RCD Nuisance Tripping: Who's Guilty and What Needs to be Done?

Vladimir Gurevich[1]

[1] Israel Electric Corp.

Received: 6 December 2012 Accepted: 31 December 2012 Published: 15 January 2013

Abstract

The reasons for nuisance tripping of residual current devices (RCD) are analyzed in the article and the affect of many external factors is discussed. Solutions are described for avoiding faulty tripping of an RCD.

***Index terms*—** residual current device, RCD, nuisance tripping, harmonic, differential current, leakage current.

1 Introduction

esidual current devices (RCD) are widely used all over the world in households and commercial enterprises as an additional protection against electric shock (RCD with differential tripping currents of up to 30 mA **??**1, **??**]) and as protection from fire, which can result from temperature increases due to current flowing through broken cable insulation and other types of equipment (RCD with tripping currents from 100 to 300 mA **??**3, **??**]).

Since RCD are used so widely, information about their nuisance tripping is in the public domain. It's one thing if power outage occurs in an apartment in a house; this can be easily fixed, by returning the RCD to its initial position. But it's absolutely a different thing if this outage occurs when complex commercial electronic equipment, computers, servers, etc are working. The losses in this case can be tremendous; and these losses can be not only material. Paragraph 7.1.81 of the Operational Codes for Electric Installations (OCEI-7) clearly prohibits installation of RCDs for electric consumers the disconnection of which can result in situations dangerous for consumers (disconnection of fire alarms, and the like). However, it is not always easy to predict the consequences of the disconnection of specific electric receivers wired through an RCD (such as computers, controlling a technological process, special communication devices and alarms, etc.). This is why the problem of nuisance tripping of RCD is very relevant. This topic is discussed in multiple articles found in special technical references **??**5 -10], it is even mentioned in catalogues of large RCD manufacturers, such as ABB, Siemens, Schneider Electric, Merlin Gerin, Legrand, Eaton, Mueller and others.

Standards **??**11, **??**2] describe two major types of an RCD, i.e., **??**C and A. While standard [13] mentions two additional types, i.e., and F. All of them differ in terms of current flowing through the RCD. For example, the AC type RCD is designed for sinusoidal alternating

Author : E-mail : vladimir.gurevich@gmx.net current only; the A type is designed for alternating sinusoidal current and rectifying current imposed to it; the B type is designed for alternating sinusoidal current with a frequency up to 1000 Hz and pulsing, direct or rectified smoothed current; and the F type ("F" stands for frequency) is designed for alternating sinusoidal or pulsing current as well as for non-sinusoidal current, which contains harmonics generated by frequency converters. Many additional types have been "invented" by manufacturers with the purpose of reducing nuisance tripping problems, such as, types U, K, AP-R, SI and others, which are not mentioned in standards. RCD can also be divided into general use devices (type Ggeneral) and selective devices (S -selective). The latter have increased differential trip currents and are equipped with trip delays. They are used in branched cascade networks.

Despite the availability of multiple types of RCDs in the market, the problem of nuisance tripping is still relevant.

2 II.

3 Analysis of Reason for RCD Nuisance Tripping

Let's make it clear from the start: we will not be discussing faulty tripping of RCD as a result of RCD's failures. Rather we will be discussing only nuisance tripping of fully functional RCDs. The reader may ask: Why? If an RCD is fully functional and meets all the requirements set for it, how can it be tripped falsely? The issue is about specific conditions and operational modes which may occur in electric mains as well as those parameters of these mains and modes of operation of electric energy consumers. Due to the high sensitivity of the RCD, the operational modes of the main and consumers characteristics powered through the RCD have a direct impact on the device and often result in its faulty actuation. a) Natural («background») leakage current to the ground through intact insulation of cables and electric loads

It is known that RCD responds to the so-called differential current, which is a difference between the phase current (or a sum of the phase currents in a 3-power network) and current in the neutral. If the current flows to a load through an RCD via a phase wire and returns to the RCD through a neutral wire, the differential current for which the RCD is set up will R XIII Issue XI Version I

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Year amount to zero. If part of the phase current that flows through the RCD is "leaked" to the ground through faulty insulation and does not return to the RCD through a neutral wire, a difference of currents will occur (differential current) to which the RCD responds. The distributed capacities related to ground wires, capacities between coils of transformers and motors related to grounded housings, capacities of multiple filters installed in the supply circuits of almost all types of electronic equipment are the ways through which current may "leak" to the ground. This is actually the current to which an intact RCD should react. According to the standards [14,15] the RCD's trip current may fall in the range of 0.5I N -I N . This means that a functional RCD with a nominal differential tripping current of 30 mA (maximum permitted current to protect people from electric shock) can be tripped at 50% of the nominal current, i.e., at 15 mA. For RCD types " " and " " the real trip current depends also on the pulsing component phase shift and according to standards **??**11, **??**2, **??**4] it falls into the range 0.11I N -2 N .

5 b) Distortion of current form in the RCD circuit

The quality of electric power in household and commercial mains tends to deteriorate continuously due to expanding application of non-linear loads, such as powerful voltage regulators, frequency converters, UPS, LED light fixtures, computers, servers, controllers and other low power electronic devices with internal impulse mode power supply that consume non-sinusoidal current from the mains. This distorted current, containing a number of high-frequency harmonics, will flow through RCD as well, see Fig. 1, Table 1.

Past research [5-10] has shown that distorted current flowing through RCDs of electro-magnetic type leads to significant changes in the threshold of its tripping. The effect of high frequency harmonics on the condition of the magnetic core of the internal current transformer of the RCD and its other elements is rather complicated and controversial. In some cases it is possible to speak of the danger of RCD malfunction, whereas in other cases -about reduction of tripping threshold, i.e., the increase of probability of faulty actuations. But high frequency harmonics not only change the RCD's tripping threshold, but also increase the total "background" leakage current through capacities of the mains and consumers. This is why we can find XIII Issue XI Version I

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Year ourselves in a situation when even a specially selected RCD, which can work with distorted currents, may still be tripped erroneously.

7 c) Impact of current impulses in the RCD circuit

Besides harmonics, electric networks of private dwellings and especially networks of commercial enterprises are affected by atmospheric and switching overvoltages. These overvoltages are "cut" by various types of protection elements, such as gas arrestors, voltage-depended non-linear resistors (varistors) and specific non-linear semiconductor elements. These protection elements are installed directly in the network as separate elements and they are part of internal power supplies of all modern electronic devices. Short (parts of milliseconds) impulses of rather high current (hundreds of Amps) occur when these devices are actuated due to overvoltages and current flow between phase and ground as well as between neutral and ground. In any case this current is actually the differential current to which RCD should react.

As a rule, internal power supplies of electronic devices [16] contain input network filters, which include capacitors as their main elements and which are connected between the phase and the ground as well as between neutral and the ground. When the power supply is switched on, these capacitors produce the current surge between phase and ground to which RCD should react. In addition it should react when the working impulse power supply (this is the main power supply for all modern electronic devices) consumes current from the network in pulses ??16]. The crest factor, in other words, is the ratio of peak value to the RMS. Current value, consumed by the load, amounts to 3, while it is 1.41 for a usual sinusoidal signal. This creates additional load for an RCD.

8 d) The effect of the direct current level on RCD performance

Unlike the above situation (see 2.2) with nonsinusoidal current flowing through an RCD, the expansion of powerful electronic devices (with their frequency converters, voltage regulators, invertors, powerful convertors and variable frequency electric drives) constitue conditions whereby high frequency sinusoidal current of pulse-width modulation and direct or rectified pulsing current flow through RCD connected to circuits with such devices. Normally RCDs of AC, A and even F types are not designed to work in circuits with this current. Since the input element of any RCD is represented by a current transformer with a ferromagnetic core (see Fig, 2), it is obvious that the characteristics of such a transformer will largely depend on the availability of direct current level in the current. In other words the moment when the RCD is actuated will not be determined by its nominal value of differential current, but by random fluctuations of load and leakage current. contact system's release pusher However, even if we select a type B RCD for these purposes, but do not take special measures, type B devices will also be affected by faulty actuations due to the influence of significant impulse current or background leakage current just like RCDs of other types.

9 III.

What Needs to be Done? In the absence of actual (measured) values of the leakage current, the OCEI (7.1.83) suggests accepting the leakage current for electric consumers based on 0.4 mA for each 1 A of the load current and for wires based on 10 microampere for 1 meter of length of a phase conductor. As an example standard ??15] provides typical values of leakage current for several types of electric equipment, see Table 2.

This means that one RCD can be connected to 4-5 computers and 1 printer located within several dozens of meters from the switchboard where the RCD is installed. How can we measure the real current of RCD actuation and the real background leakage current flowing through it? There are special devices for this; however, qualified personnel of commercial enterprises and companies can measure this current with a simple device, Figure 3, observing safety requirements. Initially, the RCD trip current is measured (by gradual reduction of resistance of R resistor) while the load is switched off. Then, the same measurement is performed with the load switched on. The difference in measurements will be the sought-for value of the background leakage current. If this value is higher than 10mA, then according to recommendations ??15] the loads should be split, i.e., install an additional RCD and split the loads between two of them. This cascade connection of RCD allows elimination of their faulty actuation in a complex network. However, it should be considered that RCD with a trip current above 30 mA cannot be viewed as a reliable protection of people from electric shock. This means that the significant portion of the upstream network does not protect people from electric shock and the RCD is used as a fire protection only. On the other hand, it does not mean that a low power consumer connected through an ordinary plug somewhere upstream cannot be protected by a separate RCD with an actuation current of 30 mA. In this situation the leakage current from all downstream cascades will not flow through this RCD and its faulty actuations can be successfully avoided providing reliable performance without nuisance tripping.

In some types of RCD marketed as "super resistant" to nuisance tripping this "resistance" is ensured due to the increase of the minimum level of differential trip current from 0.5 I N , which is actually not prohibited by standards, to 0.75 -0.8 I N . Prevention of the affect of higher harmonics on the RCD is the second option to increase the RCD's resistance to nuisance tripping. It is clear that an RCD designed to work with current containing higher harmonics will behave more predictably compared with devices, which are not intended to work with high frequency current. In fact, this is the reason why special types of RCD (B and F) including special filters and limiting the effect of harmonics were developed. RCD of type F are not manufactured as separate devices, they are manufactured as a type A RCD with expanded frequency characteristics. This is why the marking of this type of RCD usually bears two letters: AF or A-F.

Figure ?? : Incorrect (left) and correct (right) connection of non-linear load with special type RCD In the case of non-linear loads present in a network, which condition increases the level of high frequency harmonics and loads, and containing direct components, these loads should be separated from the common network in such a way so that the non-linear current and current containing the direct component do not flow through another RCD, Fig, ??., which will prevent their nuisance tripping.

It should be taken into consideration that the increased level of high frequency harmonics in the voltage leads to increase of leakages through capacities of wires and equipment, i.e., the increase of the background current thus making the use of special type RCD inefficient. The increased level of harmonics leads to an increase of voltage drops on elements connected in series (inductance chokes) built into the electronic equipment of network filters. This can result in the increase of high frequency voltage level and leakages to the ground through capacitors of these filters. At the same time past research suggests that electronic RCDs are less sensitive to harmonics than electromechanical RCDs, which may be strange at first sight. This is due to the fact that in an electronic RCD the controlled current containing harmonics is not used directly for actuation of the RCD trip unit, but is only a source of a controlling signal, which is cleared from harmonics, strengthened and converted. In order to influence the RCD trip unit, the energy of an auxiliary power supply is used. Phase voltage of the power network can be used as such a supply. An example of an electronic RCD (designated as U-type) is a device manufactured by Eaton-Moeller company under the brand dRCM-40/4/003-U+.

Unfortunately, the use of an electronic RCD (in the standards they are referred to as RCD with dependant power supply, i.e., requiring an auxiliary power supply) is not that simple. The problem is that when the contact in the neutral wire is broken, the RCD will lose its power supply and stop functioning, whereas an electromechanical RCD will actuate and disconnect a consumer due to current imbalance. Due to this, a lot of manufacturers started producing RCDs with a built-in element, which ensures its actuation and disconnection load in the case that the neutral wire is broken (in other words, when the RCD loses its power supply). In their opinion this algorithm was supposed to eliminate an obstacle in the way of using electronic RCDs. However, paragraph 7.1.77 of OCEI-7 prohibits using this RCD, which disconnects a consumer from the mains in the event of voltage outage or voltage dips in inhabited buildings. Why? The author has no reply to this question. And perhaps, not only the author, since V.A. Bulat, Doctor of Science, says the following in his recommendations regarding selection of a correct RCD [17]: XIII Issue XI Version I

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Year «Among electronic RCD or differential automatic circuit breakers t the preference should be given to those that have protection from disconnection of neutral conductor -the disconnection can lead to loss of input voltage by RCD which makes them non operable».

In some European countries the use of electronic RCDs with dependent power supply in stationary electric mains is not allowed by national standards. French standard NFC 15-100 (§ 531.2.2.2) specifies that they should not be used in electric installations of residential buildings. In Russia the concept that an electronic RCD should not be used to protect people from electric shock was shuffled from one scientific article to another for a long time. It is interesting that there was one quote (about the danger of disconnection of zero wire), that was copied by many authors word by word. However, paragraph .4.14 of the new edition **??**18] expressly says: «RCD dependant from auxiliary power supply (electronic) and independent (electromechanical) can be used in residential installations as shock hazard protection».

There are no restrictions for RCD use in the new edition of OCEI-7 also.

The international standard [19] allows using electronic RCDs in two situations:

When using an RCD as protection from indirect contact; When using an RCD in network and electric appliances services by qualified personnel. Direct contact means a contact of a person with current conducting parts inside an electric appliance, while indirect contact means a contact of a person with a casing or another part of an electric appliance, which are normally insulated and are under voltage only due to insulation breakage, Fig. 6. It is clear that the probability of RCD working in the latter case is much lower than in the former case, this is why the standard allows using electronic RCD in this case. An example of this special filter is Filter FN3268 produced by the Swiss company Schaffner **??**20]. These filters are intended for nominal load currents of 7, 16, 30, 42, 55, 75 Amps for RCDs with a differential current of 30 m and for currents 100, 130, 180 Amps for RCD with differential current of 300mA. They not only prevent the influence of high frequency harmonics on the change of the RCD trip threshold, but also reduce background leakage current, since their own leakage current is much less than the current leaking through capacities of the mains due to high frequency harmonics. This is the reason why these filters can be more efficient in preventing nuisance tripping of RCD than the use of special types RCD.

11 c) Prevention of current pulses effect on RCD performance

Actually, today it is not a problem to separate short (several milliseconds) current impulses by means of electronic circuits and block the effect of these short impulses. But when talking about very small and affordable devices (RCD) including those of electromechanical type, the only way to protect from such impulses is to use time lag so that impulses with durations less than this time lag could not activate RCD.

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According to standards **??**11, **??**2], based on actuation time, RCD are distinguished G (general) and S (selective) types. In fact, RCD do not have strict and constant times of actuation. They possess a typical reverse time-to-current feature: the higher is the differential current, the less is the time lag to disconnect the protected circuit, Table 3. In technical literature **??**21] we come across erroneous interpretations of RCD actuation time and references to three instead of two types of devices, such as immediate action (without time delay), with a little delay (type G) and with increased delay (type S), Table 4.

In fact, according to the standards there is no immediate action type device at all. Indeed, for type G RCDs unlike type S the minimum actuation time (in the IEC standard it is called minimum time of non-operation) is not standardized. In other words, theoretically it can be as small as desired.

Clearly this very small time of the general type RCD (type G) actuation does not improve its resistance to nuisance tripping, but on the other hand type S RCD are not suitable as human protection devices. Rather, type S are used to ensure selectivity in the upstream cascades of branched electric networks and have minimum actuation currents of 100 -300 m . This is why many manufacturers produce special type RCDs for differential current of 30 m (i.e., intended to protect people) with a minimal standardized actuation time of 10 msec (this means they should not be actuated even at current impulses of large amplitude and lasting less than 10 msec). Such RCDs are classified as especially resistant to faulty actuation and are marked according to the manufacturer's wish. For example, Siemens marks this RCD as type "K", while the ABB company marks them as «AP-R».

15 d) Elimination of direct component effect on RDC performance

To eliminate the effect of a direct component on RCD performance in a network, where the occurrence of this component (and also high frequency sinusoidal current) is possible, the special type B RCDs are used, which have a differential transformer manufactured using special technology. Very small power taken off from such differential transformers makes it difficult to use electromechanical RCDs, which uses this power for relocation of are leaser of the trip unit. This is why the majority of RCD manufacturers either do not manufacture type B devices at all, or manufacture them in the electronic variant instead of electromechanical. The standard [13] determines the upper limit of the sinusoidal current frequency for which in addition to XIII Issue XI Version I 37 ( ) Year e) Correct selection of RCD type is a key to successful prevention of nuisance tripping

In real conditions of operation there can be a situation when a certain separate fully intact RCD device working in a group of other RCDs of the same type and installed in the same switchboard will have a trip current rating in the network with similar consumers, which is two times less than the nominal rating (which is accepted by the standards). In situations such as this in the event of the occurrence of some detrimental factors (e.g., harmonics, current impulse, results from impulse overloading and arrester actuation, background leakage current), which do not result in tripping of other RCDs, this unit can be actuated erroneously. Moreover, if the affect of detrimental factors repeats, nuisance tripping of this RCD installed in a group of other RCDs can also repeat itself. To prevent such situations sometimes it is enough to substitute this RCD unit by the similar RCD of the same type, but with actuation current rating higher than that of the RCD which actuated erroneously.

In some cases nuisance tripping happens because of accidental combination of events, each of which separately would not result in the faulty actuation of RCD. For example, if there is a certain constant level of harmonics in the circuit, which does not lead to RCD tripping and at the same time there is a powerful current impulse (which alone does not cause actuation), the RCD can be tripped and a consumer will be disconnected. Even such sophisticated and universal units as type B RCD can be susceptible to faulty actuation due to the effect of significant impulse current or background leakage current.

To ensure reliable power supply to consumers and prevention of accidental nuisance tripping of RCD in a network with low power quality, the units should be selected in advance (during design stage) and possess a special feature which ensures protection from harmonics, impulse current and background leakage current effect. If low quality of power was not anticipated before and appeared to be low in practice or deteriorated because of substitution (addition) of consumers, the usual RCDs that were installed before (,) should be substituted by special type RCDs (F, B, U, K). Electronic RCDs are more diversified both in terms of design and in terms of functionality, but they have specific restrictions in use, which have been mentioned above.

A search for devices, which would satisfy all these requirements among dozens of RCD types manufactured by many companies, returned the following results, Table 5. As a rule, RCDs of the same type and possessing similar parameters are manufactured for nominal currents of 25, 40, 63 in twopole (for single phase mains) and four-pole (for 3-phase mains) designs. In order to save space, Table 4 shows parameters of RCD with nominal current of 40A in a four-pole design only.

I regret to say that even the latest version of the main standard on RCD **??**11] does not interpret RCD classification accurately in terms of resistance to faulty actuations. For example, according to **??**11] the devices with a standard resistance to faulty actuation are type G (general) devices, whereas devices with increased resistance to faulty actuation are type S (selective) devices. It is obvious that type S devices intended for differential current in the range of 100-300 mA and higher will be more resistant to faulty actuations compared with type G devices with actuation currents of 10 -30 m . But as was mentioned above, type S units cannot be used to protect people from electric shock. This means that according to **??**11] there is no RCD resistant to faulty actuation intended to protect people from electric shock at all. It seems that the authors of the major international standard on RCD are comfortable with this situation, since this concept has been there for a long time and is copied from one edition of the standard to another. However, the data presented in Table 5 show inconsistency of the classification offered by the standard. f) Automatic reclosing of RCD as an additional option to improve reliability of power supply to consumers

The automatic reclosing (AR) of an RCD cannot be called a means of preventing faulty actuation. It is rather a way to correct the results of nuisance tripping. However, an RCD with AR can be very efficient in solving the problem in those cases, when consumers accept short-time power supply failures. The AR function is easier to implement in some types of electronic RCDs. To return to the initial state an electromechanical RCD needs a special motor drive, which of course requires a separate auxiliary power supply. Some companies produce AR devices as separate blocks, which are installed close to RCDs of different types and reclosing them after tripping in the initial state by simulating the action of a person's hand by means of special protruding plastic lever.

1

Figure 1: Figure 1 :

[1] [2]

[2]© 2013 Global Journals Inc. (US) Volume direct, pulsing and alternating current the type B RCD should be employed at 1000 Hz. A lot of manufacturers of this type of device guarantee their operation at frequencies of up to 2000 Hz, whereas for type "B+" devices -up to 20 kHz. Type B RCD is the most universal of all other types of RCDs, but is also the most expensive.RCD Nuisance Tripping: Who's Guilty and what needs to be Done?

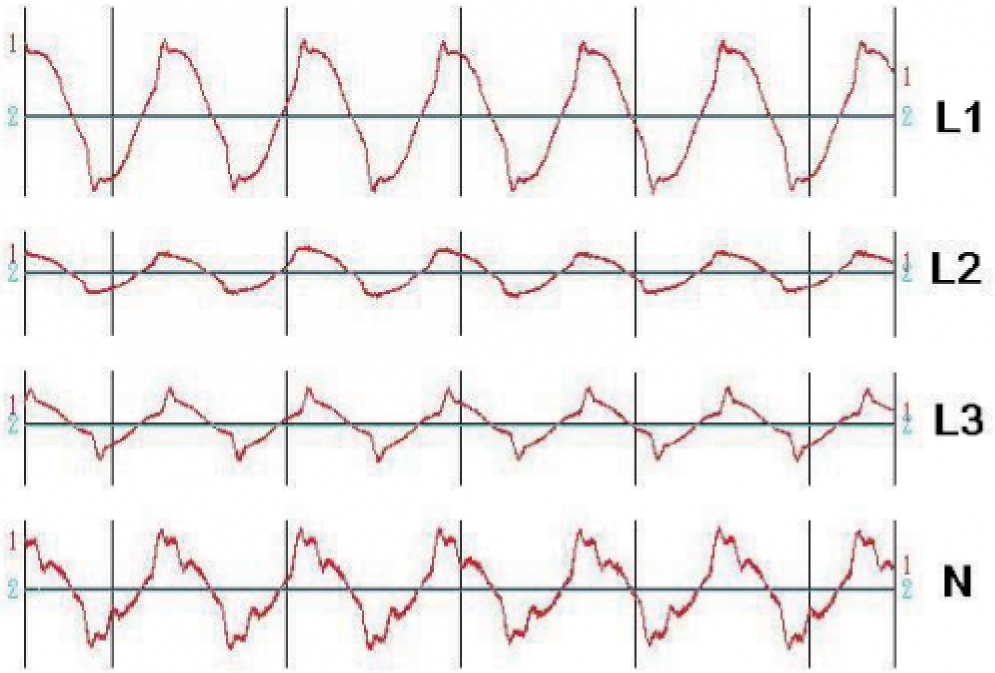

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Figure 2: Figure 2 :

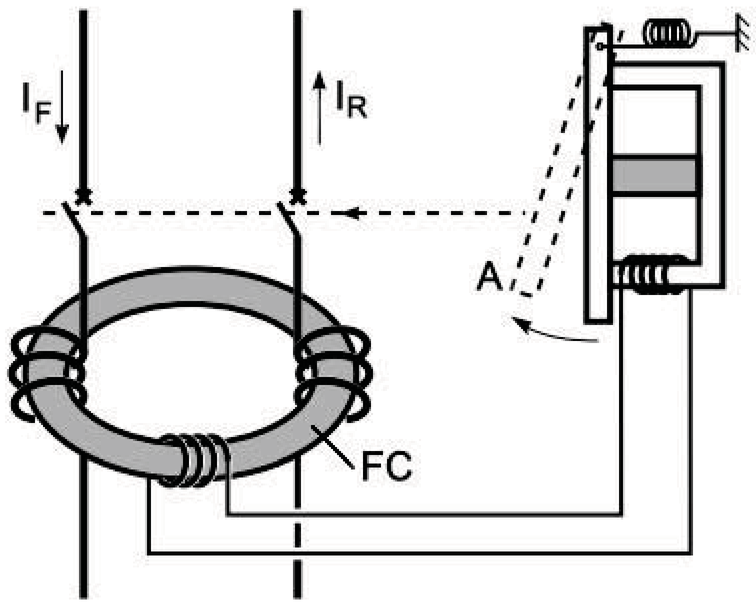

Figure 3:

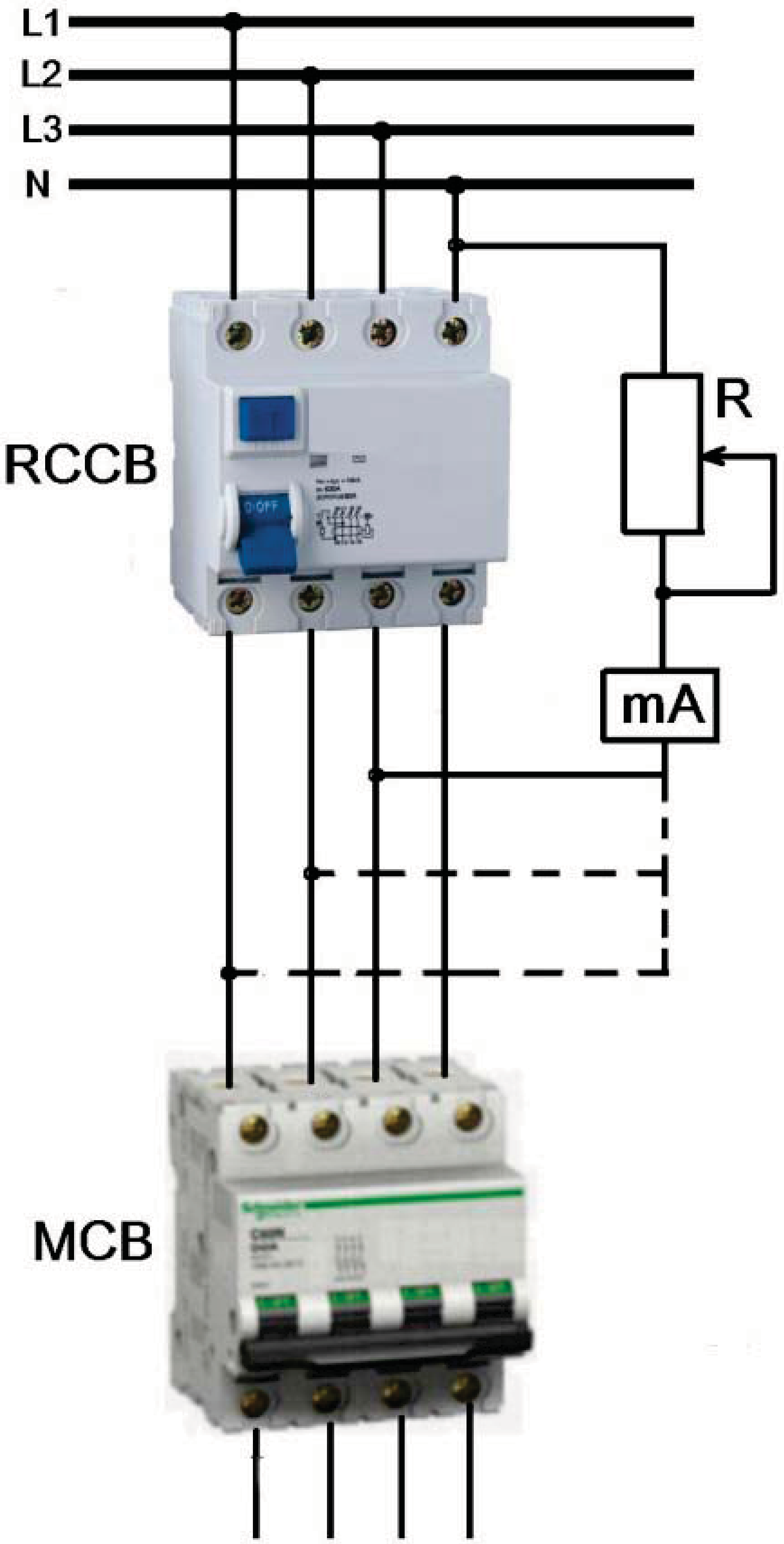

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Figure 4: Figure 3 :

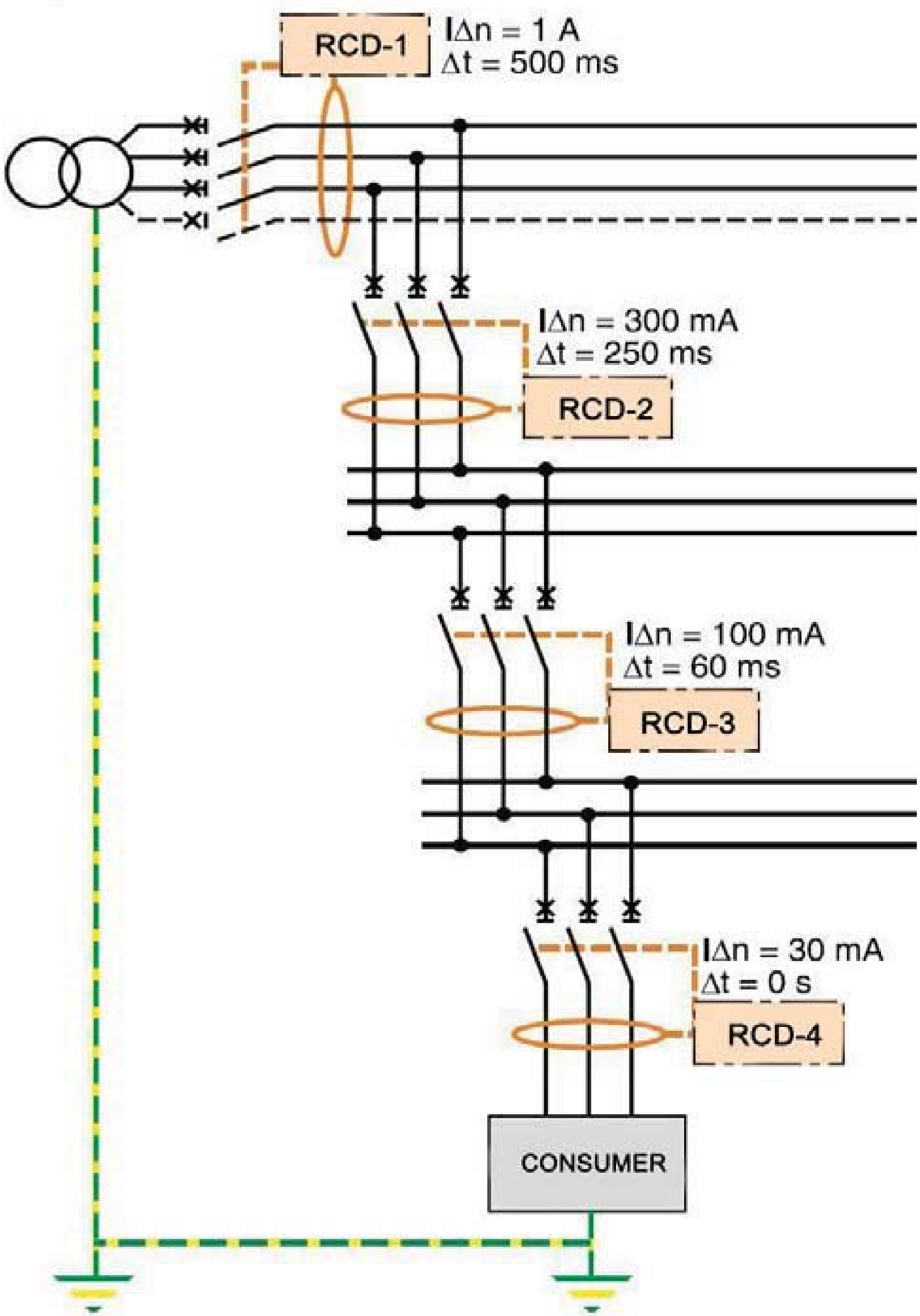

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Figure 5: Figure 4 :

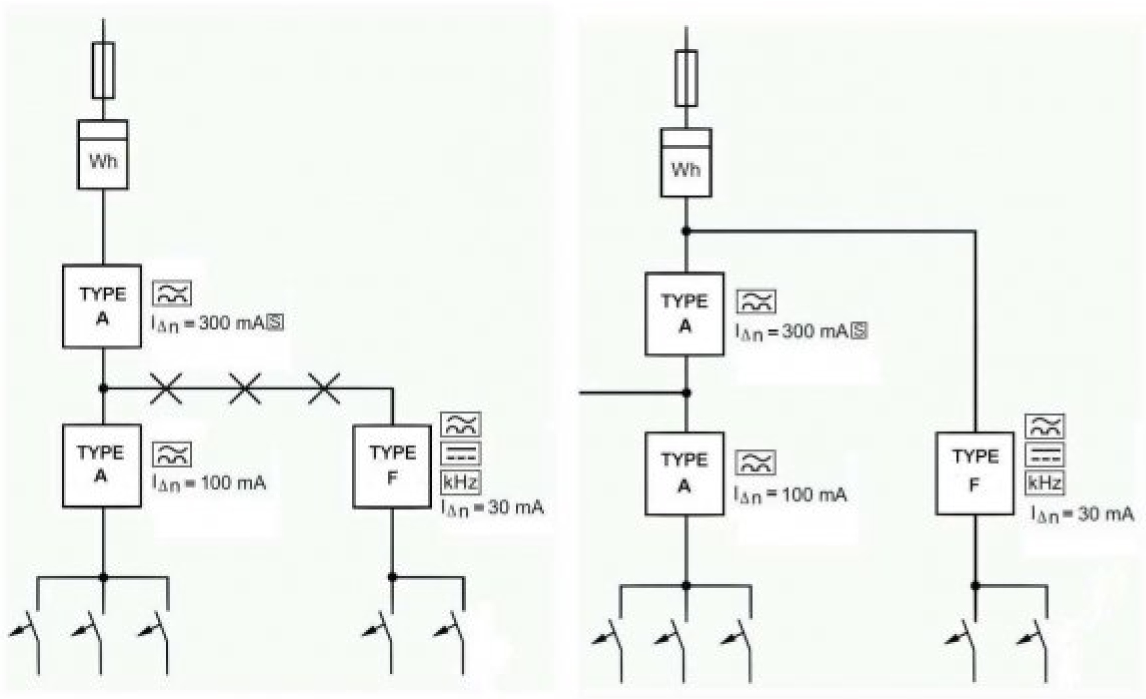

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Figure 6: Figure 6 :

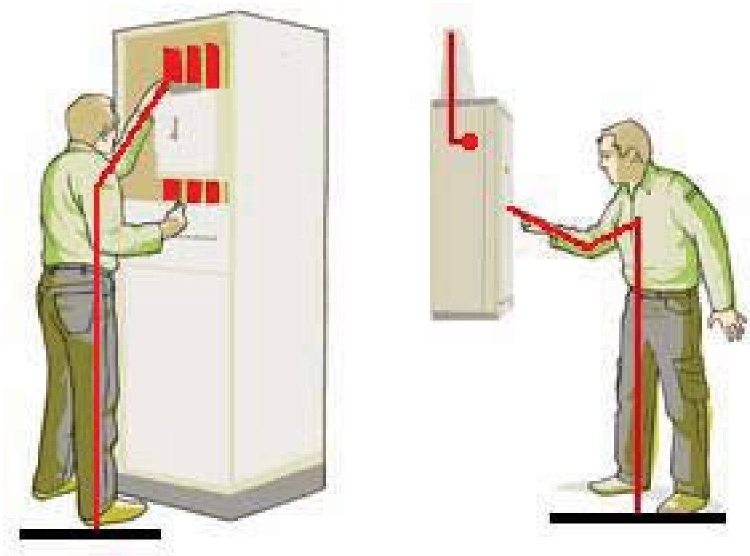

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Figure 7: Figure 7 :

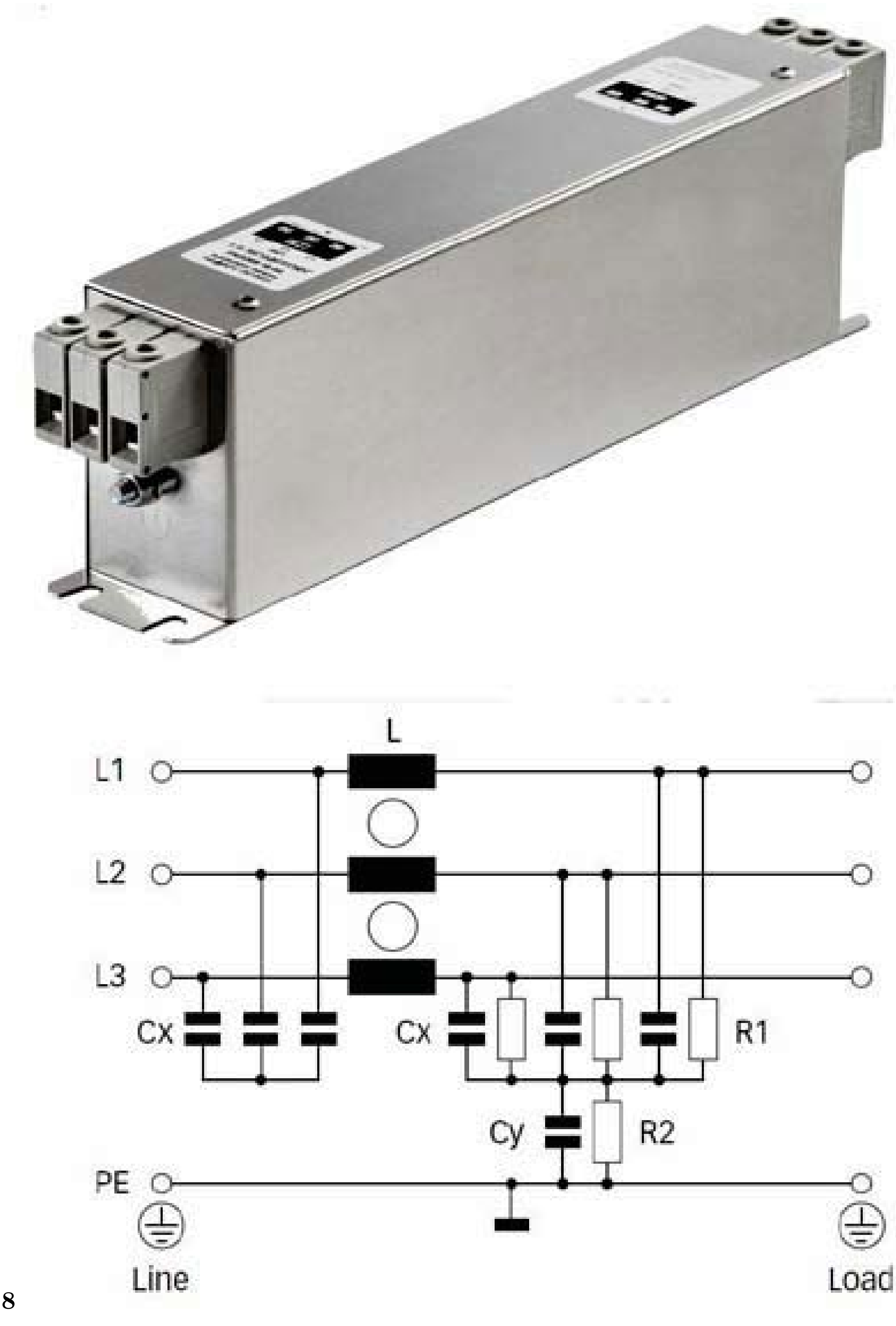

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Figure 8: Figure 8 :

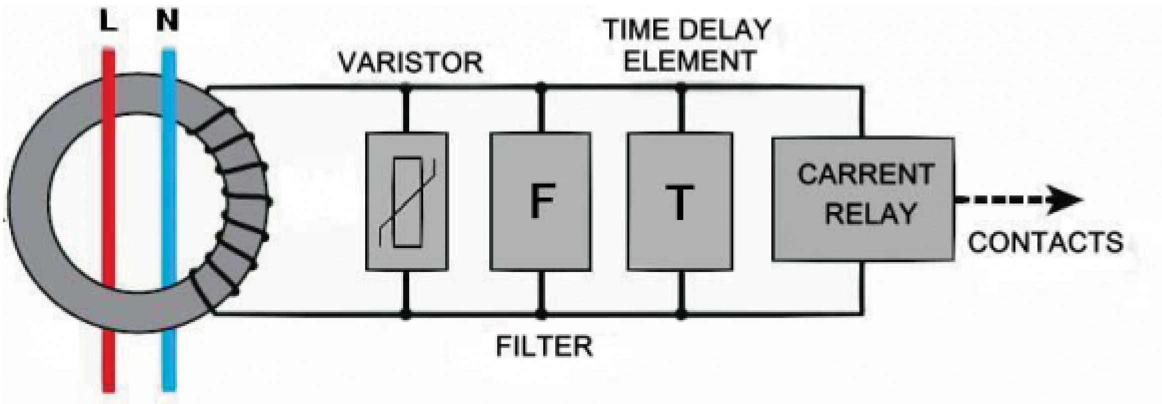

Figure 9:

Figure 10:

1

Harmonic's number	L1	Contents of each harmonic in %	L3 L2	N
1	100	100	100	100
2	1	0.9	3	1.3
3	14.6	23.7	46.3	58.2
4	0.9	0.9	2.5	1.3
5	22.5	17.3	45.2	26.8
6	0.8	3.2	2.6	4
7	15.2	10.8	34.6	21
THD, %	34.5	33	80	78

Figure 11: Table 1 :

2

electric equipment	
Electrical appliances kind	Typical leakage current, m
Computers	1 -2
Printers	0.5 -1
Portable domestic electrical appliances	0.5 -0.75
Photocopy machines	0.5 -1.5
Filters	~1.0

Figure 12: Table 2 :

3

rates of differential current according to IEC 61008-1 standard (Table 1)

RCD type	RCD trip time at variable values of differential currents I DIFF (rms.), ms					
		I DIFF	2 I DIFF		5 I DIFF	
	Min	Max	Min	Max	Min	Max
G	-	300	-	150	-	40
S	130	500	60	200	50	150

Figure 13: Table 3 :

4

	RCD type	Time delay, ms at I = I n	I = 2I n	I = 5I n	I = 500 mA
-	Common use, without time delay	<0.3	<0.15	<0.04	<0.04
G	With minimal time delay 10 ms	0.01?0.3	0.01?0.15	0.01?0.04	0.01?0.04
S	Selective, with minimal time delay 40 ms	0.13?0.5	0.06?0.2	0.05?0.15	0.04?0.15

Figure 14: Table 4 :

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No.	RCD type and manufacturer	Type	Nominal current,	Trip current, I N	Drive type	Time delay, ms (at I=I N)	Pole number
1	dRCM-40/4/003-U+ Cat. number 120850 Eaton (Moeller)	U	40	30	electronic	10	4
2	F374-40/0.03 ABB	A-F	40	30	electro-mechanical	10	4
3	F204 A-40/0.03 ABB	AP-R	40	30	electro-mechanical	10	4

Figure 15: Table 5 :

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[Note: RCD]

Figure 16:

The ABB Company also supplements their AR devices with a small transformer installed on a DIN-rail close to the RCD, which provides power to AR unit's drive from the supply mains. Some types of various AR devices are shown in Fig. **??**.

The majority of types of AR devices allow the RCD to return into its initial condition electively: automatically with a small time lag or, remotely, on command. These devices are manufactured by ABB, Schneider Electric, Legrand, Hager, Circutor, Aoelec and others.

.1 References Références Referencias