Guide to the selection of RCDs connected in series

It is crucial to coordinate up- and down-stream RCDs, especially in installations involving loads able to cause DC leakage currents.

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Foreword

The present document intends to support installers in the choice of RCDs, in applications requiring two (or more) thereof, one standing upstream and being potentially blinded by the DC leakage let through by the other(s) standing downstream. The problem is particularly relevant in installations involving loads able to cause DC leakage currents, most notably electric vehicle charging. Owing to the very dynamic applicative context of loads and installations, especially in the last decade and in the wake of sustainable energy strategies, the standardization frame is likewise quickly and profoundly evolving. Consequently, installers may be hindered in their daily practice by questions and doubts on the one side, or they may not be in the know of advantageous opportunities on the other.

The reader is assumed to be familiar with the basics of earth fault protection and RCDs. For a general introduction to RCDs purpose, classification and construction, the reader is referenced to **ABB Earth Fault Protection white paper [1] (9AKK107992A2402)**. Alternatively, the concepts essential to the understanding of this guide may be conveniently found in chapter 1, namely RCD types and their operational limits in presence of a DC current portion, including the risk of DC blinding. The problem of properly selecting the upstream RCD is introduced in chapter 2. A first solution, always possible, resorts to using type B RCDs upstream, as detailed in chapter 3. When allowed, and particularly when ABB RCDs are employed, the installer may advantageously choose a less-than-B type RCD upstream, as per ABB recommendations and as described in chapter 4.

1. Types of RCDs and the risk of DC blinding

As known [1], residual current devices (RCDs) detect earth leakage (i.e., residual current), whose waveform depends on the kind of electric power supply and on load characteristics. RCDs are classified into several types depending on detectable waveforms.

- **Type AC** RCDs detect residual sinusoidal alternating currents at power frequency (50 or 60 Hz). Type AC RCDs are suitable for general use and cover linear loads (e.g., tungsten and halogen lighting, ovens and heaters without electronics control, etc.).
- **Type A** RCDs, in addition to the detection characteristics of type AC RCDs, detect pulsating DC residual current. Such waveforms can be caused by diodes or by thyristor-based single-phase rectifier circuits, that are common in modern electronic equipment (e.g., switching mode power supplies). Type A RCDs remain **functional in the presence of a smooth direct current of up to 6 mA superimposed** to a sinusoidal or pulsed DC earth current.
  According to standard IEC 61140 [5], any pluggable electrical equipment with a rated input ≤ 4 kVA shall be designed to have an earth current with a smooth superimposed DC current component not exceeding 6 mA.
- **Type F** RCDs, in addition to the detection characteristics of type A RCDs, are specially designed to detect composite residual currents, caused by single phase variable speed drives that are present, for instance, in heat pumps, washing machines or air conditioners. Type F also has enhanced immunity against unwanted tripping (non-tripping on surge current). Type F RCDs remain **functional in the presence of a superimposed smooth direct current of up to 10 mA.**
- **Type B** RCDs are an extension of type F, with the additional capability to detect residual currents characterized by non-negligible DC, with or without ripples, and with high harmonic content up to 1 kHz. Type B RCDs are intended for protection of circuits supplying any loads not covered by Type F RCDs. These loads mainly include three-phase power converters, such as variable speed drives, and some specific single-phase applications, such as some EV charging stations, medical equipment or PV systems.

The type of RCD, AC/A/F/B, shall be selected according to the expected earth current, considering the loads that are likely to be connected to the installation. Where necessary, equipment manufacturers should specify the correct type of RCD required. As a matter of fact, loads may produce DC earth leakage, in case of fault but also in fault free conditions. Many common, modern equipment, often related to energy efficiency and energy saving, generally include nonlinear stages, such as rectifiers, switching mode supplies, frequency converters, etc. Consequently, RCDs of type A/F/B may be needed instead of type AC. Installers shall also refer to applicable national rules for the correct selection of RCDs; for instance, RCDs of type AC are not allowed in some countries.

An excessive DC content in the earth current caused by the loads, in fault free and in faulty conditions, may impair the protective function of RCDs of type AC, A and F, if such DC component exceeds the immunity level for which each type of RCD is designed, viz. 6 mA for type A and 10 mA for type F. We remind that type AC RCDs are not designed to operate with DC content of any amplitude. In all the cases above, the risk, which is termed “blinding”, relates to the internal fault sensing principle of RCDs [1]. In fact, a current transformer is commonly employed to detect time varying residual currents. An exceedingly high level of DC component in the residual current may lead to saturation of the magnetic material constituting the current transformer core, strongly decreasing its responsiveness to a time varying earth leakage stimulus. Correspondingly, the trip threshold increases, and the correct level of protection cannot be guaranteed.

On the contrary, type B RCDs are immune to any risk of blinding: They simply remain operational until tripping, when the earth leakage DC current exceeds the threshold value as per Standards, i.e., $2 \times I_{\Delta n}$ (e.g., 60 mA DC for a type B RCD with $I_{\Delta n}$ = 30 mA).

2. RCDs connected in series

In many installations, two or more RCDs are installed in series[1]: one common upstream RCD protects the distribution circuit and one or more downstream RCDs protect the final circuits; See Figure 1.

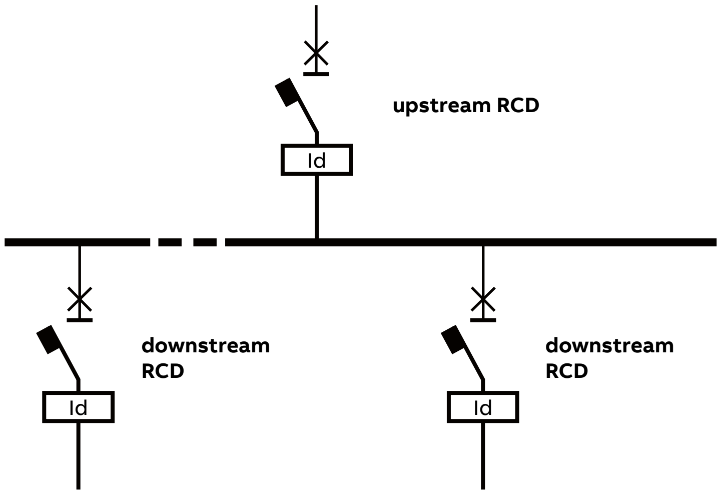

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Figure 1
Example of installation where one common upstream RCD protects the distribution circuit and several downstream RCDs protect final circuits.

First, the correct types for downstream RCD(s) must be selected, basing on load characteristics. This implies that the installation must be properly designed, so that protecting RCDs operated within their intrinsic limits. Then, the upstream RCD must be selected accounting for the total DC earth fault expected at the upstream point of installation, when the loads are in faulty and in fault-free conditions. The following conditions hold:

- If a type B RCD is installed downstream, then the maximum DC earth current let through by it (and reaching the upstream RCD) is 2 × $I_{\Delta n}$, because this is the tripping threshold of type B RCDs in case of DC residual current.
- If a type F RCD is installed downstream (and assuming that the installation had been properly designed, so that the type F RCD operated within its limits), then the maximum DC earth current expected through it (and reaching the upstream RCD) is 10 mA regardless of its $I_{\Delta n}$, because this is the maximum DC earth fault that type F RCDs may tolerate.
- If a type A RCD is installed downstream (and assuming that the installation had been properly designed, so that the type A RCD operated within its limits), then the maximum DC earth current expected through it (and reaching the upstream RCD) is 6 mA regardless of its $I_{\Delta n}$, because this is the maximum DC earth fault that type A RCDs may tolerate.
- Type AC RCDs are not expected to operate in presence of DC earth currents and therefore (assuming that the installation had been properly designed so that they operated safely) they do not contribute to the DC earth leakage that reaches the upstream RCD.

In case of two or more RCDs of type A/F/B installed in parallel downstream, the maximum DC earth current through the general upstream RCD, in the worst case, is the sum of the earth currents through each of the downstream RCDs. This is clearly a pessimistic scenario: in a real situation, DC components stemming from different subcircuits may not be simultaneously present (e.g., EV charging stations not necessarily operating at the same time), or the DC earth current from several parallel loads may at least partially compensate each other. Anyway, over long periods of time the likelihood of particularly unfavorable conditions rises, and the installation must be conservatively designed so to be on the safe side.

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Throughout this guide, we use the term “in series” for a connection as per Figure 1, as commonly intended in the installation practice. It remains understood that the upstream RCD does not necessarily see the same leakage current seen by any one of the downstream RCDs (as the correct, formal definition of “series” would require), for it generally collects the sum of said leakage currents. We believe that this abuse of terminology be for the sake of simplicity and brevity.

It is therefore essential to ensure the that RCDs installed upstream of one or more RCDs of type A, F or B are not blinded by an excessive DC earth current through them. Particularly, the RCD installed upstream must always provide protection in the event of an AC fault in the system portion under its surveillance. Some supplied loads like, e.g., electric vehicle charging, are expected to cause a non-negligible DC earth current component, also in fault free conditions. If such DC earth current component is large enough to impair the correct operation of the upstream RCD, the latter may fail to protect, e.g., a superimposed AC earth fault, as illustrated in Figure 2.

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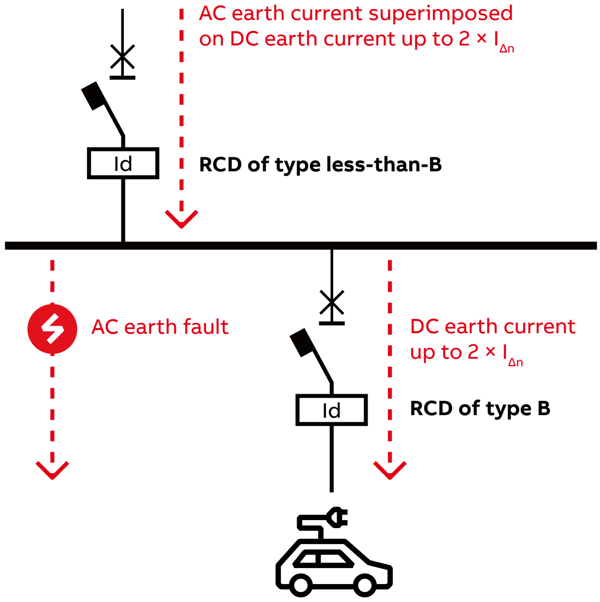
Figure 2
Typical example of installation where an upstream RCD of type AC/A/F (i.e., less-than-B) may be blinded by an excessive DC earth current let thought by a downstream RCD of type B. If not properly selected, the upstream RCD may not operate correctly, therefore failing to clear a superimposed AC fault.



For the sake of simplicity, only a two-level installation will be dealt with, considering a single RCD upstream and one or more RCDs downstream. The general, multi-level case, which may also present a different number of levels in different portions, can be addressed similarly, starting from the lowest levels, then suitably selecting the RCDs of the levels immediately above, and then moving to the levels above until the top-most RCD. Anyway, two-level installations are way more common, the multi-level case being reserved to rare exceptions.

3. The simplest solution: type B upstream

The simplest (and intuitive) solution to reduce the risk of RCD blinding is, wherever an RCD of type A, F or B is installed downstream, to select the type of the upstream RCD, if any, at least as capable as the type of any downstream RCD. That is, at least a type A upstream a type A, at least a type F upstream a type F, and a type B upstream a type B. In other words, at least the type of the most capable downstream RCD will be selected also upstream. Therefore, according to this approach, the presence of at least one type B RCD downstream requires a type B also upstream, which happens to be the most capable RCD type nowadays available; See Figure 3.

The stemming approach agrees with the requirements given in standard IEC 62477-1 [6], which recites:

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Care should be taken for the design and construction of electrical installations with RCD of type B. All the RCD located upstream of an RCD of type B up to the supply transformer shall be of type B.

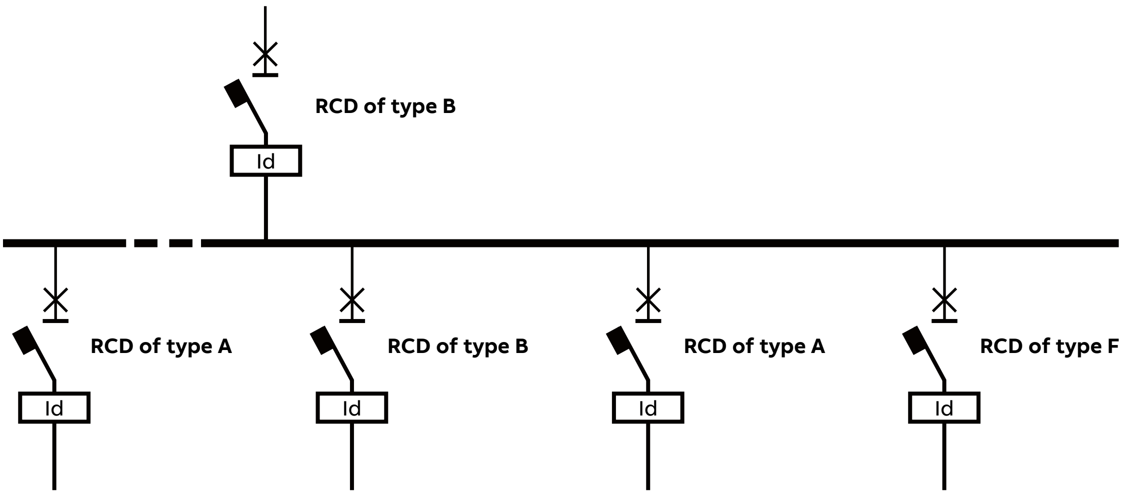

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Figure 3
Example of selection of the upstream RCD at least of the type of the most capable downstream RCD, as required in IEC 62477-1 [6].

Yet, even if no type B RCD is installed downstream, an upstream RCD of type A or F may not be enough. Precisely, if the number of downstream type A or F RCDs is too large, then the total DC earth current through the upstream RCD may be greater than 6 mA or 10 mA; See Figure 4. When the number of several parallel loads is sufficiently large, also the partial compensations between different contributions to the total DC earth current may not be enough to mitigate the problem. Unfortunately, this condition is not explicitly dealt with in IEC 62477-1 [6], but it is of relevance, and not at all uncommon. For instance, it is typical in presence of a large number of electric vehicle charging stations (when, e.g., type A or F RCDs in combination with RDC-DDs embedded in the chargers are installed downstream; See chapter 4), or of variable speed drives, or in general of loads able to create DC earth current. Situations of this kind must be analyzed with sound engineering acumen and the selection of a type B RCD upstream is always preferrable, for the latter is designed to operate correctly in the presence of DC currents of any value, up to the trip threshold, without risk of blinding.

One could summarize the above by stating that a B type upstream RCD is a simple choice that always works, meaning that the blinding risk is resolved, regardless of the nature of the installation downstream. This choice is also the safest in the future outlook, because it would continue to hold also if the downstream installation changed, for any reason.

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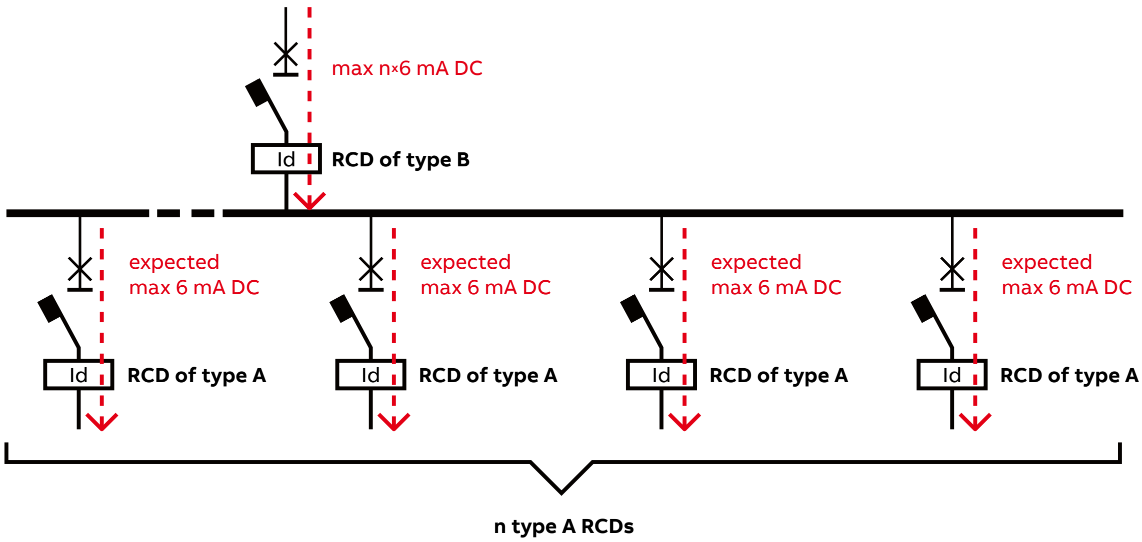
Figure 4
Example of installation where a large number of loads (in this case a number n of type A RCDs installed downstream) may cause an excessive total DC earth fault through the general, upstream RCD: in such situation it is always advisable to select an upstream RCD of type B.



4. Alternative solution with ABB RCDs

After an amendment dating 2020, the reference international standard for LV installations, IEC 60364-5-53:2019/AMD1:2020 [1], allows a second possibility, in addition to the simple rule described in chapter 3. The standard reads (§531.2.3.3.2):

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Wherever an RCD type A, F or B is installed downstream of another RCD, the upstream RCD
- shall comply at least with the requirements of the type of the downstream RCD, or
- shall be coordinated with the downstream RCD, in accordance with the manufacturer's instructions.

The first option is the rule as per chapter 3. The second option allows deviating from the previous rule, provided that the installation be authorized by the instructions of the RCD manufacturer. The ratio behind this second stipulation is that less-than-B type RCDs may tolerate a higher DC residual current level than the minimal capability prescribed by relevant product standards. To exploit these extra resources, when technically feasible and allowed by the standards, is economically advantageous for the installers and their customers.

Important warning. IEC 60364-5-53:2019/AMD1:2020 [1] is an international standard: in some countries, national standards may be more restrictive and, for instance, may not allow the second option. Therefore, installation engineers must always refer to applicable national rules for the correct selection of RCDs.

ABB RCDs can indeed tolerate higher DC residual current levels, without blinding. Consequently, in the spirit of the second bullet of IEC 60364-5-53:2019/AMD1:2020 [1], the selections as per Table 1 can be accepted, in absence of stricter local, national provisions. The compatibility of ABB RCDs to the second option as per IEC 60364-5-53:2019/AMD1:2020 [1] is stated in ABB product catalog, which is periodically updated with new products. Installers must check the presence of the compatibility statement. Whenever the compatibility statement is missing, ABB instructions cannot be interpreted as allowing any deviation from the first option of IEC 60364-5-53:2019/AMD1:2020.

With reference to the coordination as per the second option of IEC 60364-5-53:2019/AMD1:2020, all cases are divided into two families and are briefly commented in the following two sections; See also the summary in Table 1. If the conditions specified for any of the following cases are not fulfilled, the upstream RCD must be of type B. In the following, we shall refer to $I_{\Delta n,dw}$ and $I_{\Delta n,up}$ for the rated residual current of the downstream (dw, for down) and upstream (up) RCDs, respectively.

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Table 1
Selection of upstream RCD type, allowed when using ABB RCDs.

Case	Downstream RCD(s)			Upstream ABB RCD	
	Type	$I_{\Delta n,dw}$	Max quantity	Type	$I_{\Delta n,up}$
1	B	30 mA	1	A or F, general use (*)	100 mA
2			2	A or F, selective (S) (**)	100 mA
3				A or F, general use (*)	300 mA
4			5	A or F, selective (S) (**)	300 mA
5			No limit	B	//
6	A or (F + charger embedding RDC-DD, e.g., ABB Terra AC)	30 mA	10	A or F, general use (*)	100 mA
7			20	A or F, selective (S) (**)	100 mA
8				A or F, general use (*)	300 mA
9			50	A or F, selective (S) (**)	300 mA
10			No limit	B	//

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Notes
(*) RCDs for general use (instantaneous non-selective) are allowed but not recommended for this use.
(**) Time delayed industrial type ABB residual circuit breakers, including cases with a separate toroid (MRCD), according to Annex B or Annex M of IEC 60947-2 [4], are equivalent to selective, if non actuating time is ≥ 0.06 s.

The case of downstream RCDs rated $I_{\Delta n,dw}$ = 30 mA is here considered, for this is definitely the most common case. In principle, similar considerations could be drawn for RCDs with higher rated residual current, and Table 1 could be expanded accordingly. Yet, today this scenario appears to have little or no practical relevance. Future instructions will be delivered as soon as applications should emerge, requiring $I_{\Delta n,dw}$ = 100 mA or $I_{\Delta n,dw}$ = 300 mA.

In Table 1 and in the following, selective RCDs (denoted by S) are also considered. Such RCDs are characterized an intentional delay before tripping (non-actuating time), to guarantee that downstream RCDs tripped before the upstream one, i.e., selectivity. Time delayed industrial type ABB residual circuit breakers, including those with a separate toroid (MRCD), as per Annex B or Annex M of IEC 60947-2 [4], are equivalent to selective RCDs, and are thus included in relevant cases, if the non-actuating time is ≥ 0.06 s.

When consulting Table 1, Cases 1, 3, 6 and 8, it is important to notice that RCDs for general use (instantaneous non-selective) are allowed but not recommended for this use. The ratio behind the lack of recommendation is that selectivity is not guaranteed (and reasonably lost). Yet, Cases 1, 3, 6 and 8 are not unfrequently preferred by installers, in view of its lower cost, but it must be recalled that the value offered to final customers is lower in terms of service continuity, compared to a selectivity compliant installation. In order to achieve selective tripping, the upstream RCD shall be selective (S), or time-delayed, with $I_{\Delta n,up} \geq 3 \times I_{\Delta n,dw}$, as in Case 2, 4, 7 and 9, as opposed to Case 1, 3, 6 and 8, respectively.

4.1. Installations with type B RCDs downstream

The first family of cases (numbered from 1 to 5 in Table 1) relates to installations where the upstream RCD is from ABB, and one or more type B RCDs are present downstream; See, e.g., Figure 5, where $I_{\Delta n,dw}$ = 30 mA. The upstream RCD may of type less-than-B, i.e., A or F. Clearly, the case makes sense only provided that the number of downstream RCDs remains limited by a maximum quantity, as detailed in Table 1.

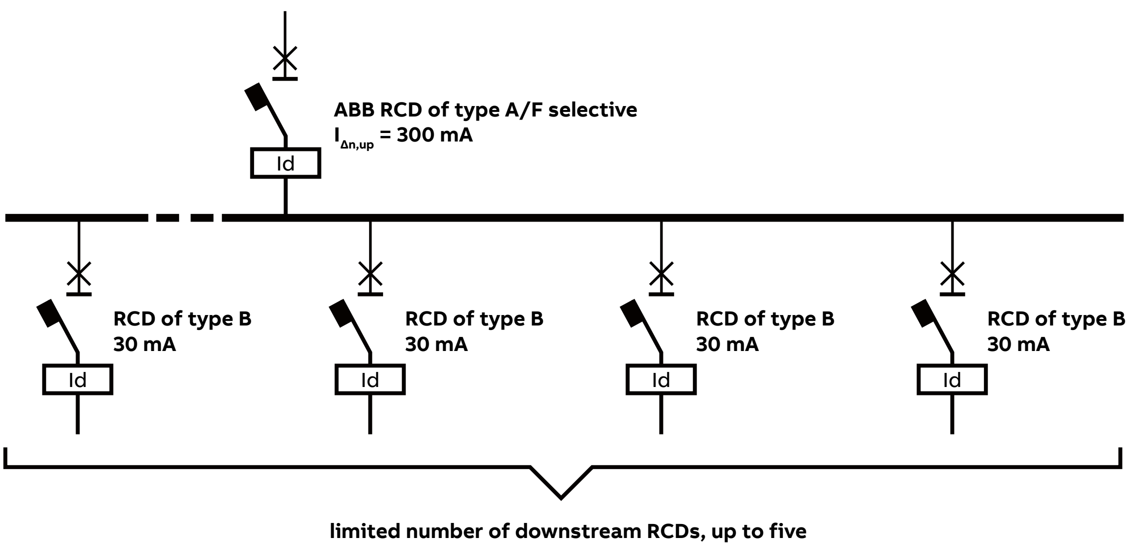

Figure 5
Example of installation where a limited number of RCDs of type B may be installed downstream a common ABB RCD of type A or F according to manufacturer's information; Refer to Table 1, Case 4.

Case 1. The upstream ABB RCD may be of type A or F, non-selective for **general use**, provided that:

- $I_{\Delta n,up}$ = 100 mA;
- No more than **one** type B RCD, rated $I_{\Delta n,dw}$ = 30 mA, is installed downstream.

Case 2. The upstream ABB RCD may be of type A or F, **selective** (S), provided that:

- $I_{\Delta n,up}$ = 100 mA;
- No more than **two** parallel RCDs of type B, rated $I_{\Delta n,dw}$ = 30 mA, are installed downstream.

Case 3. The upstream ABB RCD may be of type A or F, non-selective for **general use**, provided that:

- $I_{\Delta n,up} \geq 10 \times I_{\Delta n,dw}$ = 300 mA;
- No more than **two** parallel RCDs of type B, rated $I_{\Delta n,dw}$ = 30 mA, are installed downstream.

Case 4. The upstream ABB RCD may be of type A or F, **selective** (S), provided that:

- $I_{\Delta n,up} \geq 10 \times I_{\Delta n,dw}$ = 300 mA;
- No more than **five** parallel RCDs of type B, rated $I_{\Delta n,dw}$ = 30 mA, are installed downstream.

Case 5. The upstream RCD must be of type B if the number of downstream type B RCDs is larger than in previous cases.

4.2 Installations without type B RCDs downstream

The second family of allowable cases (numbered from 6 to 10 in Table 1) relates to the protection of mode 3 charging socket-outlets in EV charging stations; See Figure 6. Specifically, as an alternative to type B RCDs downstream, the international installation standard IEC 60364-7-722 [3] allows RCDs of type A or F, rated $I_{\Delta n,dw}$ = 30 mA, used in series with a charger embedding a protection known as Residual Direct Current Detecting Devices (RDC-DD). The latter must comply with the international product standard IEC 62955 [7] and are suitable for mode 3 charging of electric vehicles. ABB Terra AC Wallbox series of mode 3 EV chargers embed RDC-DDs. They remove the supply to the electrical vehicle in cases where a smooth residual direct current equal to or above 6 mA is detected. In fact, RDC-DD are precisely intended to prevent the blinding of the upstream type A or type F RCD. The combination of a type A or F RCD with a charger embedding RDC-DD addresses a single socket-outlet, and it is therefore termed “individual” protection of that socket-outlet. If a charging station has, for instance, two socket-outlets, then each of the two may be protected by a distinct type A/F RCD + RDC-DD combo.

As mentioned, mode 3 charging stations often embed RDC-DDs complying with IEC 62955 [7]. An example is ABB Terra AC Wallbox series. Therefore, such charging stations may be individually protected by a type A or F RCD, rated $I_{\Delta n,dw}$ = 30 mA, instead of a type B RCD. Installers must check carefully if the charging station incorporates an RDC-DD complying with IEC 62955 [7], before selecting the correct upstream RCD.

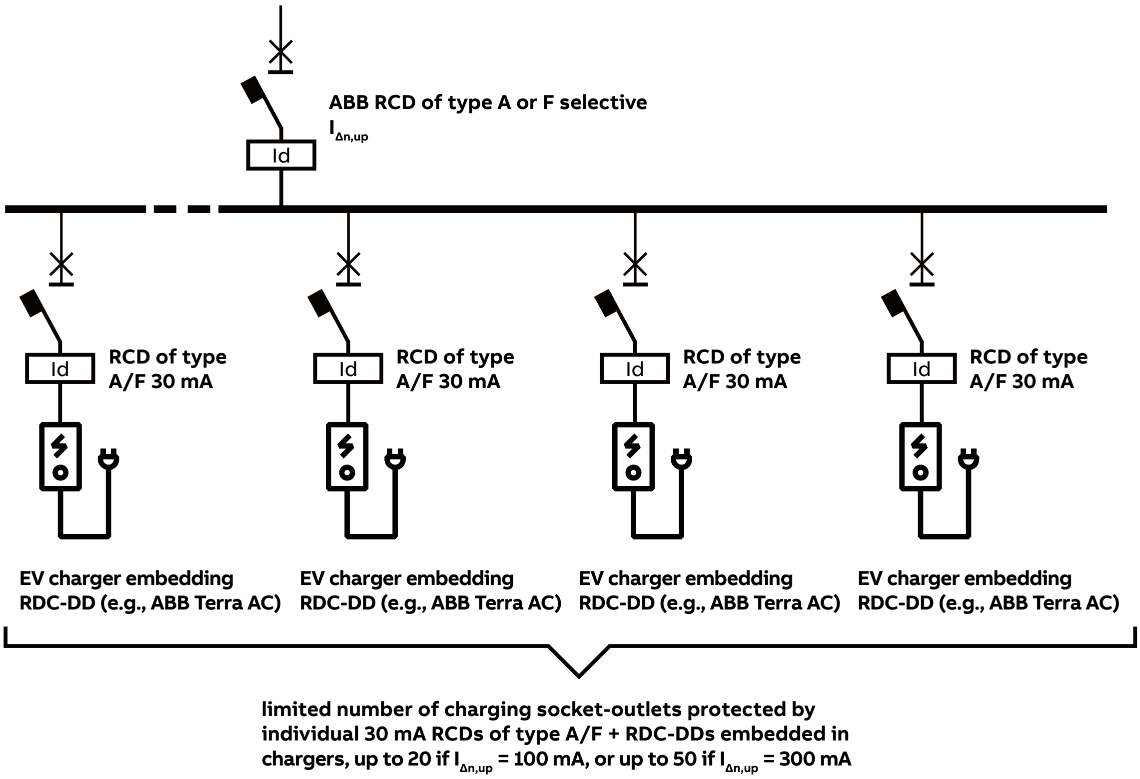

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Figure 6
Example of installation where a limited number of mode 3 charging sockets, each being protected by a 30 mA type A/F RCD + an RDC-DD embedded in the charging station, may be installed downstream a common ABB RCD of type A or F, according to manufacturer's information; Refer to Table 1, Case 7 and Case 9.

The situation is reminiscent of the use of type B RCDs downstream, but with higher maximum quantities of loads and downstream RCDs under the same upstream RCD. Indeed, the total number of type A or F RCDs and RDC-DDs embedded in chargers (and thus of electrical vehicles), downstream of a general ABB less-than-B type RCD, must be limited, in order to avoid any risk of blinding, as follows.

Case 6. The upstream ABB RCD may be of type A or F, non-selective for **general use**, provided that:

- $I_{\Delta n,up}$ = 100 mA;
- No more than **ten** parallel RCDs of type A or F, rated $I_{\Delta n,dw}$ = 30 mA, in conjunction with chargers embedding RDC-DD are installed downstream.

Case 7. The upstream ABB RCD may be of type A or F, **selective** (S), provided that:

- $I_{\Delta n,up}$ = 100 mA;
- No more than **twenty** parallel RCDs of type A or F, rated $I_{\Delta n,dw}$ = 30 mA, in conjunction with chargers embedding RDC-DD are installed downstream.

Case 8. The upstream ABB RCD may be of type A or F, non-selective for **general use**, provided that:

- $I_{\Delta n,up} \geq 10 \times I_{\Delta n,dw}$ = 300 mA;
- No more than **twenty** parallel RCDs of type A or F, rated $I_{\Delta n,dw}$ = 30 mA, in conjunction with chargers embedding RDC-DD are installed downstream.

Case 9. The upstream ABB RCD may be of type A or F, **selective** (S), provided that:

- $I_{\Delta n,up} \geq 10 \times {}_{I\Delta n,dw}$ = 300 mA;
- No more than **fifty** parallel RCDs of type A or F, rated $I_{\Delta n,dw}$ = 30 mA, in conjunction with chargers embedding RDC-DD are installed downstream.

Case 10. The upstream RCD must be of type B if the number of downstream type A or F RCDs in conjunction with chargers with embedded RCD-DD is larger than in previous cases.

References

[1] Earth Fault Protection, ABB Bulletin, 2021, https://campaign.abb.com/l/501021/2021-05-05/t8nzf2
[2] IEC 60364-5-53:2019+AMD1:2020, Low-Voltage electrical installations - Part 5-53: Selection and erection of electrical equipment - Devices for protection for safety, isolation, switching, control and monitoring.
[3] IEC 60364-7-722, Low-voltage electrical installations - Part 7-722: Requirements for special installations or locations - Supplies for electric vehicles.
[4] IEC 60947-2, Low-voltage switchgear and controlgear - Part 2: Circuit-breakers.
[5] IEC 61140, Protection against electric shock - Common aspects for installation and equipment.
[6] IEC 62477-1, Safety requirements for power electronic converter systems and equipment - Part 1: General.
[7] IEC 62955, Residual direct current detecting device (RDC-DD) to be used for mode 3 charging of electric vehicles.

Notebook

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