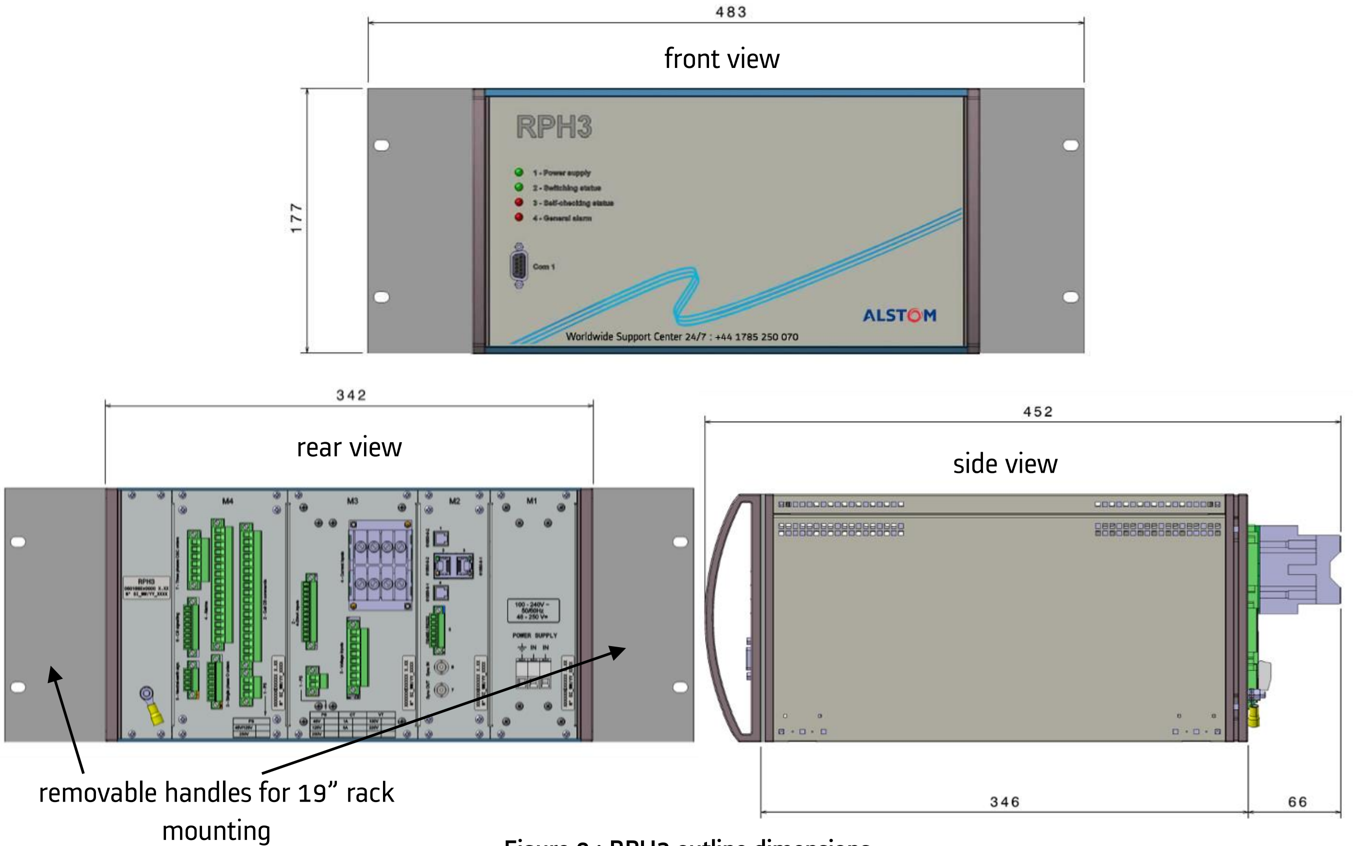


Figure 9 : RPH3 outline dimensions

[3] Some variants exist of the hardware platform. Refer to section 3-10 for further details (page 0).

3-3 Functional diagram and architecture distribution

A simplified functional diagram of the RPH3 controller within its typical environment is provided below on Figure 10:

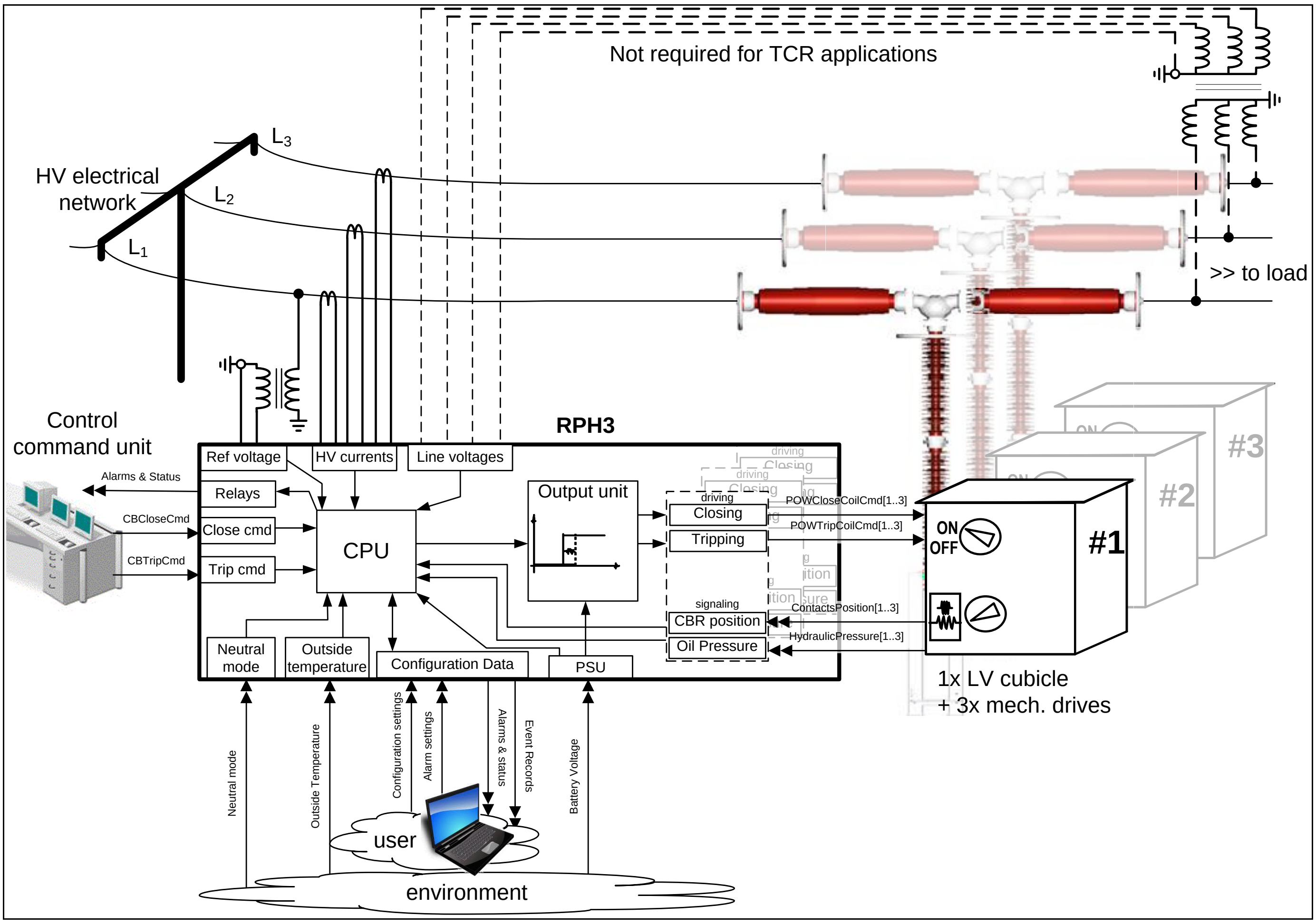


Figure 10 : RPH3 controller functional diagram (simplified)

The RPH3 is composed of a set of 5 standalone electronic modules that are assembled in a dedicated housing :

- M1 module : Power Supply Unit in charge of supplying each RPH3 module with the suitable energy.
- M2 module : Central Processing, Communication and Synchronization Unit : hosts the main CPU (DSP) and embedded OS (Linux BSP), provides access to RPH3 internal resources (2xEthernet, 2xOptical, 1x RS232/485) and optical connections for synchronization purposes.
- M3 module : Analogue Inputs Acquisition Unit in charge of monitoring the RPH3 internal temperature and sampling the input signals below :
    - DC supply voltage of CBR coils (for monitoring purpose)
    - 4-20 mA inputs (outside temperature, hydraulic pressures)
    - HV Reference voltage
    - HV voltages and currents

- M4 module : Signaling and Coils Command Unit in charge of :
    - sampling the following signals :
        - input command for CBR closing operation
        - input command for CBR tripping operation
        - neutral mode configuration of the CBR load (earthed, isolated or unknown)
        - switchgear auxiliary contacts status (a-type contacts of poles A, B and C)

    - issuing the following output signals :
        - 3 differential output commands for CBR closing coils (poles A, B and C)
        - 3 differential output commands for CBR tripping coils (poles A, B and C)
        - 5 alarm signaling contacts (1 monostable + 4 bistable relays)
        - +48 V biasing voltage for CBR auxiliary contacts acquisition

- M5 module : Front Panel management unit, in charge of driving front side LEDs and RS232/485 communication gating between the front panel "Com1" connector and the internal M2 module (20 wires HE10 flat cable).

As shown on the Figure 11 below, the RPH3 is provided with a "safety socket", externally connected on its M3 module (HV currents sampling inputs). It is required in order to prevent any risk of electrical shock in case of an unexpected disconnection of the RPH3 interface with the Current Transformers.

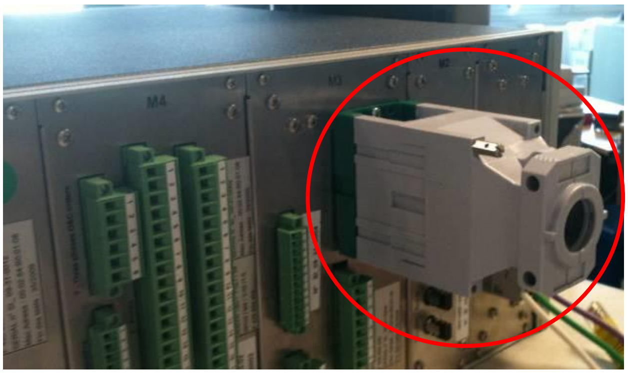


Figure 11 : safety socket on M3 module

The RPH3 embeds a dedicated MMI on a secured web server, that allows the user to access relevant internal data thanks to a standard web browser[4] such as configuration settings, event record files, real-time data and alarms, result of the last switching operations, etc..

The RPH3 can be connected to an IP network through its dedicated Ethernet interface M2.J3 (cable not included). The MMI shall be accessed this way, provided that the RPH3 IP address[5] is known from the user, as well as the relevant user name and password (further details on software access levels are given in document **[1]**).

Furthermore, the RPH3 is delivered with a PC software running under Microsoft Windows© OS[6] : the "RPH manager". It offers facilities for downloading, reading and graphical plotting up to the last 1000 event records of RPH3 units it is connected to (through the IP network).

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[4] A list of supported web browsers is provided in document **[1]**

[5] The RPH3 does not support DNS protocol ; its IP address is fundamentally static. It is delivered with a default IP address that may be changed through the MMI. For further details refer to document **[1].**

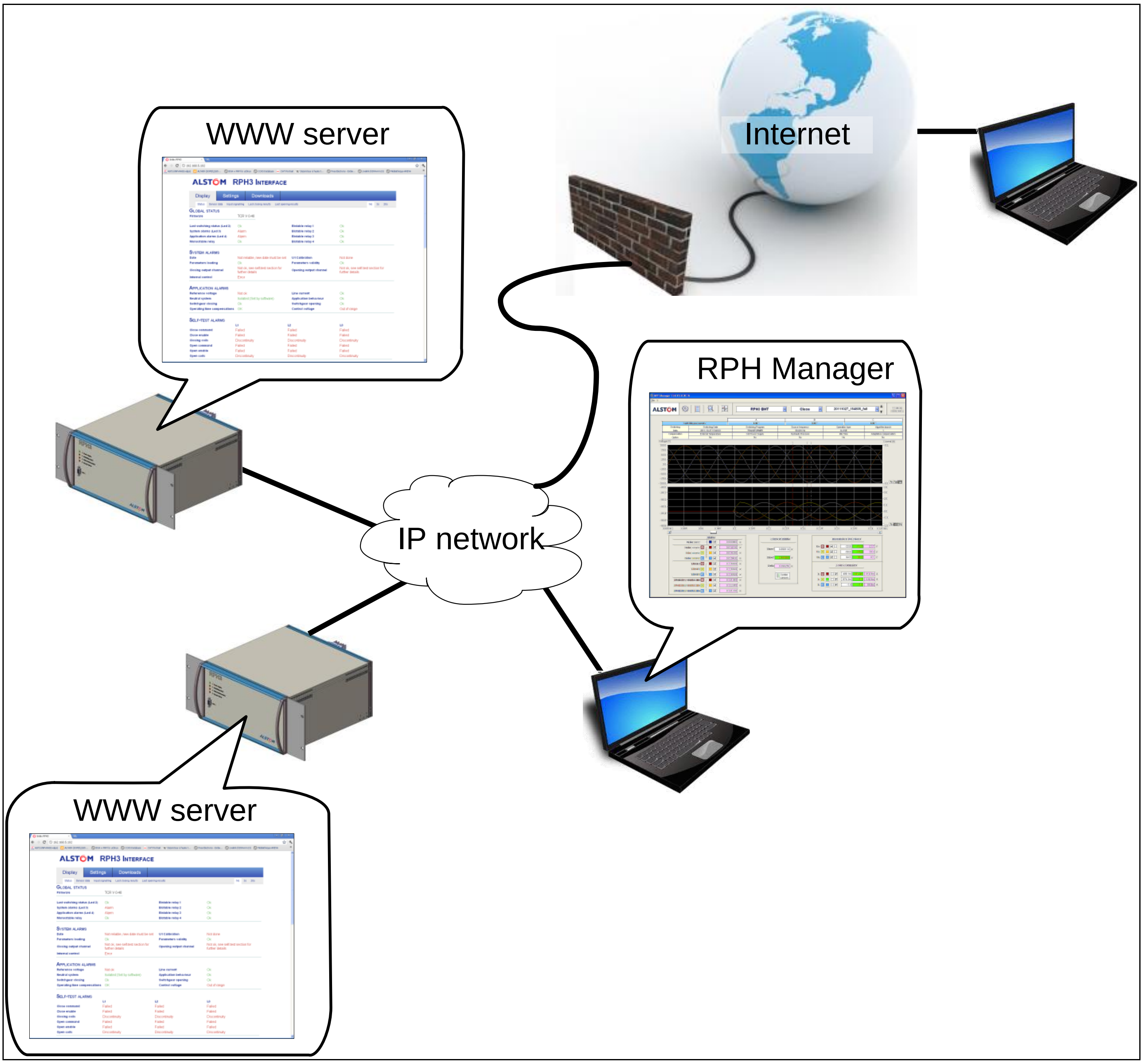

Figure 12 : RPH3 MMI distribution

Figure 13 : Ethernet connection plug (M2-J3)

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[6] Supported versions of Microsoft Windows© are identified in document **[2]**

3-4 Operating the switchgear – base features for TCR applications

As a PoW controller, the RPH3 implements the functionalities described in section 2, page 15. This manual also provides application notes in section 4, page 107.

PoW switching as assumed by the RPH3 controller within the TCR application scope can be described by the simplified Finite State Machine below (Figure 14) :

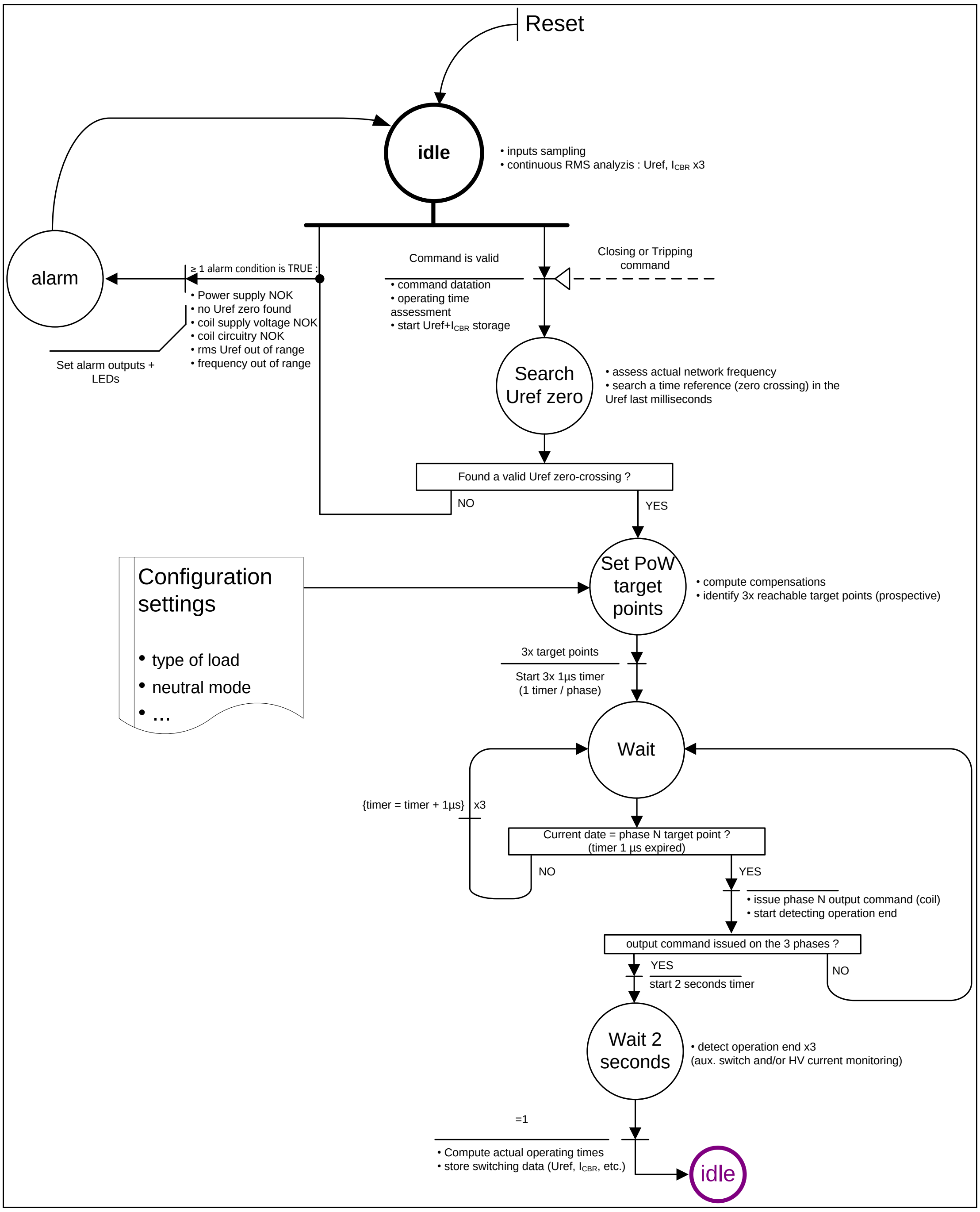


Figure 14 : RPH3 main state machine model for TCR applications

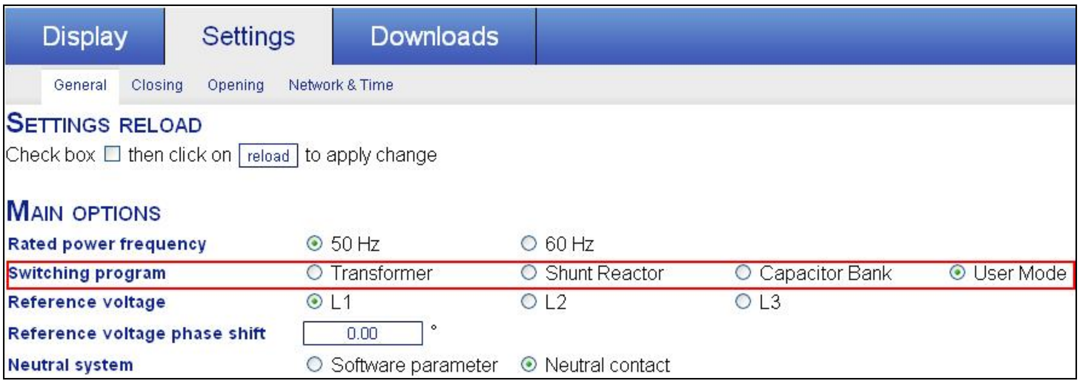
Once a valid command has been received by the RPH3 and no alarm condition is fulfilled, it selects a time reference on the reference voltage “Uref” (zero-crossing of the sine wave) and identifies the most suitable target points for the switching operation to be performed (1 target point per phase, assuming voltages are 120° el. shifted and each current is 90° el. shifted from the associated voltage).

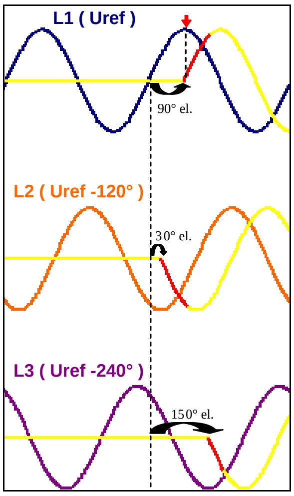
Some alarm conditions are tested at the beginning of the state machine. As soon as ≥ 1 of these conditions is fulfilled the operation is cancelled, the associated alarm is triggered and the state machine returns back to its idle state.

The RPH3 is able to manage many more alarms (refer to section 3-7, page 71), but the main algorithm may be cancelled by the most critical ones only :

- Power supply NOK : the RPH3 power supply is continuously monitored on internal polarities to be used for analogue-to-digital conversions (0V/+15V/-15V). This alarm is triggered in case ≥ 1 of these voltages is measured out of the allowed range (this range may be tuned by a software setting).
- No Uref zero found : the reference voltage did not cross 0V within the last 200 milliseconds (time frame analysis)
- RMS Uref out of range : the RMS value of the reference voltage is continuously measured by the state machine when in idle state. This alarm is triggered in case it has been measured below the threshold value (adjusted by a software setting).
- Coil supply voltage NOK : the coil supply voltage has been measured out of the allowed range (this range may be adjusted by a software setting)
- Coil circuitry NOK : this alarm is triggered in case ≥ 1 of the 3 output coil circuits was detected as discontinuous. Closing and tripping circuits are continuously monitored by the RPH3, whereas the ability of the RPH3 output MOSFET transistors to be switched ON/OFF is periodically tested (every 3 seconds).
- Frequency out of range : the actual system frequency is continuously monitored by the state machine when in idle state. This alarm is triggered as soon as this frequency was measured out of the allowed range (50 Hz ±5% or 60 Hz ±5%). The nominal frequency (50Hz or 60Hz) is to be chosen by a software setting.

According to its configuration settings, the RPH3 applies a switching strategy – or “switching program” - to select the most suitable PoW target points for the switching operation.





Each of these switching programs is describes by a set of angular shifts, identifying PoW target points with respect to the closest zero-crossing date of the reference voltage Uref.

The Table 1 below provides details of angular shifts as applied by pre-defined switching programs :

Strategy	Neutral mode	Operation	Uref angular shift	Uref time shift (ms) @50Hz	Uref time shift (ms) @60Hz	Uref + 120° angular shift	Uref + 120° time shift (ms) @50Hz	Uref + 120° time shift (ms) @60Hz	Uref + 240 ° angular shift	Uref + 240 ° time shift (ms) @50Hz	Uref + 240 ° time shift (ms) @60Hz
Transformer	grounded	closing	90°	5	4.2	180°	10	8.3	180°	10	8.3
		tripping	**90°**	**5**	**4.2**	**30°**	**1.7**	**1.4**	**150°**	**8.3**	**6.9**
	isolated	closing	90°	5	4.2	0°	0	0	0°	0	0
		tripping	**90°**	**5**	**4.2**	**180°**	**10**	**8.3**	**180°**	**10**	**8.3**
Reactor	grounded	closing	90°	5	4.2	30°	1.7	1.4	150°	8.3	6.9
		tripping	**90°**	**5**	**4.2**	**30°**	**1.7**	**1.4**	**150°**	**8.3**	**6.9**
	isolated	closing	90°	5	4.2	0°	0	0	0°	0	0
		tripping	90°	5	4.2	180°	10	8.3	180°	10	8.3
Capacitor	grounded	closing	0°	0	0	120°	6.7	5.6	60°	3.3	2.8
		tripping	**90°**	**5**	**4.2**	**30°**	**1.7**	**1.4**	**150°**	**8.3**	**6.9**
	isolated	closing	180°	10	8.3	90°	5	4.2	90°	5	4.2
		tripping	**90°**	**5**	**4.2**	**180°**	**10**	**8.3**	**180°**	**10**	**8.3**

Table 1 : RPH3 pre-defined switching programs

NOTE 1 : these shifts are given for rated frequencies only. Actual time shifts are computed in accordance to the actual system frequency as measured by the RPH3 itself. Thus any frequency drift is carried out.

NOTE 2 : the additional "User" switching program may be selected instead of pre-defined ones. It gives an opportunity to tune each angular shift through the web MMI in order to cover specific needs (loads with initially trapped energy…). However, it is highly recommended to use a pre-defined strategy when applicable.

NOTE 3 : angular shifts are independent from (pre-)arcing times; they locate the operation **target points** (current **establishment** / **interruption** dates i.e. arc **starting** instants) but not contacts mechanical touching / separation date.

The switching program shall be selected through the web MMI in accordance to the process below (Figure 15) :

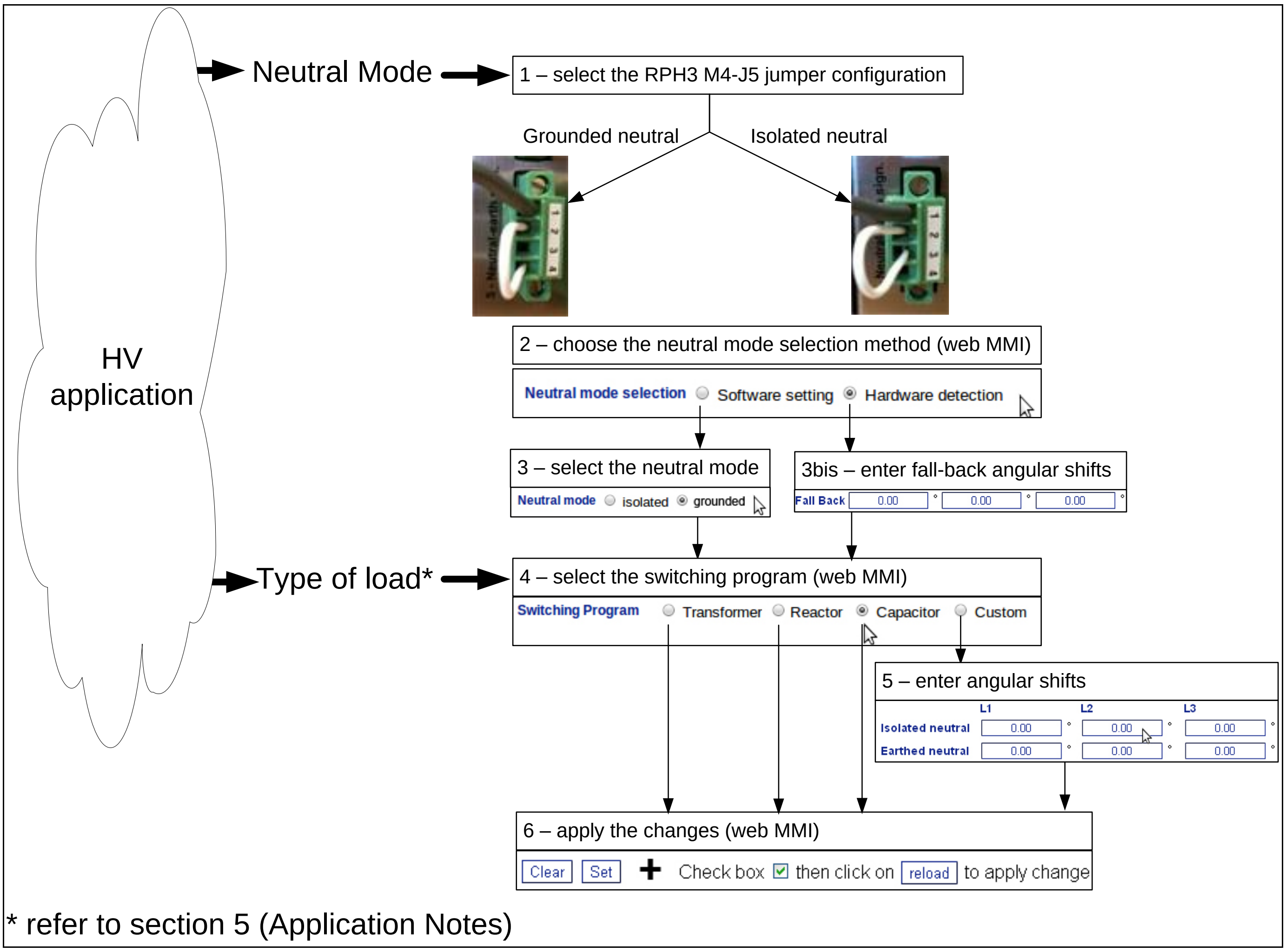


Figure 15 : switching program selection process

A pre-defined "fall-back" (backup) strategy is available for adjustment through the web MMI. It is to be applied by the RPH3 controller for CB switching in case it cannot identify the system neutral mode (if to be detected by hardware)

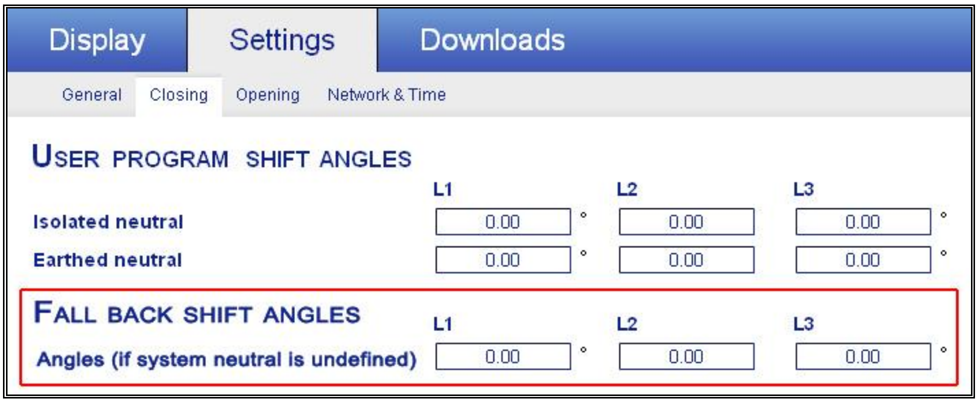


Figure 16: fall-back strategy settings (web MMI)

The following sections introduce the RPH3 interfaces to the main signals required to achieve PoW switching base features.

3-4.1 Power supply

The RPH3 controller continuously monitors the voltage it is supplied with, from which it generates internal DC voltages for operating.

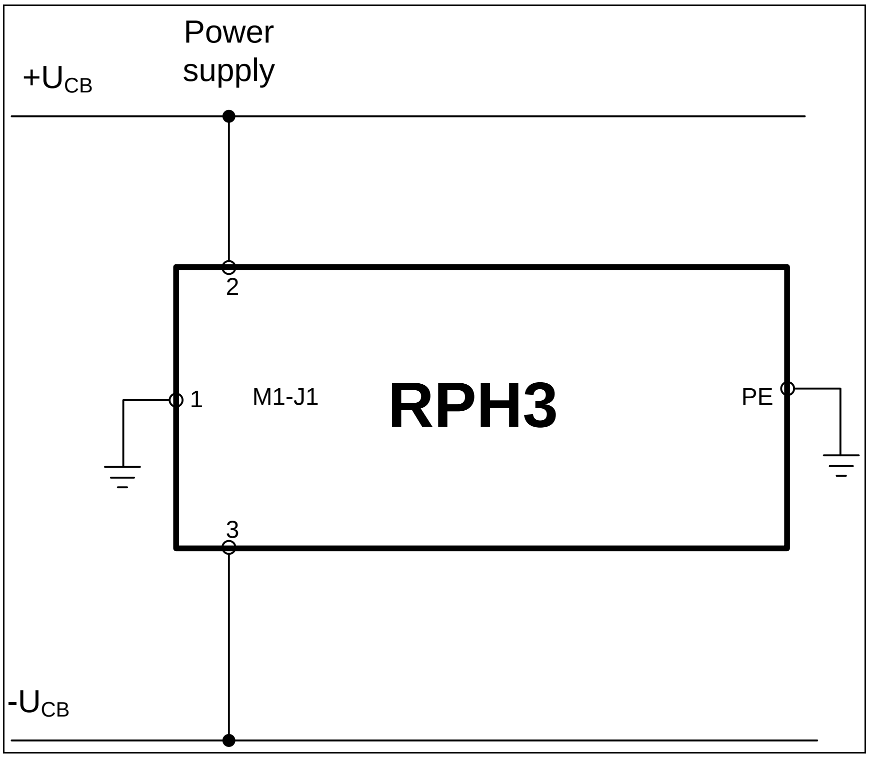


Figure 17 : RPH3 power supply

RPH3 characteristics on this interface are given below :

Rated characteristics	Min	Typical	Max	Unit
M1-J1 connector	*screw terminals – AWG22-10*			
input impedance	900	-	1200	kΩ
frequency	45	50/60	66	Hz
amplitude (AC)	100	-	240	Vrms
amplitude (DC)	48	-	353	V
power consumption	-	-	20	W
Insulation level	2000	-	-	Vrms

In case the supply voltage has been detected out of the allowed range (to be adjusted by software settings through the web MMI) the RPH3 trigs an alarm, turns OFF a dedicated LED on its front panel and opens its NC monostable output contact (pins M4-J4:2 and M4-J4:3).

<u>NOTE :</u> for safety and reliability reasons, the RPH3 controller case must be earthed through the dedicated earthing screw "PE".

3-4.2 Sampling the reference voltage

The "reference voltage" is an AC voltage as delivered by a VT, that shall be a real-time image of the high voltage present on the reference phase of the 3-phase system.

This voltage is to be used as a timing reference by the RPH3, that shall introduce the suitable PoW delay on each pole command (as described in section 2) upon the date this reference voltage next crosses 0V once the input command has been received.

<u>NOTE1 :</u> the RPH3 assumes that a 120° el. phase shift permanently exists between the 3 phases of the system, and each phase current is 90°el. shifted towards associated voltage :

L1 = reference voltage
L2 = L1 + 120 °el.
L3 = L1 + 240 ° el.

<u>NOTE2 :</u> the designation of the HV phase (L1, L2 or L3) whose reference voltage is an image of can be selected by a configuration setting in the web MMI. Refer to document **[1]** for further details.

<u>NOTE3 :</u> a software setting can be adjusted during the RPH3 commissioning in order to compensate any unexpected phase shifting introduced by complex bay layouts between the HV voltage and the RPH3 input terminals (M3-J3:7 and M3-J3:8). This may be the case for instance if the reference voltage is issued by the secondary LV winding of a generator power transformer.

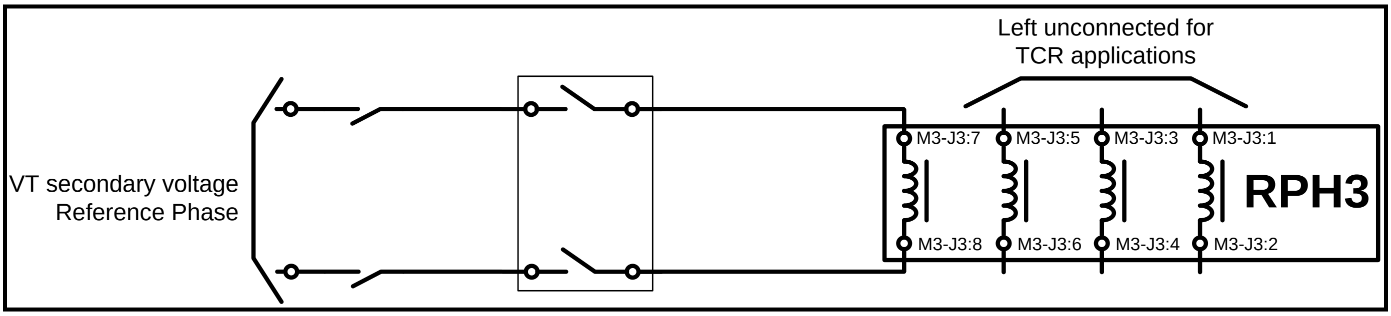


Figure 18 : Reference voltage connection

<u>NOTE4 :</u> RPH3 characteristics on this interface are given below :

Rated characteristics	Min	Typical	Max	Unit
M3-J3 connector	*MSTB 2.5/8-STF-5.08*			
input impedance	-	8	-	kΩ
frequency	45	50/60	66	Hz
amplitude (option 1)	15	100/√3	150	Vrms
amplitude (option 2)	30	220/√3	250	Vrms
RPH3 power consumption on this input	-	-	2	VA
Insulation level (measured between input and output windings)	2000	-	-	V
Measurement error	-	-	1	%

3-4.3 System neutral mode detection

As described on Figure 15 (page 32), a software setting shall be set through the web MMI for the RPH3 controller to identify the neutral mode of the application (whether it is grounded or isolated), which has a direct impact on the definition of the PoW target points.

This neutral mode can be detected by either of the 2 different methods below :

- <u>EITHER</u> by software setting (web MMI) : the user selects if the system neutral is grounded (earthed) or isolated.
- <u>OR</u> by hardware external jumper configuration on the rear connector M4-J5 :

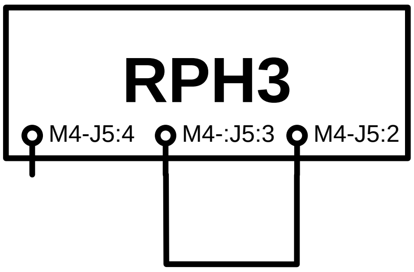
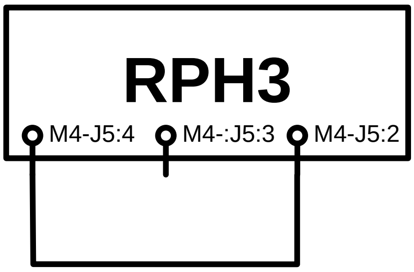
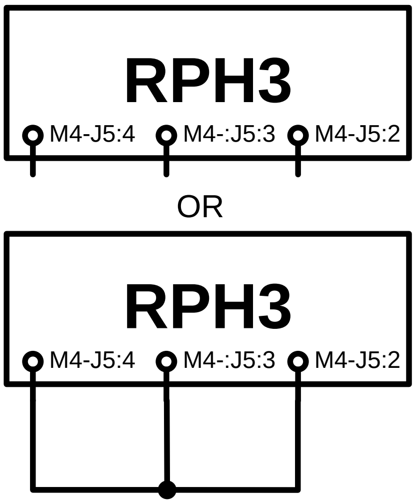
isolated neutral	grounded neutral	undefined neutral (⇒ alarm)
		
M4-J5 connector : *MC 1,5/4-STF-3.81*. Recommended wire gauge : AWG24-14		
associated screenshots (web MMI):		
		

Table 2 : neutral mode hardware detection

In case the neutral mode is undefined, the RPH3 cannot perform its nominal duty; if it receives an operation command while the associated alarm is active it applies a pre-defined backup switching strategy, for which PoW target points are to be set by software settings through the web MMI : refer to Figure 16, page 32.

Hardware detection of the neutral mode is useful in case the system neutral may be "dynamically" changed thanks to an isolator :

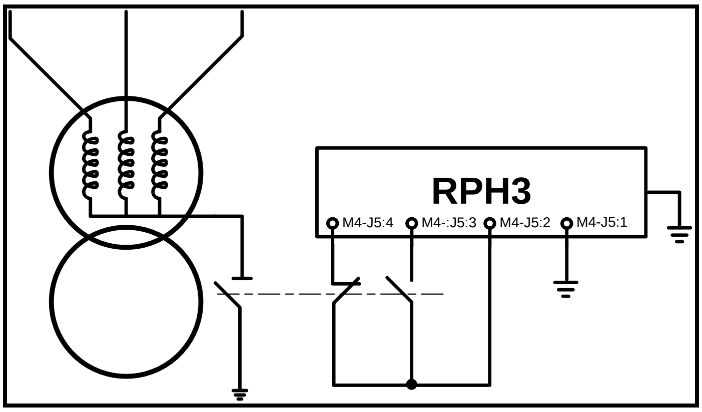


Figure 19: example use of a neutral isolator

3-4.4 Capturing switchgear tripolar operation commands

The RPH3 controller shall receive tripolar switchgear commands as logical voltage impulses from any control device :

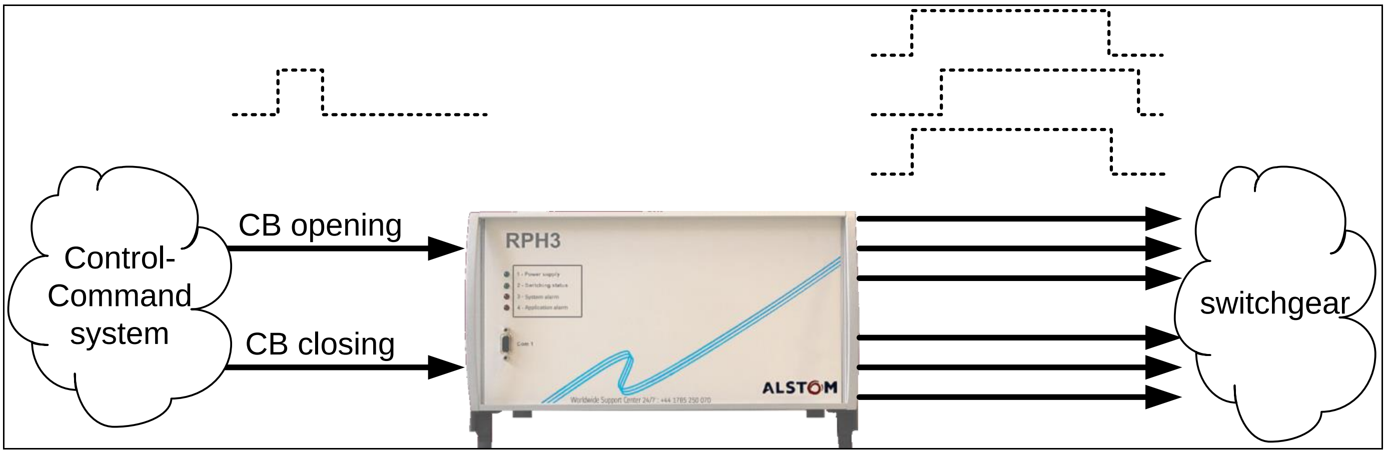


Figure 20 : sampling CB operation commands before driving CB coils

Associated inputs are opto-isolated and protected against reverse polarity.

A voltage impulse on these inputs is considered as valid by the RPH3 controller provided that its DC level is held ≥ U_{th} for a duration ≥ t_{hold} after its positive rising edge :

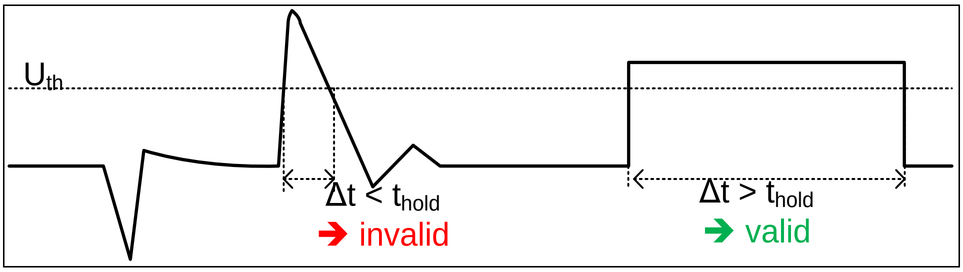


Figure 21 : tripolar command inputs filtering by the RPH3 controller

<u>NOTE 1 :</u> t_{hold} is adjustable through the web MMI (access level > User). Its default value is 80 ms.

<u>NOTE 2 :</u> U_{th} is not adjustable; its level depends on the considered RPH3 variant (refer to section 3-10 page 89) :

RPH3 variant	RPH3-PS<u>**48**</u>-CTy	RPH3-PS<u>**125**</u>-CTy	RPH3-PS<u>**250**</u>-CTy
value of U_{th}	**17 V**	**43 V**	**87 V**

Figure 22 : voltage thresholds for logical inputs filtering

<u>NOTE 3 :</u> The same filter is automatically applied by the RPH3 controller on all its logical inputs (unique value of t_{hold} for all inputs).

<u>NOTE 4 :</u> in case of rebounds on these inputs, the last rising edge is considered by the RPH3 controller for impulse starting instant.

<u>NOTE 5 :</u> the duration of the CB coils driving impulses (as issued by the RPH3) is independent from the duration of the input commands. It may be adjusted through the web MMI as described in section 0, page 38.

NOTE 6 : in case an input command is held ≥ U_{th} for a large duration (e.g. several seconds), the RPH3 controller proceeds to one single CB operation only; a rising edge is required on a command input for the operation to be processed.

NOTE 7 : once a valid command impulse has been detected by the RPH3, the associated treatment duration is ~4 seconds (signals recording). Any other valid impulse that could be detected while a previous one is being processed would be dropped by the RPH3 controller.

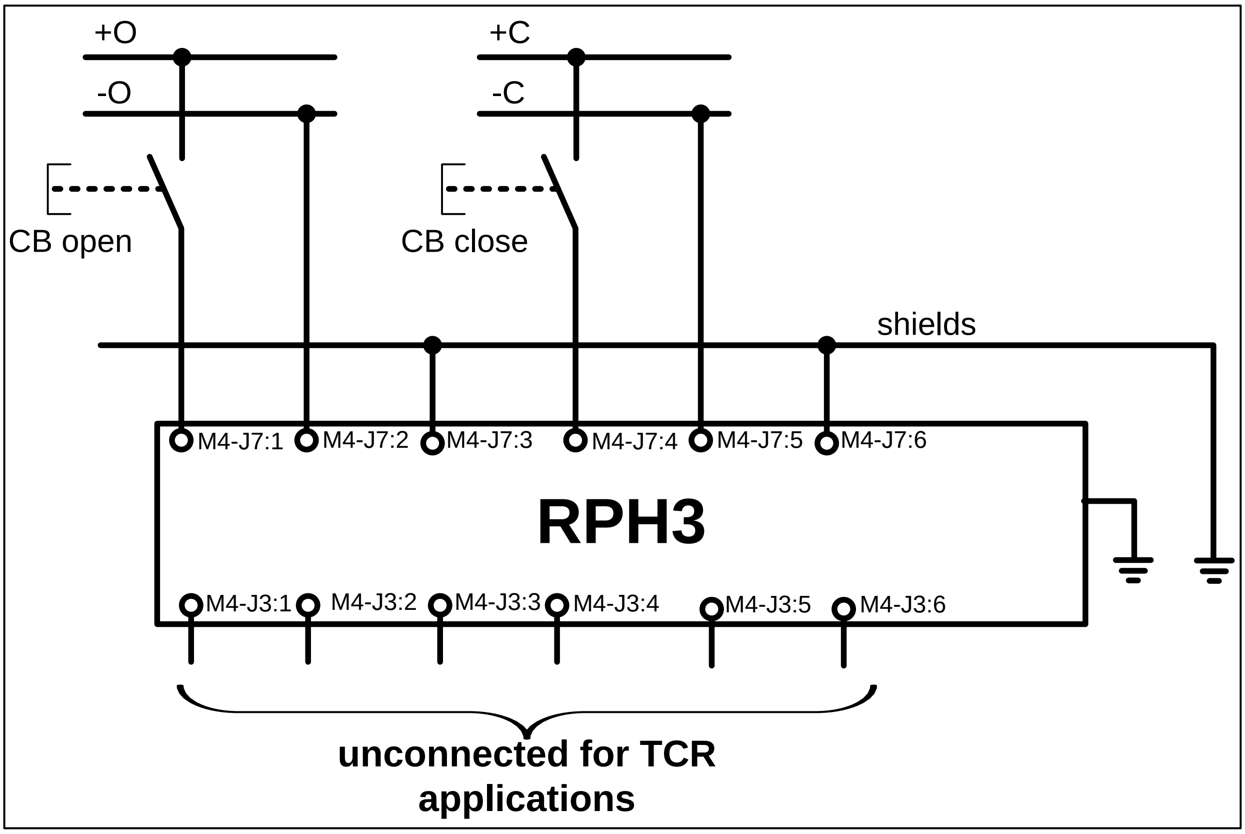


Figure 23 : closing and tripping command inputs cabling

WARNING : the 7 pins of the M4-J3 input connector shall be left unconnected for TCR applications. They are to be used for "lines" applications only. **NEVER connect tripolar command impulses to these pins, since this would burn the RPH3 controller out**.

The RPH3 characteristics on this interface are given below :

Rated characteristics	Min	Typical	Max	Unit
M4-J7 connector (CB tripolar closing and tripping commands)	*MSTB 2,5/6-STF-5.08*			
input impedance	10	-	-	MΩ
amplitude detection threshold (U_{th})	17	-	87	V_{DC}
Valid impulse duration (t_{hold})	1	80	-	ms
RPH3 power consumption on this input	2	-	-	VA

3-4.5 Driving the switchgear coils

For CB coils driving, energy is never tied by the RPH3 controller :

- neither from the coils supply voltage monitoring input (M3-J1 connector)
- nor from the input tripolar commands (M4-J7 connector)
- nor from the RPH3 power supply (M1-J1 connector)

The RPH3 controller ties 100% of the required energy from a dedicated input connector (M4-J1) for driving the CB coils through its M4-J2 connector.

This does not affect the RPH3 compliance with any switchgear : this energy management strategy ensures the RPH3 ability to drive any CB from any manufacturer.

Each CB coil is driven by a robust, dedicated output module based on MOSFET transistors, whose switching performances are factory calibrated.

One driving module is provided per CB coil to be driven : each coil driving module is independent from all others.

For higher flexibility of integration, the RPH3 controller offers 2 different connection schemes to the switchgear coils : common mode and differential mode.

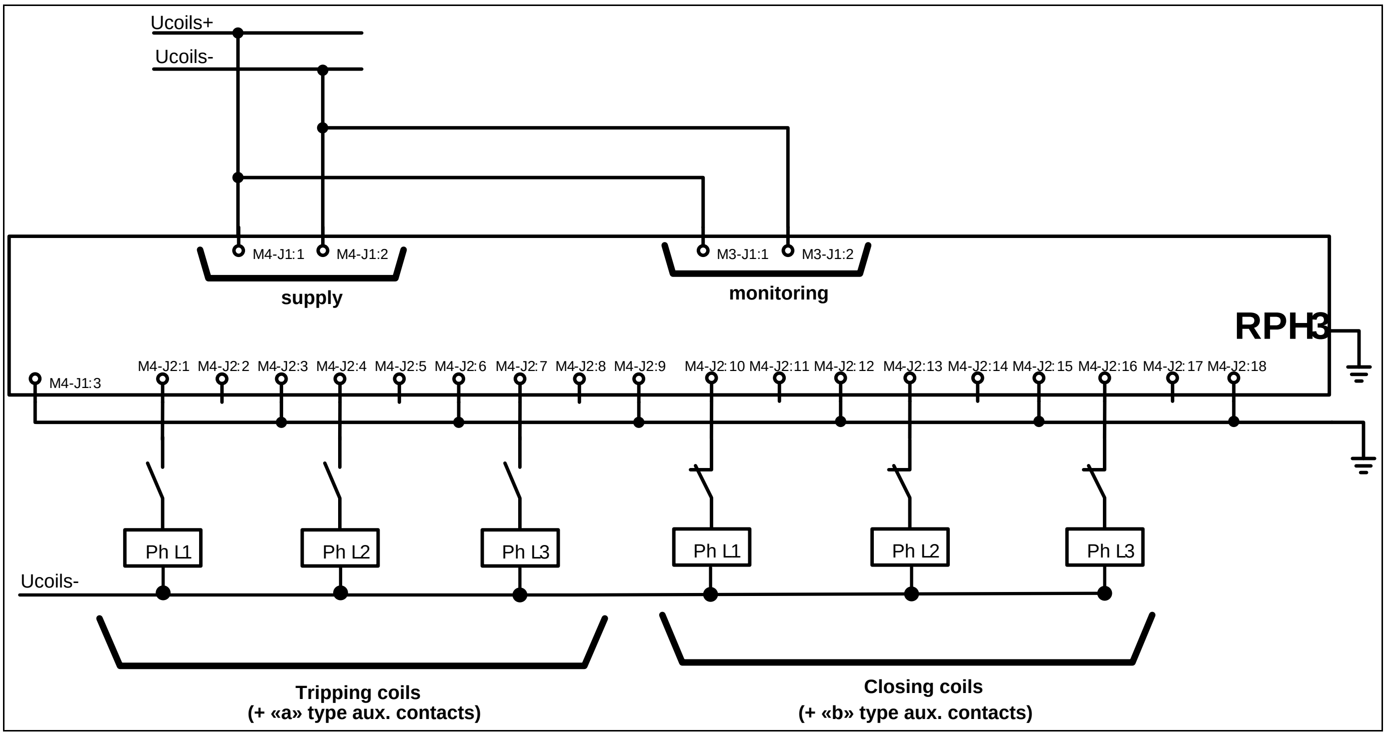


Figure 24 : CB coils driving outputs cabling : COMMON MODE scheme (switchgear in open position)

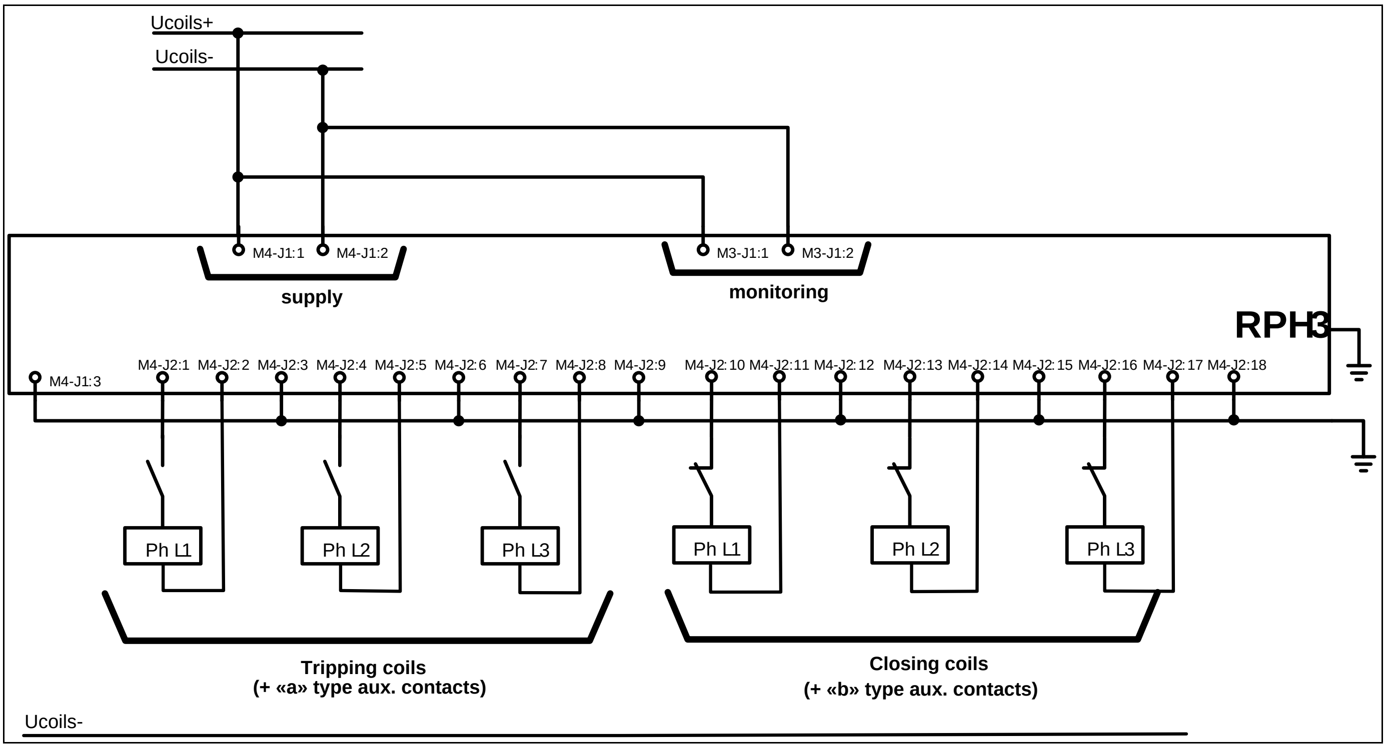


Figure 25 : CB coils driving outputs cabling : DIFFERENTIAL MODE scheme (switchgear in open position)

A software setting of the RPH3 controller must be set through the web MMI in accordance with the chosen connection scheme, as illustrated on Figure 26 below :

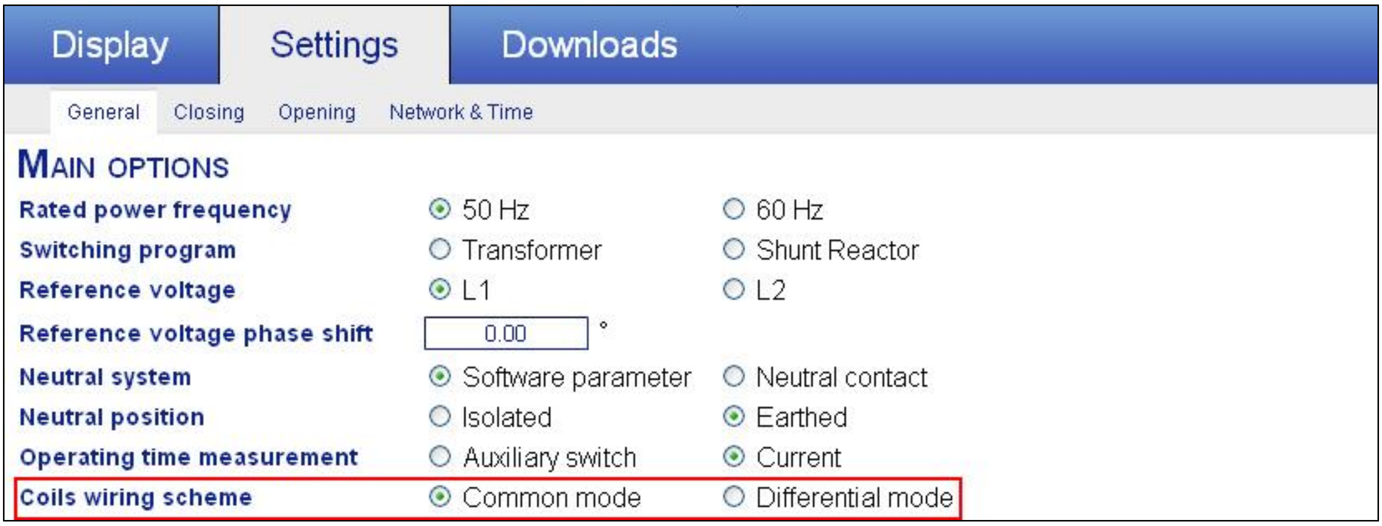


Figure 26 : web MMI : selecting the switchgear coils wiring scheme

Thanks to their design, each of these modules includes continuous diagnostic features on :

- MOSFET transistors health (ability or not to drive CB coils)
- Continuity check of CB closing and opening circuits

Thus the RPH3 controller is able to trig some system alarms in case of MOSFET failure or damaged coils, preventing undesired situations (e.g. poles discrepancy).

As shown on Figure 27 below, the results of these self-checks are accessible through the web MMI (they can also be configured for driving alarm output contacts : refer to section 3-7, page 71) :

Figure 27 : self-tests alarms (accessible from the web MMI)

NOTE 1 : all these system alarms are triggered by the RPH3 controller (as illustrated on the screenshot above) in case the DC voltage is present on M3-J1 connector (monitoring input) but not on M4-J1 connector (coil driving input). On the other hand all these alarms are kept quiet in case this DC voltage is present on M4-J1 connector, but not on M3-J1 connector. In such a situation, the RPH3 controller trigs a dedicated application alarm, as illustrated on below :

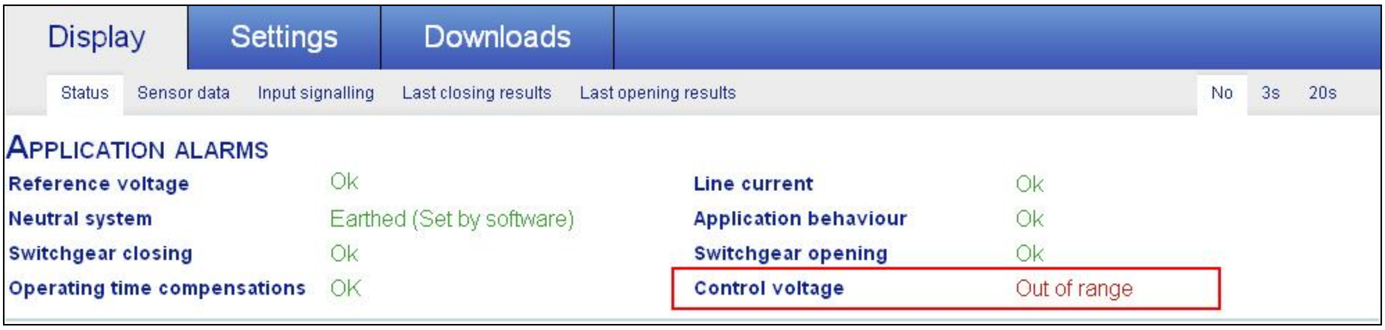


Figure 28 : control voltage alarm in case no DC voltage is present on M3-J1 RPH3 connector

Refer to section 3-7, page 71 for further description of this alarm.

NOTE 2 : the coil continuity monitoring feature as assumed by the RPH3 does not prevent the use of any other external coil monitoring device, **provided that the necessary precautions below are observed**.

- the total amount of current flowing through each coil must never be sufficient for driving unexpected CB operation (*activation* current) or preventing the coil latch to recover its idle position (*holding* current).
- an electrical separation must be ensured between all the monitoring devices, in order to prevent interactions between the RPH3 monitoring feature and external devices (e.g. use diodes / opto-isolators).
- the wiring scheme between RPH3 outputs and CB coils must be "COMMON MODE" (both in the RPH3 software setting and on the actual connection diagram).

In case ≥ 1 of these conditions is (are) not fulfilled : <u>**DO NOT use external device for coils continuity monitoring**</u>. Otherwise unexpected continuity alarms may appear.

<u>**NOTE 3 :**</u> whatever the duration of the tripolar input command impulse - provided it is long enough for being valid - the RPH3 issues 3 output impulses with a preset duration of 80 ms each, that may be adjusted by the end user (through the web MMI), as illustrated on the Figure 29 below.

<u>**NOTE 4 :**</u> the RPH3 web MMI offers a unique output impulse duration setting for each group of 3 unipolar output commands (1 group for closing commands + 1 group for tripping commands).
However, this duration may be set to different values for closing and tripping operations.

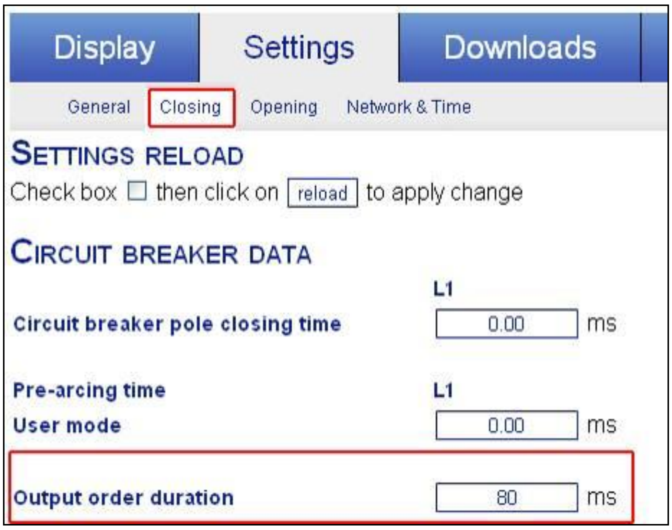


Figure 29 : duration adjustment for the 3 output closing command impulses

The RPH3 characteristics on these interface are given below :

Rated characteristics	Min	Typical	Max	Unit
M4-J1 connector (CB coils supply)	*MSTB 2,5/3-STF-5.08*			
input impedance	-	1100	-	kΩ
voltage amplitude (AC)	48	-	250	V
voltage amplitude (DC)	33	-	300	V
maximum current tied on this input (for 300 ms max)	-	-	30	A
Insulation level	2000	-	-	V
M3-J1 connector (CB coils supply voltage monitoring)	*MSTB 2,5/2-STF*			
input impedance	-	63	-	kΩ
Input voltage amplitude	48	-	250	V_{DC}
RPH3 power consumption on this input	-	-	2	VA
Insulation level	2000	-	-	V

3-4.6 Measuring switchgear operating times

The operating time of a given switchgear pole is defined as the amount of time between the instant its closing/tripping coil is being driven (impulse rising edge) and the date when the pole main contacts mechanically touch (closing operation) or separate (tripping operation). This is illustrated on the Figure 30 below :

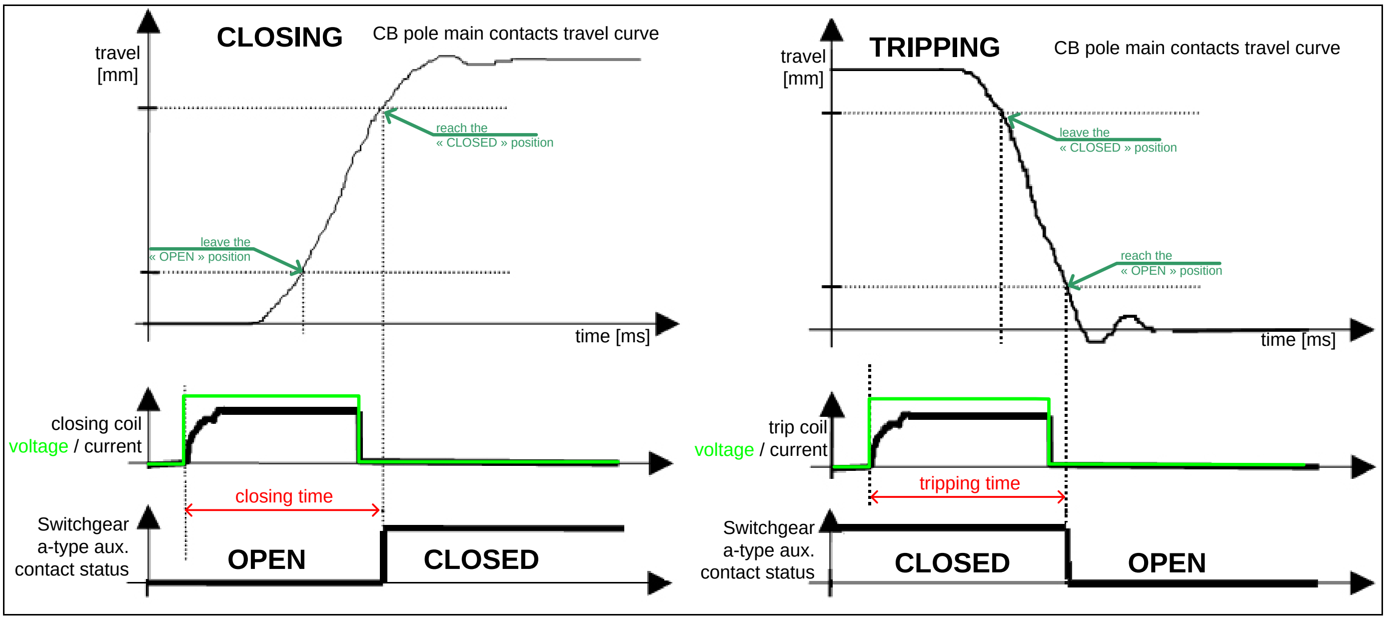


Figure 30 : operating times definition

Several parameters may affect the dynamic performances of a switchgear – and thus the operating time of its poles - from one operation to an other, among which :

- Ambient temperature
- CB coil supply voltage
- Hydraulic pressure inside the driving mechanism (if applicable)
- CBR idle time (amount of time between consecutive operations of hydraulic switchgears, if applicable)
- Unavoidable mechanical deviation (e.g. operation speed)
- etc.

The RPH3 controller shall take these parameters into account when assessing the applicable target points for a given CB operation (1 target point per pole), in order to ensure an efficient PoW synchronous switching.

Therefore, the RPH3 accurately measures the actual operating time on each pole during a CB operation, in order to compare it to the expected one, as forecasted by an internal algorithm :

$$t_{OP\_expected} = t_{OP\_rated} + \Delta t_{compensations} + \Delta t_{adaptive\_control}$$

$$\Delta t_{OP} = \left| t_{OP\_expected} - t_{OP\_measured} \right|$$

where :

- $t_{OP\_expected}$ is the expected operating time of the pole, as forecasted by the RPH3
- t_{OP_rated} is the nominal operating time of the pole (software setting through the web MMI as shown on the Figure 31 below, adjusted at RPH3 commissioning)

- $\Delta t_{compensations} + \Delta t_{adaptive\_control}$ is the amount of extra time (that may be < 0) due to the influence of these specific parameters. Refer to sections 3-5 (page 54) for further details.
- $t_{OP\_measured}$ is the actual operating time of the pole, as measured during a CB operation
- Δt_{OP} is the absolute time shift between $t_{OP\_expected}$ and $t_{OP\_measured}$.

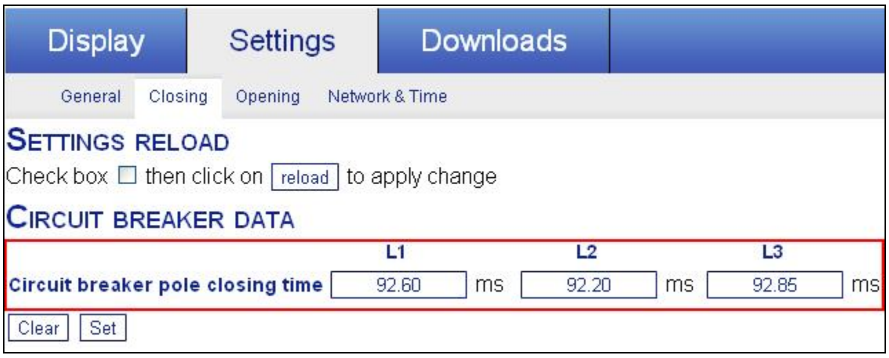


Figure 31 : setting CB rated operating times (web MMI)

Since it cannot access the switchgear main contacts directly (which are under high voltage), the RPH3 controller offers 2 different methods for measuring operating times :

- detection of the CB auxiliary contacts switching instants (interface M4-J6)
- detection of the HV current establishment / interruption instants inside the pole interrupting chamber(s) thanks to external current transformers (interface M3-J4).

The end user can choose his preferred method thanks to a software setting in the web MMI :

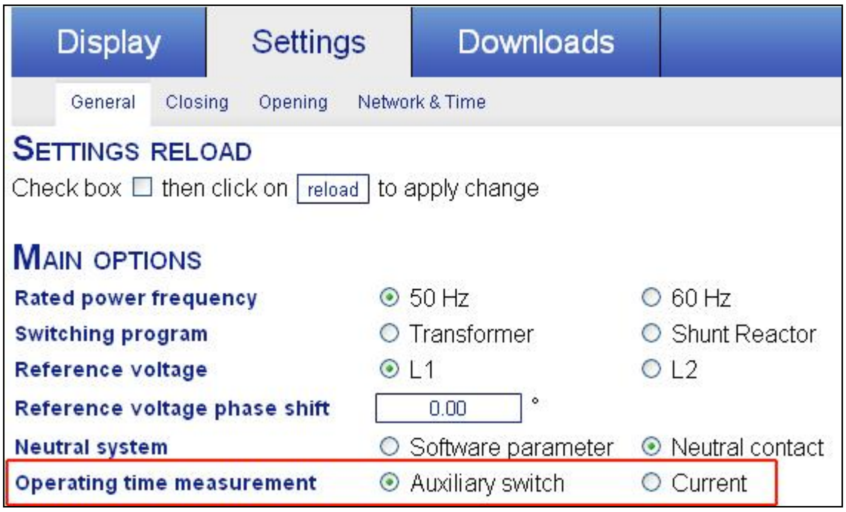


Figure 32 : web MMI : choosing the preferred method for operating times measurement

However both methods are used by the RPH3 through parallel measurement processes, so that in case one fails (leading an irrelevant value of ΔT_{OP}) the result of the other one is automatically considered for further treatments.

<u>**NOTE 1 :**</u> in case the method that failed was not the preferred one, the RPH3 trigs no alarm that is visible for the end user. However if the preferred method failed, the RPH3 trigs an application alarm (either "switchgear closing alarm" or "switchgear opening alarm" : refer to section 3-7, page 71) and considers the result of the alternative method (if valid) for assessing ΔT_{OP}.

NOTE 2 : whichever the selected method, $T_{OP\_measured}$ is compared by the RPH3 to an allowed range (to be adjusted through the web MMI as shown on the Figure 33 below).

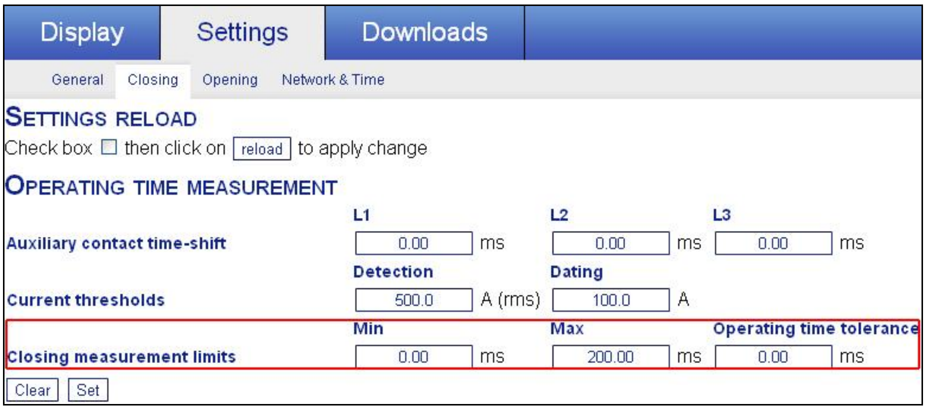


Figure 33 : operating time validity range and tolerance

Following each CB operation, the obtained values of $T_{OP\_measured}$ and ΔT_{OP} are tested for each pole by their fulfilment of the conditions below :

- $Min \leq T_{OP\_measured} \leq Max$
- $\Delta T_{OP} \leq tolerance$

As soon as ≥ 1 of these conditions is not fulfilled an application alarm is trigged by the RPH3 as shown on the Figure 34 :

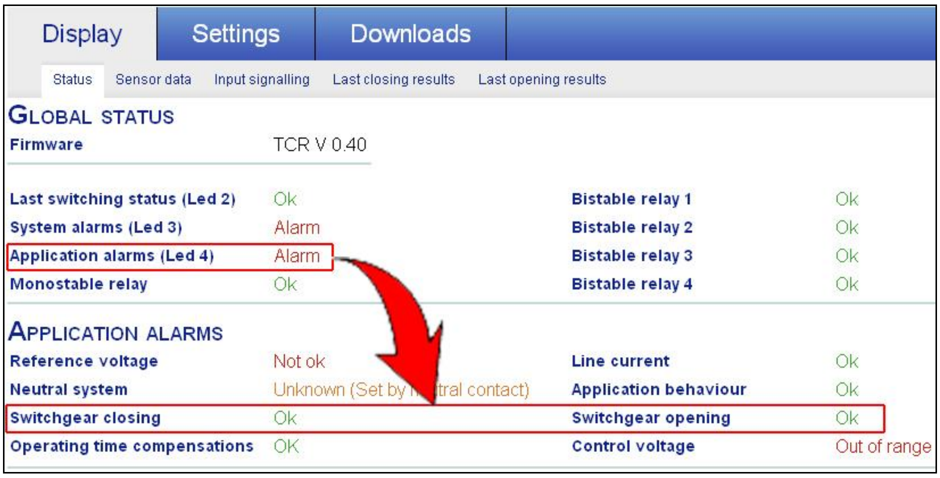


Figure 34 : alarm trigged in case of an out-of-range measured operating time

3-4.6-1 Measurement method #1 : monitoring the CB auxiliary contacts (a-type)

The RPH3 controller provides an interface connector (M4-J6) to the switchgear auxiliary contacts (a-type) :

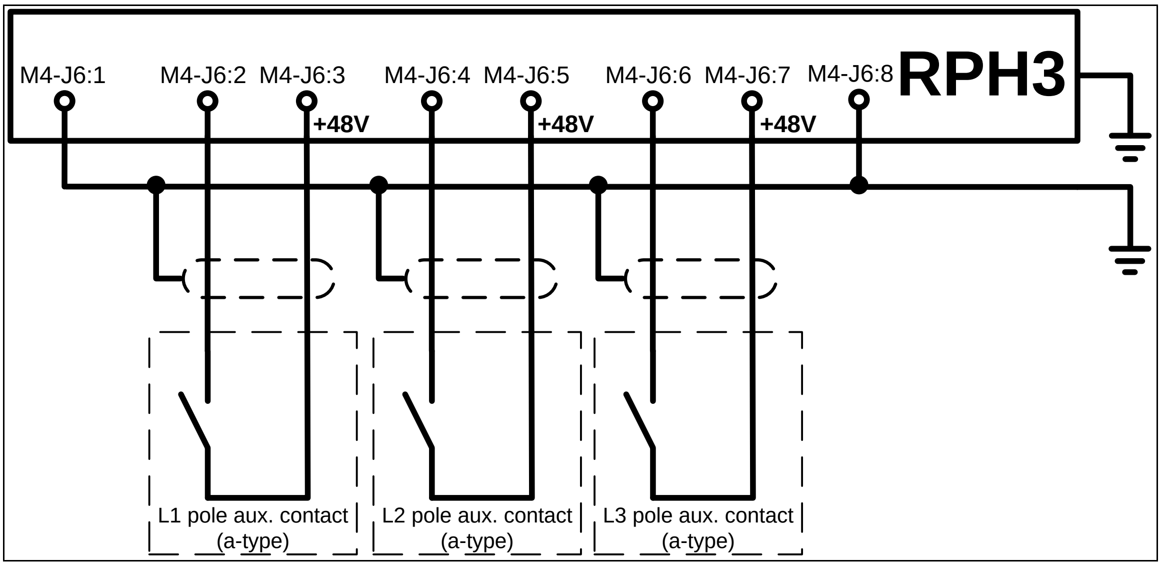


Figure 35 : switchgear auxiliary contacts connection

The RPH3 continuously delivers a +48V DC voltage for auxiliary contacts biasing (pins M4-J6:3/5/7).

According to the status of the monitored switchgear interruptor (fully closed or opened), the associated auxiliary contact (a-type) is either closed or opened so that the biasing voltage is present or not on the RPH3 dedicated input terminal (M4-J6:2, 4 or 6).

In order the RPH3 to assess the pole main contacts touching / separating instant during a CB operation, it arithmetically adds a time-shift ($\Delta_{main \rightarrow aux}$ in ms) to the auxiliary contact status changing instant (input voltage rising or falling edge), as illustrated on the Figure 36 below :

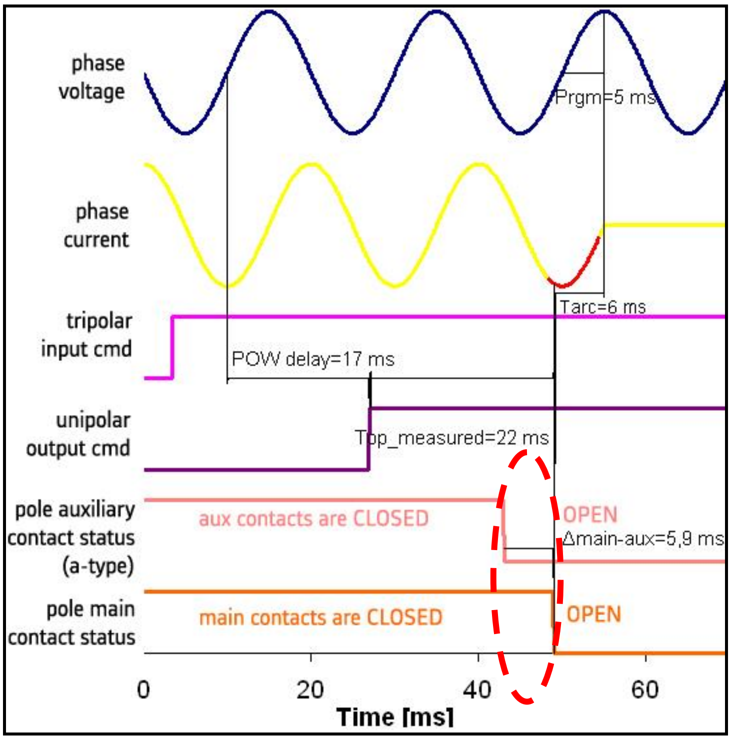


Figure 36 : auxiliary time shift definition

The value of this "auxiliary time-shift" $\Delta_{main \rightarrow aux}$ depends on the switchgear characteristics. It shall be measured several times on each CB pole separately, in usual site conditions (outside temperature).
The average value between these measurements shall be set in the RPH3 configuration settings through the web MMI, as illustrated below :

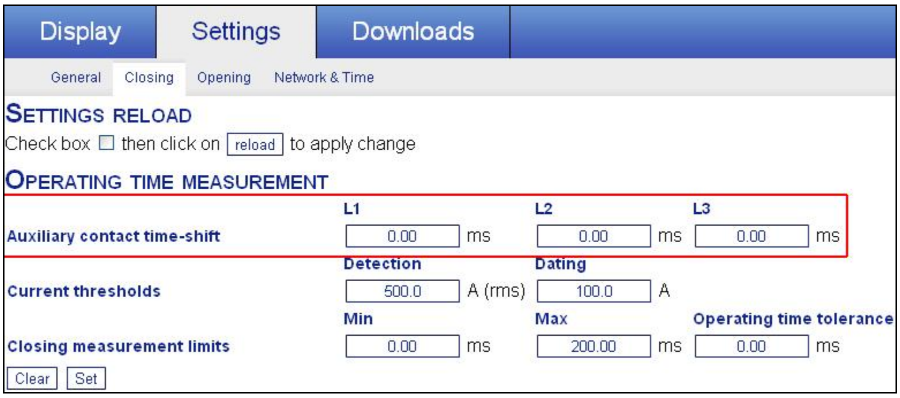


Figure 37 : auxiliary contacts time-shift adjustment

NOTE 1 : this time-shift is considered constant by the RPH3, whatever the temperature conditions and CB drive mechanism aging.

NOTE 2 : during CB tripping operations, the auxiliary contact of a given pole shall open BEFORE the main contacts mechanically separate ($\Delta_{main \rightarrow aux} > 0$), whereas it shall close slightly AFTER the main contacts mechanically touch during CB closing operations ($\Delta_{main \rightarrow aux} < 0$). However, only unsigned (positive) values shall be entered into the web MMI boxes.

3-4.6-2 Measurement method #2 : monitoring HV currents

The RPH3 controller offers an alternative method for measuring the operating times of switchgear poles, consisting in measuring the HV current flowing through its main contacts, in order to detect the interruption / establishment instant thanks to a waveform analysis.

This analysis is based on a continuous RMS assessment of the AC current before/after the pole operation and an instantaneous threshold crossing detection, as illustrated on the Figure 38 below :

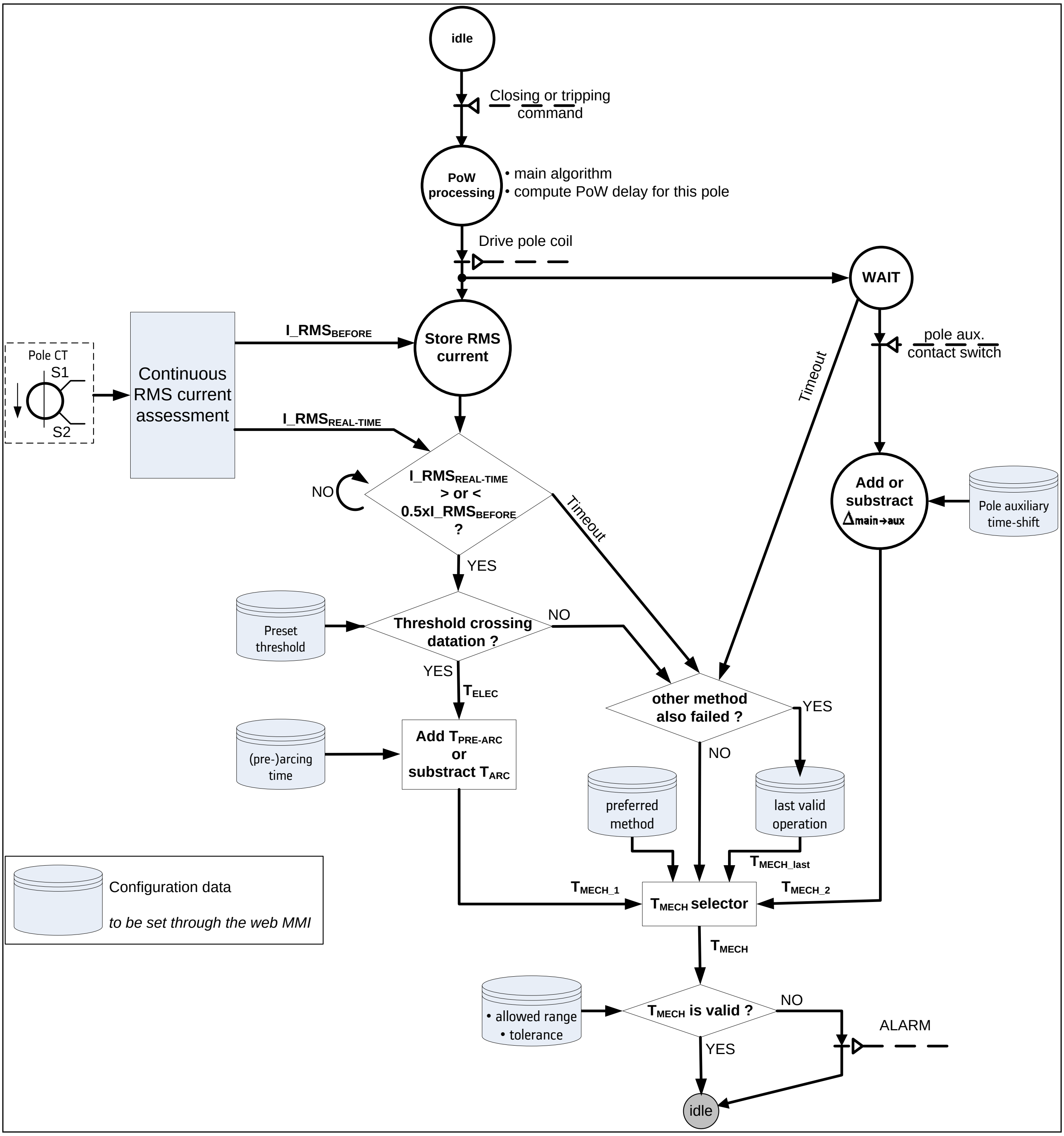


Figure 38 : operating time measurement

During a pole closing operation : as soon as the RMS current rises up above the preset “detection threshold” I_{RMS_TH}, the current initiation event is dated when its instantaneous value crosses the preset “dating threshold” I_{TH}, as illustrated on the Figure 39 below.

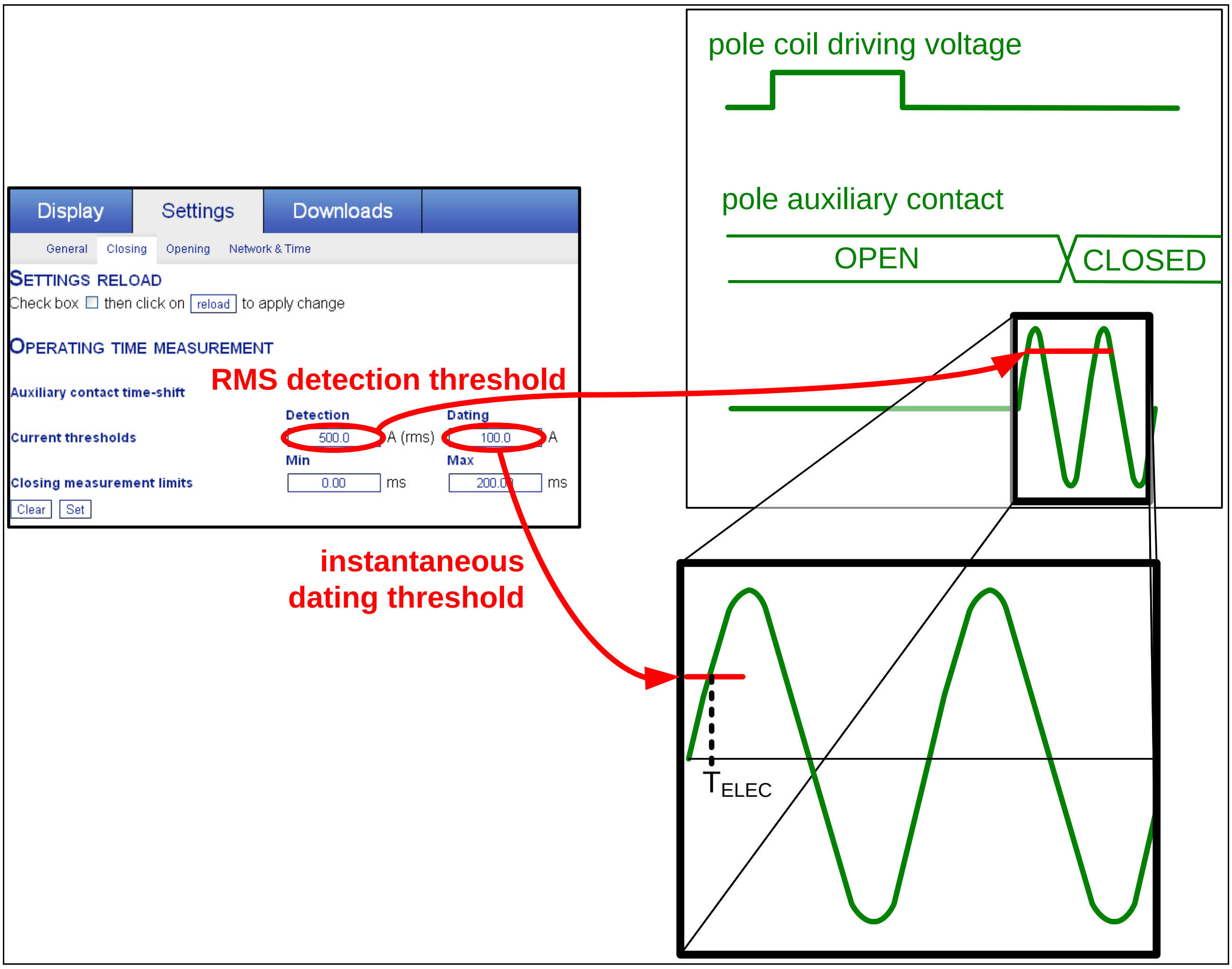


Figure 39 : waveform analysis for dating current initiation : example for a pole closing operation

In the same way during a tripping operation : as soon as the RMS current falls down below I_{RMS_TH}, the current interruption event is dated when its instantaneous value crosses I_{TH}.

Both of these thresholds shall be adjusted through software settings (web MMI) :

- 1 pair of thresholds for closing operations
- 1 pair of thresholds for tripping operations

The same thresholds apply to each pole. Recommended values are given below :

$0.3 \leq \frac{I_{RMS\_TH}}{I_{RATED}} \leq 0.5$	$0.1 \leq \frac{I_{TH}}{I_{PEAK}} \leq 0.2$

Table 3 : recommended values for current thresholds (operating times measurement method #2)

3-4.7 Sampling HV currents

The RPH3 controller shall be connected to external measurement CTs (Current Transformers) through its dedicated interface (M3-J4 connector + safety socket).

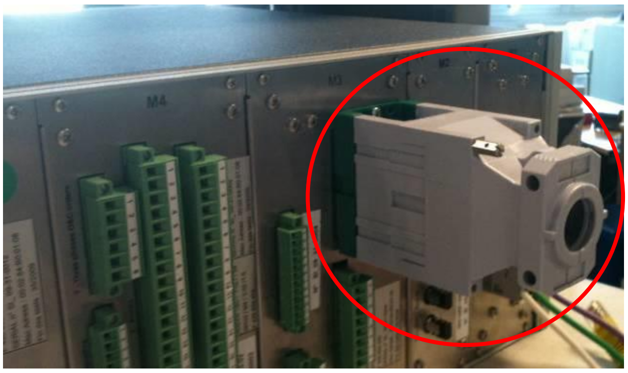


Figure 40 : safety socket on M3-J4 interface

These measurement CTs shall be wound around the 3 HV phases, as illustrated below :

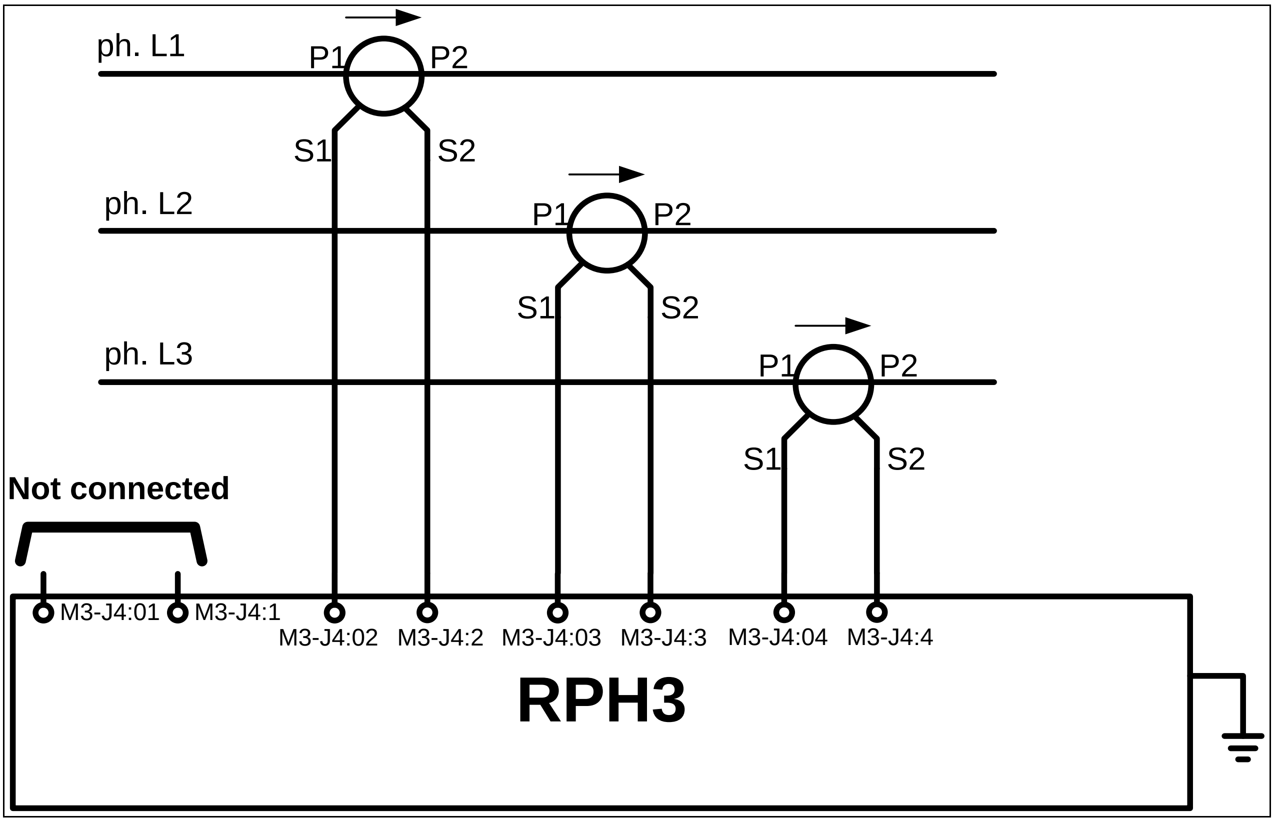


Figure 41 : HV current measurement interface

Recommended measurement CTs shall be accurate (recommended precision class : 0.5 / 1 / 3), suitable for 50/60 Hz applications, and have a nominal output current (secondary winding) of either 1 A or 5 A (output power ≈ 5 VA).

For safety reasons it is important to prevent maintenance people from spurious overvoltages that may appear across CT terminals during secondary winding disconnection. This safety socket ensures to short circuit CT secondary winding at disconnection, so that such overvoltages cannot appear.

The current transforming ratio shall be known by the RPH3 controller, so that it can assess the actual HV current flowing through each switchgear pole.
These settings shall be adjusted by the user at RPH3 commissioning through the web MMI, as illustrated below :

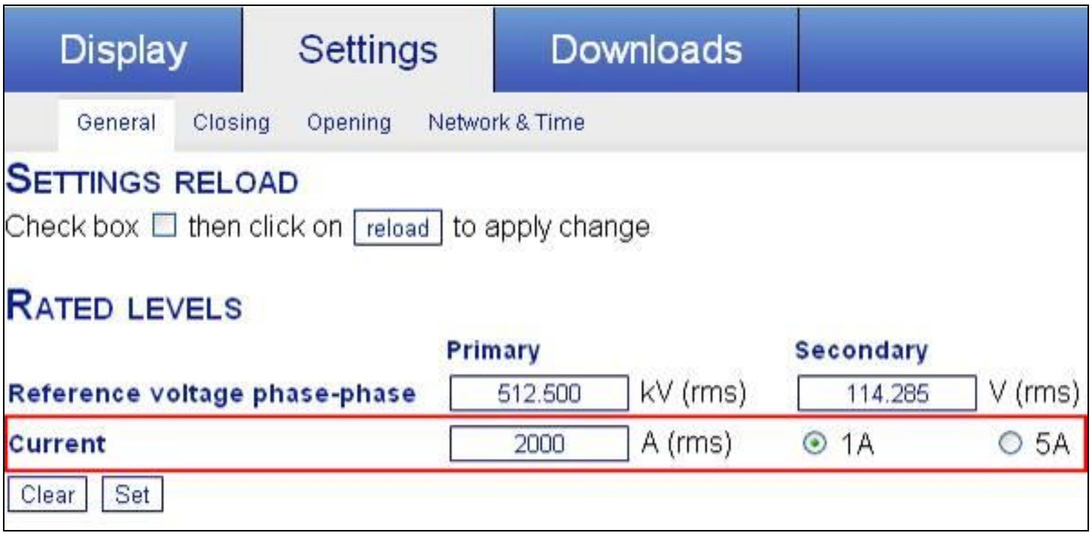


Figure 42 : current transforming ratio settings (web MMI)

Thanks to this transforming ratio, the RPH3 controller is able to assess the instantaneous current on each pole during a switchgear operation and continuously compare it to a preset threshold, to be adjusted through the web MMI as illustrated on Figure 43 below :

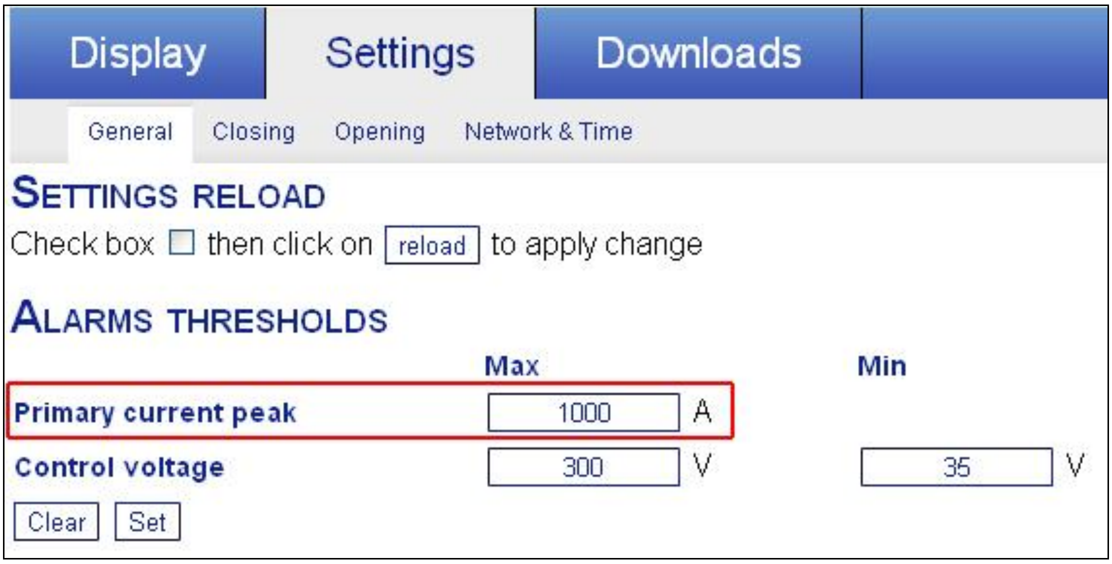


Figure 43 : instantaneous HV current threshold adjustment (web MMI)

In case this current exceeds the preset threshold, the RPH3 controller trigs an alarm and keeps it active until the next operation command is received :

Figure 44 : instantaneous HV current alarm (web MMI)

For E&C purposes, the RPH3 additionally offers a "real-time" monitoring feature of the HV currents through its web MMI, as illustrated below :

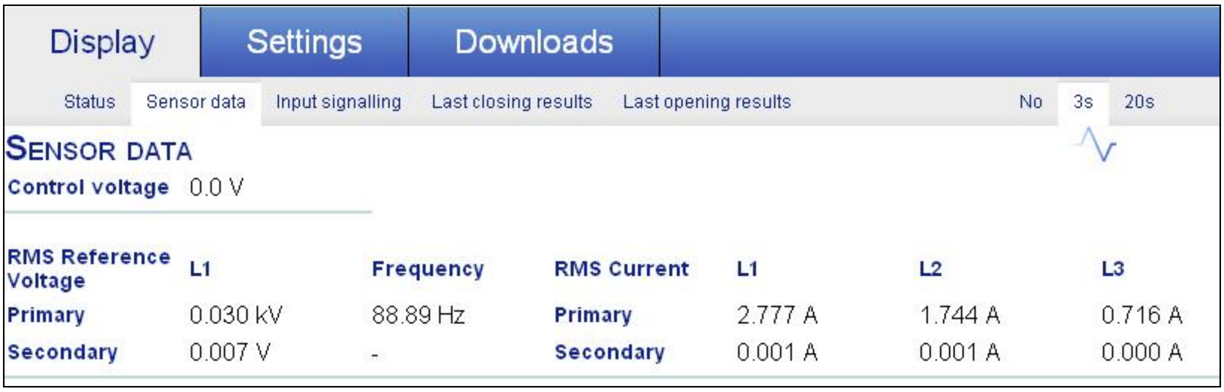


Figure 45 : "real-time" monitoring of HV currents for E&C purposes

The RPH3 characteristics on this interface are given below :

Rated characteristics	Min	Typical	Max	Unit
M3-J4 connector	*MSTB 2,5/3-STF-5.08*			
differential input impedance (between S1 and S2 connection terminals)	0	0	0.1	Ω
current amplitude	-	1 or 5	-	A
RPH3 power consumption on this input	-	5	-	VA
Insulation level	2000	-	-	V

3-4.8 Sampling HV line voltages

The RPH3 controller may sample the 3 HV line voltages thanks to dedicated VTs, primary windings of which shall be connected to the switchgear terminals on the side where the circuit elements to be (de-)energized are located. Although it is not requested for TCR applications, this connection is mandatory for line switching applications, in order the RPH3 to be able to assess the beating voltage across each switchgear pole on re-closing operations (refer to section 4-5 page 116 for further details).

AC voltages as delivered by these VTs are real-time images of the system 3 phase voltages.

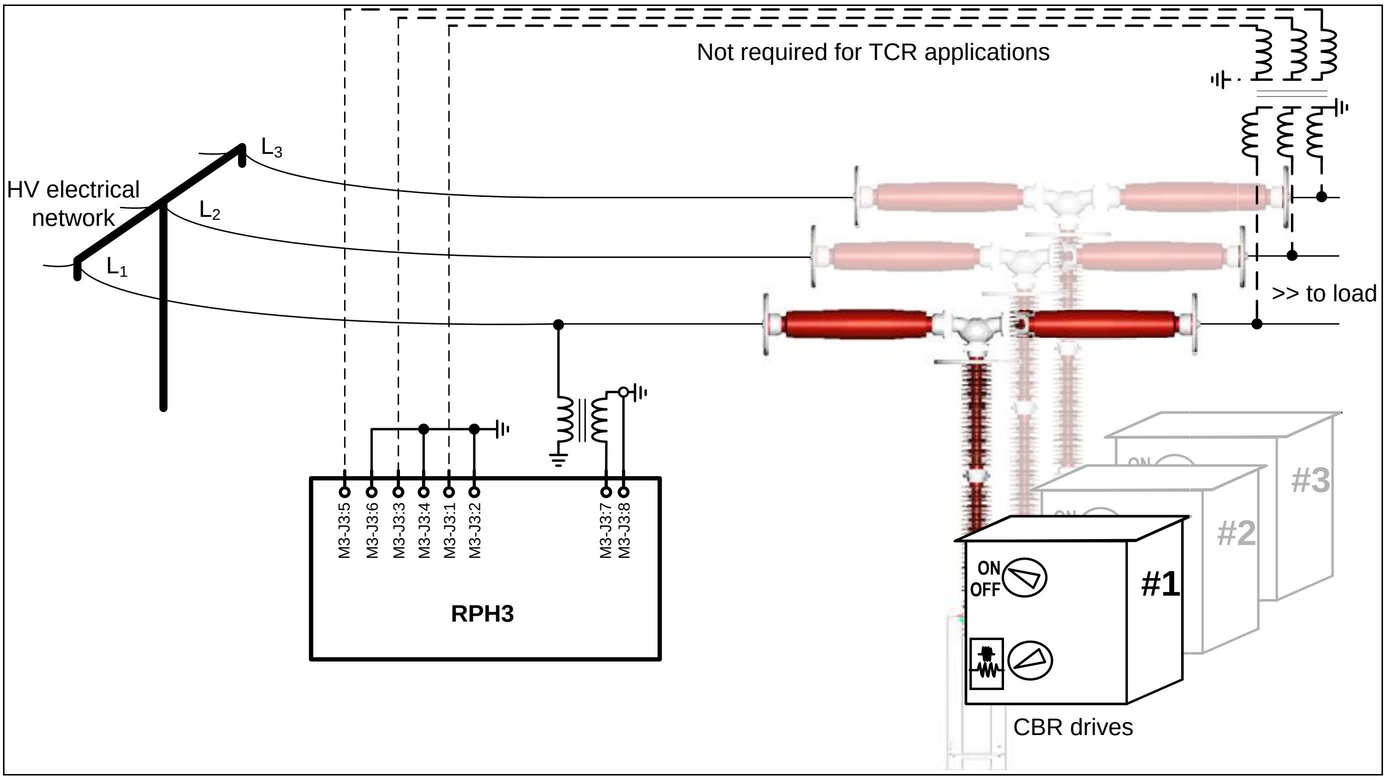


Figure 46 : connecting HV line voltages interface

<u>NOTE1 :</u> the VTs shall be chosen so that the nominal RMS voltage across their secondary windings (connected to the RPH3) is either 100V/√3 (option VT100) or 220V/√3 (option VT220).

<u>NOTE2 :</u> For line switching applications (firmware "RPH3-L"), the VT transforming ratios shall be adjusted by a software setting (through the web MMI) as illustrated below :

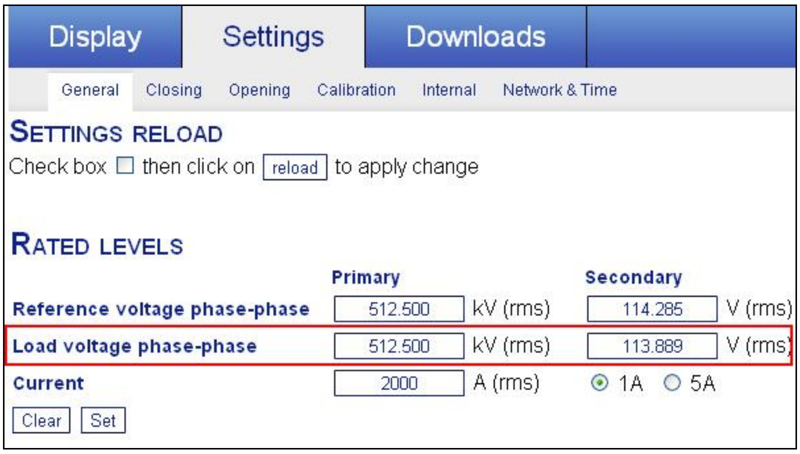


Figure 47 : VT transforming ratio setting for HV line voltages

<u>**NOTE3 :**</u> For commissioning and maintenance purposes, the actual voltage levels are accessible through the web MMI (authorized access levels only) :

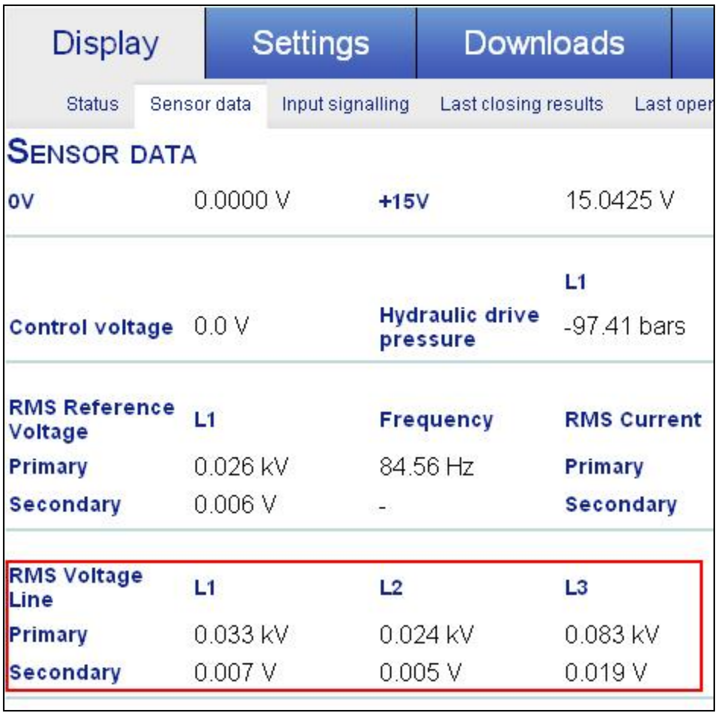


Figure 48 : HV line voltages measurements

RPH3 characteristics on this interface are given below :

Rated characteristics	Min	Typical	Max	Unit
M3-J3 connector	*MSTB 2.5/8-STF-5.08*			
input impedance	-	8	-	kΩ
frequency	20	-	60	Hz
input voltage (option VT100)	15	100/√3	150	Vrms
input voltage (option VT220)	30	220/√3	330	Vrms
RPH3 power consumption on this input	-	-	2	VA
Insulation level	2000	-	-	V
Measurement error	-	-	1	%

3-5 Compensation of switchgear operating times

3-5.1 Overall principle

The operating time of each CB pole during openings and closings are significantly dependant on several factors :

- ambient temperature
- CB coils supply voltage
- Hydraulic pressure (for CB with hydraulic driving mechanisms)
- CB idle time (amount of time between 2 successive CB operations – for hydraulic CBs only)
- Other factors (drive dynamic performances, aging, etc.)

When processing a CB operation command, the RPH3 shall take these factors into account while forecasting the expected operating time on each CB pole, in order to ensure HV current establishment / interruption at target dates :

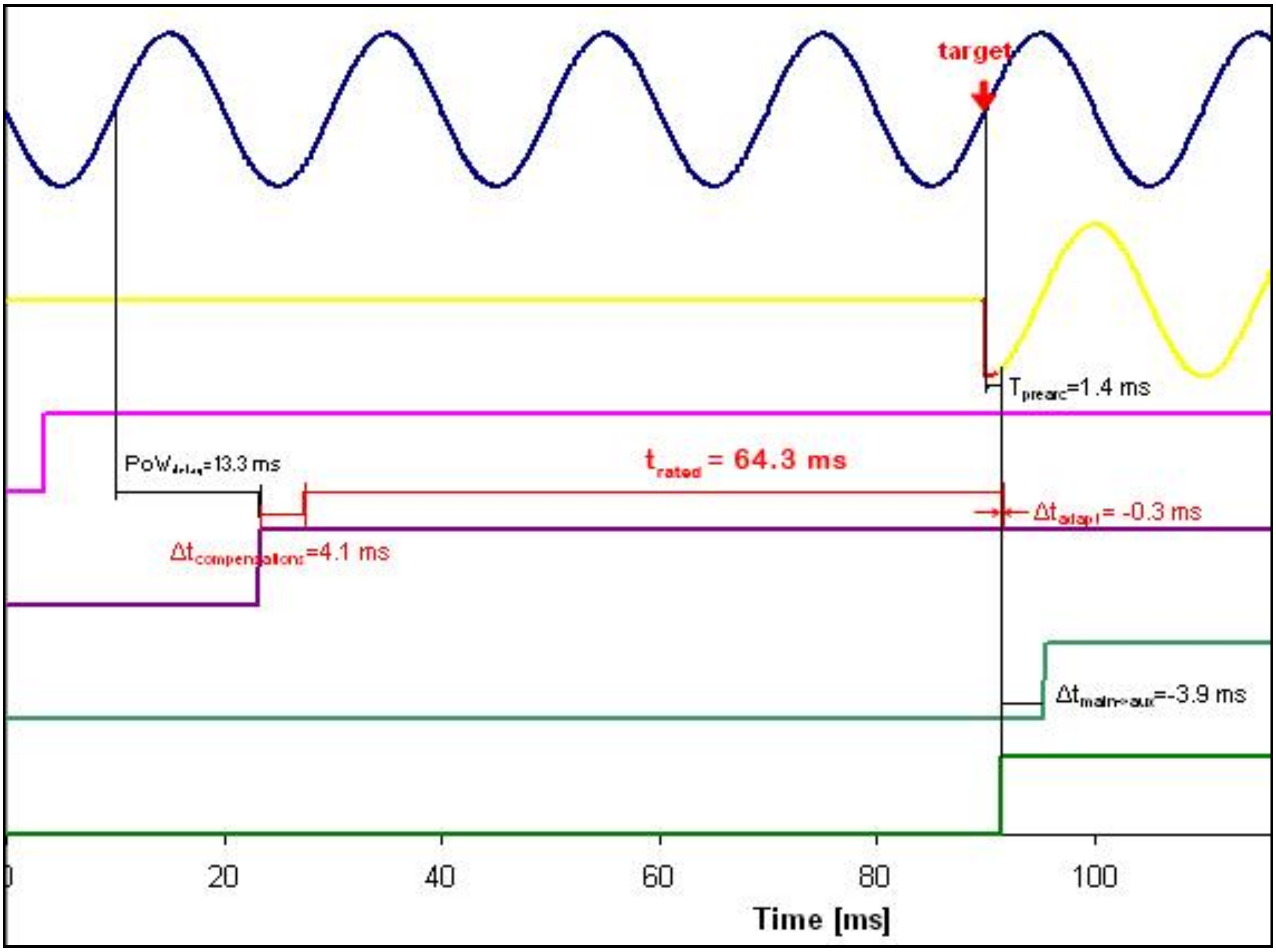


Figure 49 : compensations : example on a closing operation

$$t_{operation} = t_{rated} + \Delta t_{compensations} + \Delta t_{adapt}$$

where :

- $t_{operation}$ = expected operating time of the concerned CB pole, as forecasted by the RPH3 controller
- t_{rated} = operating time of the pole as measured on site during CB commissioning in conditions as close as possible to rated conditions (temperature = 20°c, coil voltage = U_{rated}, hydraulic pressure = P_{rated}, etc.)
- $\Delta t_{compensations}$ = sum of the time compensations due to factors that the RPH3 can measure / assess and that follow linear compensation laws :
    - ambient temperature
    - CB coils supply voltage
    - Hydraulic pressure (for CB with hydraulic driving mechanisms)
    - CB idle time (amount of time between 2 successive CB operations – for hydraulic CBs only)
- $\Delta t_{adaptive\_control}$ = sum of the time compensations due to all other factors that cannot be measured by independent processes or follow stochastic compensation laws (CB aging, etc.).

Each of these contributions to the overall compensation time of a given pole operation can be independently enabled or disabled through a software setting in the web MMI :

Figure 50 : compensation contributions enabling / disabling

The following sections describe how these different contributions are assessed by the RPH3 controller.

3-5.2 Contribution of the ambient temperature

For outdoor applications, ambient temperature may significantly impact the switchgear performance : in a global approach CBs are slower at low temperatures.

3-5.2-1 Compensation law

For each kind of operation (CB closing and CB tripping) the RPH3 controller embeds a table of 11 values of compensation time indexed by temperatures (10°C steps), that shall be adjusted through the RPH3 web MMI during commissioning (access level ≥ Supervisor), as illustrated below :

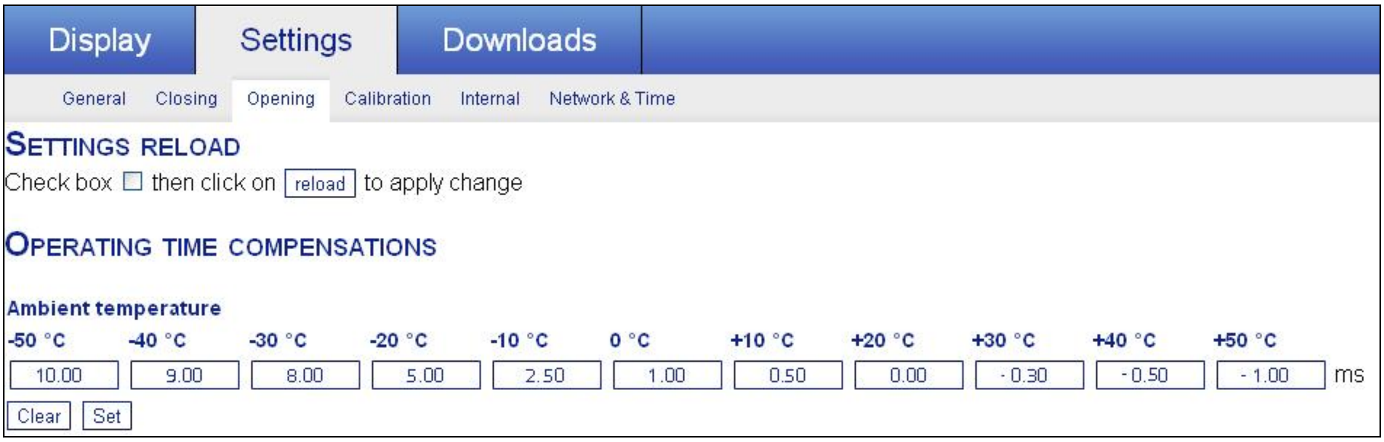


Figure 51 : temperature compensation table setting in the web MMI (access level ≥ Supervisor)

This table gives the contribution (in ms) of the pole operating time compensation for a given ambient temperature, thanks to a linear interpolation between 2 adjacent points on the curve below :

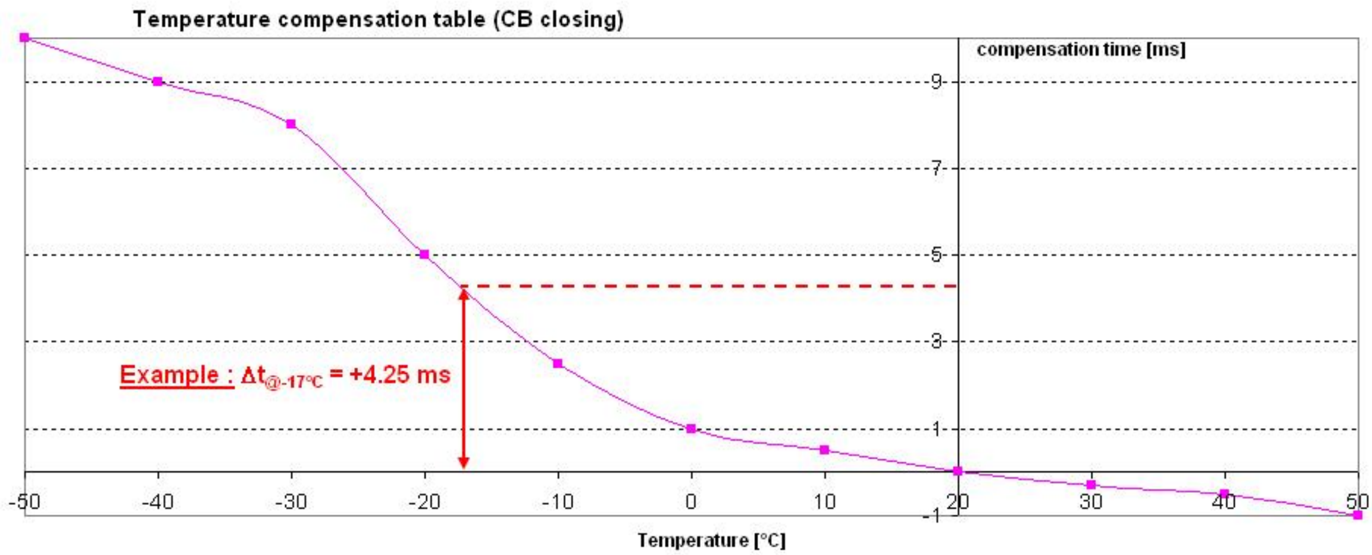


Figure 52 : temperature compensation characteristic (linear interpolation) : example for closing operations

NOTE : the compensation tables may be filled with different values for opening and closing operations

3-5.2-2 Measuring the ambient temperature

The RPH3 continuously samples the ambient temperature thanks to a dedicated sensor that shall be installed outside, in a location with no direct exposure to sun beams or wind. The sensor is to be supplied by the RPH3 itself (+24V_{DC} output).

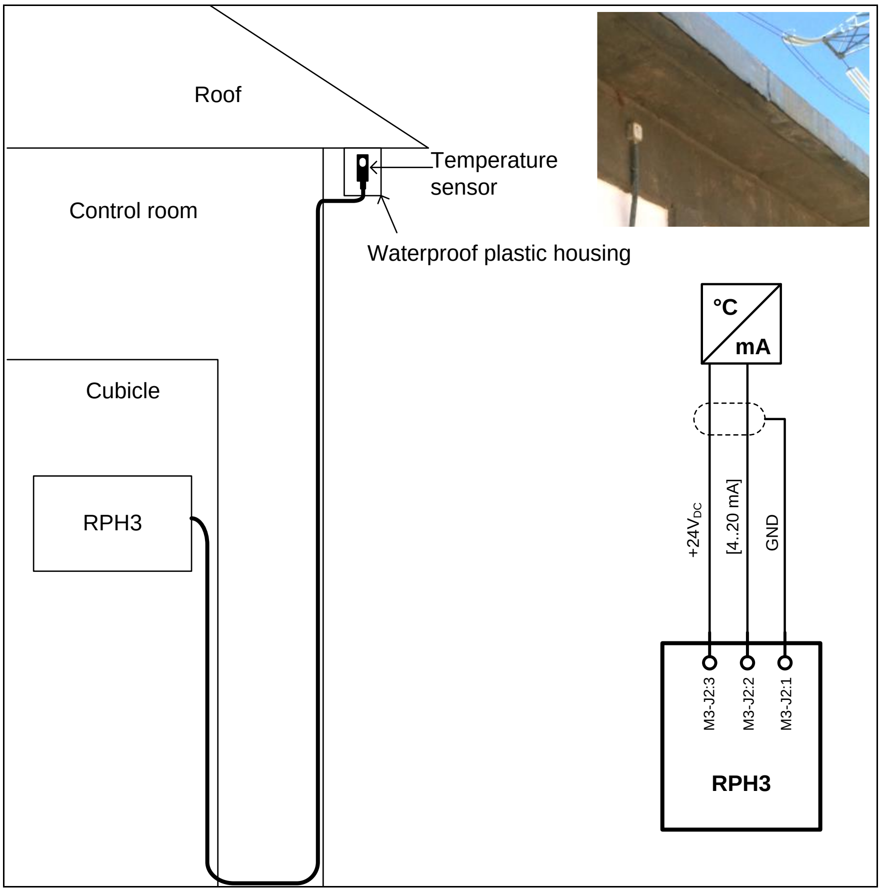


Figure 53 : typical installation of the ambient temperature sensor

Any kind of temperature sensor might be installed, provided that its interface to the RPH3 is a standard [4…20 mA] (+24V) analogue signal. The scaling factors shall be adjusted through the web MMI :

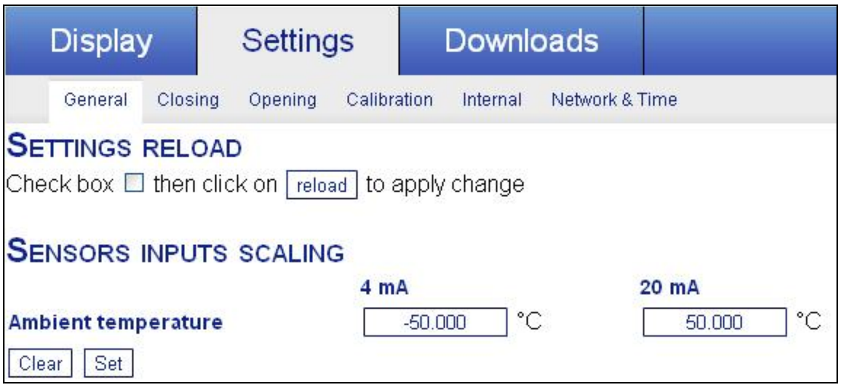


Figure 54 : web MMI : adjusting the temperature sensor scaling factors (access level ≥ Supervisor)

RPH3 characteristics on this interface are given below :

Rated characteristics	Min	Typical	Max	Unit
M3-J2 connector	*MC 1,5/12-STF-3.5*			
input impedance (pins 2:1)	99	100	101	Ω
input impedance (pins 2:3, pins 1:3)	16	-	-	kΩ
sensor supply voltage	-	24	-	V_{DC}
input current (as delivered by the sensor)	-	[4...20]	-	mA
output power (as delivered to the sensor)	-	-	2	VA
Measurement error	-	-	3	%

3-5.3 Contribution of the CBR control voltage

Switchgear actuators are usually made of coils driving a mechanism thanks to magnetic forces (Lenz law) : the mechanical load is proportional to the current square. Since the rising rate of the current is U/L - where L is the coil inductance and U the control voltage as applied to the coil – any change on the voltage level directly impacts the mechanical load, and hence the operating time. This influence is compensated by the RPH3 controller.

3-5.3-1 Compensation law

For each kind of operation (CB closing and CB tripping) the RPH3 controller computes $\Delta t_{voltage}$ as an amount of time to be added to the nominal expected operating time of a switchgear pole thanks to the below formula :

$$\Delta t_{voltage} = \left(\frac{U_{rated}}{U_{meas}} - 1 \right) .kU.Top_{rated}$$

where :

- U_{rated} = rated level of the coils supply voltage (software setting in the web MMI)
- U_{meas} = actual level of the coils supply voltage, as sampled by the RPH3 controller at the time it received the operation command impulse.
- Top_{rated} = rated operating time of the concerned CB pole, as measured under nominal conditions at $U = U_{rated}$ during a CB operation <u>of the same nature</u> (i.e. during a CB opening operation in case of an open command, or a CB closing operation otherwise).
- kU = compensation factor as a percentage (software setting in the web MMI).

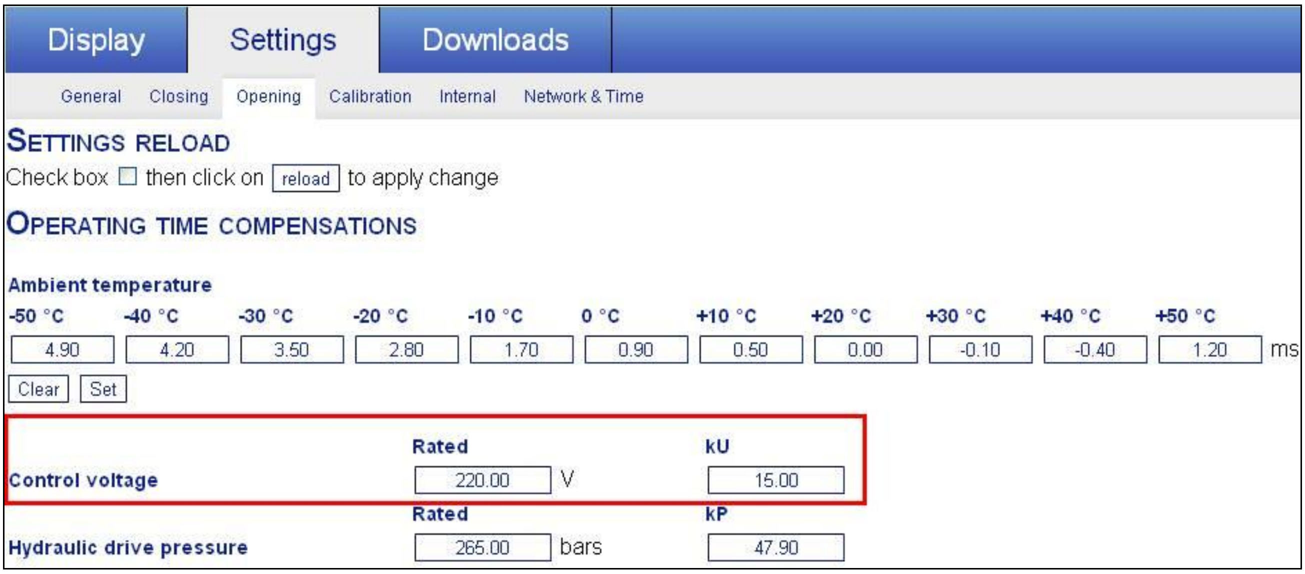


Figure 55 : web MMI : voltage compensation settings

For information, kU shall be assessed during commissioning (or switchgear type tests) as :

$$kU[\%] = \frac{(Top)_{U_{low}} - (Top)_{U_{rated}}}{\left(\frac{U_{rated}}{U_{low}} - 1\right).(Top)_{U_{rated}}}.100$$

Where :

- $\{(Top)_{U_{rated}}; U_{rated}\}$ is the nominal operating point of the concerned pole (coils voltage = U_{rated})
- $\{(Top)_{U_{low}}; U_{low}\}$ is an other operating point of the same pole, obtained while coils are supplied with a voltage lower than U_{rated} (all other parameters being the same i.e. ambient temperature, hydraulic pressure, etc.)

<u>NOTE :</u> the kU factor may be set to different values for opening and closing operations

Example of kU assessment for closing operations : case of T155-2 CB fitted with an hydraulic drive

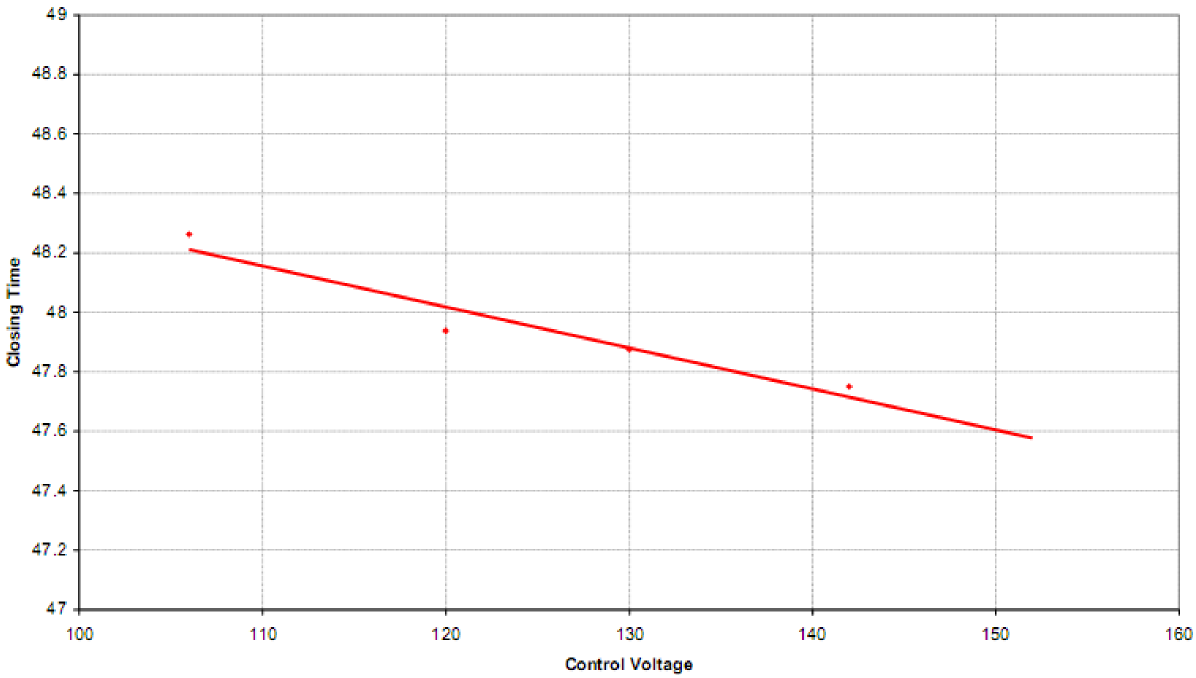


Figure 56 : coils supply voltage compensation characteristic

- Operating point #1 (measurement under rated conditions) : $\left\{(Top)_{Urated} = 47.9ms; U_{rated} = 125V\right\}$
- Operating point #2 (rated conditions + low voltage) : $\left\{(Top)_{Ulow} = 48.3ms; U_{low} = 100V\right\}$

➔ Voltage compensation factor :

$$kU = \frac{48.3 - 47.9}{\left(\frac{125}{100} - 1\right).47.9} = 3.3\%$$

3-5.3-2 Sampling the CBR coils supply voltage

The RPH3 controller (module M3) is able to measure by itself the coils supply voltage. No additional equipment is required, as illustrated below :

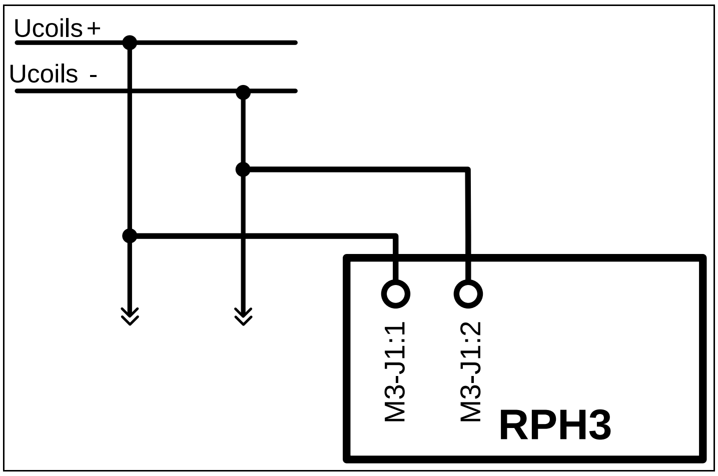


Figure 57 : connecting coils supply voltage monitoring interface

The RPH3 characteristics on this interface are given below :

Rated characteristics	Min	Typical	Max	Unit
M3-J2 connector		*MSTB 2,5/2-STF*		
input impedance	-	63	-	kΩ
input voltage amplitude	48	-	250	V_{DC}
RPH3 power consumption on this input	-	-	2	VA
Insulation level	2000	-	-	V
Measurement error	-	-	3	%

3-5.4 Contribution of the hydraulic pressure

The operating time of a switchgear pole is directly dependent on the amount of energy available in its driving system during the concerned operation.
Therefore, spring based mechanism are designed for operating at constant energy (proportional to the spring charge square, which is a geometrical parameter), whereas the energy available in hydraulic drives accumulators may not be the same from one operation to an other.

Hence the RPH3 controller shall continuously measure the hydraulic pressure via external sensors and assess its contribution for operating time compensation.

3-5.4-1 Compensation law

For each kind of operation (CB closing and CB tripping) the RPH3 controller computes $\Delta t_{pressure}$ as an amount of time to be added to the nominal expected operating time of a switchgear pole thanks to the below formula :

$$\Delta t_{pressure} = \left(\frac{P_{rated}}{P_{meas}} - 1 \right) .kP.Top_{rated}$$

where :

- P_{rated} = rated level of the hydraulic pressure (software setting in the web MMI)
- P_{meas} = actual level of the hydraulic pressure, as sampled by the RPH3 controller at the time it received the operation command impulse.
- Top_{rated} = rated operating time of the concerned CB pole, as measured under nominal conditions at $P = P_{rated}$ during a CB operation <u>**of the same nature**</u> (i.e. during a CB opening operation in case of an open command, or a CB closing operation otherwise).
- kP = compensation factor as a percentage (software setting in the web MMI).

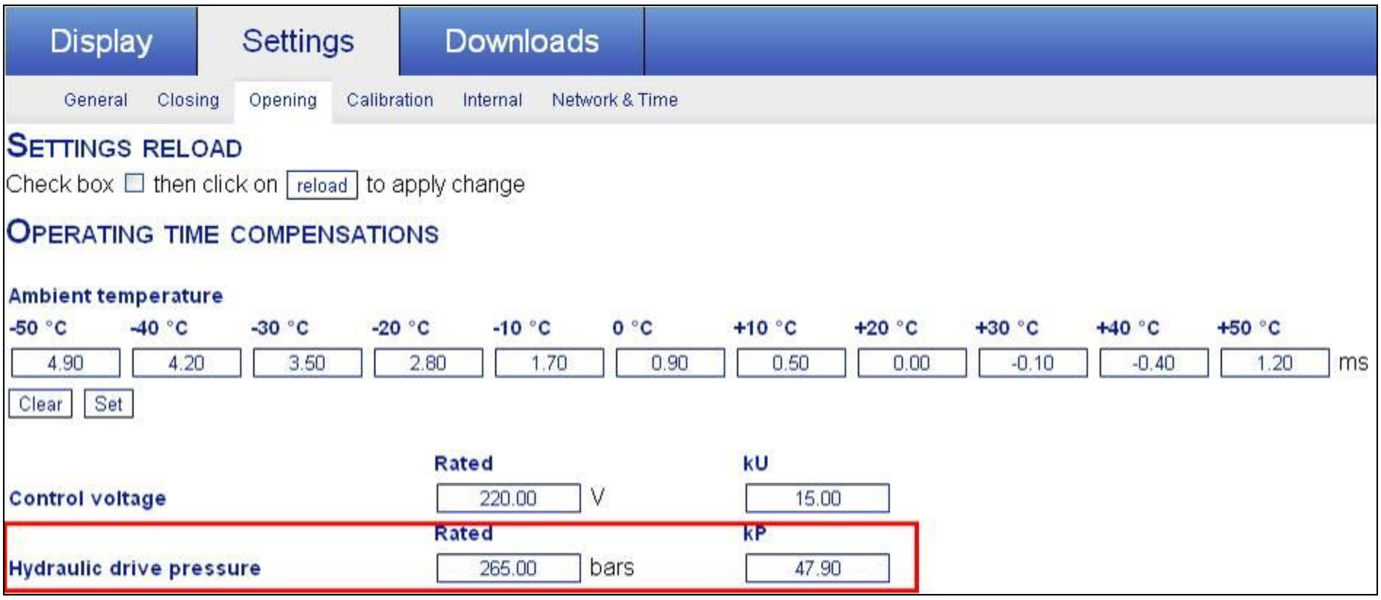


Figure 58 : web MMI : pressure compensation settings

<u>NOTE :</u> the **kP** factor may be set to different values for opening and closing operations

For information, kP shall be assessed during commissioning (or switchgear type tests) as :

$$kP[\%] = \frac{(Top)_{P_{low}} - (Top)_{P_{rated}}}{\left(\frac{P_{rated}}{P_{low}} - 1\right).(Top)_{P_{rated}}}.100$$

Where :

- $\{(Top)_{P_{rated}};P_{rated}\}$ is the nominal operating point of the concerned pole (hydraulic pressure = P_{rated})
- $\{(Top)_{P_{low}};P_{low}\}$ is an other operating point of the same pole, obtained while the pressure in the concerned hydraulic accumulator(s) is lower than P_{rated} (all other parameters being the same i.e. ambient temperature, coils supply voltage, etc.)

Example of kP assessment for closing operations : case of T155-2 CB fitted with an hydraulic drive

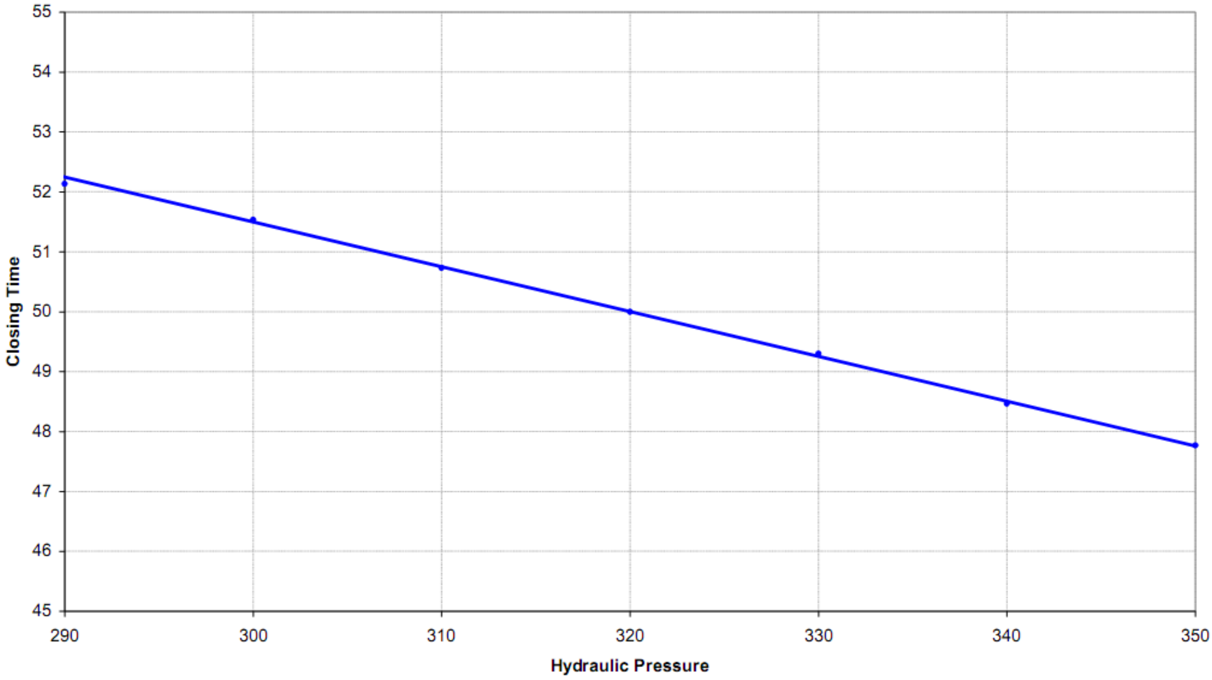


Figure 59 : hydraulic pressure compensation characteristic

- Operating point #1 (measurement under rated conditions) : $\{(Top)_{Prated} = 47.6ms; P_{rated} = 350b\}$
- Operating point #2 (rated conditions + low pressure) : $\{(Top)_{Plow} = 53.1ms; P_{low} = 280b\}$

➔ Pressure compensation factor :

$$kP = \frac{53.1 - 47.6}{\left(\frac{350}{280} - 1\right).47.6} = 46.2\%$$

3-5.4-2 Sampling the hydraulic pressure

Any kind of pressure sensor might be installed, provided that its interface to the RPH3 is a standard [4…20 mA] (+24V) analogue signal. The scaling factors shall be adjusted through the web MMI :

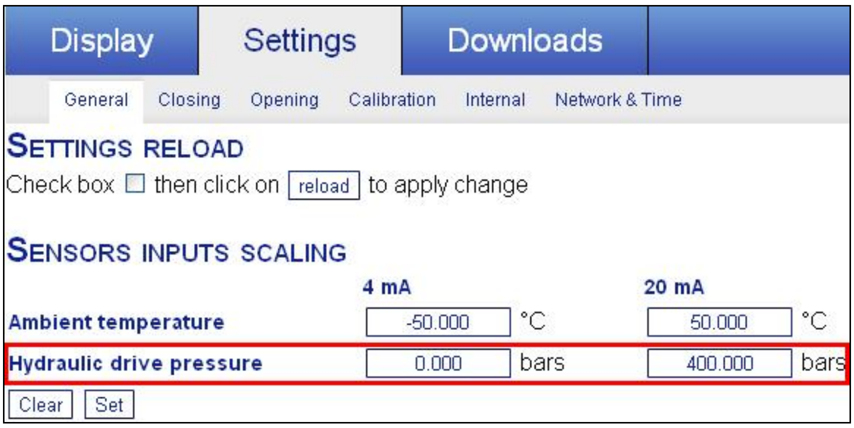


Figure 60 : web MMI : adjusting the hydraulic pressure sensor scaling factors (access level ≥ Supervisor)

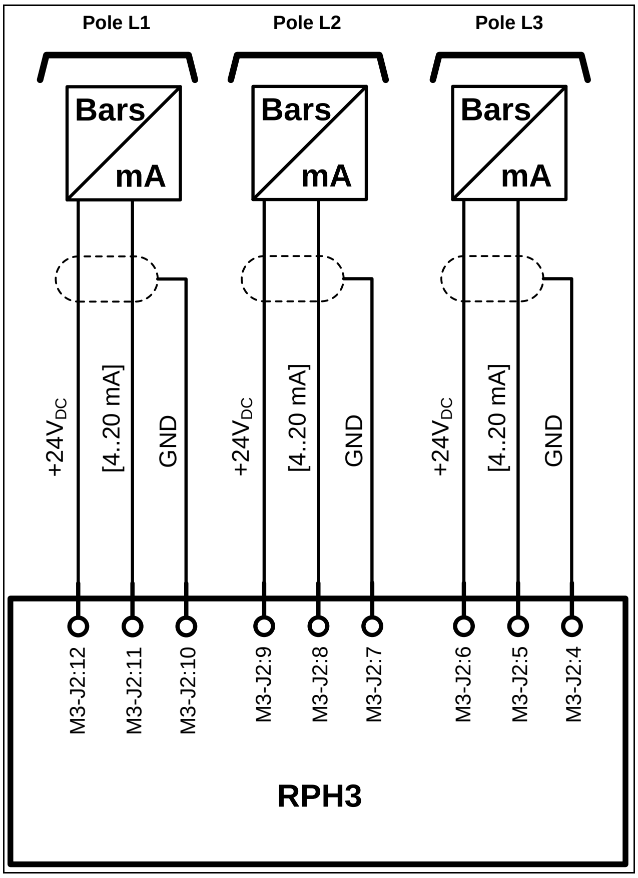


Figure 61 : connecting hydraulic pressure sensors

The RPH3 characteristics on this interface are given below :

Rated characteristics	Min	Typical	Max	Unit
M3-J2 connector	*MC 1,5/12-STF-3.5*			
input impedance (pins 5:4, pins 8:7, pins 11:10)	99	100	101	Ω
input impedance (pins 6:4, pins 9:7, pins 12:10)	16	-	-	kΩ
sensors supply voltage	-	24	-	V_{DC}
input current (as delivered by each sensor)	-	[4…20]	-	mA
output power (as delivered to each sensor)	-	-	2	VA
Measurement error	-	-	3	%

3-5.5 Contribution of the switchgear idle time

A specific compensation shall be enabled (software setting in the web MMI) in case the switchgear is not frequently operated. The inactivity (idle) time of a circuit breaker has a significant influence on its operating times, especially if driven by an hydraulic mechanism.

3-5.5-1 Compensation law

As assumed by the RPH3 controller, compensation of the idle time contribution to switchgear operating times is based on Cigré technical conclusions, according to the below formula computing Δt_{idle} as an amount of time to be added to the nominal expected operating time of a given switchgear pole :

$$\Delta t_{idle} = A.\left(1 - e^{\frac{T_{idle}}{B}}\right)$$

Where :

- A and B = integer parameters to be set by software through the web MMI (by default A = 2ms and B = 10 days). Precise values of A and B parameters shall be measured during switchgear type tests by the manufacturer.

- T_{idle}= amount of time (in days) elapsed since the last switchgear operation.

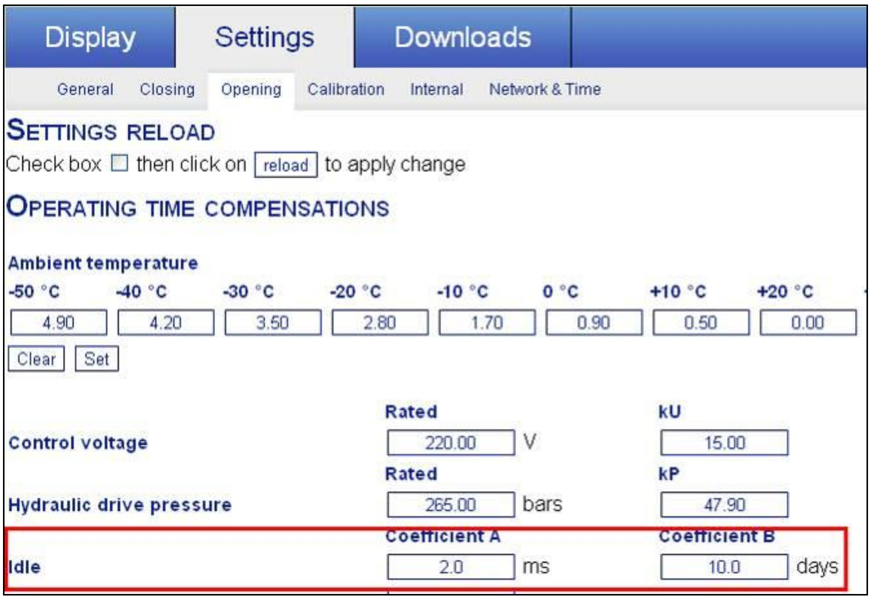


Figure 62 : web MMI : idle time compensation settings

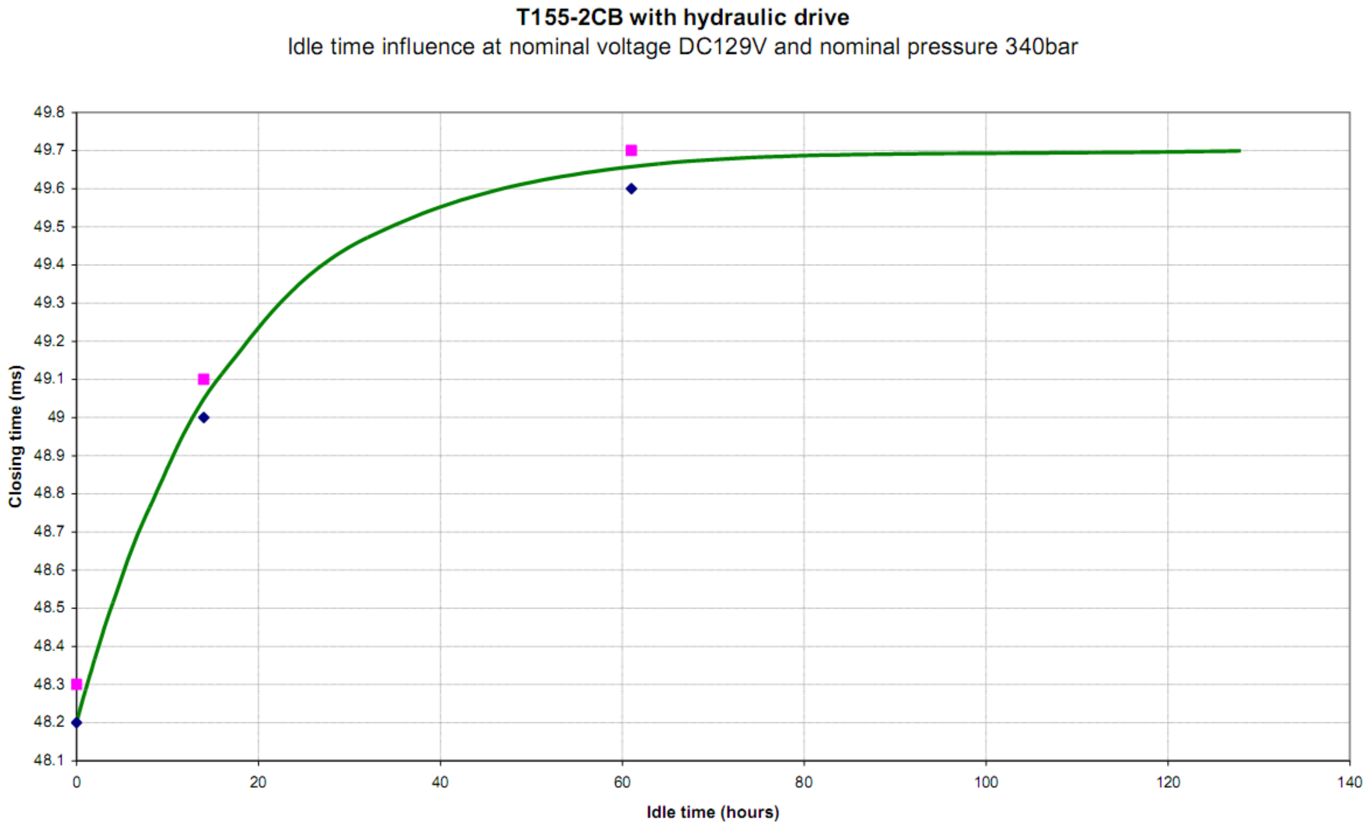


Figure 63 : idle time compensation law characteristic

NOTE : **A** and **B** weighting factors may be set to different values for opening and closing operations.

3-5.5-2 Measuring the switchgear idle time

The idle time T_{idle} of the switchgear is measured by the RPH3 controller itself as the amount of time (in days) elapsed since the last switchgear operation. It is reset each time the switchgear is operated, whichever the type operation (opening or closing).

3-5.6 Contribution of all other factors : the adaptive control

At long term, the operating time of a given switchgear pole may still vary from one operation to an other, even if major environmental conditions are kept constant (ambient temperature, hydraulic pressure, etc.)

The remaining deviation may be due to several other factors that cannot be precisely assessed (aging, electro dynamical efforts, etc.). However, the combination of these factors may significantly affect the pole operating time, thus introducing a time shift between the expected operating time (as **forecasted** BEFORE the operation) and the actual one (as **measured** AFTER the operation).

Therefore, the RPH3 controller embeds a specific feature in order to compensate this extra time (i.e. decrease this deviation after a few operations) : this feature is called "adaptive control".

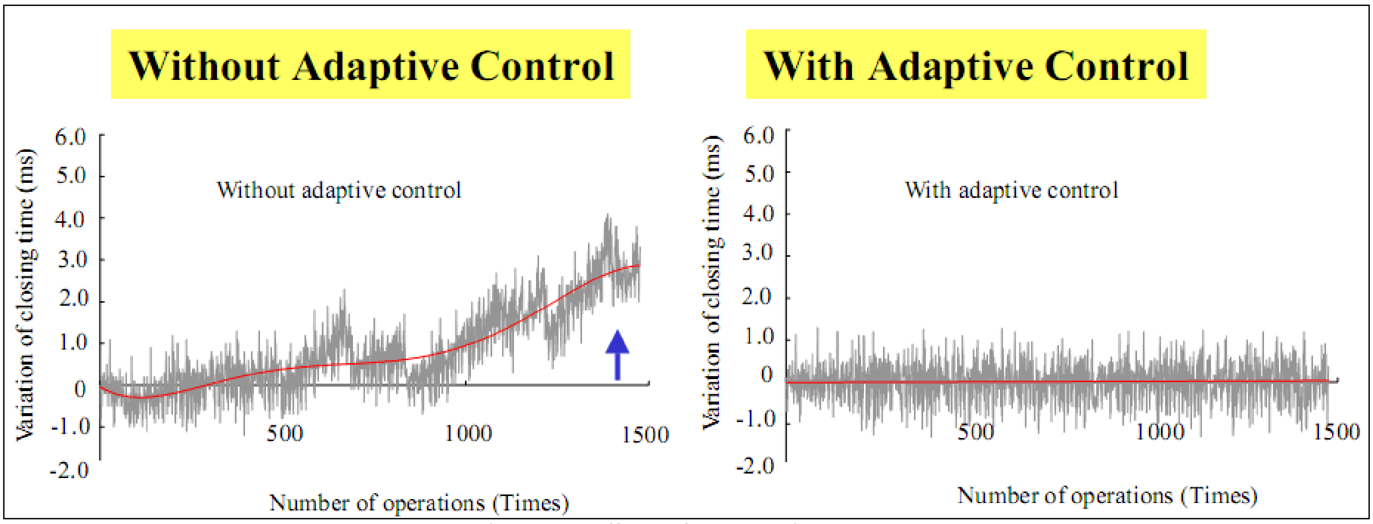


Figure 64 : effects of the adaptive control

Data source : Mitsubishi

3-5.6-1 Compensation law

The adaptive contribution of a given pole for a given operation (N) is defined as a fraction of the time shift between the forecasted operating time during the last similar operation (N-1) and the actual one (as measured by the RPH3 controller).

The adaptive contribution for the operation number N is calculated as follows :

$$\Delta t_{adapt_N} = K.\left(t_{measured_{N-1}} - t_{commissioning} - \Delta t_{compensations_{N-1}}\right) + (1-K).\Delta t_{adapt_{N-1}}$$

where :

- **K** = weighting factor. It shall be chosen in the range [0.0; 0.5] in order the adaptive control loop to be faster or slower : the closer to 0.5 the less operations are required for the adaptive contribution to be compensated (but the precision is lower). The closer to 0 the more operations will be required, but the algorithm is more precise. K = 0.3 is the default setting recommended by GE Grid Solutions.

- $t_{measured_{N-1}}$ = operating time of the concerned pole as measured by the RPH3 after completion of the last similar operation (i.e. opening or closing).
- $t_{comissioning}$ = rated operating time of the concerned pole, as measured with a separate equipment during switchgear commissioning on site.
- $\Delta t_{compensations_{N-1}}$ = sum of the compensations as computed on the concerned pole by the RPH3 controller during the last similar operation: includes all compensations (towards ambient temperature, hydraulic pressure, idle time and coils supply voltage) computed on the previous similar CB operation (N-1).

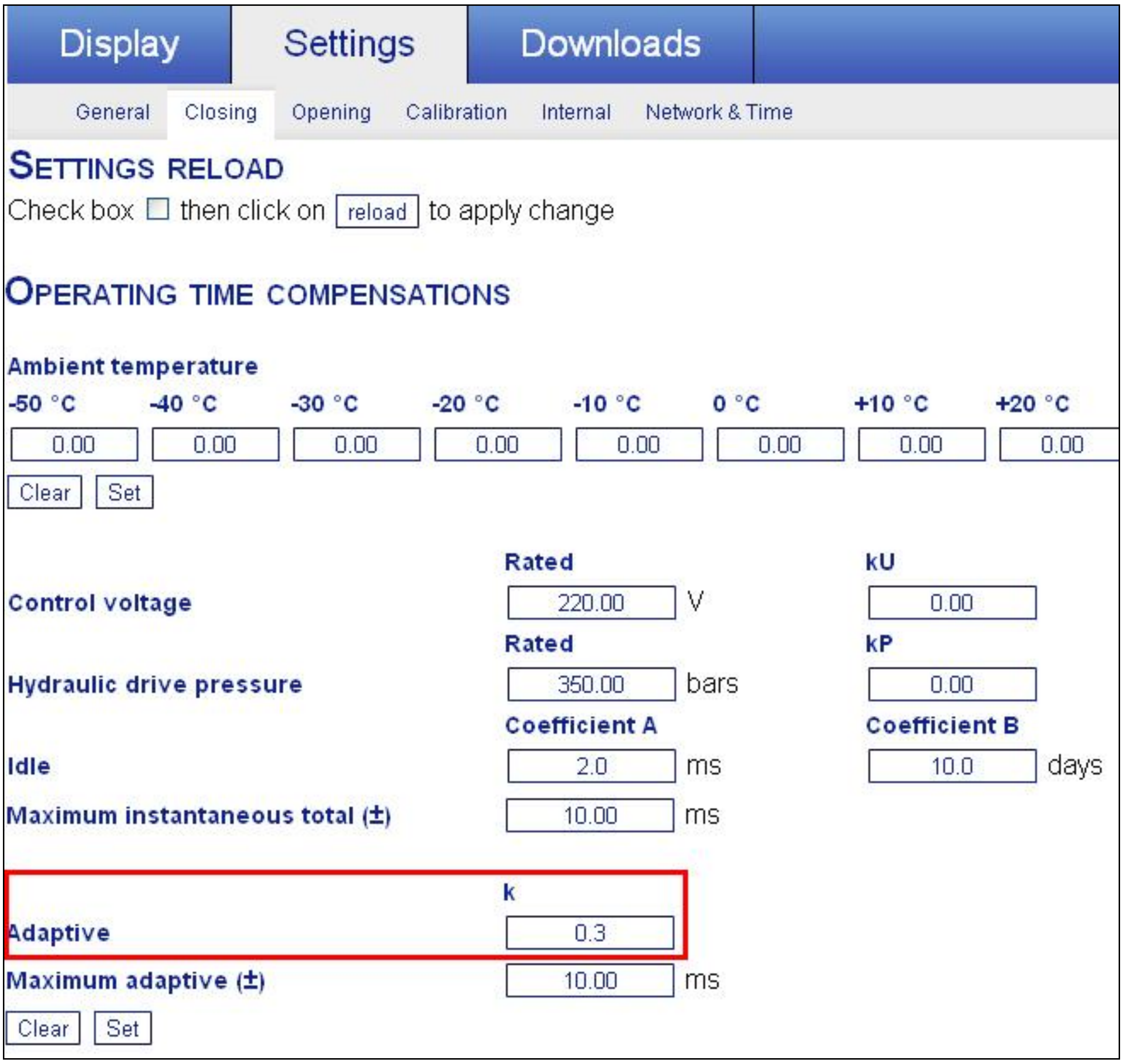


Figure 65 : web MMI : adaptive control weighting factor adjustment

<u>NOTE :</u> the adaptive control weighting factor K is unique for both closing and opening operations.

3-6 Compensations clamping

Several reasons could lead the operating time of a given CB pole to change roughly from 1 operation to the next one (maintenance, testing, unexpected disturbances, etc.).

In such cases, the RPH3 controller shall trig some alarms (refer to section 3-7, page 71). But these situations may also “corrupt” the time compensations and adaptive control feature, since they would lead a large difference between the expected (forecasted) operating time and the actual one (as measured after the operation). In order to prevent the resulting high values of $\Delta t_{compensations}$ and Δt_{adapt} to artificially “oversize” the operating time forecast during the next CB operation, the RPH3 uses a “clamping” function, that limits both of these time shifts to maximum absolute values (in ms), that may be adjusted by software setting through the web MMI :

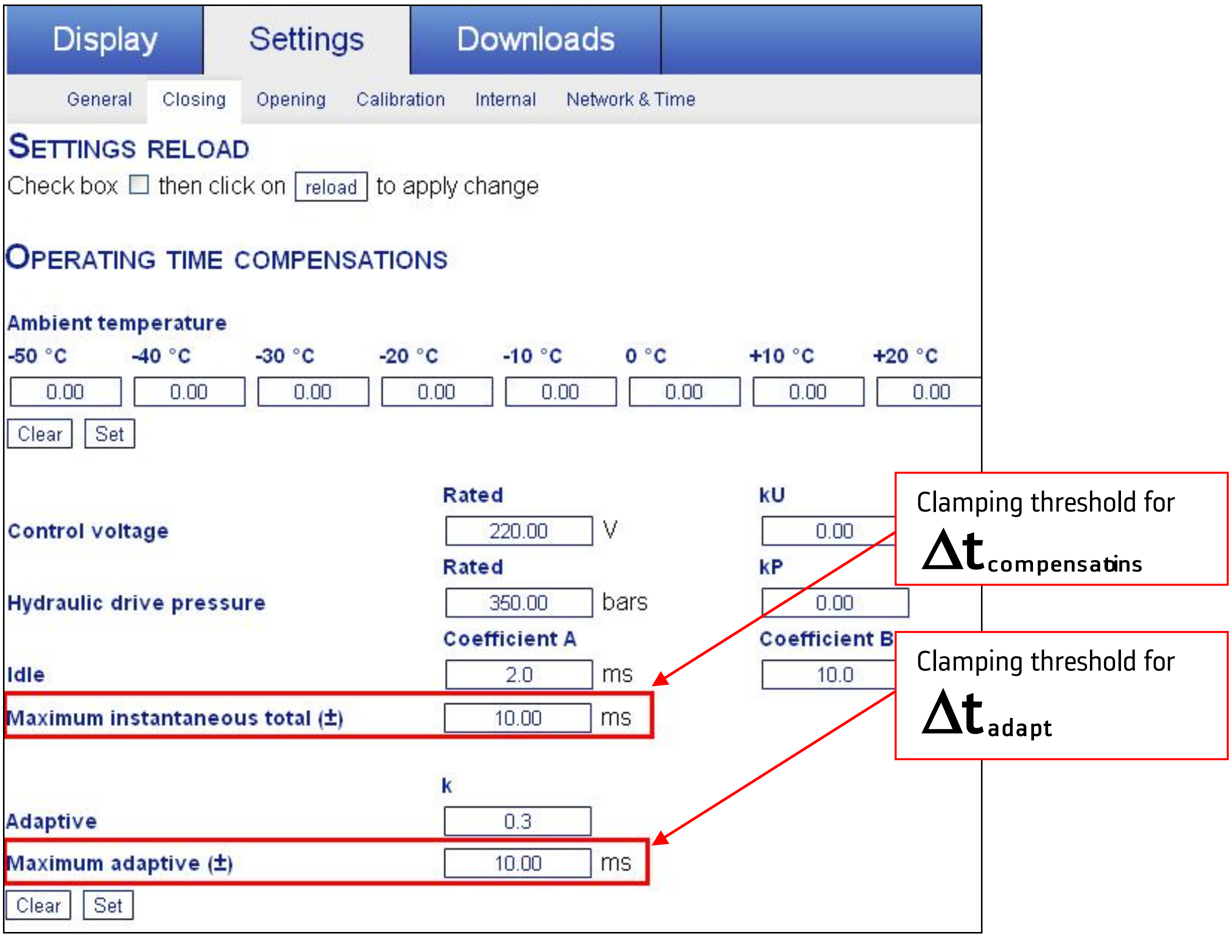


Figure 66 : web MMI : adjusting compensations and adaptive control clamping feature

<u>NOTE 1 :</u> both “clamping” thresholds are defined as absolute values, so that the sign of $\Delta t_{compensations}$ and Δt_{adapt} is respected by the clamping functions.

<u>NOTE 2 :</u> “clamping” thresholds are defined once for both opening and closing operations. It is not possible to apply a threshold value for closing operations which differs from the one for opening operations.

3-7 Alarms, real-time data and switching records

The RPH3 controller is able to provide the user with useful information on its own status (auto-diagnostic), the switchgear status and the application history (switching records).

These data are accessible either in “real-time” mode (e.g. periodically refreshed measurements and current status of alarms) or in “dated event” mode (e.g. switching records, alarms history).

The RPH3 web MMI (embedded software) provides access to real-time data (including the current status of all alarms), and also to the data associated to the most recent PoW switching operation attempt (non-volatile memory).

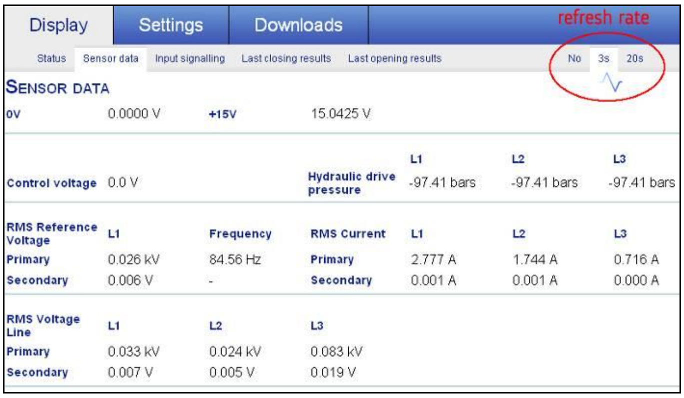


Figure 67 : accessing real-time data (web MMI)

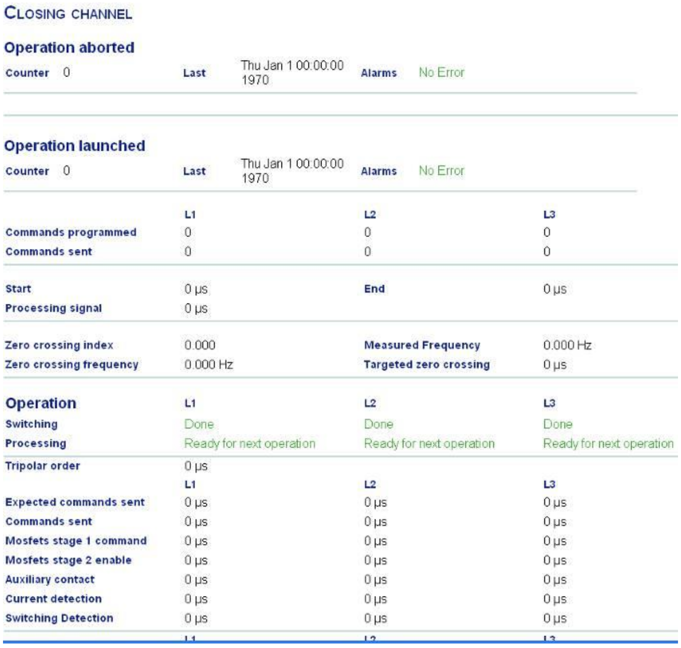


Figure 68 : accessing last PoW switching data (web MMI)

3-7.1 Real-time data

The following data are accessible in real-time mode through the RPH3 web MMI :

Sensors Data	unit
Coils supply voltage measurement (DC)	V
Hydraulic drive pressure (1 measurement/phase)	Bars
Ambient temperature	°C
Reference phase identification (L1, L2 or L3)	-
Reference voltage measurement at VT secondary winding (RMS value)	V
Reference voltage at VT primary winding (RMS value, assessed from measurement at VT secondary)	kV
Reference voltage frequency measurement at VT secondary winding	Hz
Current measurement through CT secondary winding (RMS value, 1 measurement / phase)	A
HV Current flowing through CT primary winding (RMS value, 1 assessment / phase from measurement at CT secondary)	kA

Input signaling & main settings summary	possible values
Switching program to be applied during the next CB operation	TRANSFORMER, REACTOR, CAPACITOR, USER PROGRAM
Associated shift angles for CB closing operations	° (angular)
Associated shift angles for CB opening operations	° (angular)
Status of the system neutral mode, as detected by RPH3 Hardware (wire bridge) or set by MMI software setting	UNKNOWN, EARTHED, ISOLATED
Preferred strategy for operating time measurement	HV CURRENT, AUX. CONTACTS
List of currently enabled contributions to switchgear operating times	AMBIENT TEMPERATURE, CONTROL VOLTAGE, HYDRAULIC DRIVE PRESSURE, CB IDLE TIME, ADAPTIVE CONTROL
Status of switchgear auxiliary contacts (1 aux. contact / CB pole)	OPEN, CLOSED, UNKNOWN

Global Status	possible values
Firmware version	TCR VX.YY, LINE VX.YY
Last switching result (front red led “2 – Switching status”)	OK, ALARM
Alarm relay “All-or-Nothing” (monostable relay)	OK, ALARM
Alarm relay “flip-flop” (bi-stable) #1	OK, ALARM
Alarm relay “flip-flop” (bi-stable) #2	OK, ALARM
Alarm relay “flip-flop” (bi-stable) #3	OK, ALARM
Alarm relay “flip-flop” (bi-stable) #4	OK, ALARM
System alarm (front red led “3 – System alarm”)	OK, ALARM
Application alarm (front red led “4 – Application alarm”)	OK, ALARM

System alarm details	possible values
Date	RELIABLE, NOT RELIABLE
U/I calibration status	OK, NOT DONE
Parameters Loading	OK, NOT OK
Parameters Validity	OK, NOT OK
RPH3 closing output channel status (internal self-test)	OK, NOT OK
RPH3 opening output channel status (internal self-test)	OK, NOT OK
Internal check (self-test)	OK, ERROR
Analogue sensors inputs status (4-20 mA)	OK, AT LEAST ONE DOESN'T WORK
Application alarm details	**possible values**
Reference voltage	OK, OUT OF RANGE FREQUENCY, OUT OF RANGE AMPLITUDE
HV current peak value (as measured during the last switching operation)	OK, OVER USER-DEFINED THRESHOLD
System neutral mode as detected by RPH3 Hardware (wire bridge) or set by MMI software setting	UNKNOWN, EARTHED, ISOLATED
Application behaviour (internal algorithm self-test results)	OK, ALGO STEP X ALARM
Switchgear closing time (as measured on each CB pole during the last closing operation : refer to section 0, page 42) ✓ Min ≤ $T_{OP\_measured}$ ≤ Max ? ✓ ΔT_{OP} ≤ tolerance ?	OK, ALARM
Switchgear opening time (as measured on each CB pole during the last opening operation : refer to section 0, page 42) ✓ Min ≤ $T_{OP\_measured}$ ≤ Max ? ✓ ΔT_{OP} ≤ tolerance ?	OK, ALARM
Operating time compensation clamping (refer to section 0, page 70) : ✓ Min < $\Delta t_{compensations}$ < Max ? ✓ Min < Δt_{adapt} < Max ?	OK, COMPENSATION OUT OF RANGE, ADAPTIVE CONTROL OUT OF RANGE
Control voltage (coils supply DC voltage, instantaneous measured value) ✓ Min < U_{meas} < Max ?	OK, OUT OF USER-DEFINED RANGE
Ambient temperature (instantaneous measured value) ✓ Min < Ambient temperature < Max ?	OK, OUT OF USER-DEFINED RANGE
Hydraulic drive pressure (instantaneous measured values inside each hydraulic drive) ✓ Min < P_{meas}¨(L1) < Max ? ✓ Min < P_{meas}¨(L2) < Max ? ✓ Min < P_{meas}¨(L3) < Max ?	OK, OUT OF USER-DEFINED RANGE

Self-test alarm details	possible values
Self-diagnostic of the RPH3 ability to close each CB pole (test result)	OK, FAILED
Self-diagnostic of the RPH3 ability to open each CB pole (test result)	OK, FAILED
CB closing enable self-diagnostic result (for each CB pole)	OK, FAILED
CB opening enable self-diagnostic result (for each CB pole)	OK, FAILED
CB closing coils continuity test result (for each pole)	OK, Discontinuity
CB opening coils continuity test result (for each pole)	OK, Discontinuity

NOTE 1 : data periodical refresh rate can be adjusted through the web MMI to :
- 0 (no refreshment),
- 3 seconds,
- or 20 seconds

NOTE 2 : for erection, commissioning, maintenance and factory calibration features, the RPH3 web MMI offers additional access levels, that provide access to other data in real-time mode (for advanced users only).

3-7.2 Alarm signaling

The RPH3 controller includes 2 visual indicators (red LEDs on its front panel) and 5 relay-driven output contacts that are dedicated to alarm signaling (i.e. warning the user in case alarms are trigged by the RPH3 controller).

Its front panel also includes 2 additional green status LEDs (to be lit ON while a normal operation is on progress).

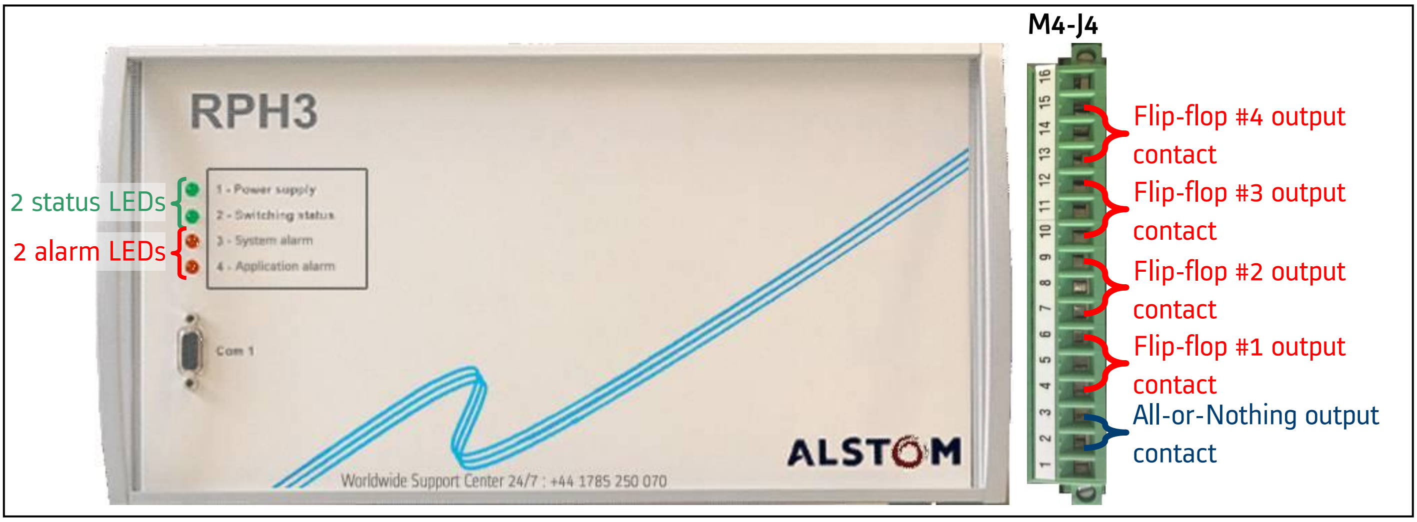


Figure 69 : front panel LEDs and alarm relay-driven output contacts

The term "alarm" stands for a signal that might be turned ON (activated) by the RPH3 controller in case ≥ 1 condition(s) is (are) fulfilled at a given instant. The RPH3 processing cycle towards triggable alarms is the following :

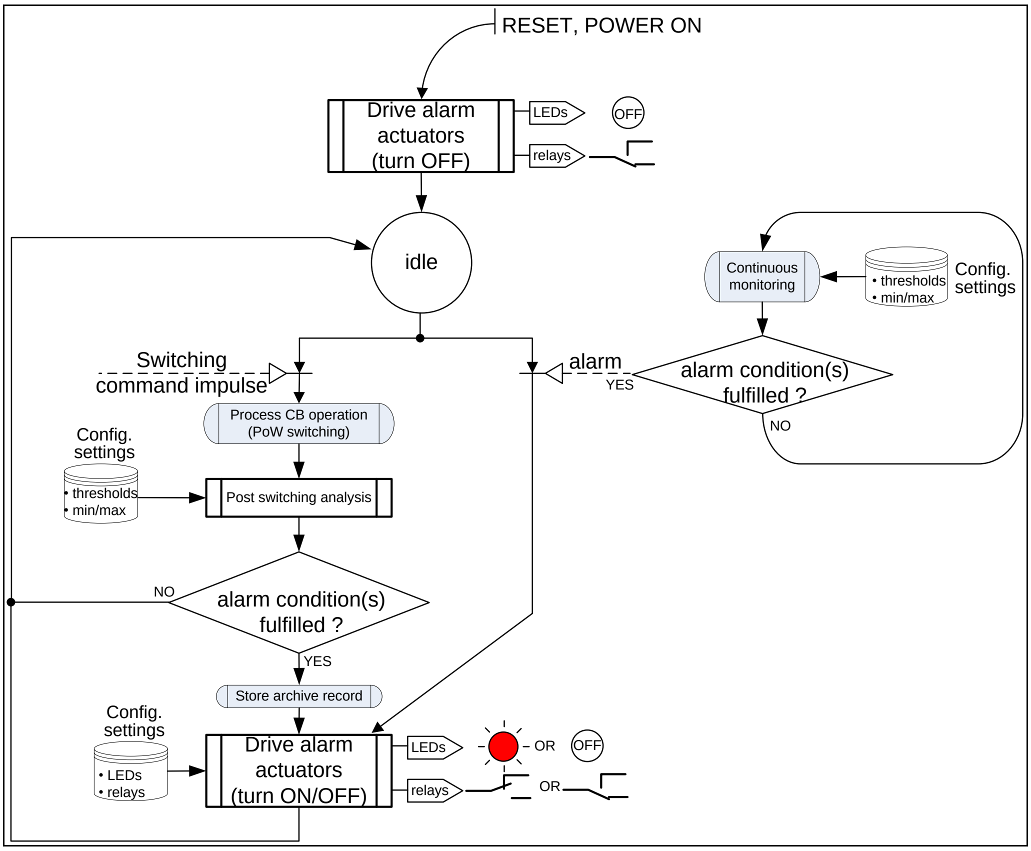


Figure 70 : alarm processing cycle

3-7.2-1 green status LED : "1 - Power supply"

This visual indicator is associated to a continuous monitoring feature of the RPH3 power supply: it is turned and maintained ON as long as the available power on M1-J1 terminals is sufficient for normal operating, (see Figure 82, page 90). It is OFF in case the available power is out of the allowed range (this range depends on the considered RPH3 variant : refer to section 3-10, page 89).

3-7.2-2 Green status LED : "2 – Switching status"

This visual indicator is OFF while no switchgear PoW operation is on progress. It is turned ON while a PoW switching operation is being processed by the RPH3 controller, and maintained for ~4 seconds (until the end of signals recording process : refer to section 3-7.3 page 81 for further explanations).

WARNING : This light **IS NOT** an alarm; its status (ON or OFF) does not mean that a problem occurred during the last PoW switching operation. It is actually driven as an "activity" LED, indicating that a PoW switching operation is currently being processed by the RPH3 controller.

3-7.2-3 Red alarm LED : "3 – System alarm"

This visual indicator is associated to "system level" group of alarms : it is turned ON as soon as ≥ 1 of the conditions below is fulfilled (see Table 4), and automatically hold ON until none of these conditions is fulfilled anymore (logical OR function between alarm conditions) :

Conditions triggering system alarms	
Name	***Description***
Date	The current date has not been properly set : use the web MMI to adjust it
U/I calibration	A problem has been detected in internal current and voltage calibrations as performed by the factory during RPH3 manufacturing process. Please contact GE Grid Solutions.
Parameters loading	A problem has been detected during the software settings loading process. Restart the RPH3 controller. If the alarm is still ON, please contact GE Grid Solutions.
Parameters validity	A problem has been detected between software settings. Restart the RPH3 controller. If the alarm is still ON, please contact GE Grid Solutions.
Opening output channel	A problem has been detected by the continuous monitoring feature of the switchgear opening control channel : either a discontinuity in the external CB opening circuit or an RPH3 internal issue with MOSFET switching transistors. Check the continuity of the monitored circuit, disconnect any additional continuity monitoring device and restart the RPH3 controller. If this alarm is still ON, ensure that the software setting "Coils wiring scheme" is well set in line with the actual wired connections between the RPH3 connector M4-J2 and the switchgear opening coils ("common-mode" scheme or "differential mode" scheme).
Closing output channel	A problem has been detected by the continuous monitoring feature of the switchgear closing control channel : either a discontinuity in the external CB closing circuit or an RPH3 internal issue with MOSFET switching transistors. Check the continuity of the monitored circuit, disconnect any additional continuity monitoring device and restart the RPH3 controller. If this alarm is still ON, ensure that the software setting "Coils wiring scheme" is well set in line with the actual wired connections between the RPH3 connector M4-J2 and the switchgear opening coils ("common-mode" scheme or "differential mode" scheme).
RPH3 internal self-check	An internal failure has been detected. Restart the RPH3 controller. If the alarm is still ON, please contact GE Grid Solutions.
Analogue sensors	A problem has been detected on RPH3 controller wired interface with ≥ 1 analogue sensor(s). Check the connections with all external sensors (temperature probe, CTs, VTs, 4-20 mA hydraulic pressure sensors…) and restart the RPH3 controller. If this alarm is still ON, check the RPH3 settings related to these sensors (ensure that temperature compensation is disabled if no temperature probe is connected, etc.)

Table 4 : conditions driving front alarm LED "3 - System alarm"

<u>**NOTE :**</u> system alarms cannot be manually "cleared" or "acknowledged". The only way for a user to turn this light OFF is to identify the root cause of this alarm and solve the associated issue.

3-7.2-4 Red alarm LED : "4 – Application alarm"

This visual indicator is associated to "application level" group of alarms : it is turned ON as soon as ≥ 1 of the conditions below is fulfilled (see Table 5), and automatically hold ON until none of these conditions is fulfilled anymore (logical OR function between alarm conditions) :

Conditions triggering application alarms	
Name	***Description***
Reference voltage	The reference voltage has been measured out of range by the RPH3 controller (either in frequency or in magnitude) for a duration > 200 ms. Please check the reference voltage waveform.
Line current	The HV line current has been measured out of range by the RPH3 controller (either in phase or in magnitude). Please check the proper connection of current measurement CTs. In case no CT is to be connected to the RPH3 (operating time measurement through switchgear auxiliary contacts instead of line current measurement), disable the current monitoring option (see Figure 32 page 43) and try again to operate the switchgear. Otherwise, please adjust the allowed range for line current through the web MMI (measuring CT settings : refer to Figure 42 page 50). If the alarm is still ON, ask GE Grid Solutions for a U/I calibration check.
System neutral	The system neutral, as detected by the RPH3 controller thanks to a wire bridge on connector M4-J5, does not match its expected configuration (e.g. it has been detected as earthed or undefined whereas it is expected to be isolated). Check that the wire bridge is well connected on M4-J5 connector and that well suits the end application neutral mode.
Application behaviour	The RPH3 internal main application algorithm encountered a failure. Restart the RPH3 controller. If this alarm is still ON, please contact GE Grid Solutions.
Last switchgear closing operation	The switchgear closing time has been measured out of range on ≥ 1 CB pole(s) during the last closing operation : ✓ Either Max < $T_{OP\_measured}$ ✓ Or $T_{OP\_measured}$ < Min ✓ Or ΔT_{OP} > tolerance refer to section 0, page 42 for further details on $T_{OP\_measured}$ and ΔT_{OP}. If needed, adjust associated settings through the web MMI (Min, Max, tolerance) and try again to operate the switchgear so that this alarm is cleared.
Last switchgear opening operation	The switchgear opening time has been measured out of range on ≥ 1 CB pole(s) during the last opening operation : ✓ Either Max < $T_{OP\_measured}$ ✓ Or $T_{OP\_measured}$ > Max ✓ Or ΔT_{OP} > tolerance refer to section 0 (page 42) for further details on $T_{OP\_measured}$ and ΔT_{OP}. If needed, adjust associated settings through the web MMI (Min, Max, tolerance) and try again to operate the switchgear so that this alarm is cleared.
Switchgear operating time compensations	≥ 1 of the switchgear operating time compensation contribution has been measured out of range (and clamped) : ✓ Either Max < $\Delta t_{compensations}$

	✓ Or $\Delta t_{compensations}$ < Min ✓ Or Max < Δt_{adapt} ✓ Or Δt_{adapt} < Min refer to section 0, page 70 for further details on $\Delta t_{compensations}$ and Δt_{adapt}. Check that currently enabled compensation contributions are well required, and check associated Min and Max thresholds (adjust them if needed), then check that all associated sensors are well connected (CTs, CB auxiliary contacts, hydraulic pressure sensors, ambient temperature probe, etc.). Then try again to operate the switchgear. If this alarm is still ON reset the adaptive times to 0 through the web MMI (access level > User) and try once again to operate the CB. If this alarm could not be cleared this way please contact GE Grid Solutions.
Control voltage	The control voltage (coils supply DC voltage, instantaneous measured value) has been measured out of range : ✓ Either $\mathbf{Max} < \mathbf{U}_{meas}$ ✓ Or $\mathbf{U}_{meas} < \mathbf{Min}$ Check that the coils DC voltage supply is well present on **<u>BOTH</u>** RPH3 connectors M3-J1 **<u>AND</u>** M4-J1.
Ambient temperature	The ambient temperature has been measured out of the specified range : ✓ Either Max < Ambient temperature ✓ Or Ambient temperature < Min Check the proper connection of the temperature probe, and if needed adjust the Min and Max thresholds through the web MMI.
Hydraulic drive pressure	The hydraulic pressure inside ≥ 1 pole driving mechanism(s) has been measured out of the specified range (instantaneous value) : ✓ Either Max < $\mathbf{P}_{meas}$(L1) ✓ Or $\mathbf{P}_{meas}$(L1) < Min ✓ Or Max < $\mathbf{P}_{meas}$(L2) ✓ Or $\mathbf{P}_{meas}$(L2) < Min ✓ Or Max < $\mathbf{P}_{meas}$(L3) ✓ Or $\mathbf{P}_{meas}$(L3) < Min Check the actual pressure inside each pole driving mechanism, and if needed adjust associated alarm thresholds Min and Max.

Table 5 : conditions driving front alarm LED "4 – Application alarm"

<u>NOTE :</u> application alarms cannot be manually "cleared" or "acknowledged". The only way for a user to turn this light OFF is to identify the root cause of this alarm and solve the associated issue.

3-7.2-5 Relay-driven alarm output contacts (x 5)

Many different alarm conditions may be allocated to each of the 5 relay-driven output contacts of the RPH3 controller (connector M4-J4).

This allocation is to be set through the web MMI software, as illustrated on Figure 71 below :

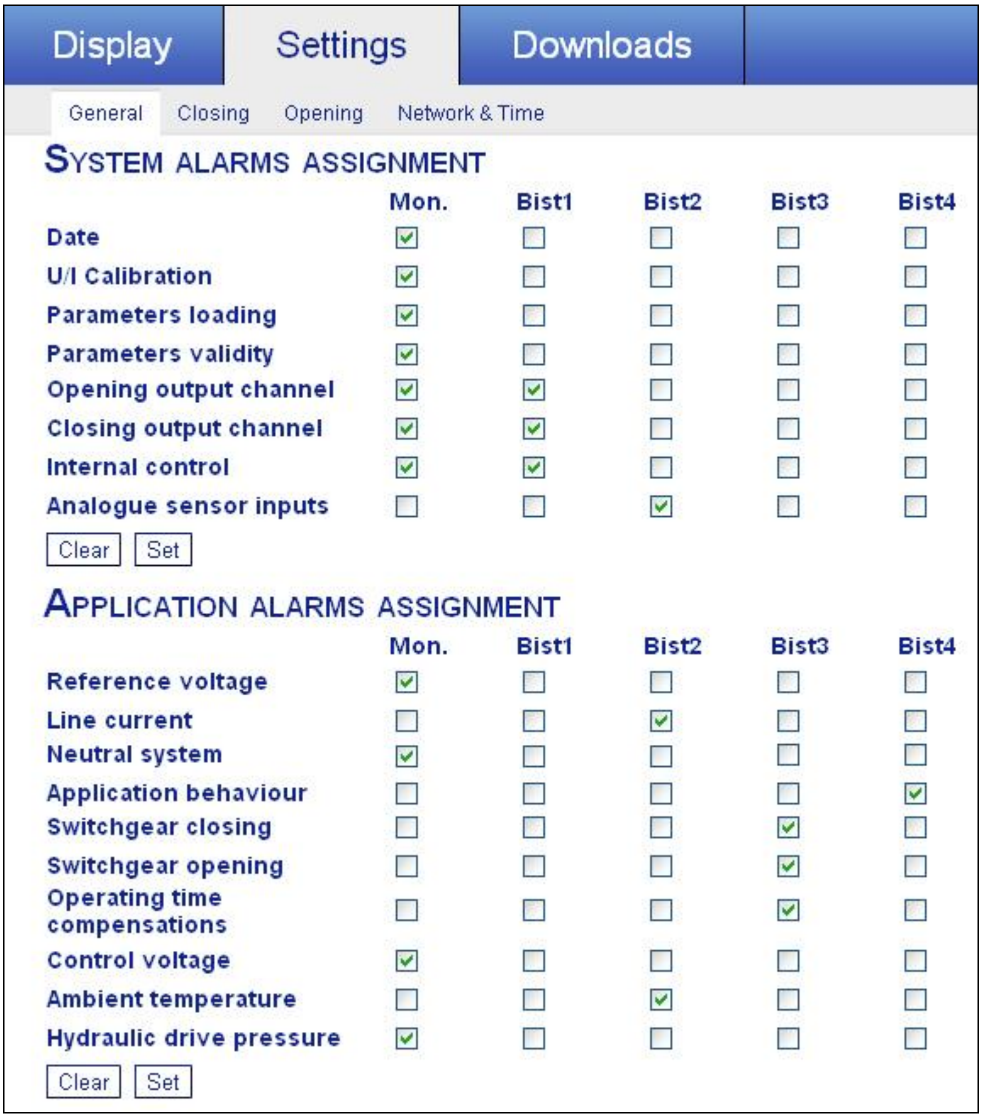


Figure 71 : alarm allocation setting through the web MMI software

As soon as ≥ 1 condition(s) is (are) fulfilled, associated relay-driven output contacts whose associated box is checked are switched and maintained until this (those) condition(s) is(are) cleared, as shown in the Table 6 below :

Relay contact (M4-J4)	**Monostable ("All-or-nothing")**	**Bistable #1 ("flip-flop")**		**Bistable #2 ("flip-flop")**		**Bistable #3 ("flip-flop")**		**Bistable #4 ("flip-flop")**	
terminals / status	2-3 NO	4-5 NC	5-6 NO	7-8 NC	8-9 NO	10-11 NC	11-12 NO	13-14 NC	14-15 NO
power OFF	open	keep current state		keep current state		keep current state		keep current state	
alarm ON	open	open	closed	open	closed	open	closed	open	closed
alarm OFF	closed	closed	open	closed	open	closed	open	closed	open

Table 6 : Relay-driven alarm output contacts status

<u>NOTE 1 :</u> in case the RPH3 controller is switched OFF, the 4 contacts driven by bistable ("flip-flop") relays keep their current state until the next power ON, whereas the single contact driven by the monostable relay is automatically opened. Whatever the considered contact, all alarm conditions are automatically tested at power ON, and contacts are switched in accordance to the result of this last test.

<u>NOTE 2 :</u> if the RPH3 controller is to be by-passed through the monostable relay alarm contact ("All-or-nothing", M4-J4 pins 2 and 3), GE Grid Solutions recommends to apply for this contact the allocation shown on Figure 71 above.

3-7.3 PoW switching history (CB operation records)

The RPH3 web MMI (embedded software) provides access to data associated to the most recent PoW switching operation attempt.

But data associated to older switching operations are also stored into the RPH3 non-volatile memory, as binary encoded files with the "*.arch" extension.

Figure 72 : downloading the last 1025 switching records (web MMI)

1 archive file is automatically generated and stored by the RPH3 controller after each PoW switching attempt (even if the operation failed or was aborted for any reason).

"Small" archive files contain detailed data (measurements, alarms, etc.) as collected by the RPH3 controller during associated switching operations. Up to 1025 "small" archives can thus be recorded, corresponding to the last 1025 operation attempts.

"Full" archive files contain the same data, and also 4 seconds of signal sampled values (voltages, currents, pole auxiliary contacts, etc.). These detailed data might be useful for deep post-operation analysis features. The RPH3 controller is able to store 1 "full" archive file for each of the last 25 switching attempts.

All archive files are downloadable through either the web MMI (Figure 72 above) or the optional software "RPH manager".
However, these data are encoded into binary files that can be decoded and processed by the optional software "RPH manager" only. Refer to document **[2]** for details on this software tool.

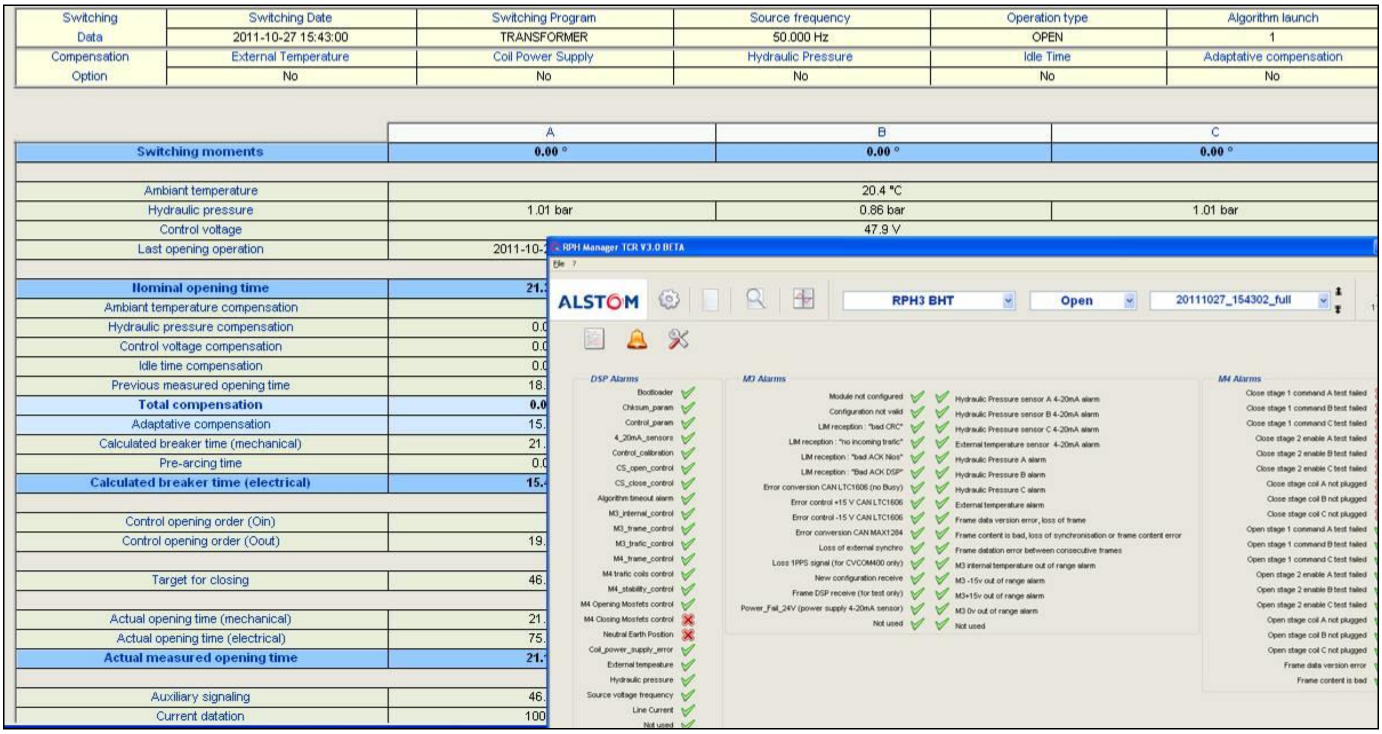


Figure 73 : RPH Manager software : PoW switching detailed data and alarm history

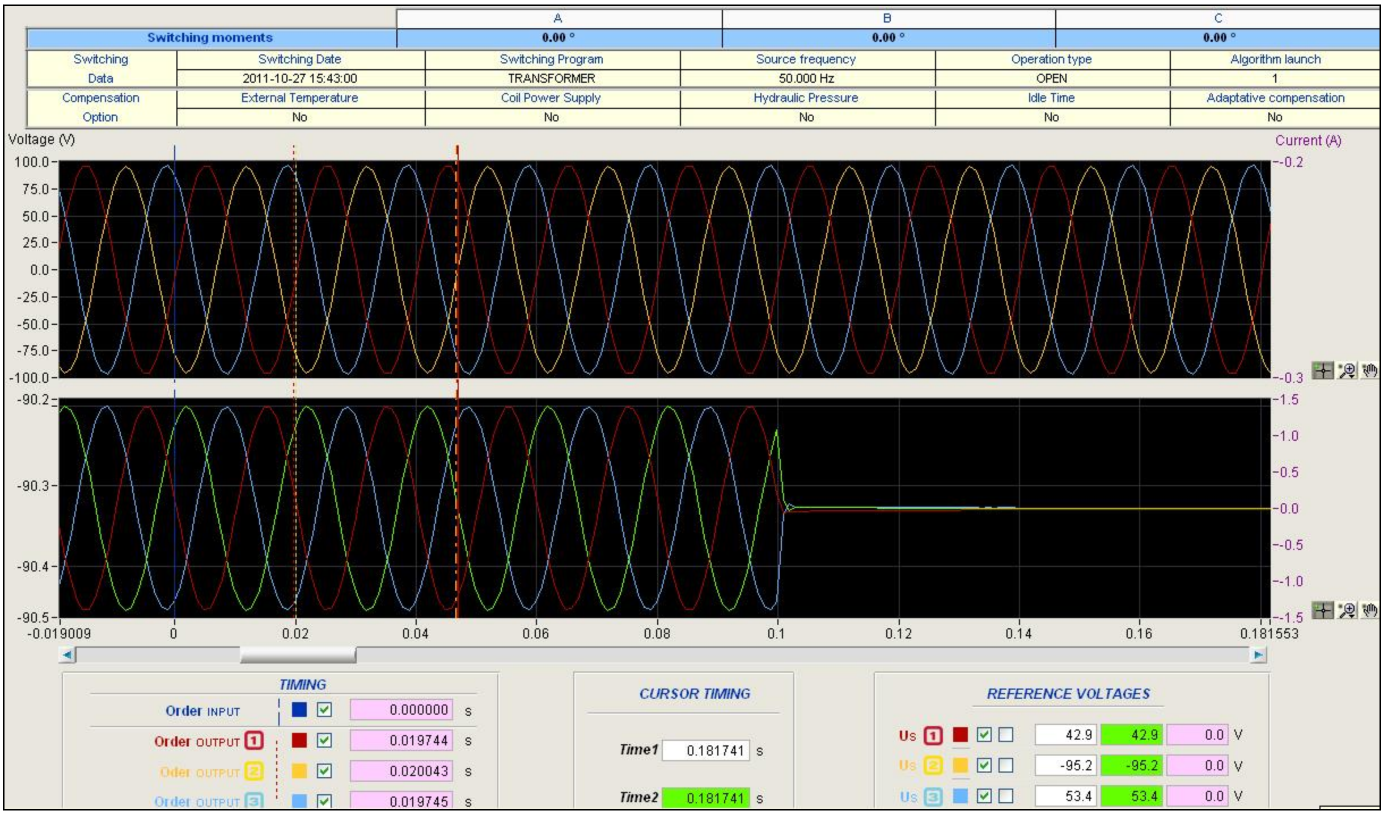


Figure 74 : RPH Manager software : complete waveform viewer

For any reason, the user can create a full archive file at any time from the web MMI, just clicking the button “Create an archive now”. This will start recording all signals for 4 seconds, and store the detailed waveforms into a new “full archive” file.

3-8 Networking, communication & real time clock

The RPH3 controller is able to act as a node on an IP network, through Ethernet IEC 61850-9-2 over an electrical interface (RJ45, connector M2-J3) as well as an optical interface (MT-RJ, connector M2-J1).

Its IP configuration is the following :

- Default address : 192.168.5.2 (may be changed through the web MMI)
- Default net mask : 255.255.255.0 (may be changed through the web MMI)
- IP host name : none
- IP work group name : none
- IP user name : none

Some of these settings may be edited through the web MMI, as illustrated on Figure 75 below :

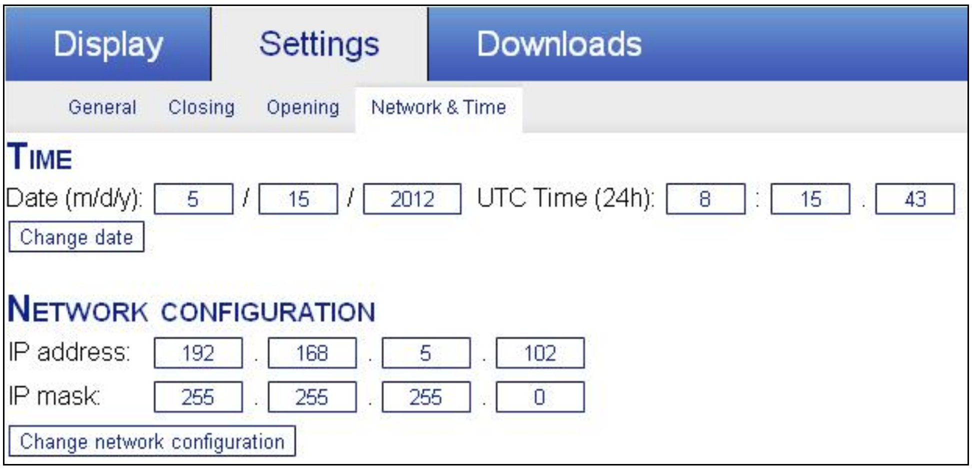


Figure 75 : RPH3 network IP settings and clock adjustment

One can also edit the current date and time, to be used by the RPH3 controller for time tagging (events recording).

NOTE 1 : these settings are not lost in case of power OFF.

NOTE 2 : date and time may be synchronized to an external time clock server, provided it is reachable on the IP network. It can also be synchronized through a dedicated optical link (interface ST optical). Contact GE Grid Solutions for further details.

WARNING : the RPH3 IP addressing mode is static only (no dynamic addressing is possible through DHCP). Hence it is important to remind its IP address. Otherwise a scan of the IP network is required in order to identify the RPH3 controller.

3-9 Configuration settings

For a correct configuration of a given RPH3 controller, the following data must be gathered and used to adjust RPH3 internal settings through its web MMI, prior to launching any CB operation.

3-9.1 End application related data

- System rated frequency (Hz)
- System neutral mode : effectively grounded, isolated, grounded through an NGR (Neutral Grounding Reactor)…
- Rated HV phase-phase voltage level (kV rms)
- Rated HV current level flowing through each switchgear pole (A rms)
- Kind of load to be switched by the CB (capacitor, 3x single-phase reactor, 1x tri-phase reactor, 3x single-phase power transformer, 1x tri-phase transformer, etc.)

3-9.2 External sensors related data

- Transforming ratios for installed CTs and VTs (Rated RMS levels at primary and secondary windings)
- Rated output currents @ 4 mA and 20 mA for ambient temperature transducer
- Rated output currents @ 4 mA and 20 mA for hydraulic pressure transducers (if applicable)

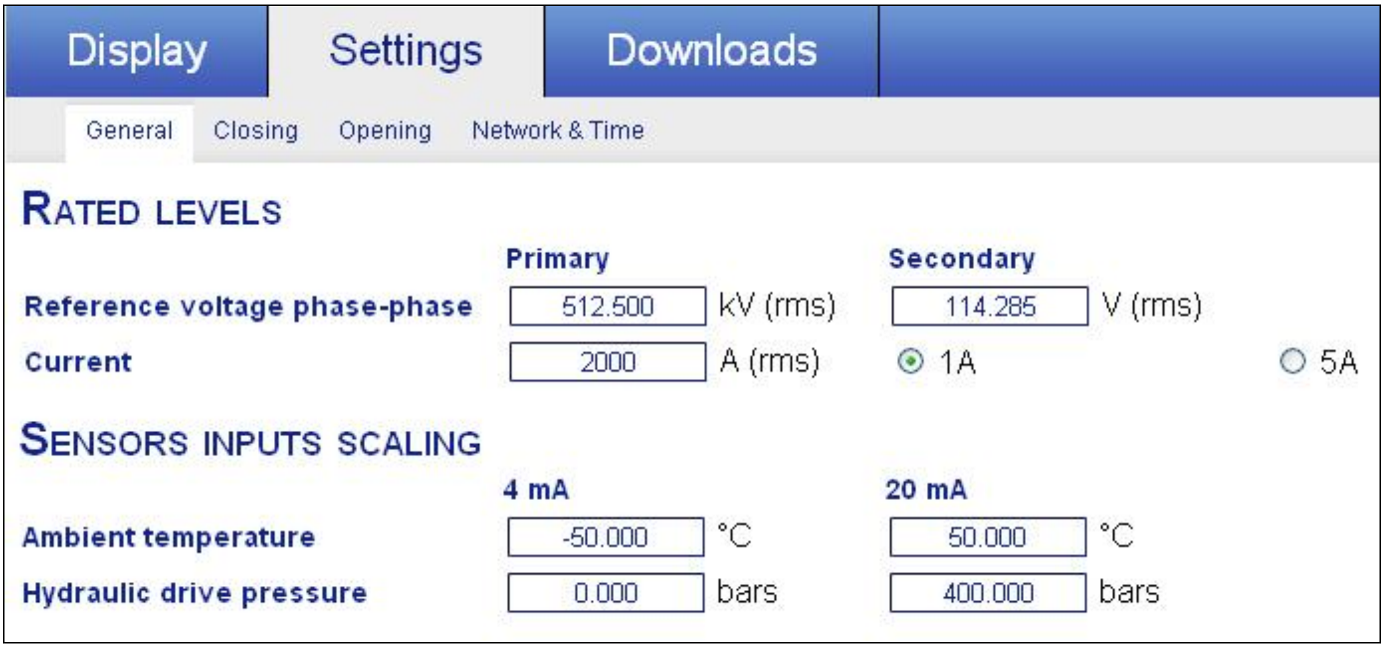


Figure 76 : external sensors related settings

3-9.3 Switchgear related data

- Rated operating times + time shifts between main and auxiliary contacts for each switchgear pole **<u>as measured on switchgear end installation site in rated conditions</u>** (nominal ambient temperature, nominal hydraulic drive pressure and nominal control voltage).
- Pre-arcing time (for closing operations) and arcing time (for opening operations) of each CB pole.
- Preferred method for CB operating times measurement (current establishment/interruption instants or CB auxiliary contacts switching instants)
- RMS current detection threshold (A rms) + instantaneous current dating threshold (A) for measurement method by current establishment / interruption : refer to section 3-4.6-2, page 47.
- Control voltage level (V) : rated DC voltage used for coils supplying and tri-polar closing and opening impulses.
- Operating times compensation laws for both CB closing and opening operations versus contributions of :
    - Ambient temperature ➔ table from -50°C to +50 °C by steps of 10°C
    - Control voltage ➔ kU factor assessment for both opening and closing operations : refer to 3-5.3-1, page 58.
    - Hydraulic pressure (if applicable) ➔ kP factor assessment for both opening and closing operations : refer to 3-5.4-1, page 62.
    - Switchgear idle time (if applicable) ➔ A and B factors assessment : refer to 3-5.5-1, page 66.
- Adaptive control weighting factor ➔ refer to 3-5.6, page 68.

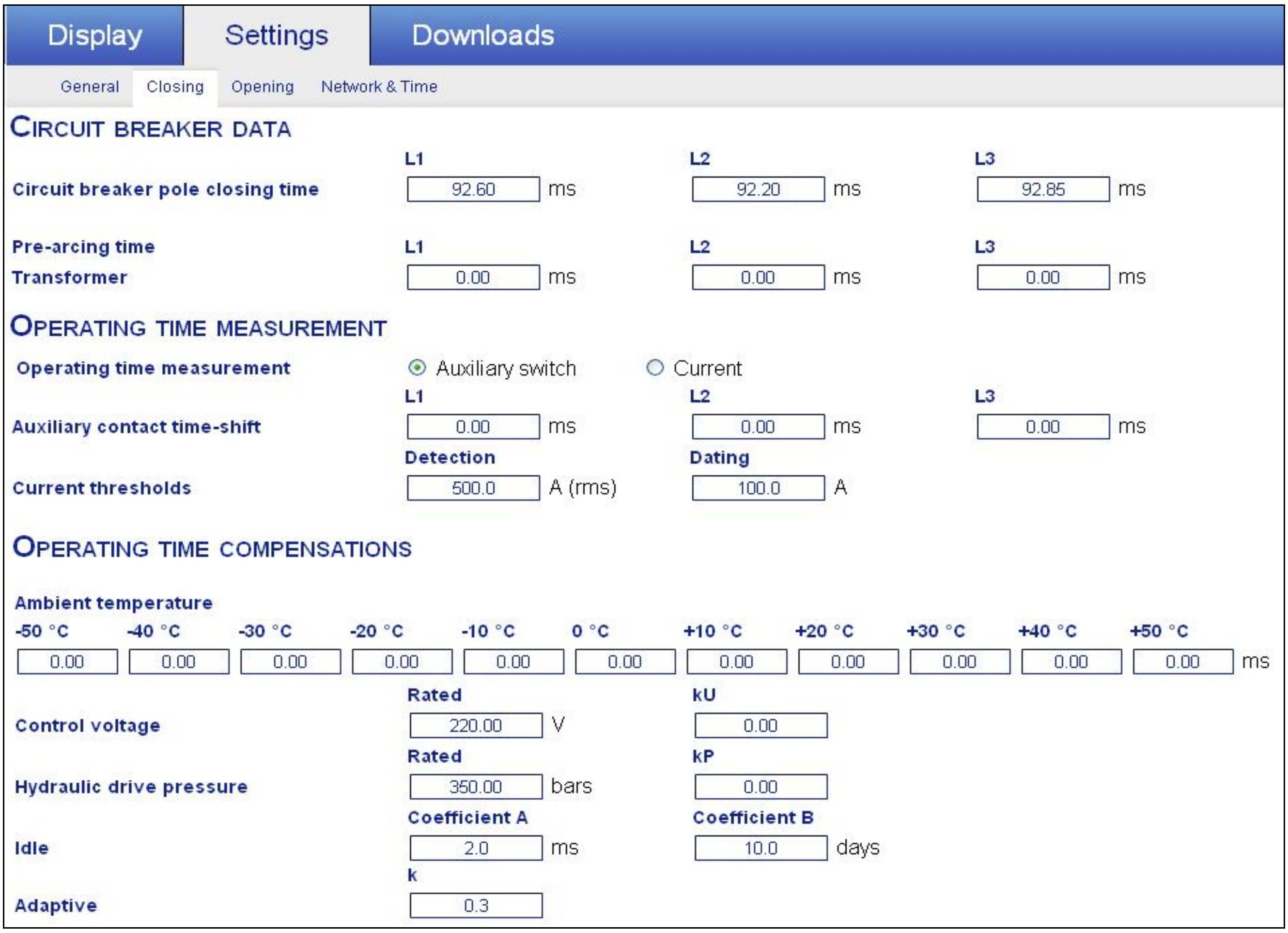


Figure 77 : Switchgear related settings : example for CB closing

NOTE : arcing times (for opening operations) and pre-arcing times (for closing operations) shall be adjusted with the highest reachable accuracy, in order PoW switching to be efficient on transients limitation (refer to sections 2 for detailed explanations).

Optimal values shall be given by the CB manufacturer.

As an alternative, approximate values may also be computed from the data listed in section 3-9.1 and the followings :

- RDDS of each pole interruptor (a given CB pole may be made of ≥ interruptors)
- Rated closing speed of each pole (depends on the driving mechanism)
- Gas mixture composition (pure SF_6 or combined with CF_4, N_2…)
- Rated gas pressure and P1 low pressure alarm threshold
- Presence or not of grading capacitors parallel to CB interruptors

3-9.4 PoW control related data

- Selected system neutral mode (grounded or isolated) + chosen detection method (Software or Hardware) : refer to 3-4.3 page 35.
- Wiring scheme of the switchgear coils (common mode or differential mode) : refer to 0, page 38.
- Reference phase identification (L1, L2 or L3) and initial phase-shift (refer to 3-4.2, page 34 for further details)
- List of enabled contributions to the CB operating times compensation (refer to 3-5, page 54)
- Selected PoW switching program (transformer, capacitor, shunt reactor or user program)

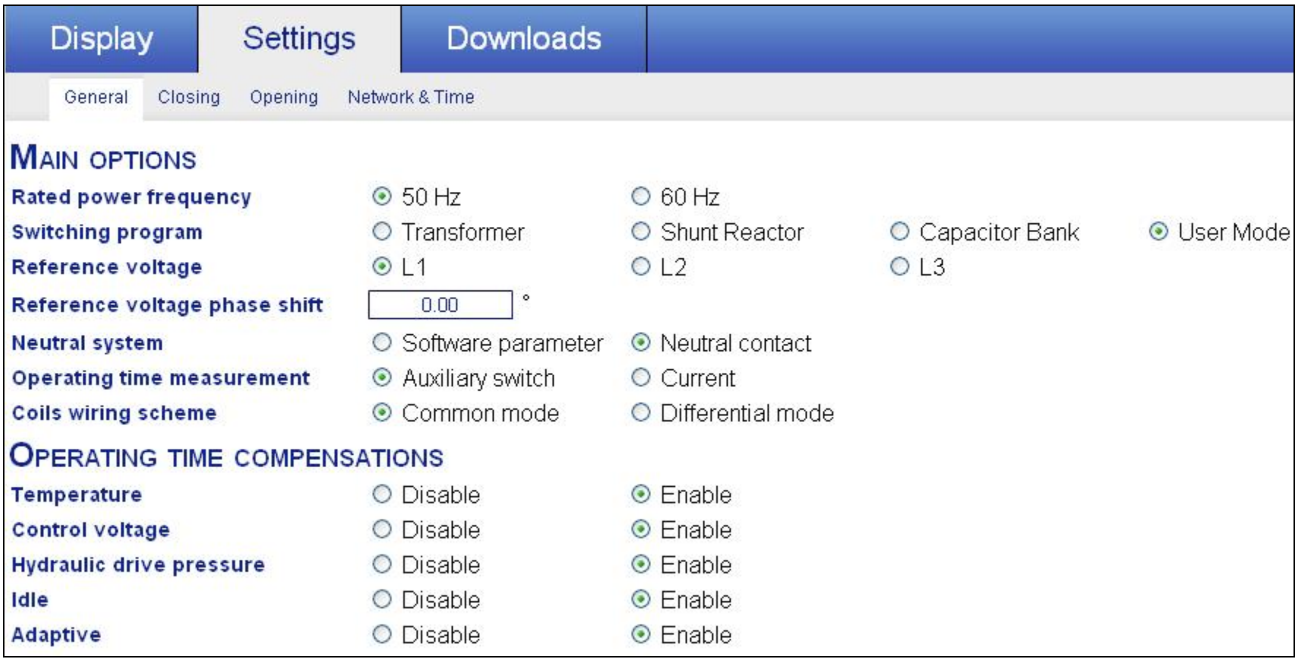


Figure 78 : PoW control related settings

- PoW shift angles for fall-back strategy during CB opening and closing operations (in case the chosen system neutral mode detection method is "hardware") : refer to 3-4.3
- Custom PoW shift angles for CB opening and closing operations (in case switching program = "user mode"):
  - For isolated neutral mode and grounded neutral mode
- Duration of the output unipolar commands (coil energization voltage impulses): refer to 0, page 38.

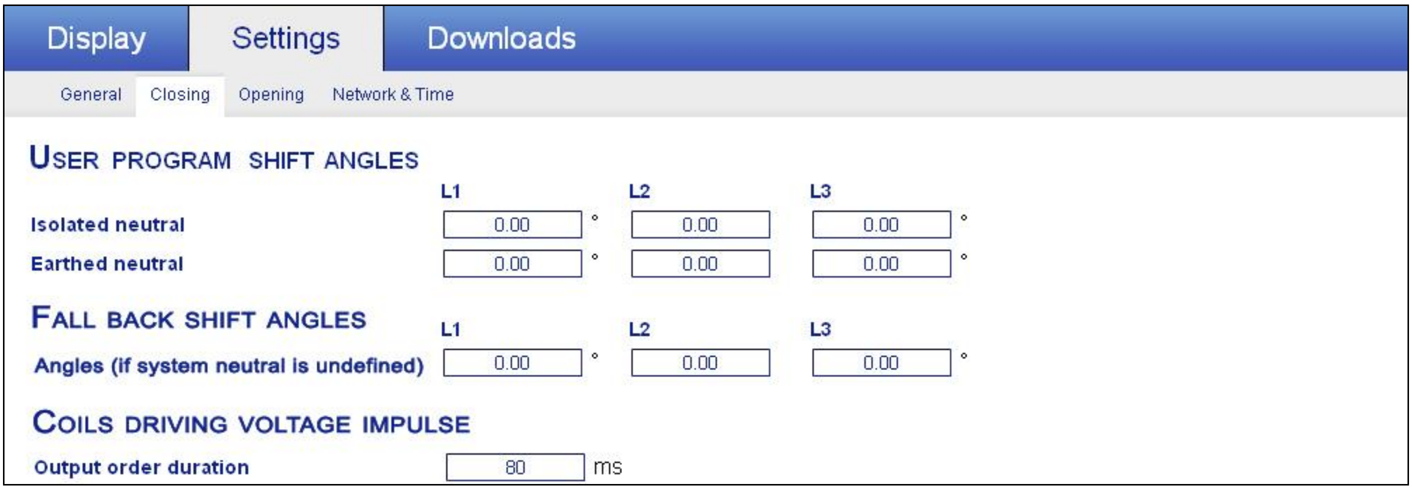


Figure 79 : PoW control related settings : example for CB closing (switching program = "user mode")

3-9.5 Alarms signaling related data

- Thresholds to be applied for application alarms and system alarms

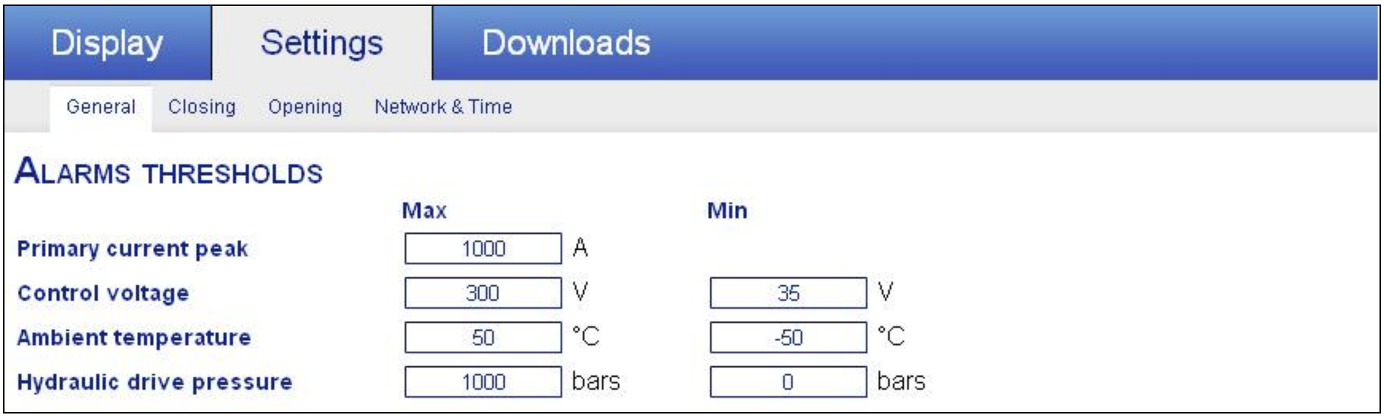


Figure 80 : Alarms signaling related settings – general thresholds

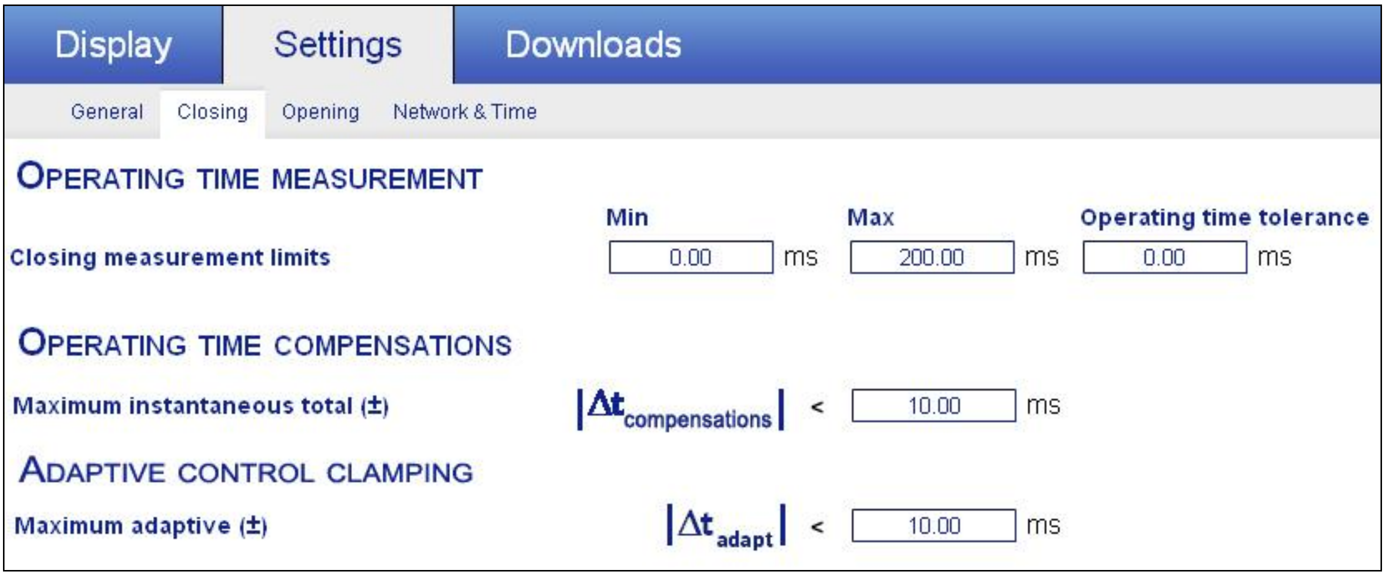


Figure 81 : Alarms signaling related settings –operating time limits & compensations clamping

- System alarms and Application alarms assignment matrix to dedicated relay-driven output contacts : refer to 3-7.2-5 and Figure 71, page 79.

3-10 RPH3 variants

The RPH3 controller was designed as a global 19'' rack integrating 5 single electronic modules connected through internal links and with removable terminal blocks at their backs for external wiring.

As introduced in section 3-3, the 5 single modules are :

M1 module Power Supply
M2 module Digital signal processing & Communication
M3 module Acquisition & Digital conversion
M4 module I/O, monitoring and CB coils driving commands
M5 module Front panel signalisation module

Each built RPH3 rack shall be customized depending on :

- Rated DC voltage for CB coils supply (48V, 110-125V or 220-250V)
- Rated current flowing through CT secondary windings (1A, 5A)

The RPH3 variant depends on these characteristics, that size the individual modules, as encoded below :

RPH3 TCR-PSx-CTy

Rated current through CT secondary windings
1 (1A)
5 (5A)

Rated CB Coils supply voltage
48 (48V DC)
125 (110V to 125V DC)
250 (220V to 250V DC)

Hence the 6 available variants are the following (modules M1, M2 and M5 being standard) :

Product variant	Description	M3 module variant	M4 module variant
RPH3 TCR-PS48-CT1	- RPH3 supply 48V DC - CT 1 Amp - CB coils supply 48V DC	M3-PS48-CT1-VT220	M4-PS48
RPH3 TCR-PS48-CT5	- RPH3 supply 48V DC - CT 5 Amps - CB coils supply 48V DC	M3-PS48-CT5-VT220	M4-PS48
RPH3 TCR-PS125-CT1	- RPH3 supply 110-250V DC - CT 1 Amp - CB coils supply 110-125V DC	M3-PS250-CT1-VT220	M4-PS125
RPH3 TCR-PS125-CT5	- RPH3 supply 110-250V DC - CT 5 Amps - CB coils supply 110-125V DC	M3-PS250-CT5-VT220	M4-PS125
RPH3 TCR-PS250-CT1	- RPH3 supply 110-250V DC - CT 1 Amp - CB coils supply 220-250V DC	M3-PS250-CT1-VT220	M4-PS250
RPH3 TCR-PS250-CT5	- RPH3 supply 110-250V DC - CT 5 Amps - CB coils supply 220-250V DC	M3-PS250-CT5-VT220	M4-PS250

3-11 Pinout description

The following drawing (Figure 82) introduces the RPH3 terminals layout and designation.

Each connector is defined by its module location and one identification index : for instance M4 power supply terminals connector is defined as M4-J1.

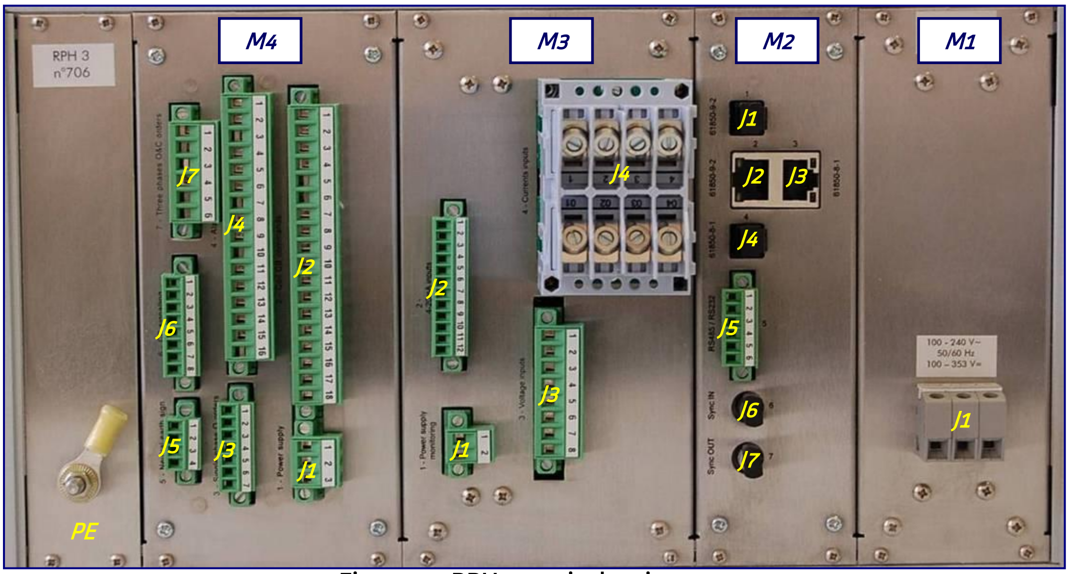


Figure 82: RPH3 terminal assignment

<u>NOTE 1 :</u> to make the maintenance operations easier (that shall be restricted to relay replacement), the connectors are all different and removable.

<u>NOTE 2 :</u> each connector is provided with its own local shield input, in order to minimize external coupling of electromagnetic perturbations with the RPH3. Earthing shall be located as close as possible to the electronics.

3-11.1 M1 Module terminals

M1-J1 – RPH3 POWER SUPPLY		
Power supply	M1-J1 : 1	Ground
	M1-J1 : 2	Phase or Polarity /+
	M1-J1 : 3	Neutral or Polarity /-

3-11.2 M2 Module terminals

M2 Communication ports			
61850-9-2 optical link	M2-J1		*MT-RJ (AFBR 5903)*
61850-9-2 copper link	M2J2		*RJ45*
61850-8-1 copper link	M2J3		*RJ45*
61850-8-1 optical link	M2J4		*MT-RJ (AFBR 5903)*
RS485 / RS232 serial link	M2J5 : 1	RS232 TX iso	*MC 1,5/6-STF-3.81*
	M2J5 : 2	GND iso	
	M2J5 : 3	RS232 RX iso	
	M2J5 : 4	RS485 A	
	M2J5 : 5	RS485 TERM	
	M2J5 : 6	RS485 B	
Sync IN optical link	M2J6		*HFBR 1414Z*
Sync OUT optical link	M2J7		*HFBR 2412Z*

3-11.3 M3 Module terminals

M3-J1 – OUTPUT COIL SUPPLY MONITORING		*MSTB 2,5/2-STF*
Recommended wire gauge	AWG24-12	
DC supply	M3-J1 : 1	Polarity /-
	M3-J1 : 2	Polarity /+

M3-J2 – 4-20mA INPUTS		*MC 1,5/12-STF-3.5*
Recommended wire gauge	AWG28-16	
Ambient temperature	M3-J2 : 1	Shield
	M3-J2 : 2	Signal
	M3-J2 : 3	+ 24V
Hydraulic pressure L1 phase	M3-J2 : 4	Shield
	M3-J2 : 5	Signal
	M3-J2 : 6	+ 24V
Hydraulic pressure L2 phase	M3-J2 : 7	Shield
	M3-J2 : 8	Signal
	M3-J2 : 9	+ 24V
Hydraulic pressure L3 phase	M3-J2:10	Shield
	M3-J2:11	Signal
	M3-J2:12	+ 24V

M3-J3 – VOLTAGES INPUTS		*MSTB 2.5/8-STF-5.08*
Recommended wire gauge	AWG28-16	
Line voltage L1 phase	M3-J3 : 1	S1
	M3-J3 : 2	S2
Line voltage L2 phase	M3-J3 : 3	S1
	M3-J3 : 4	S2
Line voltage L3 phase	M3-J3 : 5	S1
	M3-J3 : 6	S2
Source voltage	M3-J3 : 7	S1
	M3-J3 : 8	S2

M3-J4 – CURRENT INPUTS (ENTRELEC Safety socket)		*ESSAILEC CC-I-VA-2*
Recommended wire section	1 - 2.5 mm²	
Not used input	M3-J4 : 01	Not used
	M3-J4 : 1	Not used
Load current / L1 phase	M3-J4 : 02	S1
	M3-J4 : 2	S2
Load current / L2 phase	M3-J4 : 03	S1
	M3-J4 : 3	S2
Load current / L3 phase	M3-J4 : 04	S1
	M3-J4 : 4	S2

3-11.4 M4 Module terminals

M4-J1 – CB COIL SUPPLY		*MSTB 2,5/3-STF-5.08*
Recommended wire gauge	AWG24-12	
Switchgear coil command supply	M4-J1 : 1	Coil command /+
	M4-J1 : 2	Coil command /-
	M4-J1 : 3	Shield

M4-J2 – CB COIL OUTPUT COMMAND		*MSTB 2,5/18-STF-5.08*
Recommended wire gauge	AWG24-12	
Tripping output / L1 phase	M4-J2 : 1	Coil O Phase A /+
	M4-J2 : 2	Coil- O Phase A /-
	M4-J2 : 3	Shield
Tripping output / L2 phase	M4-J2 : 4	Coil O Phase B /+
	M4-J2 : 5	Coil O Phase B /-
	M4-J2 : 6	Shield
Tripping output / L3 phase	M4-J2 : 7	Coil O Phase C /+
	M4-J2 : 8	Coil O Phase C /-
	M4-J2 : 9	Shield
Closing output / L1 phase	M4-J2 : 10	Coil C Phase A /+
	M4-J2 : 11	Coil C Phase A /-
	M4-J2 : 12	Shield
Closing output / L2 phase	M4-J2 : 13	Coil+ C Phase B /+
	M4-J2 : 14	Coil C Phase B /-
	M4-J2 : 15	Shield

Closing output / L3 phase	M4-J2 : 16	Coil+ C Phase C /+
	M4-J2 : 17	Coil C Phase C /-
	M4-J2 : 18	Shield

M4-J3 – TRIPPING COMMAND DETECTION		*MC 1,5/7-STF-3.81*
Recommended wire gauge	AWG24-14	
Shield	M4-J3 : 1	Shield
Tripping command detection / L1 phase	M4-J3 : 2	O phase A /+
	M4-J3 : 3	O phase A /-
Tripping command detection / L2 phase	M4-J3 : 4	O phase B /+
	M4-J3 : 5	O phase B /-
Tripping command detection / L3 phase	M4-J3 : 6	O phase C /+
	M4-J3 : 7	O phase C /-

M4-J4 – OUTPUT ALARMS		*MSTB 2,5/16-STF-5.08*
Recommended wire gauge	AWG24-12	
Shield	M4-J4 : 1	Shield
All-or-noting relay	M4-J4 : 2	Alarm mon.1b
	M4-J4 : 3	Alarm mon. 1a
Flip-flop relay 1	M4-J4 : 4	Alarm bist. 1b (NC)
	M4-J4 : 5	Common bist. 1
	M4-J4 : 6	Alarm bist. 1a (NO)
Flip-flop relay 2	M4-J4 : 7	Alarm bist. 2b (NC)
	M4-J4 : 8	Common bist. 2
	M4-J4 : 9	Alarm bist. 2a (NO)
Flip-flop relay 3	M4-J4 : 10	Alarm bist. 3b (NC)
	M4-J4 : 11	Common bist. 3
	M4-J4 : 12	Alarm bist. 3a (NO)
Flip-flop relay 4	M4-J4 : 13	Alarm bist. 4b (NC)
	M4-J4 : 14	Common bist. 4
	M4-J4 : 15	Alarm bist. 4a (NO)
Shield	M4-J4 : 16	Shield

M4-J5 – NEUTRAL EARTH SIGNALING		*MC 1,5/4-STF-3.81*
Recommended wire gauge	AWG24-14	
Shield	M4-J5 : 1	Shield
Neutral / Earth signaling	M4-J5 : 2	+48V common
	M4-J5 : 3	N/E NO
	M4-J5 : 4	N/E NC

M4-J6 – CB AUX. SIGNALING		*MC 1,5/8-STF-3.81*
Recommended wire gauge	AWG24-14	
Shield	M4-J6 : 1	Shield
Auxiliary contact / L1 phase	M4-J6 : 2	CB position / L1 phase
	M4-J6 : 3	+48V common
Auxiliary contact / L2 phase	M4-J6 : 4	CB position / L2 phase
	M4-J6 : 5	+48V common

Auxiliary contact / L3 phase	M4-J6 : 6	CB position / L3 phase
	M4-J6 : 7	+48V common
Shield	M4-J6 : 8	Shield

M4-J7 - CB COIL INPUT COMMAND		*MSTB 2,5/6-STF-5.08*
Recommended wire gauge	AWG24-12	
Tripping input	M4-J7 : 1	Tripping input / +
	M4-J7 : 2	Tripping output / -
	M4-J7 : 3	Shield
Closing input	M4-J7 : 4	Closing input / +
	M4-J7 : 5	Closing input / -
	M4-J7 : 6	Shield

3-12 Connection diagrams

This section provides recommended typical connection schemes of the RPH3 controller for TCR applications. Software configuration settings shall be set in accordance to actual wiring scheme.

3-12.1 Case earthing, power supply and System neutral mode

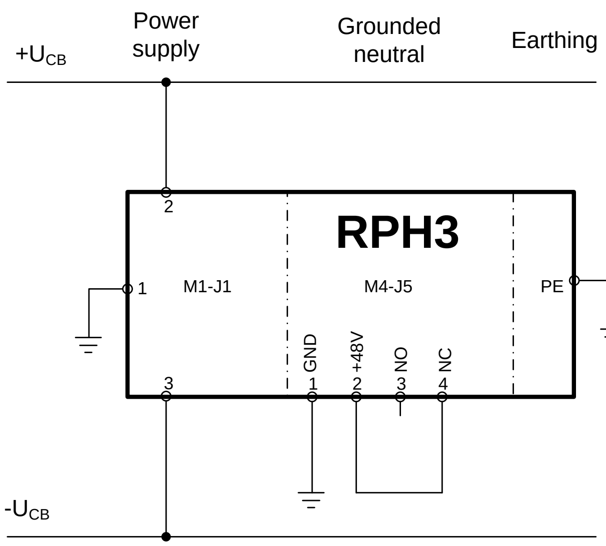


Figure 83 : power supply & grounded system neutral wiring

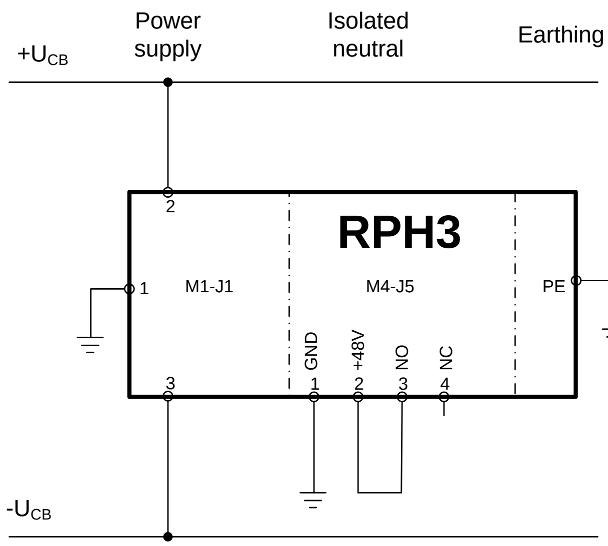


Figure 84 : power supply & isolated system neutral wiring

NOTE 1 : the RPH3 controller case must be systematically earthed through the PE terminal (earthing external screw)

NOTE 2 : the wire bridge for system neutral mode (grounded or isolated) must be selected in accordance with the associated software setting (refer to section 3-4.3, page 35). No bridge is required in case the system neutral mode is determined by software setting (see Figure 15, page 32).

NOTE 3 : the RPH3 delivers a +48V DC voltage on its pin M4-J5:2 for bridge bias. DO NOT connect any external source on this pin !

NOTE 4 : for more flexibility, an external switch may be used as a "neutral isolator" between M4-J5 pins 2, 3 and 4 in order to change automatically from a grounded mode to an isolated mode (might be useful for switching between PoW shift angles).

3-12.2 Reference voltage

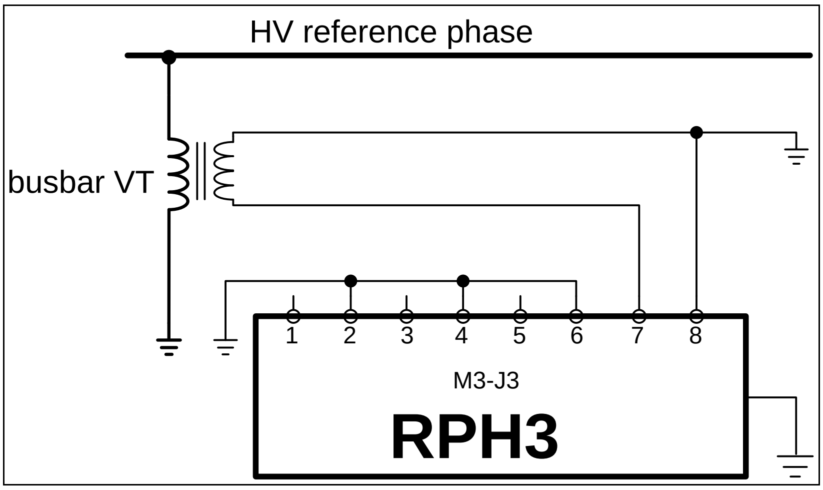


Figure 85 : Reference voltage : typical wiring

3-12.3 Analogue sensors

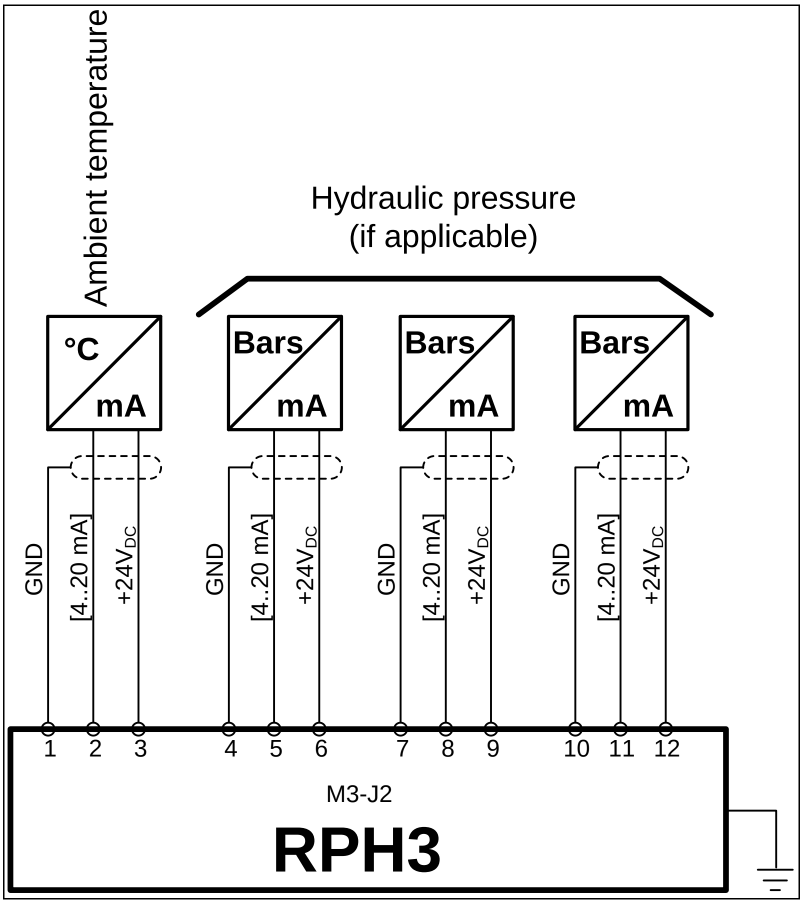


Figure 86 : ambient temperature & hydraulic pressure transducers : typical wiring diagram

<u>**NOTE :**</u> Calibration data associated to the analogue sensors must be adjusted through the web MMI : refer to section 3-9, page 84.

3-12.4 switchgear control and RPH3 by-passing

By-passing the RPH3 controller may be useful in case it cannot assume its duty for any reason (the reference AC voltage is missing, the RPH3 is not supplied, etc.)

However, such a by-pass shall be enabled or not depending on the end application, since it leads uncontrolled switching of the HV switchgear (no synchronization at all). Therefore, as soon as the RPH3 controller is by-passed huge overvoltages and/or inrush currents may occur, with associated consequences on the HV network, switchgear aging, etc.

The following drawings illustrate how to implement such a by-pass upon possible connection schemes.

NOTE : the CB coils connection scheme (common mode or differential mode) must be selected in accordance with the associated software setting (refer to Figure 26, page 39)

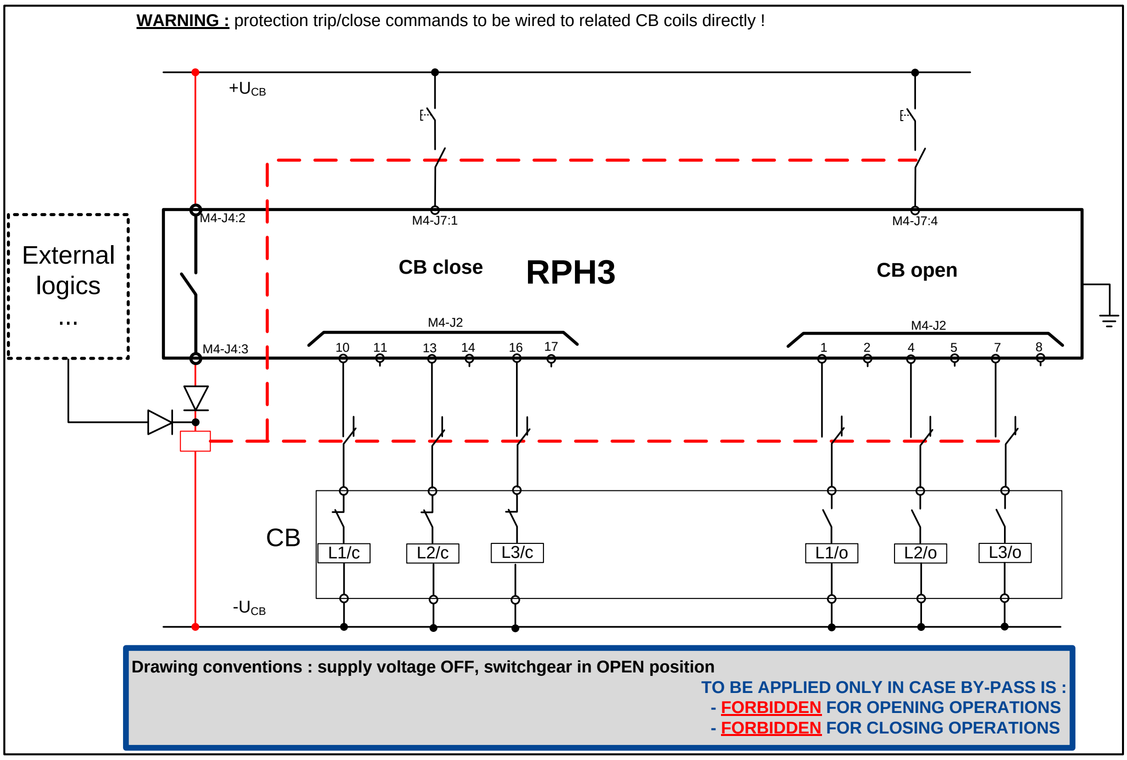


Figure 87 : by-passing diagram - forbidden on both channels (common mode variant)

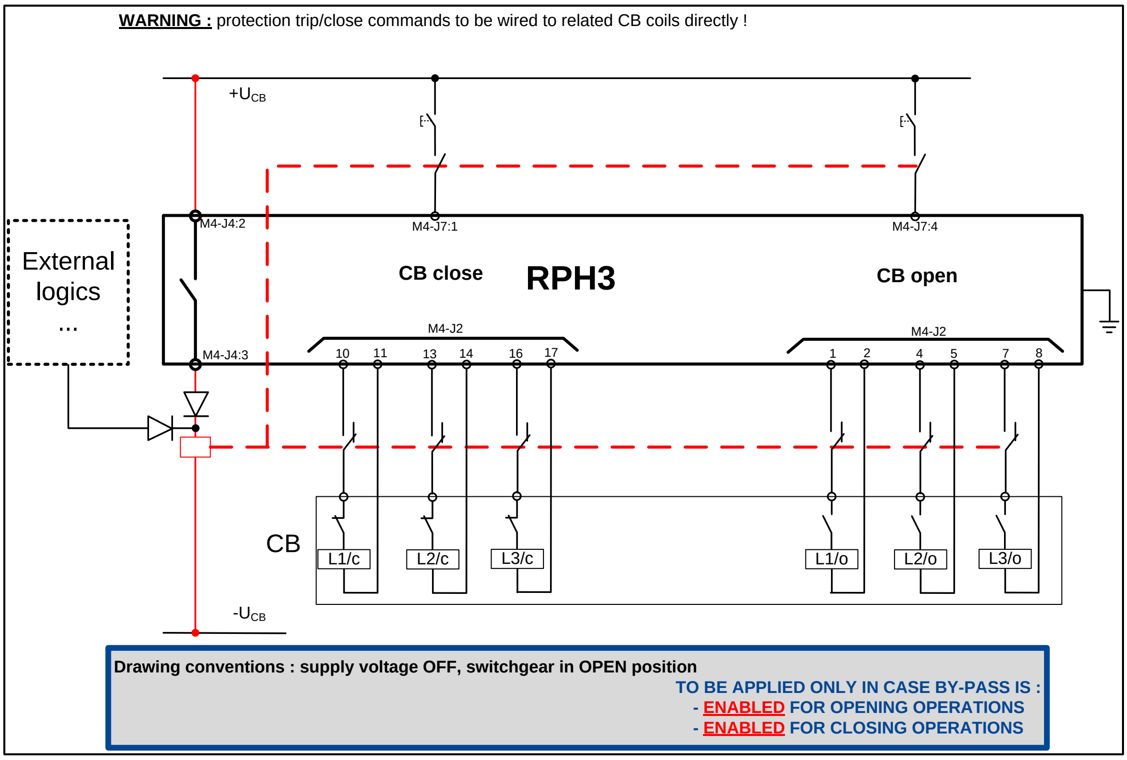


Figure 88 : by-passing diagram - forbidden on both channels (differential mode variant)

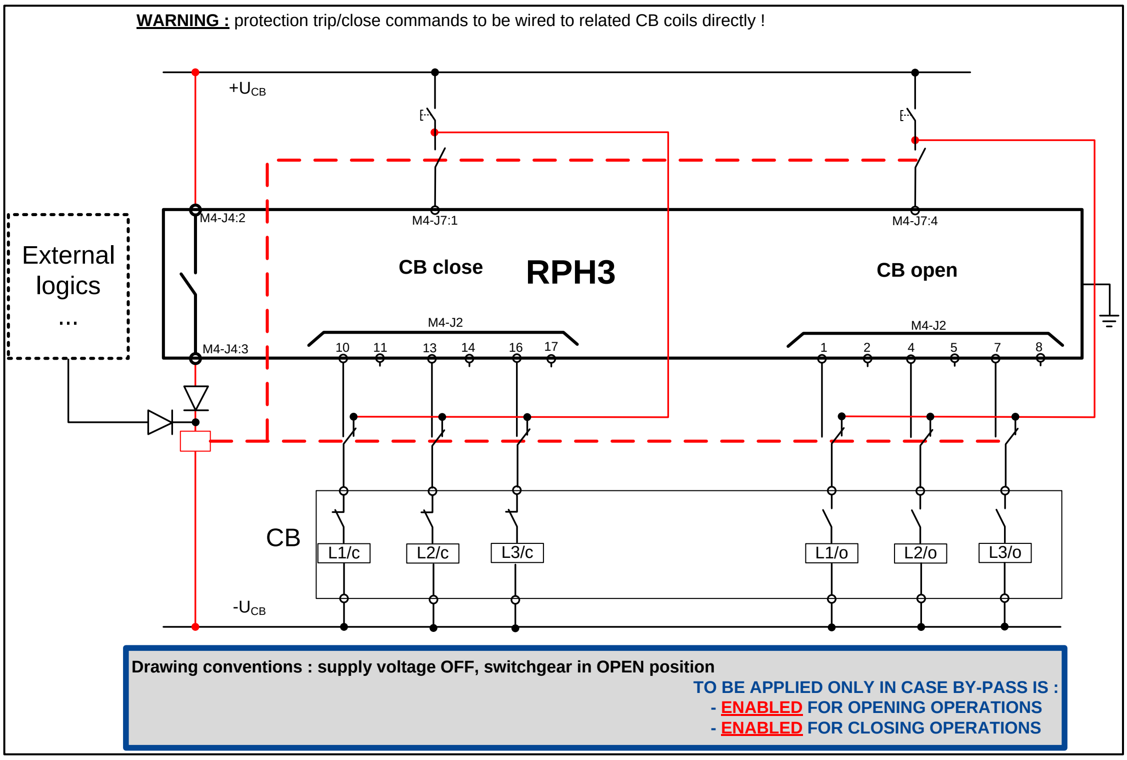


Figure 89 : by-passing diagram - enabled on both channels (common mode variant)

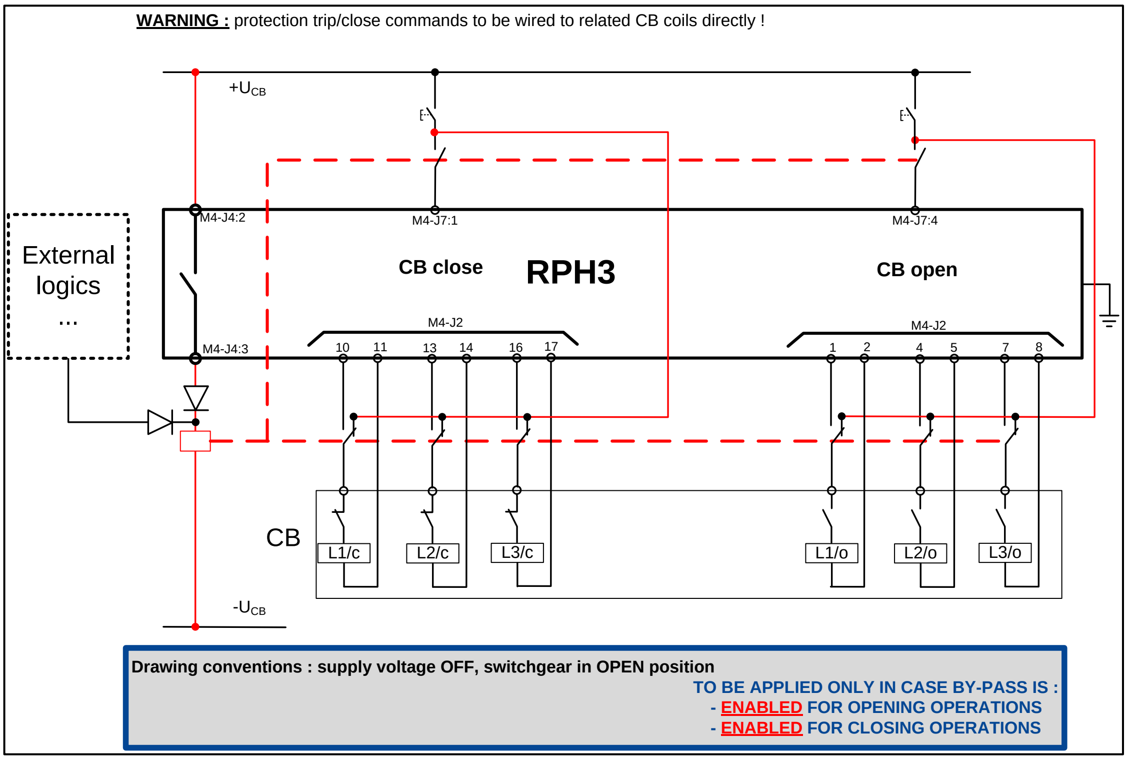


Figure 90 : by-passing diagram - enabled on both channels (differential mode variant)

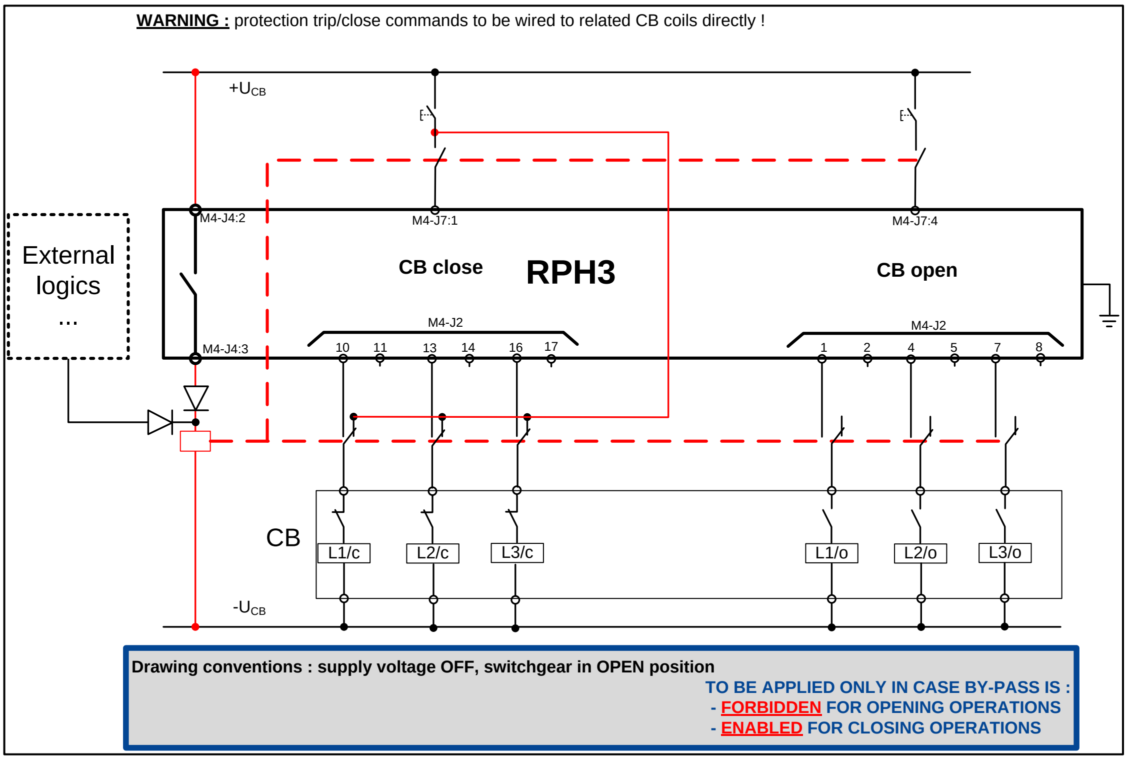


Figure 91 : by-passing diagram - enabled on closing channel only (common mode variant)

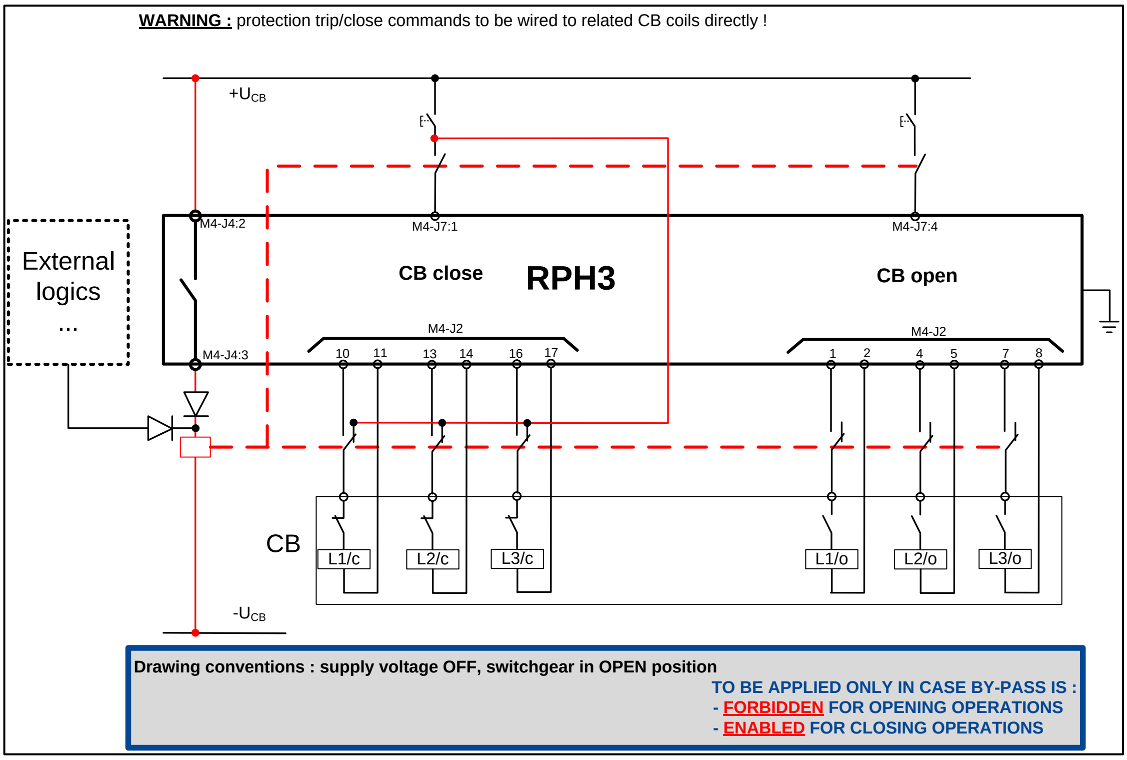


Figure 92 : by-passing diagram - enabled on closing channel only (differential mode variant)

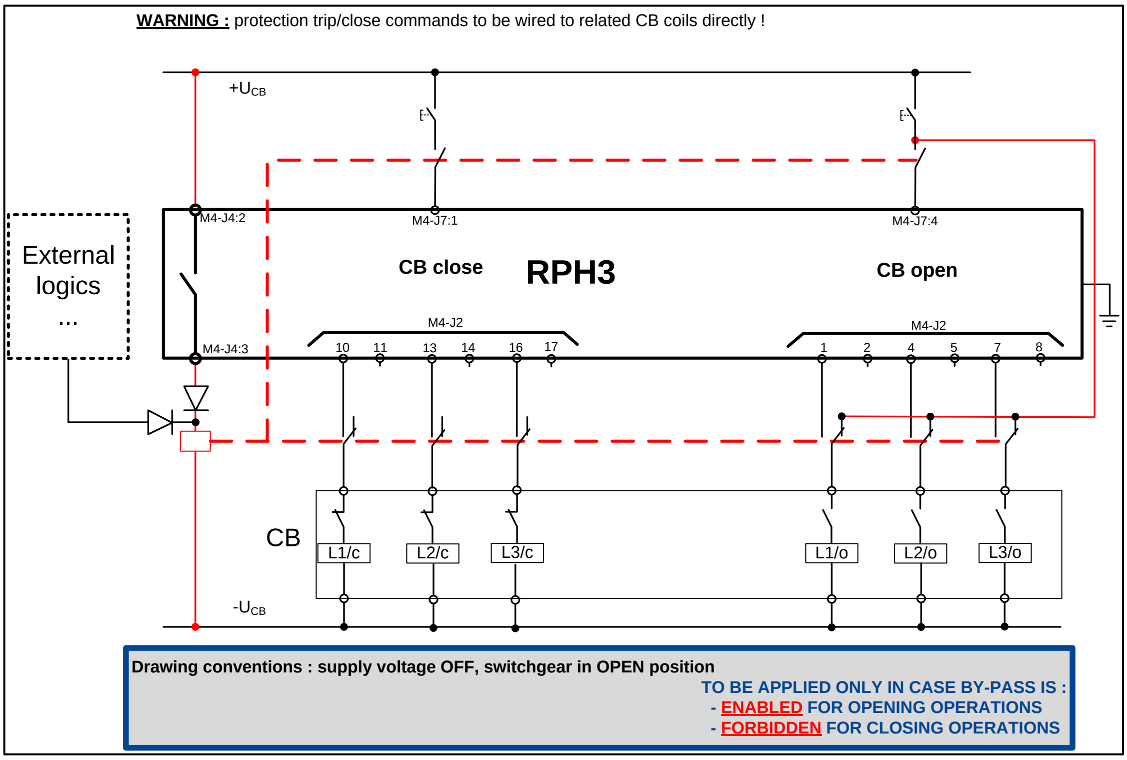


Figure 93 : by-passing diagram - enabled on opening channel only (common mode variant)

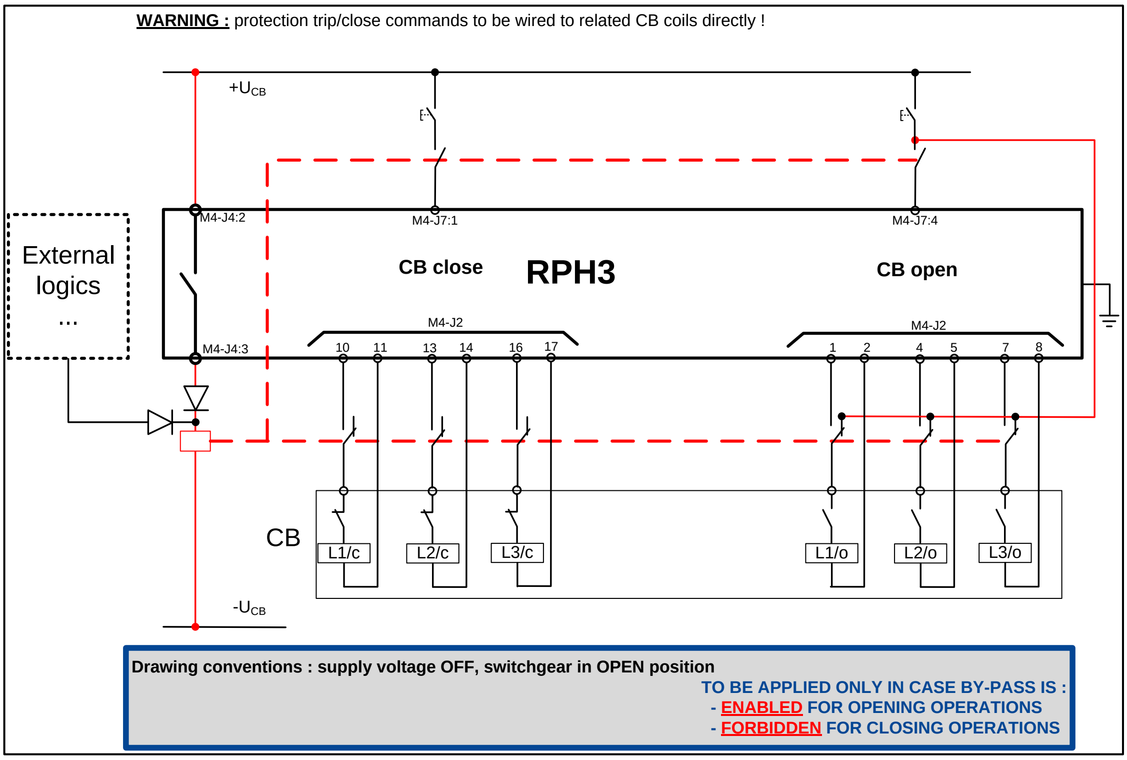


Figure 94 : by-passing diagram - enabled on opening channel only (differential mode variant)

3-12.5 relay-driven alarm contacts and switchgear signaling

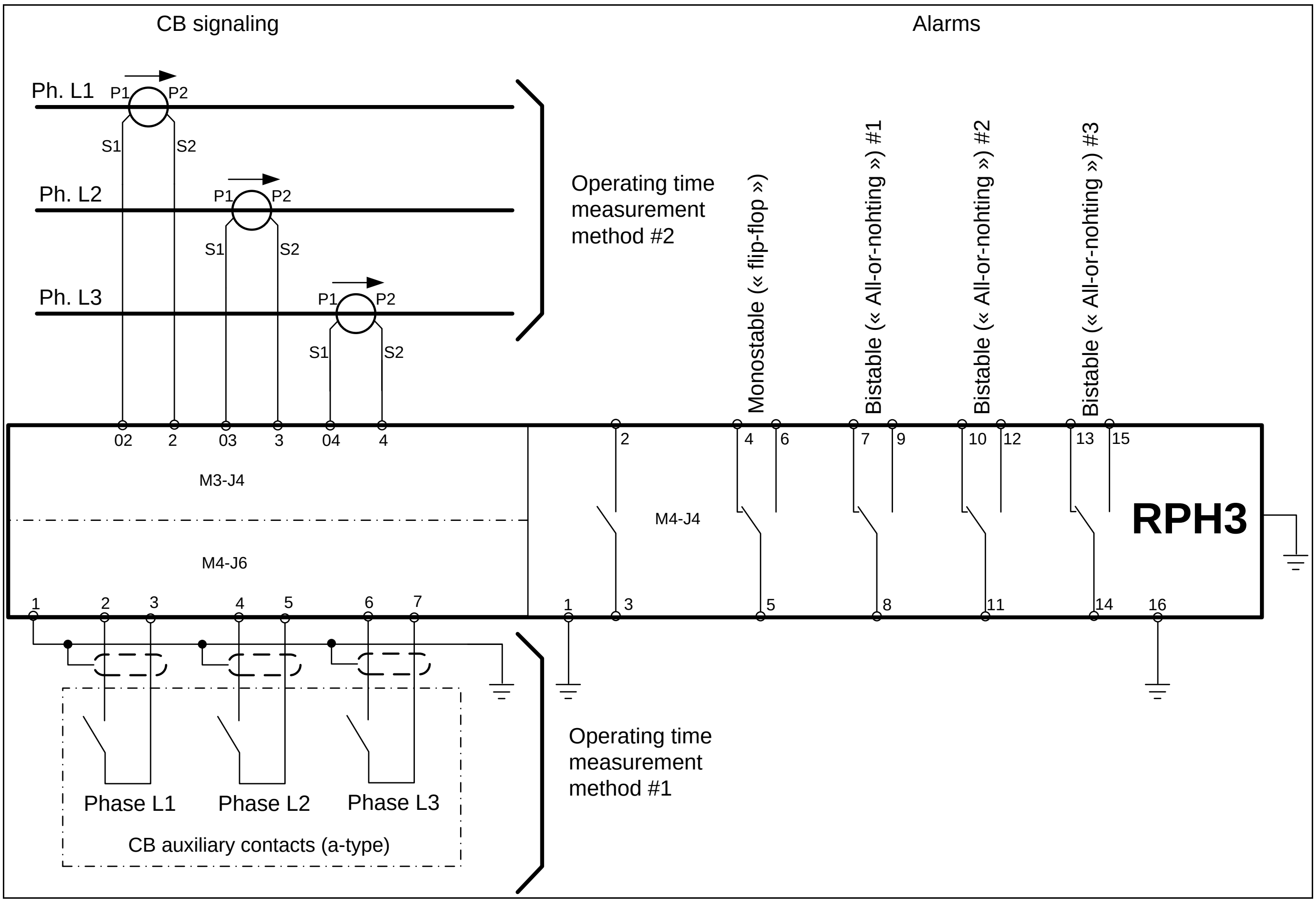


Figure 95 : CB signaling & relay-driven alarm contacts : typical wiring diagram

<u>NOTE 1 :</u> CB signaling is used by the RPH3 controller to assess switchgear operating times thanks to two different methods :

- HV currents establishment / interruption measurement (through line CTs)
- CB auxiliary contacts switching instants measurement

The preferred method is to be selected by a software setting. Connections associated to the preferred method are mandatory, while the other ones are optional. But they may be useful for the alternative method to be taken into account in case the preferred one failed for any reason. Therefore, GE Grid Solutions recommends to connect the RPH3 to both line CTs and auxiliary contacts. Refer to section 3-4.6 page 42 for further details.

<u>NOTE 2 :</u> the line CTs are also required for the RPH3 controller to measure switched HV currents.

<u>NOTE 3 :</u> current inputs are potential-free. Hence it is not required for M3-J4 pins to be grounded.

3-13 Technical data

Dimensions (LxHxW)

RPH3 housing is designed for mounting in a 19’’ – rack or wall mounting.

Height	4U
Depth	400 mm max
Width	19’’

Protection

IP20

Rated frequency (reference voltage)

50 / 60 Hz ±10 %

Power Supply

Range 1 100 to 240 V AC / 50-60Hz
Range 2 48 to 353 V DC
Power consumption < 20 W

CB coil voltage

Rated	48-250 V DC
Operating	33-300 V DC

CB coil current

Maximum allowed current through each CB coil : 10 A / phase for 300 ms.

Time accuracy for data acquisition

Resolution < 0.1 ms

Operating time acquisition accuracy over ambient temperature range [-25°C to +50 °C]

Resolution < ± 0.1 ms

Sensors input accuracy

Control voltage	± 3%
Ambient temperature	± 3%
Hydraulic pressures	± 3%

Reference voltage input

Rated level (RMS)	100/√3 V AC or 220/√3 V AC
Operating range (RMS)	15-105 V AC or 30-250 V AC
Rated frequency	50 Hz or 60 Hz ± 10%
Power consumption of measuring inputs	< 2 VA
Insulation level between input & output windings	2 kV rms
Acquisition accuracy	1%

Current inputs

Rated level I_{RATED} (RMS)	1A or 5A
Rated short time current	200 A for 1s
Operating range	0.5x I_{RATED} to 3 x I_{RATED}
Power consumption of measuring inputs	< 2 VA at 3x I_{RATED}
Acquisition accuracy	3%

Analogue sensors inputs (ambient temperature, hydraulic pressures)

Operating range	4-20 mA
Rated supply voltage	24V (delivered by the RPH3 controller)

Relay-driven output contacts

Monostable relay contact ("All-or-Nothing" : M4-J4:2/3)

1 contact per relay	NO (Normally Open)
Operating voltage	250 V DC
Max rated DC current	5 A
Max overload	100A for 30 ms
Breaking power	10 VA under 48 V DC with L/R = 20 ms
Insulation level	4 kV in common mode
	1 kV in differential mode

Bistable relays contacts ("Flip-Flop")

2 contacts per relay	1x NO (Normally Open) + 1x NC (Normally Closed)
Operating voltage	230 V DC
Max rated DC current	5 A
Max overload	100A for 30 ms
Breaking power	10 VA under 48 V DC with L/R = 20 ms
Insulation level	4 kV in common mode
	1 kV in differential mode

RoHS

EU2002/95/EG

Reliability

MTBF (MIL-HDBK-217)	150 000 hours (> 17 years)

Operating temperature range

Room temperature	-25°C to +50°C
Cold	IEC 60068-2-1 -25°C ±3°C
Dry heat	IEC 60068-2-2 +50°C ±2°C
Wet heat	IEC 60068-2-3 +40°C ±2°C +93% HR ±3% 48 h

Dielectric Compatibility

Dielectric strength	IEC 60255-5 CM 2kV – 50/60 Hz for 1 minute DM 1kV – 50/60 Hz for 1 minute
Insulation resistance	> 100 MΩ at 500 V
Impulse voltage	CM ±5 kV 0.5 J DM ±1 kV 0.5 J
Voltage tolerance	IEC 60255-6 DC -30% to +20% AC -30% to +15%
DC supply interruption	IEC 61000-4-29 50% dip : 100 ms Interruption : 20 ms
Immunity to conducted common mode	IEC 61000-4-16 Level 4 Disturbance 0 to 150 kHz Continuous : 30 V @ 50 Hz or 60 Hz 1 sec : 300V @ 50 Hz or 60 Hz
Ripple on DC input power port	IEC 61000-4-17 Level 3 10% of the rated value

Electromagnetic Compatibility

Electrostatic discharge	IEC 61000-4-2 Level 4 8 kV contact 15 kV air
Radio frequency impulse	IEC 61000-4-3 Level 3 10 V/m – 80 MHz to 1 GHz

	1kHZ sine modulation @ 80%
Fast transient burst	IEC 61000-4-4 Level 4 Conducted : 4 kV 2.5 kHz Radiated : 2 kV 2.5 kHz (4 kV on G15 group)
Surge immunity	IEC 61000-4-5 Level 4 CM 4 kV DM 2 kV
Conducted disturbances	IEC 61000-4-6 Level 3 10 V 150 kHz to 80 MHz 1kHZ sine modulation @ 80%
Immunity to magnetic disturbances	IEC 61000-4-8 Level 5 100 A/m continuous – 1000 A/m 3s 1kHZ sine modulation @ 80%
Immunity to high frequency disturbances	IEC 61000-4-12 Level 3 CM 2.5 kV CM DM 1 kV (200 Ω) 100 kHz 50c/s 1 MHz 400c/s (2s, F=2.5 kHz)
Electromagnetic compatibility class A	EN 55022

Internet ports

100 Base Fx & Tx	
Protocols	TCP/IP – HTTP
Interface	RJ45 electrical or MTRJ optical

Clock synchronization ports

Interface ST optical

Terminal blocks

Terminal blocks with screws type PHOENIX CONTACT MSTB 2.5 or MC 1.5 (male + female assembly) are used for all connections, except the followings :

- Communication ports
- Connection to CT primary windings (ENTRELEC safety connection kit / ESSAILEC type)
- Power supply and voltage inputs direct connection of cables on AWG 24-10 type blocks.

All connections are accessible on the rear panel of the RPH3 controller, except the RS232/RS485 communication port (located on the front panel).

4 APPLICATION NOTES

4-1 Scope of PoW switching applications

PoW switching with the RPH3 "TCR" shall be considered in applications listed in the Table 7 below. For other applications, contact GE Grid Solutions support.

Application	Random switching effects	Synchronous switching effects	
		Added value	target point definition with respect to the previous zero of the phase voltage
CBR closing operations			
energizing power transformers or 3-core reactors (initially discharged)	High inrush currents	Limit inrush currents	Closing at voltage that minimizes transient magnetic flux. target point = voltage peak (90° el.)
energizing uncompensated transmission lines (capacitive load)	High voltage surges	Limit transient overvoltages	target point = voltage zero (0° el.)
energizing transmission lines compensated by shunt reactors *	High voltage surges	Limit transient overvoltages	Closing at source zero-voltage target point = voltage zero (0 ° el.)
energizing single banks of capacitors	High voltage surges	Limit transient overvoltages	target point = voltage zero (0° el.)
energizing "back-to-back" banks of capacitors	High voltage surges	Limit transient overvoltages	target point = voltage zero on the bank to be energized (0° el.)
CBR opening operations			
de-energizing transformers or shunt reactors	High voltage surges	Limit transient overvoltages	target point = current zero (90° el.)
de-energizing transmission lines compensated by shunt reactors	High voltage surges	Limit transient overvoltages	target point = current zero (90° el.)
de-energizing banks of capacitors (single bank or back-to-back)	High voltage surges	Limit transient overvoltages	target point = current zero (90° el.)

Table 7 : typical applications for PoW switching

* in case transmission lines are compensated by shunt reactors, PoW switching with standard "capacitor" switching program may or not be applicable, depending on the compensation efficiency (if "over-compensated", the line turns inductive). Contact GE Grid Solutions support for further details.

<u>NOTE :</u> in case a **N**eutral **G**rounding **R**eactor is to be used for grounding inductive loads (reactors or transformer primary windings), the neutral mode shall be set to "isolated" and the RPH3 switching program shall be selected as described in section 4-6 page 123.

4-2 Switching HV transformers and 3-core reactors

This section describes the strategy used by the RPH3 for synchronous switching of transformers of any kind.

However, transformer banks whose primaries are wounded around independent single magnetic cores are considered as single core shunt reactors instead of transformers. For this kind of load refer to section 4-3, page 113.

The switching program "Transformer" shall be selected with the appropriate neutral mode ("grounded" or "isolated") when switching no-load power transformers, in order to prevent the below undesirable conditions to occur :

- High inrush currents that mechanically stress the transformer windings through resulting strong electro-magnetic forces. These inrush currents slowly decay down to the steady-state magnetizing level within several seconds.
- Temporary harmonic voltages that may lead to unexpected tripping operations of some protection relays.

NOTE : for transformers with primary windings in delta connection, the neutral mode setting shall be set to "isolated".

4-2.1 Closing operations

For this scope of applications, the target points for closing are chosen so that the flux that will appear in the transformer at closing dates equals the permanent flux that would exist if its 3 phases were permanently energized.

Note: closing on transformers with residual flux is not yet supported by the RPH3.

In order to prevent transients, the target point for closing each phase is thus defined as the associated voltage peak :

grounded neutral (with phase-phase coupling)

For loads with grounded neutral, each CBR pole might obviously be closed about 1/3 period timewise after each other.
But this 1st level approach does not take into account the mutual coupling existing between phases (via the iron core in case of 3 core transformers or via the low-voltage winding in case of transformer banks).

Actually the first phase to be closed is the reference one, which is switched on its voltage peak (90° el. after voltage zero). Once it has been closed, the magnetic flux in the associated core rises up to its nominal value, and closes via both the remaining, non-energized cores (a half to each). Thus closing of the two remaining phases occurs ¼ period later (90° el.), so that the current can start flowing immediately and without transient process as shown on the Figure 96.

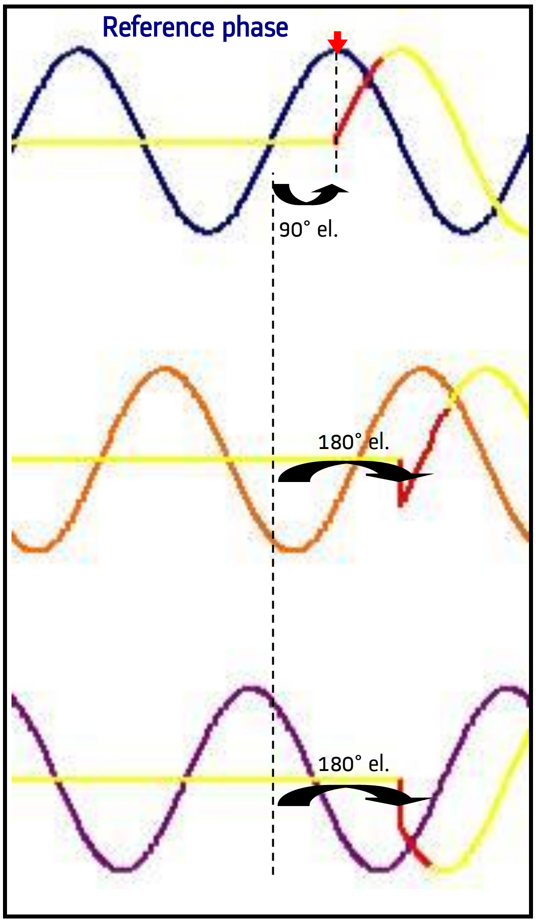
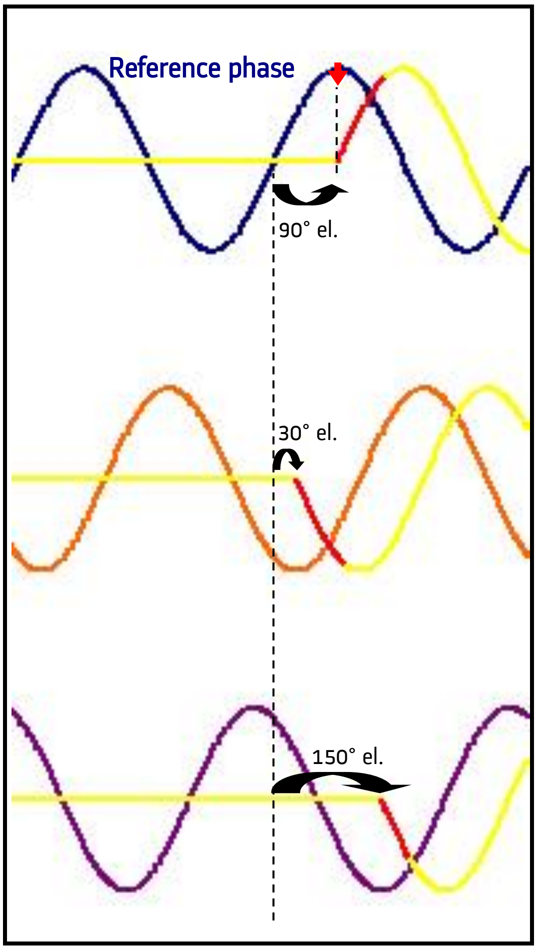


Figure 96 :
switching sequence while energizing a transformer or 3-core reactors (grounded Neutral)

grounded neutral (no phase-phase coupling)



In case of grounded transformer banks with secondary or tertiary windings in star connection the mutual coupling is null between phases.

In this specific case the load is to be considered as a group of 3 single-core reactors and thus the target point for each phase shall be defined on the associated voltage peak as illustrated on the Figure 97.

Figure 97 :
switching sequence while energizing a grounded transformer bank with secondary or tertiary windings in star connection

isolated neutral

For loads with isolated neutral, closing one single phase makes no sense. Two phases shall be closed first, at a date when their phase-to-phase voltage is maximum, i.e. ¼ period before the reference phase peak as illustrated on the Figure 98 :

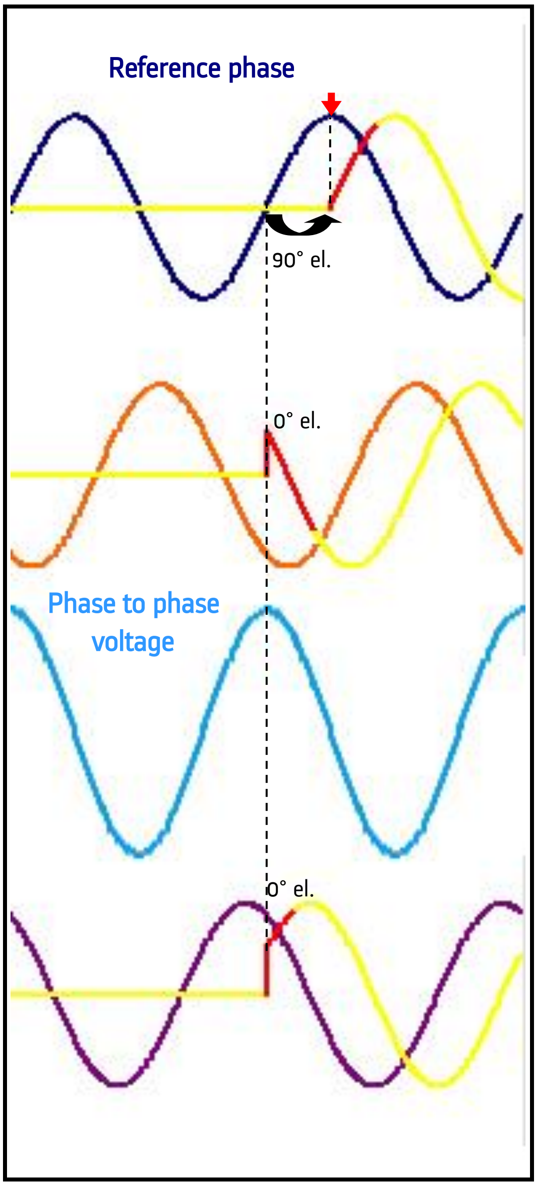


Figure 98 :
switching sequence while energizing a grounded transformer bank with secondary or tertiary windings in star connection

4-2.2 Tripping operations

Interrupting small inductive currents may lead to high switching surges in case current chopping or restriking occurs in the switchgear interruptors.

grounded neutral

The Figure 99 provides an illustration of the switching sequence as applied by the RPH3 in case of a grounded neutral mode of the load :

The current through each phase is interrupted on the associated voltage peak.

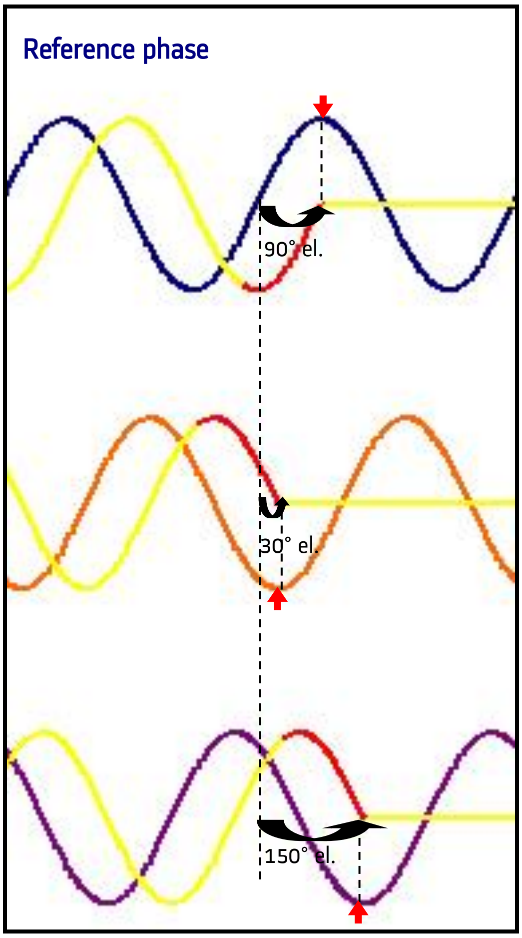


Figure 99 :
switching sequence while de-energizing a transformers or reactors (grounded Neutral)

isolated neutral

For loads with isolated neutral, the reference phase is opened first on its voltage peak, followed by both remaining phases on the peak of their phase-phase voltage (corresponding to a zero crossing of the reference voltage), as shown on the Figure 100 :

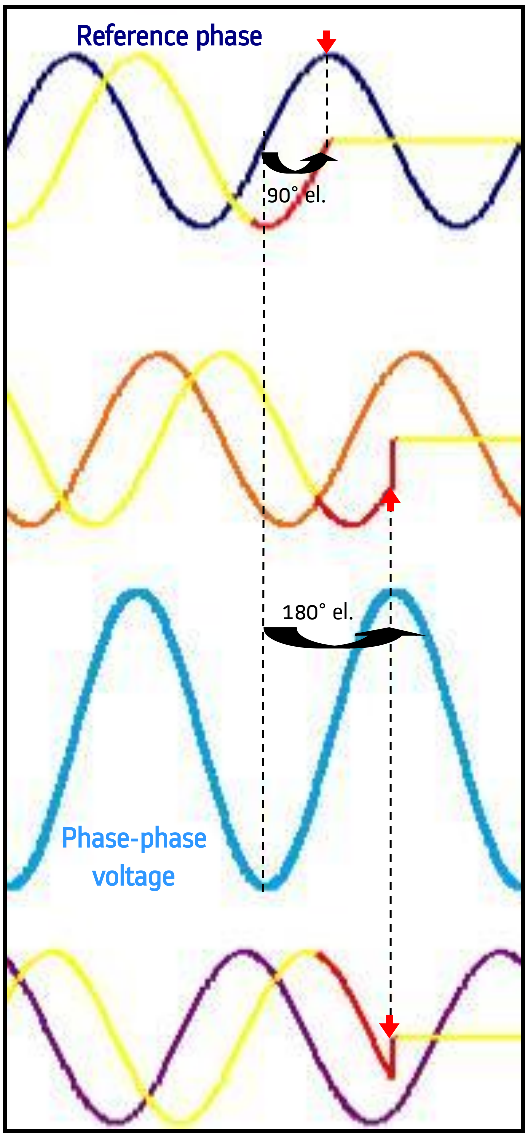


Figure 100 :
switching sequence while de-energizing transformer s or reactors (isolated Neutral)

4-3 Switching non-saturable single-core HV shunt reactors

The switching program “Shunt reactor” shall be selected with the appropriate neutral mode (“grounded” or “isolated”).

In case the RPH3 is to be used for synchronous opening only, then the program “Transformer” may also be used (target points for opening are the same in those 2 programs).

4-3.1 Closing operations

For this scope of applications, the target point for each phase is chosen synchronous to the associated voltage peak in order to prevent transient processes, since there is no mutual coupling between the phases, as illustrated below :

grounded neutral

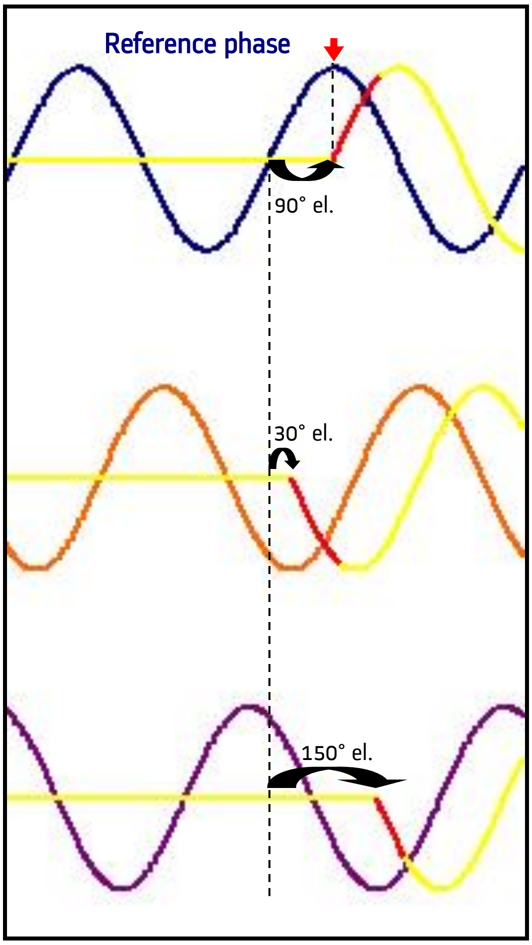


Figure 101 : switching sequence while energizing a single core reactor (grounded Neutral)

isolated neutral

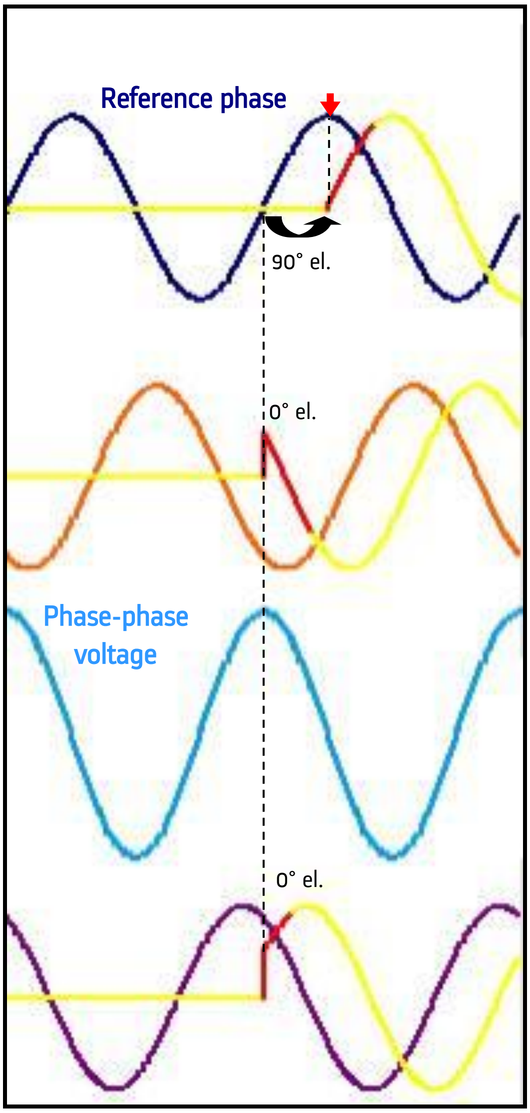


Figure 102 : switching sequence while energizing a single core reactor (isolated Neutral)

4-3.2 Tripping operations

The RPH3 operates the same way for switchgear opening on reactors as on transformers. Refer to section 4-2.2 for further details.

4-4 Switching HV capacitors

High inrush currents and high voltage surges may occur in case of random switching of capacitors, especially if switching takes place at voltage peaks. The effect of parallel switching of capacitors may be particularly serious ("back-to-back" applications), since high voltage surges may occur due to reflections at the end of radial networks, whose effects can be limited by PoW switching.

The switching program "Capacitor" shall be selected with the appropriate neutral mode ("grounded" or "isolated").

4-4.1 Closing operations

4-4.1-1 Single banks of capacitors

When a bank of initially unloaded capacitors is to be energized, it first behaves as a short-circuit (voltage 0 across its terminals) to be charged by high magnitude / high frequency inrush currents. The voltage across the capacitor thus rises with its charging process from 0 up to the HV nominal level.

grounded neutral

The voltage depression occurring at the beginning of the charging process may affect the quality of the system power. This is why the target point for energizing capacitor banks is chosen synchronous to each voltage zero (as shown on the Figure 103), thus limiting both the magnitude and frequency of charging currents.

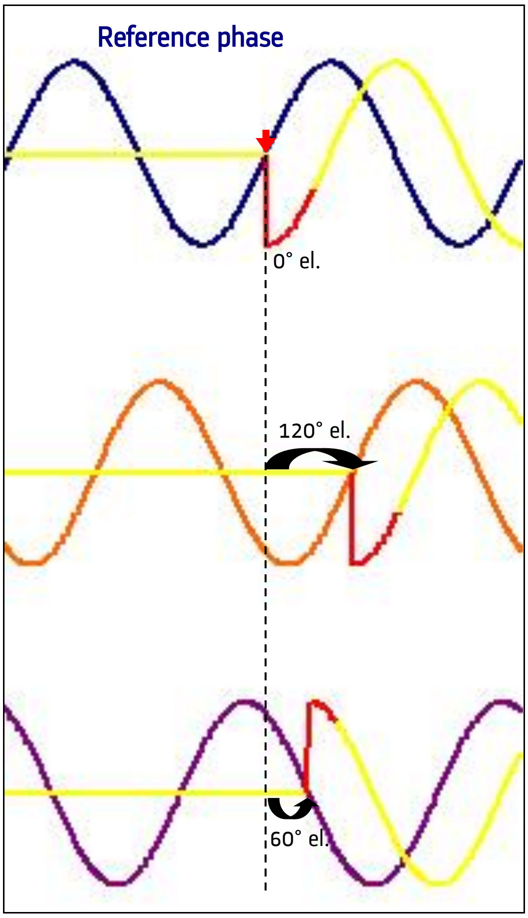


Figure 103 :
switching sequence while energizing a single capacitor bank (grounded Neutral, initially discharged)

isolated neutral

For loads with isolated neutral, closing one single phase makes no sense. Two phases shall be closed first, at a date when their phase-to-phase voltage is zero, i.e. $\frac{1}{4}$ period before the reference phase zero as illustrated on the Figure 104.

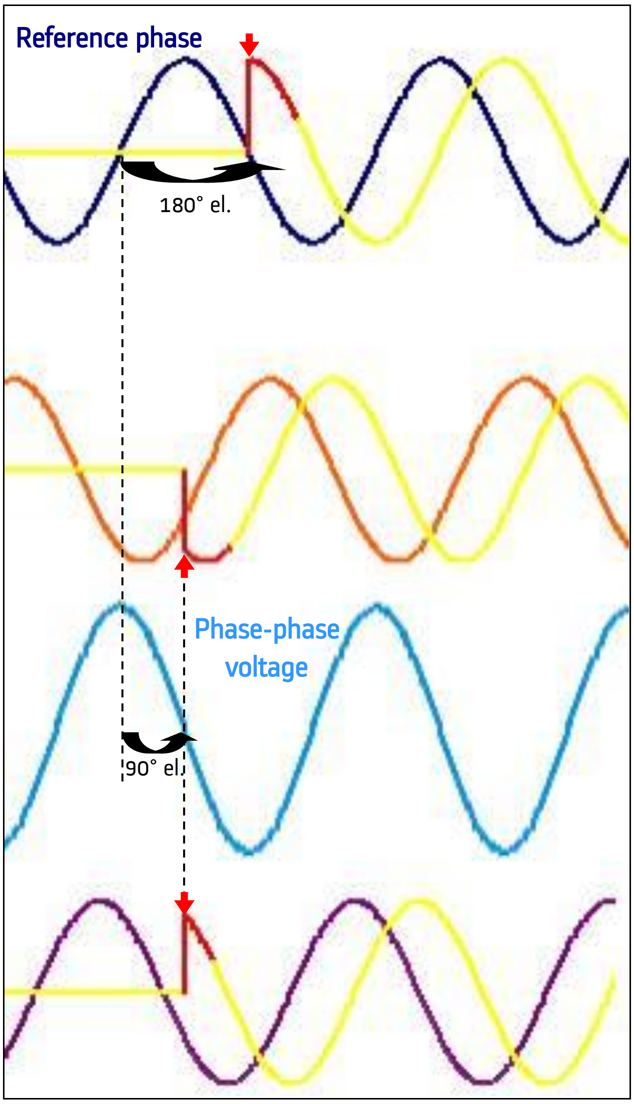


Figure 104 :
switching sequence while energizing a single capacitor bank (isolated Neutral, initially discharged)

4-4.1-2 banks of capacitors in "back-to-back" applications

Inrush currents magnitude and frequency are even higher in case a second capacitor bank is energized in close proximity to the first one. The impedance of their interconnecting circuit is the first limiting factor of inrush currents. But even with high impedance interconnecting circuits, a significant depression may occur on the system voltage during this "back-to-back" energizing of the capacitor bank.

In such a case, the most suitable target point for energizing the first capacitor bank (initially discharged) is at a time when its voltage is the same as across the second capacitor bank (initially charged).
The only solution is to select a target point synchronous to voltage zeroes on each bank, as illustrated in section 4-4.1-1 above.

4-4.2 Tripping operations

Breaking capacitive currents is not an issue for modern switchgears. That does not imply significant transient processes.
In case the RPH3 is used for synchronous tripping operations on capacitor banks it applies the same target points as for transformers (refer to section 0).

4-5 Switching HV transmission lines

For this kind of applications, the RPH3 shall be used with the dedicated variant of the embedded firmware : "RPH3-L".

4-5.1 Closing operations

Switchgear closing and re-closing operations on unloaded transmission lines generate a voltage wave which, when reflected from the open end of the line, may lead to significant overvoltages along the length of the line with a maximum near its termination point.

The magnitude of such overvoltages may have a very significant impact on the cost of the line since it determines the insulation level for each tower of the line.

Re-closing operations on lines lead to higher overvoltages than those generated by single closing. This is due to the fact that the line may have retained a trapped charge with the opposite polarity. The voltage thus obtained may double the magnitude of the one that would have been obtained from a single closing operation on the same unloaded line. Nevertheless, re-closing shall be operated only in case a fault occurred anywhere on the network, and associated transient processes to be limited by the PoW controller depend on the applied protection strategy for re-closing :

- Single-phase re-closing : this strategy does not lead to any significant transients since the line was uncharged by the fault (chances of re-closing on trapped charge are limited to the scenarii of two-phase faults and untimely three phase re-closings)

- 3-phase re-closing : this strategy may lead to high overvoltages since the re-closing of at least the 2 safe phases out of 3 (> 90% of line faults are due to single-phase failures) is performed on trapped charge.

Thus the optimal strategy to be applied by the RPH3 consists in closing or re-closing each CBR interruptor when the voltage across its terminals is as close as possible to zero so as to propagate the smallest possible voltage wave along the line and thus limit the overvoltage.

But applying such a strategy requires to consider the presence of line VTs and their kind (design), as they significantly impact the line charging process. They can be of 2 different types :

- ''inductive'' VTs that discharge the line,
- or ''capacitive'' VTs (conventional or not) that don't.

4-5.1-1 Lines fed by Inductive Voltage Transformers

Following an opening of the unloaded line, inductive VTs will quickly discharge the line (usually in less time than it takes for re-closing). Therefore the (re-)closing is to be operated on a discharged line the same way it would be operated on a discharged capacitor as illustrated on the Figure 105 below :

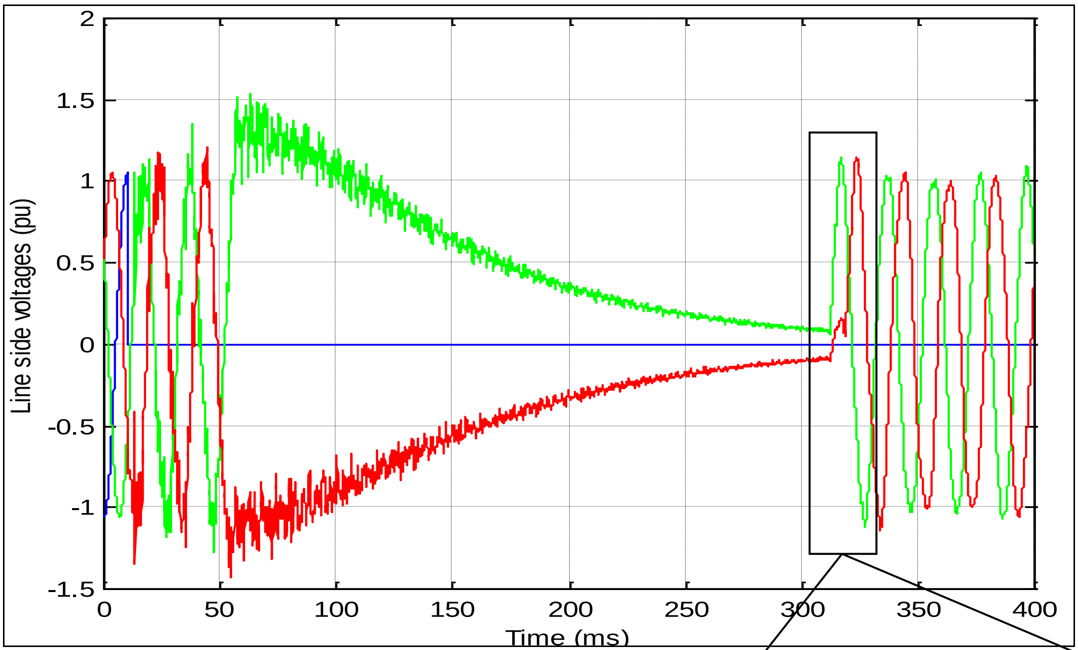
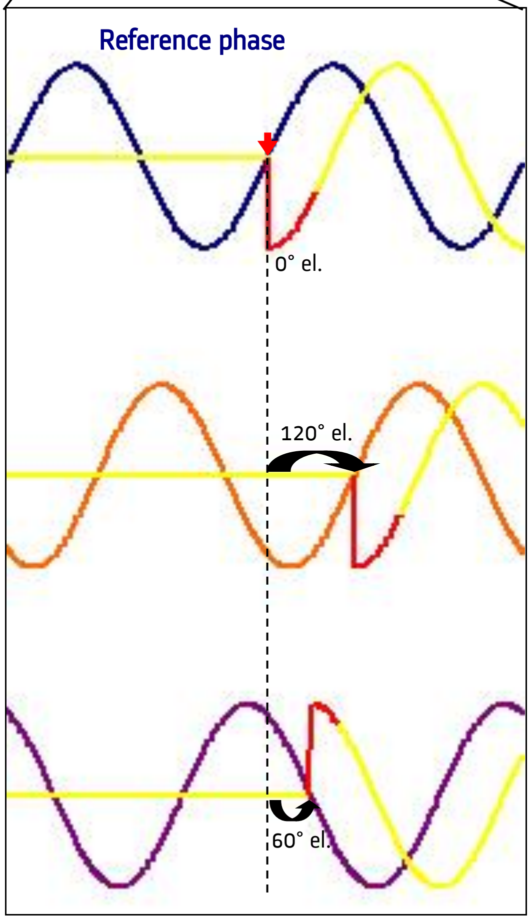


Figure 105 : discharge and (re-)closing on an uncompensated line fed by an inductive VT

uncompensated lines fed by inductive VTs grounded neutral



The PoW target point for each phase shall thus be defined on a voltage zero for both closing and re-closing operations, as shown on the Figure 106.

Figure 106 : switching sequence while (re-)closing on uncompensated lines fed by inductive VTs (grounded Neutral)

uncompensated lines fed by inductive VTs
isolated neutral

In case the neutral mode of the system is isolated, closing one single phase makes no sense. Two phases shall be closed first, at a date when their phase-to-phase voltage is zero, i.e. $\frac{1}{4}$ period before the reference phase zero as illustrated on the Figure 107.

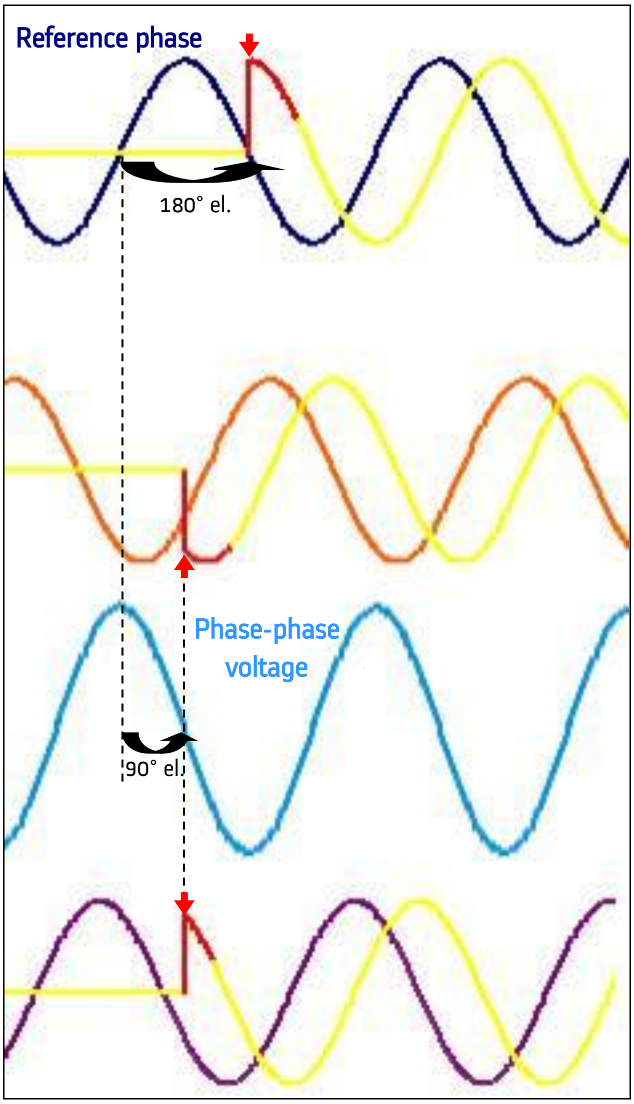


Figure 107 :
switching sequence while (re-)closing on uncompensated lines fed by inductive VTs (isolated Neutral)

4-5.1-2 Lines fed by Capacitive Voltage Transformers

For this kind of application, the PoW (re-)closing operation shall be carried out a different way, according to the charge level of the line :

- in case the line is fully discharged the operation shall be managed as a single closing on a capacitive load (refer to section 4-4.1 for a detailed description).

- otherwise the trapped charge held by the line may change as a function of atmospheric conditions. Since the VT has no ability to measure the trapped charge, it is necessary to assess it (estimation).

The RPH3 Controller automatically assumes this assessment and operate the CBR thanks to the sequence below () :

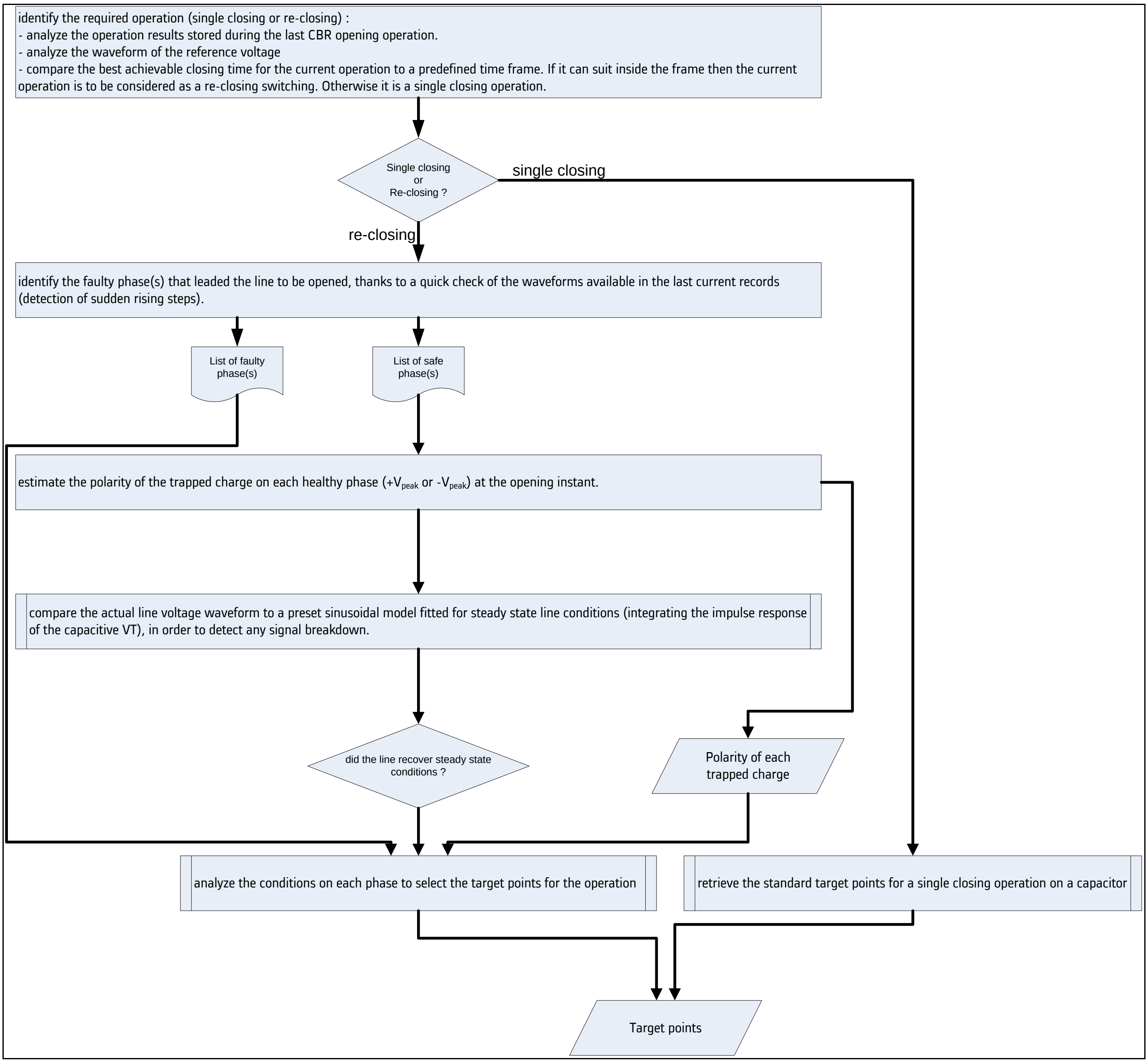


Figure 108 : RPH3 algorithm for line (re-)closing on uncompensated transmission lines fed by capacitive VT

Once the above algorithm has been completed, each pole is (re-)closed synchronous to a peak of the reference voltage whose sign matches the polarity of the charge trapped in the associated phase of the line, as shown on the Figure 109 below :

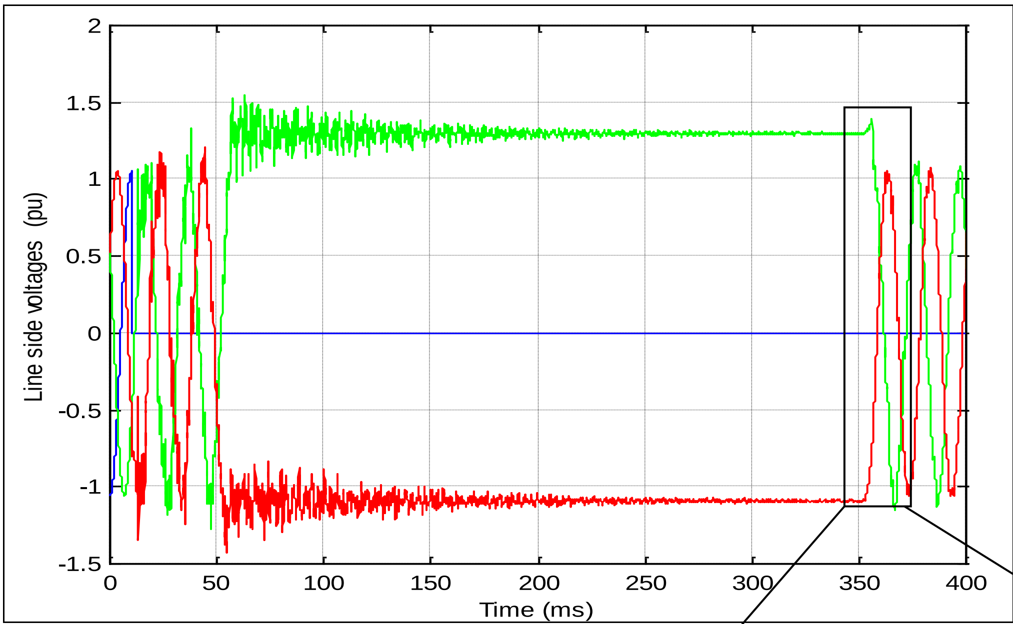
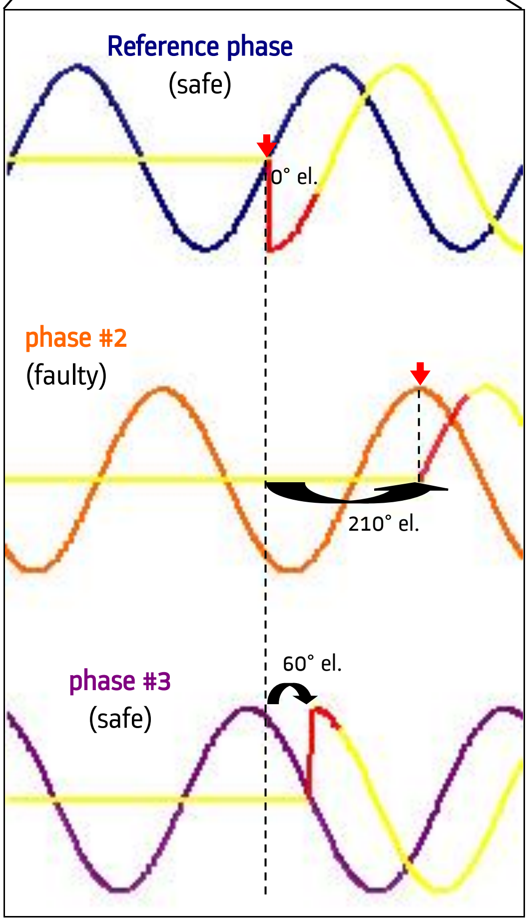


Figure 109: (re-)closing on an uncompensated line fed by a capacitive VT

uncompensated lines fed by capacitive VTs
grounded neutral



The PoW target point for each phase shall thus be defined on a voltage peak for re-closing operations with respect to the polarity of the trapped charge, as shown on the (example where only phase #2 is supposed faulty with a positive trapped charge)

Figure 110 :
switching sequence while re-closing on uncompensated lines fed by capacitive VTs (grounded Neutral)

4-5.1-3 Lines compensated by shunt-reactors

Lines compensated by shunt reactors constitute a case apart since once this kind of lines have been opened, an oscillation appears on the line voltage at a frequency somewhere in the range of 50 to 90% of the network frequency. Thus the voltage appearing across the switchgear terminals shows various degrees of fluctuation, depending on the degree of compensation.

The degree of the shunt compensation for a line can vary from one instant to the next depending on the power carried out by the line. A line may have zero, one, or several shunt reactors connected to it at different times, depending on the load. These compensation differences translate into frequency differences on the line side that entails a beat pattern waveform of the voltage (voltage difference between source and line side) at the switchgear terminals that will be compensation dependent (see Figure 111and Figure 112).

The optimum strategy in this case, still consists in closing or reclosing the switchgear when the voltage across its terminals is as close as possible to zero but, in this case the conditions on the line side cannot be calculated and have to be real-time assessed. The optimal switching moment for re-closing is at the minimum of the voltage beat.

To allow a controlled switching for this application, the RPH3 Controller first performs an identification of healthy / faulty phases and then selects the most suitable target point for re-closing on each phase as described in section 0.

The RPH3 Controller uses its powerful algorithms to quickly assess parameters and mathematically creates a best fit representation of the oscillating voltage wave on the line. Measurements are taken within fixed time windows and then analyzed with Prony's method.

In parallel to running this algorithm, the RPH3 Controller estimates the steady state source voltage using a simplification algorithms (steady-state sine wave).

Once the above tasks have been completed, the RPH3 Controller uses all of the above (now stored) parameters/information, to best predict the line voltage and the voltage beat pattern envelope at the switchgear terminals. Using this voltage-beat-pattern, the RPH3 Controller software endly computes a set of best timing possibilities for each phase reclosing operation, from which it extracts a set of optimal reclosing dates for each phase and selects the three-phase reclosing time set which yields the smallest delay between the first and last phase reclosing.

If, for any reason, (EMC transients, line waveforms severely distorted…), the software does not reach a liable set of reclosing dates by the end of a settable time window, the default strategy is applied by the RPH3 as a backup : re-closing at zero-crossing of source side voltages (refer to section 4-4.1-1)

NB: The voltage wave on the line side is best described as a sum of sinusoidal and exponential functions (damping, with a long time constant). The damping component has no influence on the localization of the beat pattern minimum and thus is neglected afterwards.

The sinusoidal component has a fundamental frequency ranging between 20 and 50 Hz.
It is essential that the measurement of this line signal is as accurate as possible in order to guarantee accuracy of reclosing times.

Inductive voltage transformers are usually up to the task, but capacitive voltage transformers (CVT), which are tuned to the industrial frequency won't be able to accurately reproduce the line oscillations.

If the line is fed by a CVT, it is then mandatory to implement another three-phase voltage measurement solution : whether a NCIT or a pure capacitive one.

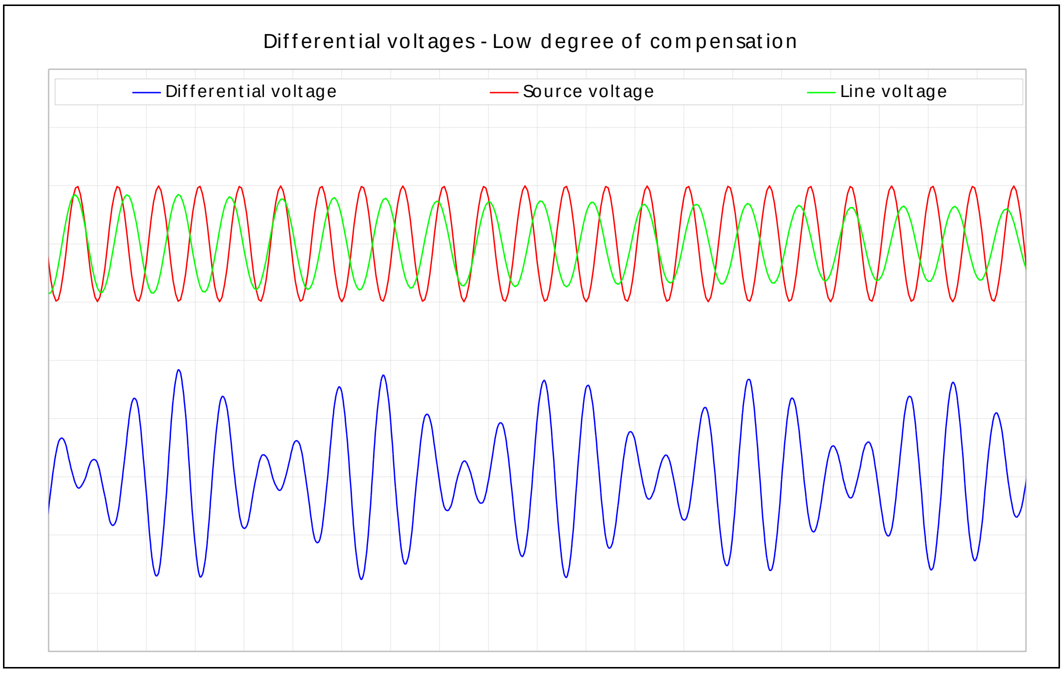


Figure 111 : voltage waveforms - lines with a high compensation degree

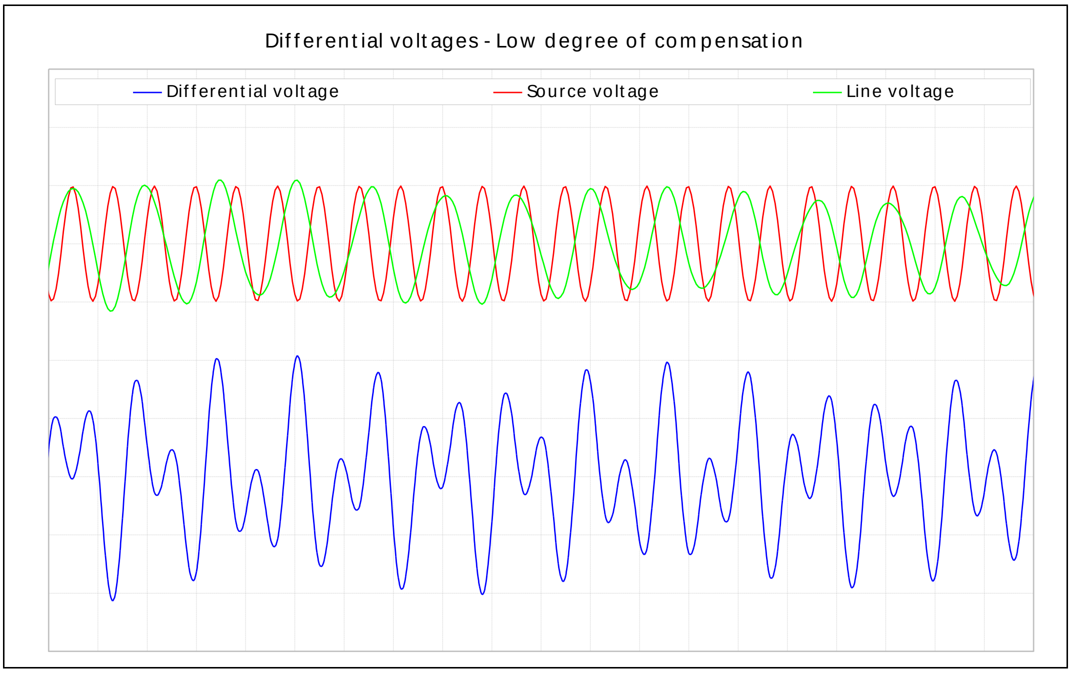


Figure 112 : voltage waveforms - lines with a low compensation degree

4-5.2 Tripping operations

Opening operations on lines (compensated or not) shall be operated the same way as on capacitor banks. Refer to section 4-4.2 for further details.

4-6 Switching inductive loads fitted through a Neutral Grounding Reactor

Shunt reactors as well as transformer primary windings may be grounded via a fourth reactor (Neutral Grounding Reactor – NGR).

In such a case, optimal PoW target points for switchgear opening operations may differ from the ones of pre-defined RPH3 switching programs, depending on the inductance ratio r between this fourth reactor and the load reactors :

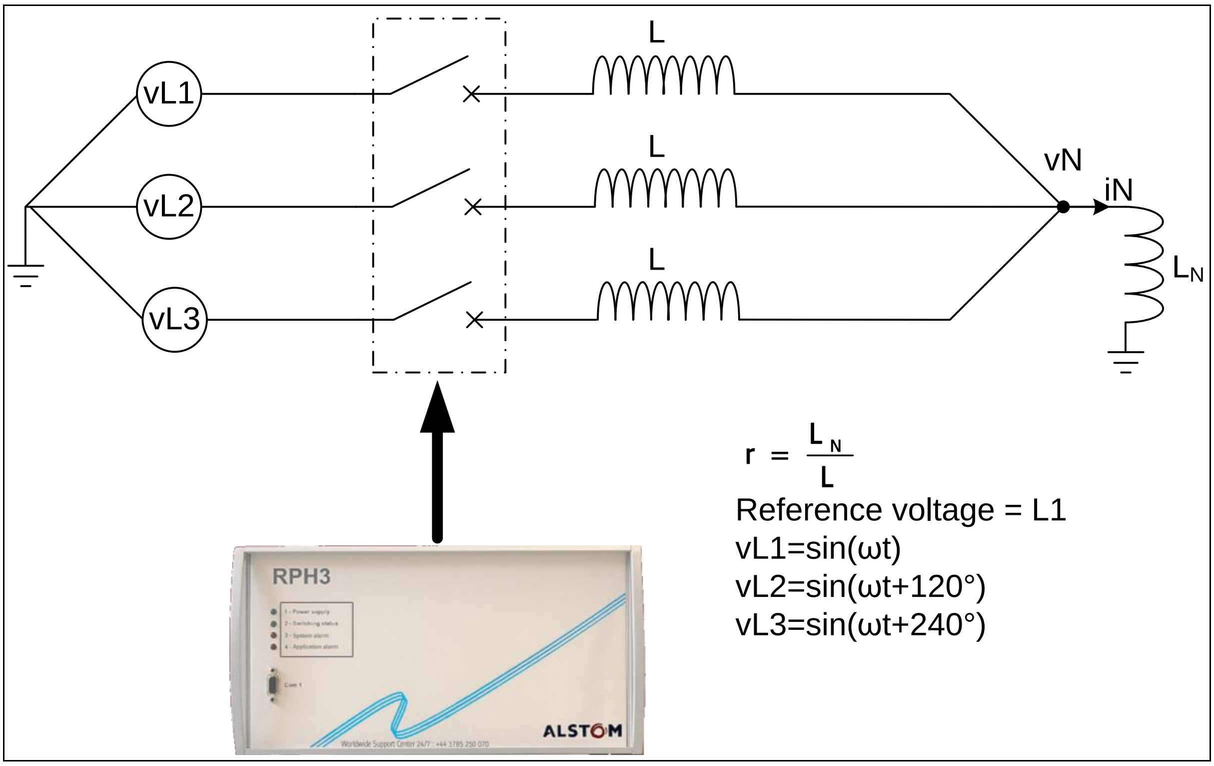


Figure 113 : inductive load neutral grounding through an NGR

RPH3 pre-defined switching strategies correspond to special cases where r=0 (neutral mode = “grounded”) and r = +∞ (neutral mode = “isolated”) : in such cases currents zero-crossing dates correspond to voltage peaks (shift angles = +90°/+30°/+150° for r=0, +90°/+180°/+180° for r = +∞).

Applying such strategies in case r is neither null nor infinite would introduce an error in the localization of current zero-crossing dates. In any case, this error never exceeds ~1.4 ms (@ 60Hz) or ~1.7 ms (@ 50Hz).

In order to ensure a maximum error of 0.5 ms in current zero-crossing dating b y the RPH3 controller, GE Grid Solutions recommends to consider the following ranges :

- r < 0.3 → Neutral mode shall be set to “grounded” and a pre-set switching program shall be selected.
- r > 1 → Neutral mode shall be set to “isolated” and a pre-set switching program shall be selected.
- 0.3 ≤ r ≤ 1 → Neutral mode shall be set to “isolated” and a custom switching program shall be selected (“user mode”).

In the last case, the shift angles to be considered shall be computed as follows (with respect to the reference voltage zero-crossing date) :

RPH3 switching program	Load	Operation	Uref			Uref + 120°			Uref + 240 °		
			angular shift	time shift (ms)		angular shift	time shift (ms)		angular shift	time shift (ms)	
				@50Hz	@60Hz		@50Hz	@60Hz		@50Hz	@60Hz
"User"	Transformer	closing	90°	5	4.2	180°	10	8.3	180°	10	8.3
		tripping	***Special***			**30°**	**1.7**	**1.4**	**150°**	**8.3**	**6.9**
"User"	Reactor	closing	90°	5	4.2	30°	1.7	1.4	150°	8.3	6.9
		tripping	***Special***			**30°**	**1.7**	**1.4**	**150°**	**8.3**	**6.9**

Table 8 : custom switching program for switching inductive loads fitted with NGR

For boxes filled with the "Special" string, the formula below shall be computed :

$$\text{Special} = 90° + \text{ArcTan}\left(\frac{\sqrt{3}}{3 + \frac{2}{r}}\right)$$

where $r = \frac{L_N}{L}$.

<u>NOTE 1 :</u> the switching sequence shall be kept unchanged compared to the one if the system neutral is effectively grounded (r = 0) or isolated ($r = +\infty$) :

1. Uref + 120°
2. Uref
3. Uref + 240°

<u>NOTE 2 :</u> the inductance of a given reactor is obtained from its rated voltage U_r and rated power P in the considered application by :

$$L = \frac{U_r^{\,2}}{P.\omega}, \text{ where } \omega = 2.\pi.f$$

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