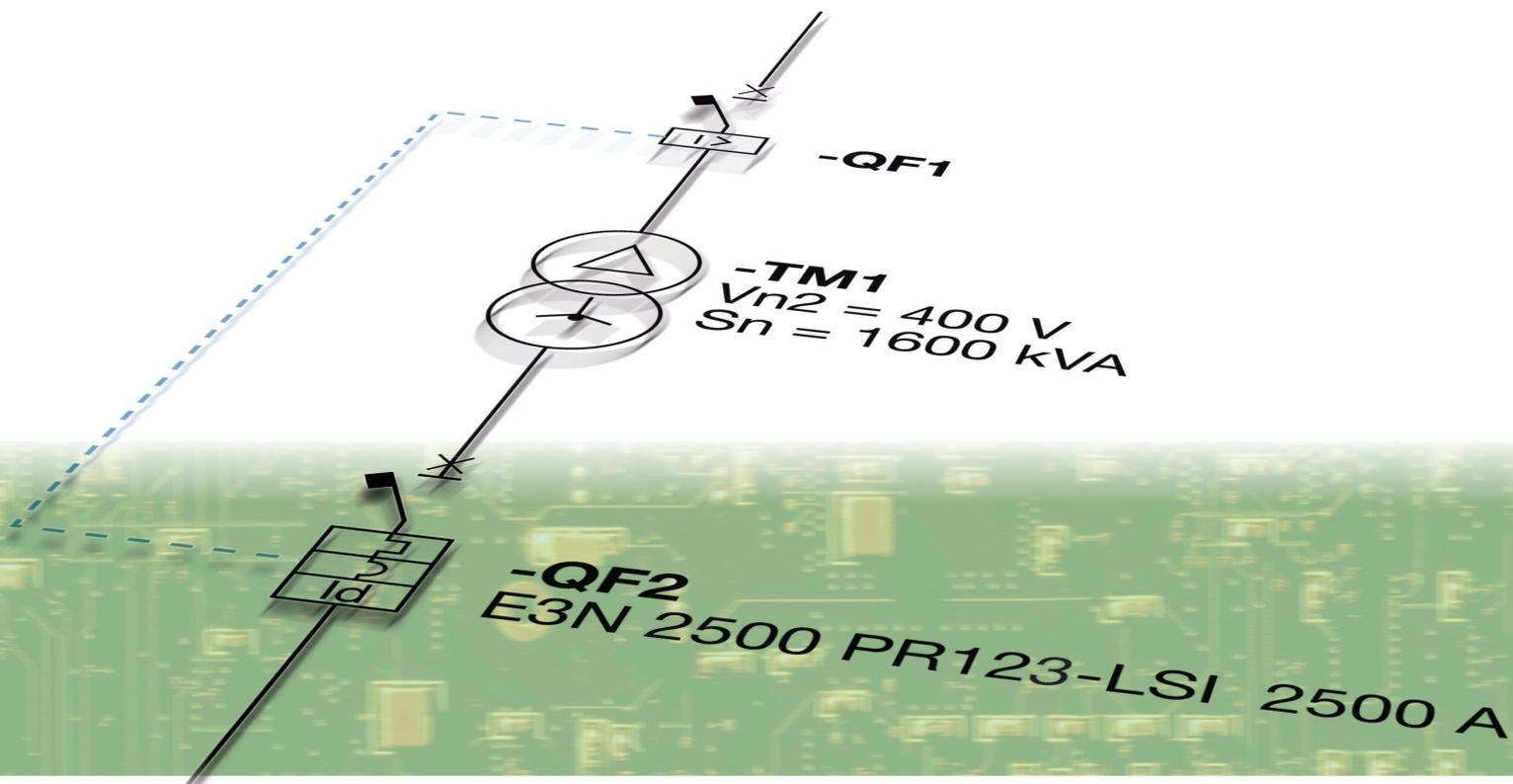


White paper

Integration between the MV protection and control unit REF542 and the LV protection trip unit PR123: selectivity and earth fault



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1. Introduction

This White Paper describes the possibilities of integration between ABB medium and low voltage protection trip units, paying particular attention to the protection and control unit type REF542 (for MV) and the protection trip unit PR123 (for LV).

Two different application fields are taken into consideration:

- **coordination with the medium voltage for an earth fault upstream the relevant protection on the low voltage side**
- **selectivity between two MV and LV protection units**

A fault between the windings of a transformer secondary or in the section immediately on the supply side of the LV circuit-breaker (also called “restricted earth fault”) cannot be easily detected by the protections on the primary of the MV/LV transformer. As a consequence, it could be necessary to provide for a dedicated protection against this kind of fault, so that fire hazard is limited as much as possible and people’s safety is guaranteed.

Achieving correct MV/LV selectivity may sometimes be complicated. The difficulties can be solved by means of suitable coordination strategies.

2. Theoretical outline

2.1 Restricted Earth Fault

Restricted earth fault protection (also known as “Restricted Earth Fault”, acronym REF) is applied in order to detect earth faults occurring both on the secondary winding of the distribution transformers as well as on the connection cable between the transformer and the LV circuit-breaker, faults which could be unlikely detected by the protections placed on the primary winding (e.g. by the transformer residual current protections against internal faults), because of their modest intensity.

A possible solution to detect and eliminate this type of fault, is using an external toroid connected to the star centre of the transformer and using the signal coming from this device to open the MV circuit-breaker and disconnect the fault.

Figure 1 (REF Protection)

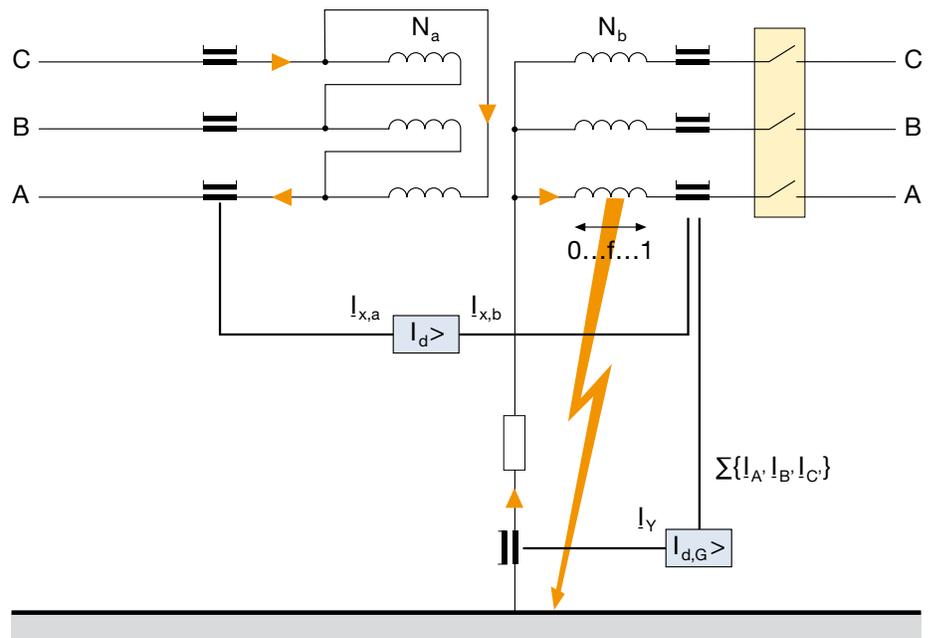


Figure 1 shows a principle diagram comprising a MV/LV earthed delta-star transformer, where the symbol $I_{d,G}>$ identifies the protection REF (restricted earth fault) whereas $I_d>$ indicates the residual current protection of the transformer. The distribution system on the LV side is type TN-S.

Taking into consideration an earth fault on the secondary windings of the transformer, it is evident that the single-phase earth fault on the LV side is seen from the MV side as a two-phase fault.

By means of some simple calculations, it is possible to demonstrate how, while the REF protection is able to detect the whole fault current, the residual current protection of the transformer sees only a percentage (even if very small) of the fault current.

For example, for a 20 kV / 400 V earthed delta-star transformer, if the fault occurs at halfway of a winding, the residual current protection of the transformer shall detect a current which is 0.6% of the effective earth fault current. This could make it impossible to set the residual current protection of the transformer so that it can trip with such a low threshold.

It is necessary to point out that the toroid connected on the star centre detects also every current deriving from an earth fault on the load side (non-restricted earth fault); therefore it is necessary to provide a protection able to discriminate (time selectivity) between the two fault typologies.

The solution offered by the protection trip units by ABB is defined "Double G". For further information on the "Double G" function, it is possible to consult the technical documentation given by ABB.

2.2 Selectivity between medium and low voltage

With protection selectivity it is meant the capability of the trip unit (or, more generally, of the protection) to distinguish the type of fault and its location and to trip only in case of faults occurring in the area for which the protection is provided.

To carry out a selectivity study between MV and LV circuit-breakers, it is necessary to insert in a logarithmic diagram (referred to a defined voltage) the main parameters, that is:

1. for the transformer:
 - magnetizing curve;
 - rated current;
 - short-circuit current of the busbars on the LV side;
 - short-time current of the transformer.

2. for the upstream network:
 - time-current characteristic of the protection device owned by the distribution Authority.

Once these information have been traced out, the protection curve on the LV side can be drawn, taking into account the following limitations:

- the transformer must be protected against overload;
- the protection must be selective in comparison with other LV protections.

Once the curve of the LV protection is known, the limits of the MV protection can be defined keeping into account that:

- it must protect the transformer against overload (if this protection is not already guaranteed by the protection on the LV side);
- it must not trip during the inrush phase of the transformer;
- it must not interfere with the MV protection owned by the distribution Authority.

3. Application examples and wiring logic

3.1 Restricted Earth Fault

The example of Figure 3 shows a plant, comprising:

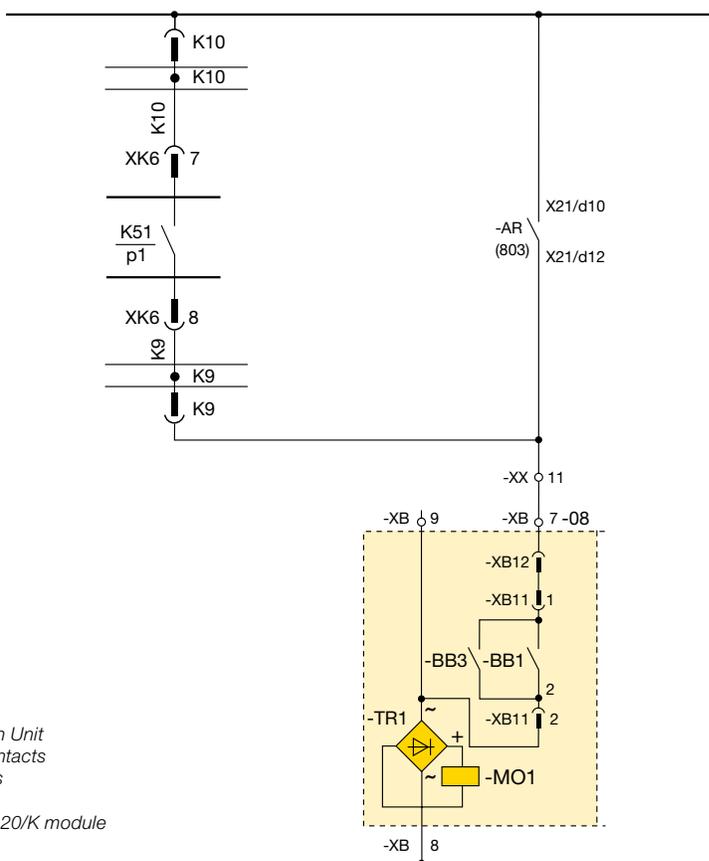
- a protection circuit-breaker on the MV side, equipped with REF542 protection and control unit;
- a MV/LV distribution transformer (with a TN-S distribution system on the LV side);
- a main LV circuit-breaker type Emax equipped with PR123 LSIG trip unit;
- different moulded-case circuit-breakers to protect the outgoing feeders towards the loads.

In order to guarantee proper coordination and protection against the earth faults which can occur in the plant of the figure, it is necessary that:

- in case of earth fault in the part of the plant between the transformer and the Emax circuit-breaker (that is in case of restricted earth fault), the MV circuit-breaker opens (afterwards it is possible to choose whether to keep the LV circuit-breaker closed or to open it);
- in case of earth fault in the area between the opened circuit-breaker and the moulded-case circuit-breakers, only the main LV circuit-breaker opens;
- in case of earth fault in the load area, only the moulded-case circuit-breaker immediately on the supply side opens.

In order to make the MV circuit-breaker open, it is sufficient to send a signal to its opening coil. As an example, here is given a single line wiring diagram for the control of the opening coil of the MV release using a signaling contact (K51/p1) of the remote signaling module PR120/K:

Figure 2

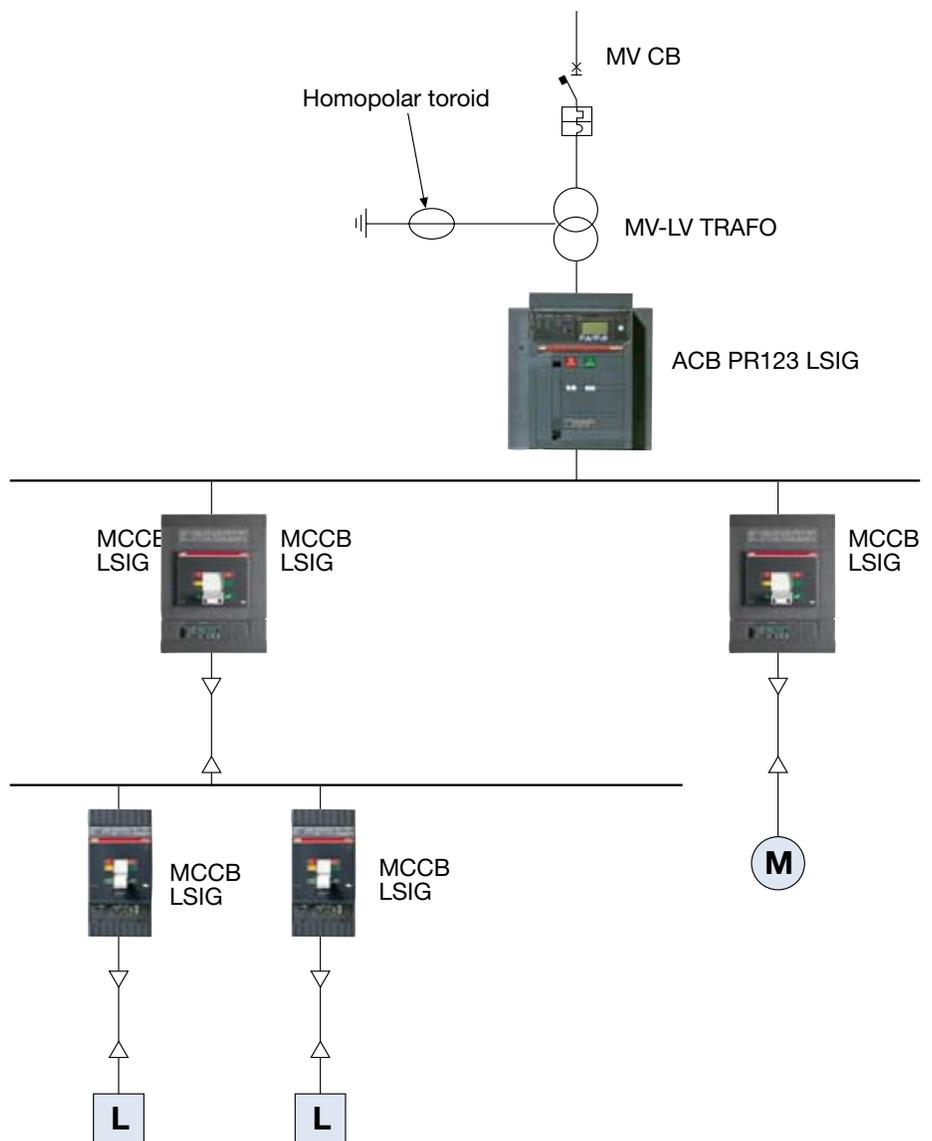


Caption
 AR: REF 542 Protection Unit
 BB1, BB3: Auxiliary contacts
 TR1: AC/DC converters
 MO1: Opening coil
 K51/p1: Contact of PR120/K module

The circuit-breaker opening, commanded by the REF542 protection unit following up the trip of any of the protections, occurs through the closing of AR contact. Then the opening signal is transmitted to the coil MO1 through the rectifier TR1. The auxiliary contacts BB1 and BB3 (able to report the circuit-breaker status) can be used, for example, to prevent the opening coil from being supplied when the circuit-breaker is open or to create interlocks.

To command the opening through a circuit-breaker type EMAX, it is possible to use one contact of the signaling modules PR120/K (internal) or PR021/K (external) controlled by PR123 LSIG trip unit. These signaling modules are able to signal from remote the alarms and the trips of the circuit-breaker and can be programmed according to the events to be signaled.

Figure 3



In detail, to realize what described above, it is necessary to use:

- a SACE Emax air circuit-breaker equipped with an electronic trip unit PR123/P LSIG;
- a PR120/K module (or PR021/K) mounted on the trip unit;
- a homopolar toroid to be mounted on the earthing of the star center of the transformer and connected to the electronic trip unit.

As pointed out, in case of an earth fault occurring in the area of the plant between the transformer and the main LV circuit-breaker, it is necessary that the MV circuit-breaker opens so that the fault can be disconnected.

To command the opening of the MV circuit-breaker, it is necessary that the contact K51/p1 of PR120/K module is set as followed:

- reference event: “Gext alarm (blocked trip)”
- status: NO (normally open)
- latching function: not selected
- time-delay upon closing: selected

(To prevent the LV circuit-breaker from being opened by the protection, it is possible to set to “Off” the “trip enable” of Gext function).

The reference event is chosen as “Gext alarm (blocked trip)” so that such signal is maintained for all the duration time of the fault up to its extinction; besides, the contact shall be duly delayed to give the internal protection G (Gint) the time to trip, in case the fault occurs on the load side of the main LV circuit-breaker.

To guarantee the correct setting of K51/p1 contact, it is possible to use PR010/T test and signaling unit or the software SD-Pocket (for PDA) and SD-TestBus (for PC).

As an example, the following Figure shows the main window of PR120/K module as it appears in the program SD-TestBus:

Figure 4



For further information on the function “double G”, available on the trip units type PR123/LSIG and PR333/LSIG, reference must be made to other ABB technical documents.

The programmable contact shall be put in series with the opening coil of the MV circuit-breaker as previously pointed out. As a consequence, the correct sequence of the events is the following:

- a fault occurs on the supply side of the main LV circuit-breaker;
 - the Gext protection is activated by the fault current flowing through the toroid;
 - the K51/p1 contact changes its status moving to closed position;
 - the opening coil of the MV circuit-breaker is energized, thus being opened;

- a fault occurs on the load side of the main LV circuit-breaker:
 - the Gext protection is activated by the fault current flowing through the toroid;
 - also the Gint protection is activated by the fault current equal to the resultant of the currents flowing through the active conductors (phases plus neutral);
 - the Gint protection, being set so as to be faster than the Gext protection, causes the opening of the main LV circuit-breaker;
 - the K51/p1 contact does not change status and consequently does not energize the opening coil of the MV circuit-breaker, which remains in closed position.

3.2 Selectivity between medium and low voltage

3.2.1 Description of the plant

The study of selectivity between medium voltage and low voltage for the plant of Figure 5 is here briefly illustrated.

Here are the characteristic parameters of the plant:

- characteristics of the supply side network:
 - rated voltage $U_n = 20 \text{ kV}$
 - three-phase symmetrical short-circuit current $I_{k3} = 12.5 \text{ kA}$
 - protection against overcurrents IEEE 51:
 - first threshold: $I > \leq 250 \text{ A}$, $t \leq 0.5 \text{ s}$
 - second threshold: $I >> \leq 790 \text{ A}$, $t \leq 0.12 \text{ s}$

- 20/0.4 kV cast resin transformer:
 - apparent rated power $S_n = 1600$ kVA
 - short-circuit voltage $U_k = 5,7$ %
 - rated current at the primary $I_{t1} = 46$ A
 - rated current at the secondary $I_{t2} = 2309$ A
 - three-phase short-circuit current referred to the secondary $I_{k3LV2} = 40.5$ kA
 - three-phase short-circuit current referred to the primary $I_{k3LV1} = 810$ A
 - short-time current: 770 A for 2 s
- main MV circuit-breaker:
 - QF1: HD4/R equipped with REF542 PLUS
- connected LV circuit-breakers:
 - QF2: SACE Emax E3N 2500 PR122/P-LSI
 - QF3: SACE Emax X1N 1600 PR332/P-LSI
 - QF6: SACE Tmax T7S 1000 PR232/P-LSI

Figure 5

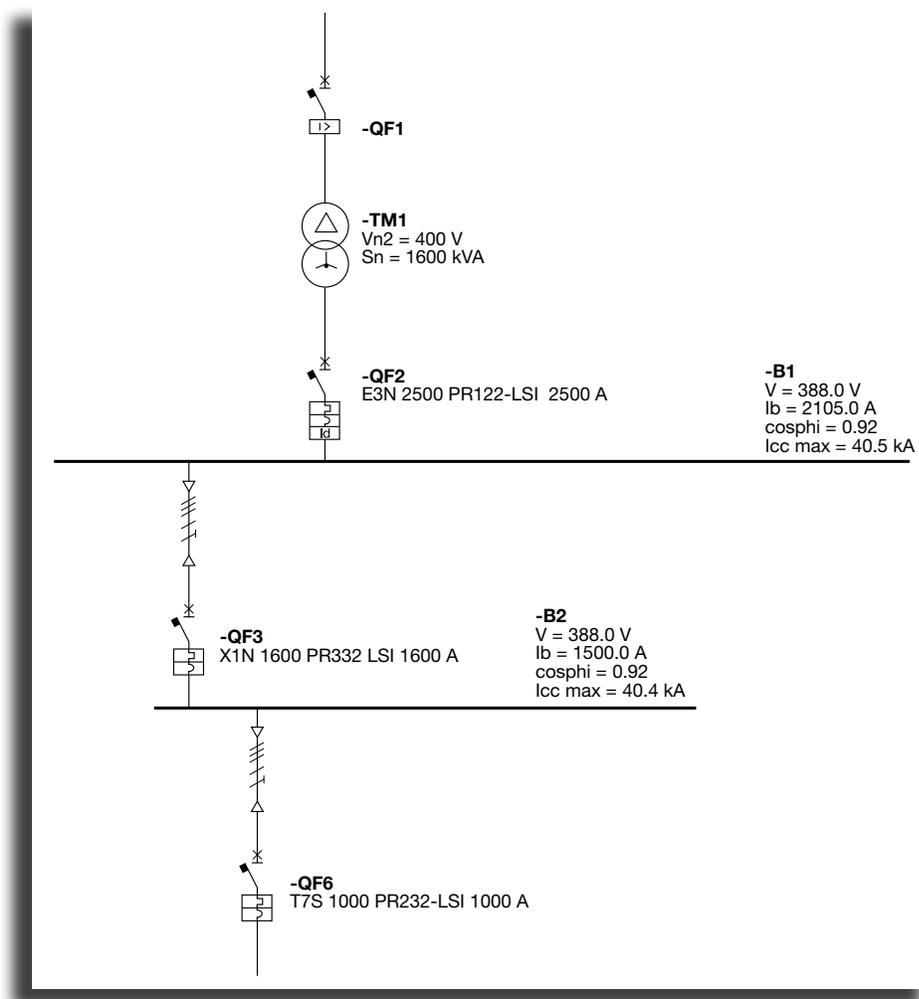
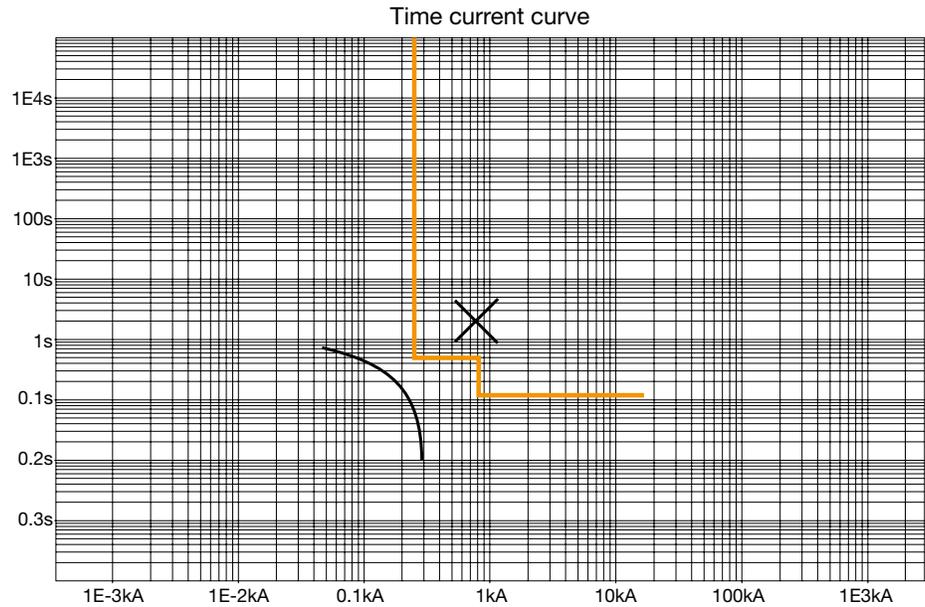


Figure 6 shows the data relevant to the transformer (in black) and to the MV protection (in orange) at 20 kV reference voltage:

Figure 6

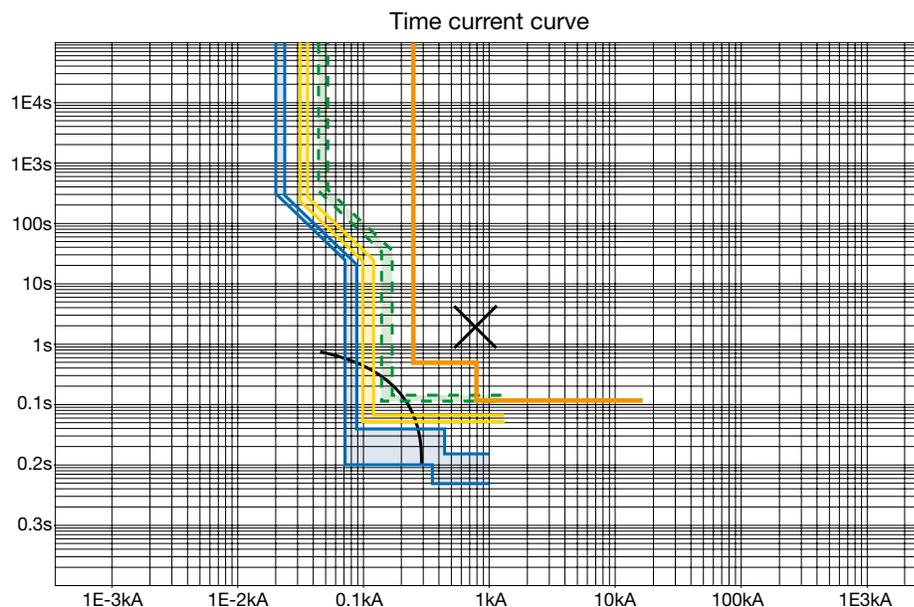


The main LV circuit-breaker must be selective with the circuit-breakers on the load side.

By supposing to set at 2100 A ($I1=0.84 \times I_n$) the threshold $I1$ of the Emax circuit-breaker, it is possible to trace the curves of the circuit-breakers on the LV side.

A possible solution is shown in the following graph

Figure 7



It can be noticed that total selectivity is guaranteed between X1 and T7 circuit-breakers through an effective setting of S protection.

By analyzing the graph, please observe that, to get a good selectivity level with the circuit-breakers X1 and T7 positioned on the load side, Emax air circuit-breaker cannot be selective with the MV protection due to a fault on the LV busbar B1. In fact, if such a fault occurred, both QF2 and QF1 would open.

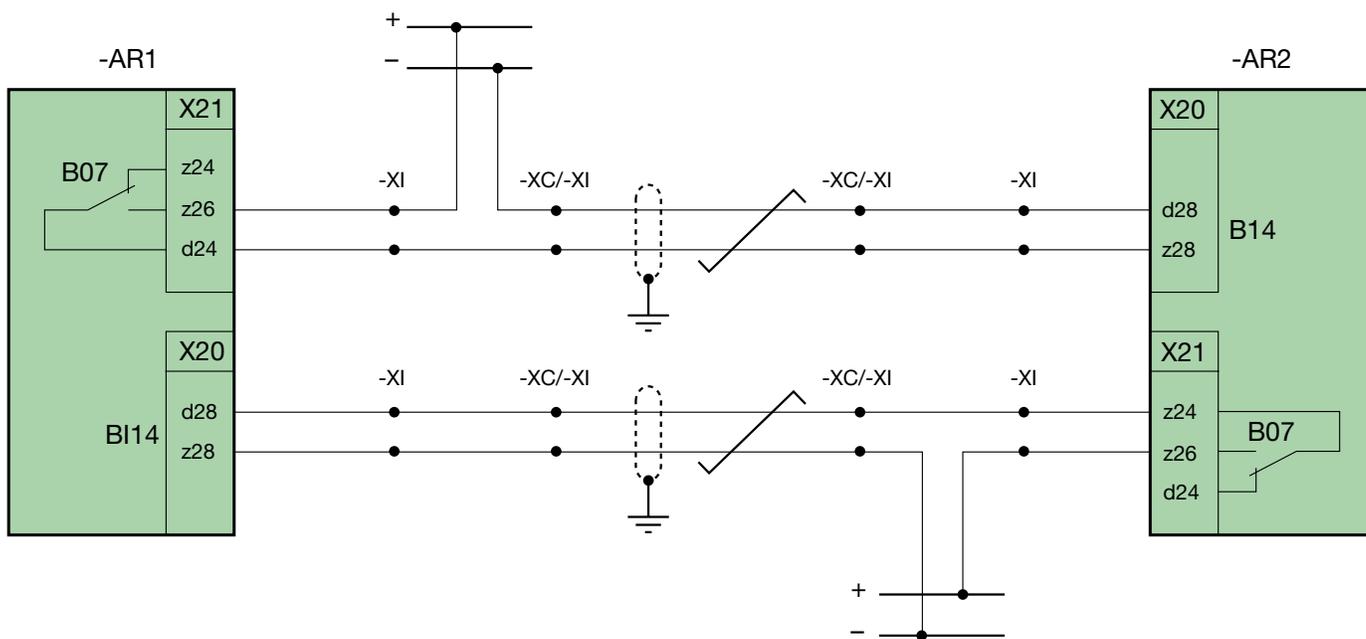
In order to avoid this event, the most simple solution would be implementing logic or zone selectivity by sending a signal to block the MV release through the zone selectivity outputs present on the Emax trip unit PR123, thus integrating into a single selectivity chain also the MV circuit-breaker. Unfortunately this is not directly possible, because the voltage of the physical signal used for the zone selectivity on REF542 PLUS shall be comprised between 48 and 240V DC, whereas the zone selectivity connection used on the trip units PR123 (as well as PR122), using a voltage of 24V DC (auxiliary voltage more often used in LV plants).

To solve this problem it is possible to use as block signal a signal coming from the modules PR120/K or PR021/K, set to the event "S timing".

3.2.2 The solution using PR120/K signaling unit: wiring logic

REF542 PLUS unit has many input and output contacts. In particular, BI14 binary input and B07 binary output can be used to block the protection functions between interlocked REF542 PLUS (Figure 8). The input is used to receive the block signal, and the output to send the signal. The wiring diagram of the inputs/outputs is shown in the scheme below, where with AR1 and AR2 two REF542 PLUS releases are indicated:

Figure 8
(Wiring of REF542 Plus for the management of the Zone Selectivity)



As already pointed out, the binary inputs can be used for voltages in the range from 48 to 240V DC.

By analyzing the direct current performances (reported in the table of Figure 9) of the contacts of PR120/K module (also valid for PR021/K) it is possible to verify that the module is suitable as interblock of REF542 PLUS.

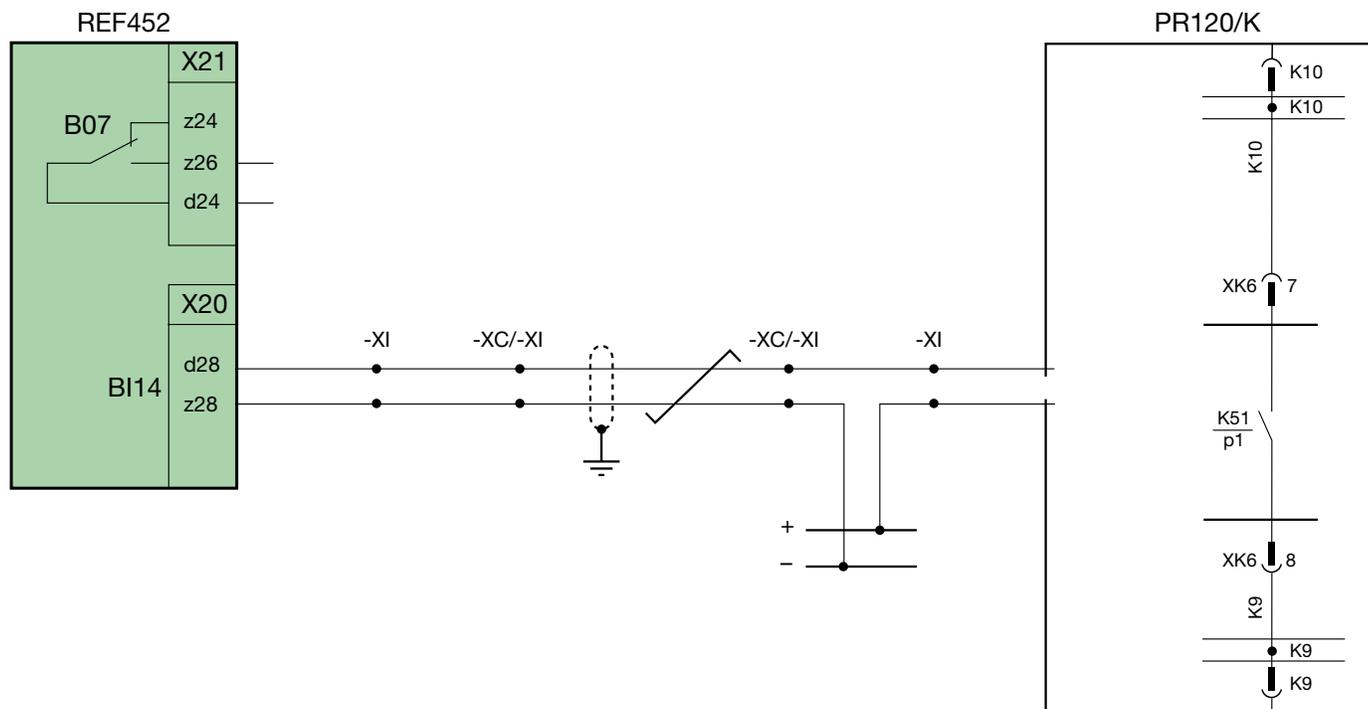
Figure 9

Type of contact	SPST
Max switching voltage	130 VDC
Max switching current	5 A
Max switching power	175 W
Breaking capacity at 35 VDC	5 A
Breaking capacity at 120 VDC	0.2 A
Breaking capacity at 250 VAC	-
Breaking capacity at 380 VAC	-
Contact/coil insulation	
Contact/contact insulation	

Here is an example of wiring using the contact K51/P1 of PR120/K module at a voltage of 48 V DC (this can be obtained analogously also with PR021/K module).

Figure 10

(example of interblock obtained by wiring a PR120/K module with REF542 Plus)



To set properly K51/p1 contact, it is possible to use the test and signaling unit PR010/T or the programs SD-Pocket (for PDA) or SD-TestBus (for PC); to send the block signal to the MV product, it is necessary that the contact K51/p1 is set as follows:

- reference event: "S timing"
- status: NO (normally open)
- latching function: not selected
- time-delay upon closing: 0.0

To guarantee a correct functioning of the zone selectivity with a MV device, it is necessary that the minimum opening time of the MV circuit-breaker is not lower than 120 ms (for the protection against phase faults) or 150 ms (for the protection against earth faults).

4. Analysis of the necessary equipment

4.1 Signaling unit for the interlock between low and medium voltage

To realize an interlock between medium voltage and low voltage, as seen in the previous clauses, it is necessary to use one of the signaling units compatible with SACE Emax circuit-breakers. These units allow remote signaling of circuit-breaker alarms and trips and can be set by the user by means of the test and signaling unit PR010/T or the programs SD-Pocket (for PDA) or SD-TestBus (for PC). Reference must be made to the previous clauses for the setting of the contacts.

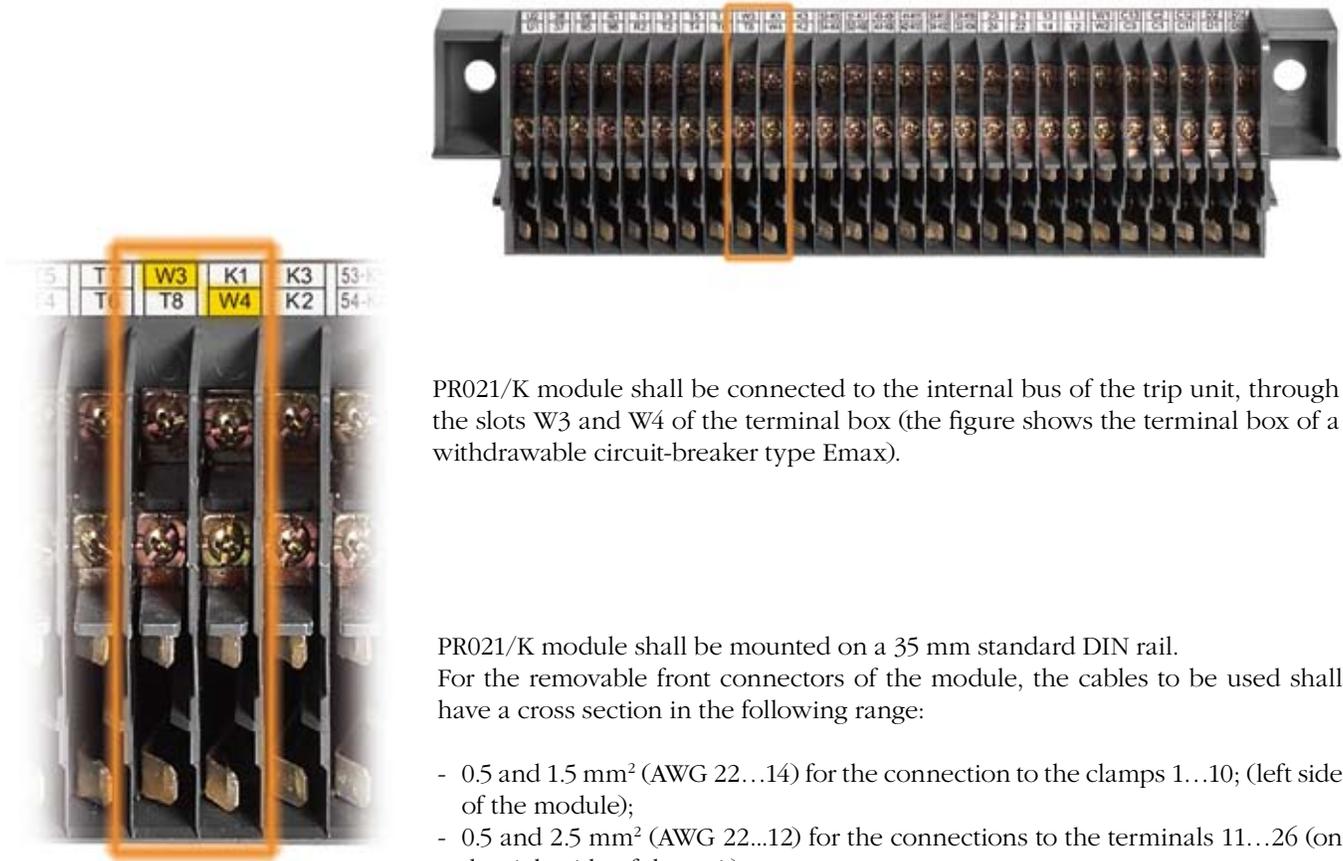
4.1.1 PR021/K module

Figure 11 (PR021/K module)



PR021/K signaling module converts the digital signals of the protection units into electrical signals via 8 normally open contacts.

For the proper functioning a 24V DC supply is needed: since an earth-insulated auxiliary voltage is required, it is necessary to use “galvanically insulated converters” complying with the Standards IEC 60950 (UL1950) or any equivalent device.

Figure 12

PR021/K module shall be connected to the internal bus of the trip unit, through the slots W3 and W4 of the terminal box (the figure shows the terminal box of a withdrawable circuit-breaker type Emax).

PR021/K module shall be mounted on a 35 mm standard DIN rail.

For the removable front connectors of the module, the cables to be used shall have a cross section in the following range:

- 0.5 and 1.5 mm² (AWG 22...14) for the connection to the clamps 1...10; (left side of the module);
- 0.5 and 2.5 mm² (AWG 22...12) for the connections to the terminals 11...26 (on the right side of the unit).

4.1.2 PR120/K module

Figure 13 (PR120/K module)

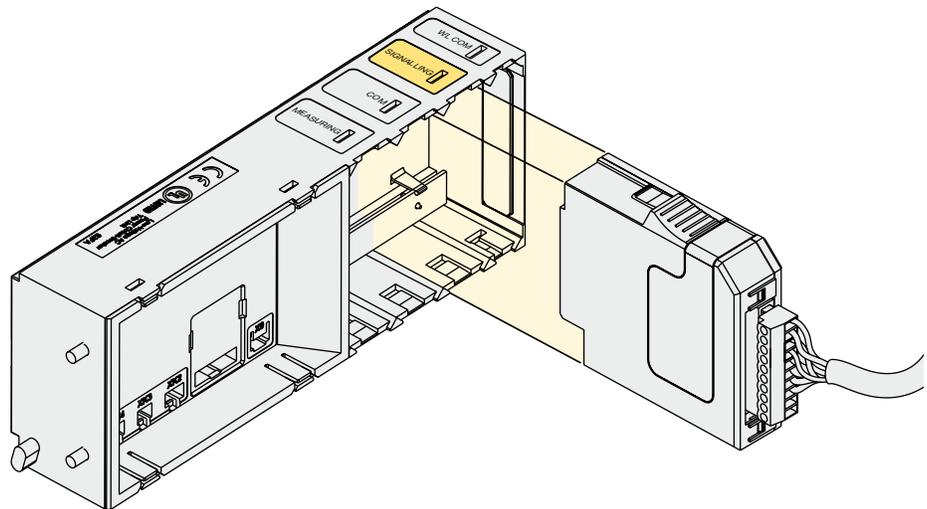


The internal signaling module PR120/K (mounted on the back part of the release) is supplied by trip units (in case the auxiliary supply is provided on it) or by PR120/V voltage module.

PR120/K is equipped with four trip units, whose contacts are called K51/p1, K51/p2, K51/p3 and K51/p4.

These contacts can signal different events which can be selected by the user among those included in the standard list; however, the user can associate to the 4 contacts “customized” events by selecting “Custom” from the menu and setting the required signal through PDA, SD-Testbus or PR010/T.

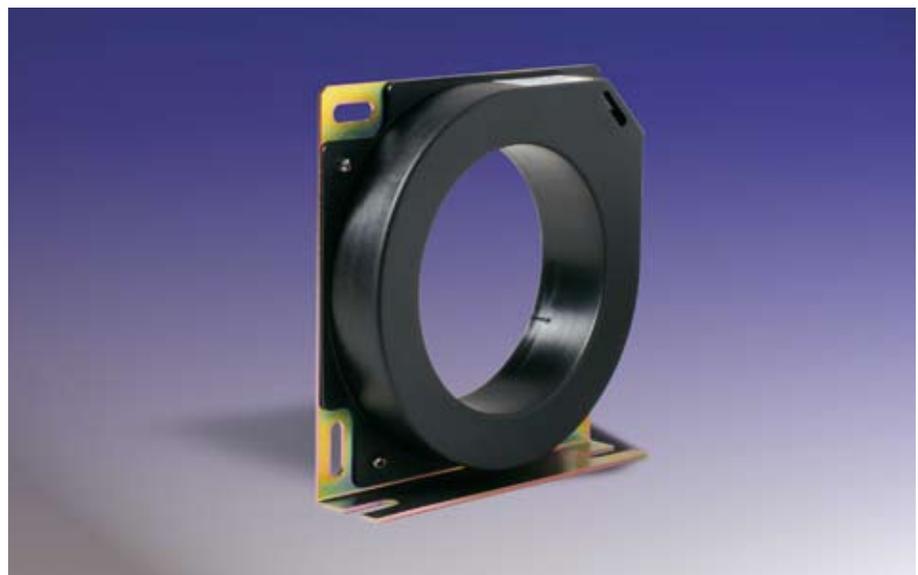
The outputs on the contact terminal box are identified by the terminals K4, K6, K8, K10.

Figure 14 (installation of PR120/K module)

4.2 Homopolar toroid for the star center of the transformer

The rated current of the toroid can be set to 100A, 250A, 400A or 800A by using different combinations of connections.

The connection between the homopolar toroid and the terminals T7 and T8 of the terminal box shall be realized using a corded shielded two-wire cable (BELDEN type 8762/8772) with length not exceeding 15 m. Shielding shall be earthed on the CB side and on the current sensor side.

Figure 15 (the homopolar toroid)

4.3 Wiring between MV and LV circuit-breakers

Wiring between LV and MV circuit-breakers can be realized by means of a two-pole shielded cable to obtain selectivity between MV and LV as shown in clause 3.3.

Due to the very low currents absorbed by the inputs of ABB MV releases, it is possible to reach wiring distance up to 800 meters.

Figure 16



A suitable cable for this application is “BELDEN 82841” (nominal characteristic impedance 120 Ohms, nominal conductor DC resistance @ 20 °C 24 Ohms/1000 ft., max. recommend current 4 Amps per conductor @ 25 °C).

5. Bibliography

- Installation and service instruction, “Installation, service and maintenance instructions for low voltage air circuit-breakers Emax”
(code 1SDH000460R0002)
- Instruction Manual, “SACE PR021/K signaling unit”
(code 1SDH000559R0002)



Due to possible developments of standards as well as of materials, the characteristics and dimensions specified in this document may only be considered binding after confirmation by ABB SACE.

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