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Study of RCD on Industrial Commercial and Residential Electrical Safety – A Hazard Awareness

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Abstract. Every human relies on electricity to power the operation and comfort of their businesses and homes. And they expect their electrical installations to be secure, to protect people from the risk of shock or electrocution, and to protect buildings against the risk of electrical fire. Although the municipal laws on electrical health and defensive equipment continue to improve, many risks still remain today. Hence the paper reflects on the real development in the electrical safety industry through innovative engineering technologies covering all sorts of industrial, business, residential safety. Thus, during the electrical faults, the paper studies the function and importance of highly sensitive residual current device (RCD) and its defensive techniques. RCD is a protective device that detect the electrical faults and switch off the electricity automatically.

Keywords: electrical shock; fire hazards; electrical safety; RCD

1. Introduction

Electromechanical devices could create an electrical shock and fire hazards by their own existence. During the construction of these devices one of the most critical aspects is to add effective protection against electric shocks and fire hazards to them. Residual Current Device (RCD) that can be referred to as a life-saving system intended to protect from lethal electric shock if anyone hit something live, like a bare cable. In addition, which can provide electronic fire safety. RCDs provide a specific degree of security that regular circuit breakers and fuses can't do. For example, when mowing the grass, you cut through the cable and inadvertently hit the uncovered active wires or a defective device overheats allowing electrical current to spill to earth. The electrical current flowing through circuits is tracked by the residual device for securing it. During the tracking process if electricity is detected flowing in unexpected direction, automatically RCD can turn off the particular circuit reducing the risk of serious injury and death.

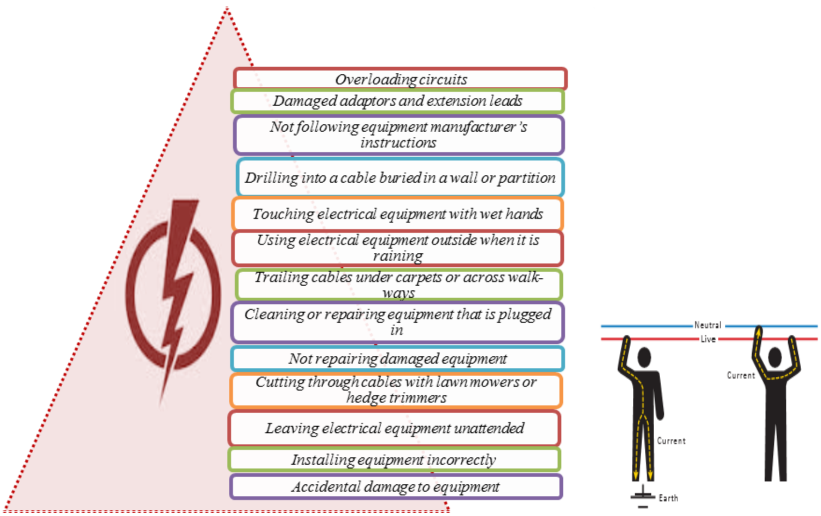

Figure 1. Electrical hazards and current flow in direct contact

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Electrical devices like television, battery chargers, toasters, computers, electrical cookers, washing machines used to draw electrical power. In a house electrical installation comprised of three components (i) fuse or circuit breakers in main switch, (ii) lighting point and the permanent wiring to the power, and (iii) related power outlets, lights, switches on load side. However, there are certain possible dangers mentioned in Fig 1, even the fuse and circuit breakers are installed to the residential load.

1.1 Significance of electric shock protection for human life safety

The influence of electric shock on human body is complex, as they depend on both the time it flows and the current value. Ventricular fibrillation is the key reason people die from electric shock when the heart fails its usual pulse of contraction. The electric could happen directly, when direct contact with bare conductor or when contacting the equipment with leakage current. For instance, a current may be felt in the body of as small as 0.5 mA (0.0005 A), but usually the affected person will not be shocked. Currents between 0.5 mA and 10 mA are likely to be uncomfortable, triggering involuntary muscle contractions, but typically do not have any harmful effect. A 10 mA current (0.01 A) is considered the let-go threshold. When current is greater than this, it is not being possible to loosen the grip on an electrically active device. Currents that last for a long time between about 10 mA and 50 mA may cause severe breathing trouble, disrupt heart function, and muscle contractions. Considerable currents of more than 50 mA (0.05 A) can results burns, breathing problems, cardiac arrest and damages to tissue. With the size and length of the current the probability of this occurring increases. Alternating current (a.c.) is high risky than direct current (d.c.) because it affects the heart's natural rhythm more often.

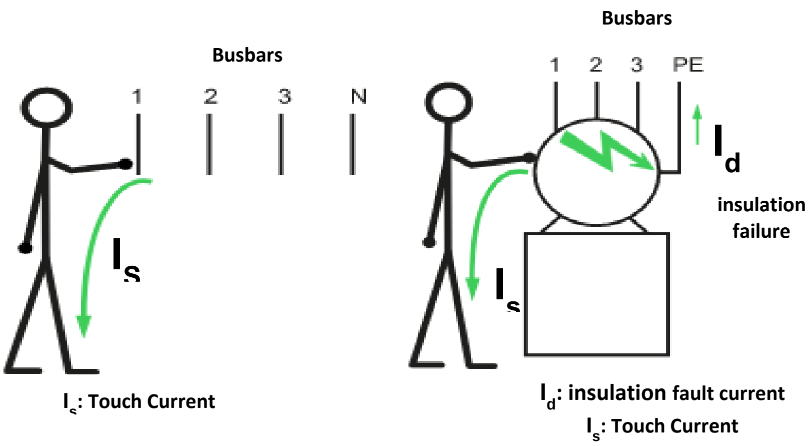

Figure 2. Effect of electric shock during direct and indirect contact

Standard EN 61140[1] discuss the fundamental safety rules for high voltage system and low voltage systems. Especially, hazardous live parts which is permitted and not permitted to accessible has been explained. Similarly, in IEC / HD 60364 standard defined specific rules on protection against electrical shock for low-voltage systems and in HD 60364-4-41[2] low voltage electrical installation is described. Protection against basic contact and fault protection must be employed for safety purpose. Indirect contact protection is mostly rectified through auto cut-off supply, which is the most common form of defence against indirect contact. In the case of a line-to-earth failure, hazardous voltage can appear at the current-using equipment's metal enclosure, and due to indirect contact there is a risk of electrocution (Figure 2). An RCD can be employed as uncoupling device. These systems technically provide safety precautions in case of direct and indirect contact with the live conductor. A person can be rescued from fatal electric shock through only the reliable high sensitivity RCD by providing residual current rated does not exceeding 30 mA, that is assumed as ventricular fibrillation threshold [3]. In many applications contemporary current-use device uses power converters for controlling the power absorbed and regulate the speed of the motor. Power converters are used at

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industries as well as household appliances. Nowadays, residual current devices (RCDs) are widely adopted to protect from electric shock in low-voltage power systems.

1.2 Necessity of preventing electrical faults and fire hazards

Electric fires in cables and connections are caused by electric arcs, earth leakage current, overloads and short circuits. Two types of faults are possible to occur within the electrical circuit. First if a live component comes in contact with the earthed metal works causes earth fault. It usually happens if a washing machine motors fails with insulation failure. Second, when a live conductor comes in contact with the neutral conductor may leads to short circuit current. This faults should be quickly detected and terminated because it may cause drastic heating and damages the electrical installation will result in set fire. The country wise registered accident data with their current are shown in Figure 3.

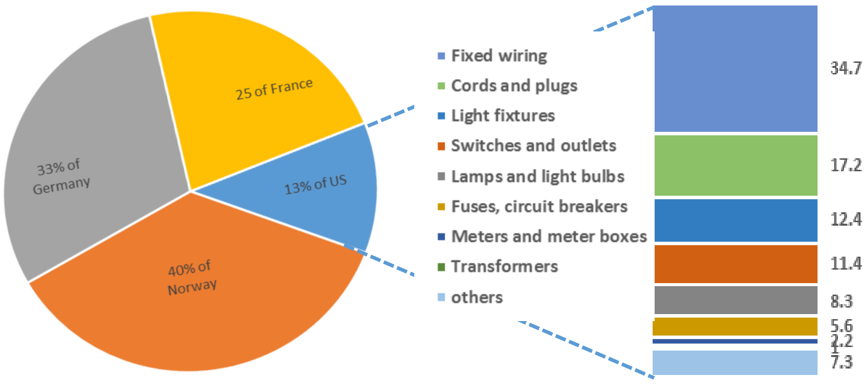

Figure 3. Proportions of electrical fires **[4]** and causes of electrical distribution **[7], [8]**

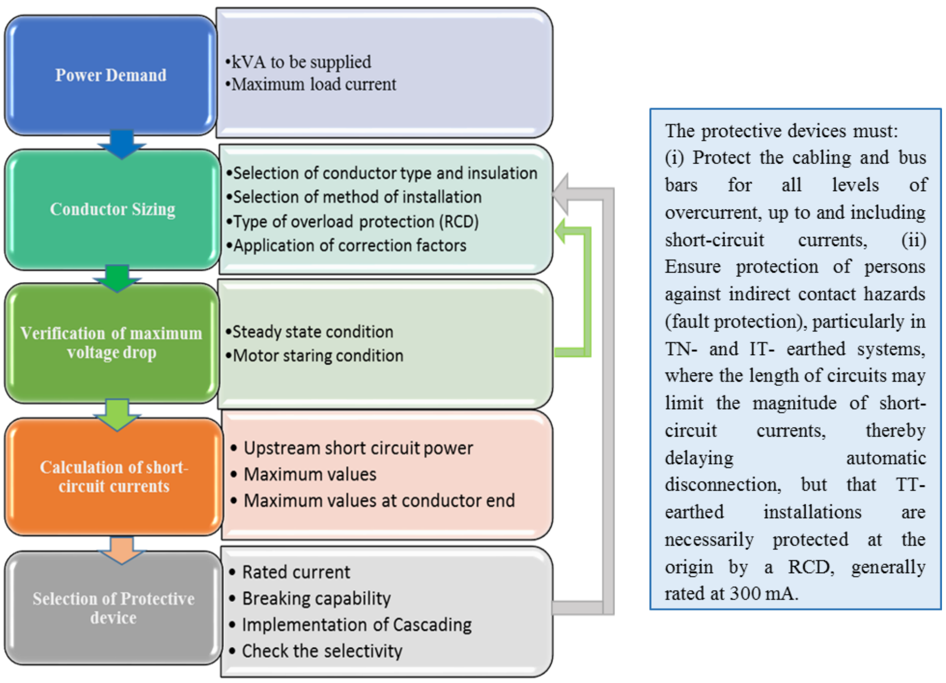

Figure 4: Flow chart of selection of overcurrent protective device

Every year in Europe 2,000,000 fires are registered, causing more than 4,000 deaths, and 70,000 people are hospitalized because of serious injuries. On average, buildings account for 90

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percent of fires in the EU. Electricity is a source of domestic fires which is reported quite frequently in [3]. Every year there are 280000 electrical fires in homes [4]. An electrical installation organization [4] reported the electrical fires proportions of different countries based up on the region and the investigative methods; 13 percent in the United States, 25 percent in France, 33 percent in Germany and 40 percent in Norway. In addition, according to the National Fire Protection Association's new statistics [5]; 41200 home structure fires are only due to 'electrical delivery' each year. Earlier figures compiled by FEMA [6] revealed very similar results: the fifth-ranking cause of fires was electrical distribution, the fourth-ranking cause of fire deaths and the second-ranking cause of property damage. The proportions of electrical fires and the causes of electrical distribution are depicted in Figure 3 and the preventive methods are imparted in Figure 4.

2. Fault protection devices for Electrical Hazards

In general, there are various types of the safety devices used in electrical and electronic circuits. Among these, safety devices used to avoid electrical hazards are fuses and circuit breakers, residual current circuit breaker (RCCB), residual current circuit breaker with overload protection (RCCBO), earth leakage circuit breaker (ELCB), and residual current device (RCD) as shown in Figure 5.

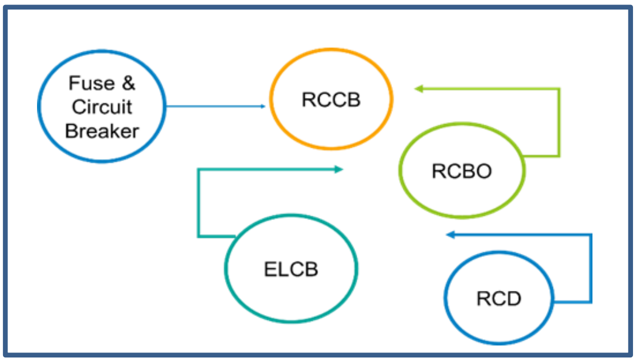


Figure 5: Different types of protection devices

2.1 Fuses and circuit-breakers:

Contrary to common opinion, the fuse in an appliance socket is not intended to protect the device from overload but to protect the flexible wire that provides it from overheating in the event of failure (i.e. short circuit or earth failure). It should be consistent about what and not what a wire fuse does. If a device develops a fault the following problems may happens: A current that is too big causes the fuse to melt, (ii) prevents current flow, (iii) prevents flex overheating and causes fire, (iv) prevents further damage to the equipment. An integrated electromagnetic trip switch could secure the device itself. Consequently, as a result of direct contact, fuses and circuit breakers cannot provide protection against the very tiny electrical currents that pass through the body to earth. Residual current devices can afford this safety as defined in this technical article provided they have been selected correctly.

2.2 Residual current circuit breaker (RCCB):

It is a mechanized switch together with the tripping feature of residual current connected in it. Essentially, it can only sever the circuit when leakage current to the earth. But, short circuit fault or over current cannot be detected by the RCCBs they need to be attached to a fuse or MCB (Miniature Circuit Breaker) in line. RCCBs usually have a break up power and fault-making of 1 kA. This means that if it is a fault to Earth they can accommodate a 1 kA fault on their own. The Wiring Laws allow other tools to provide protection for a line to neutral short circuits and overloads. The system used for protection against short circuits could boost the RCCB's short circuit rating when working together. RCCBs provide protection against earth leakage but a big point to bear in mind when installing them it should always be mounted in combination with a properly designed SCPD (Short Circuit Protective System).

2.3 Residual current circuit breaker with overload protection (RCBO):
It is also a residual current system with a built-in MCB. RCBO is equivalent to residual current circuit breaker and MCB. Residual current circuit breaker together with overload protection have a significant act in (i) short circuit current and overload protection, (ii) earth fault current protection. The RCBO can be used in each one of the circuit, so that if fault occur in one circuit it does not affect the subsequent circuits.

2.4 Earth leakage circuit breaker (ELCB):
This circuit breaker is mainly designed mainly for industrial requirement. It allows the selectivity between different circuit breakers through adjusting the threshold of tripping delay and residual current. Its main function is to protect from ground breaker fault and works with combination with circuit breaker. ELCB follows the IEC 62020, standard which focus on monitoring and isolation of the network. It also shields human lives from electric shocks. The primary usage is for the manufactures who need the tripping time in the production chain.

2.5 Residual current device (RCD):
An additional direct contact protection is provided by RCD. It measures the current size of the neutral and live conductors. Also the circuit of the residual current device is design to easily detachable following the size of the threshold size. The RCDs reacts within 0.04 seconds and it is rated 30mA. If anyone touches the RCD circuit directly one do experience the nonlethal electric shock.

3. Critical review on high sensitivity residual current device (RCD)

High sensitive residual current device uses residual current for its operation at rated 30 mA or less, if offers many protections against the electrical hazards from interaction with live parts. Different reasons to fall in fault is considered which includes (i) improper maintenance, (ii) abrasion and bending of connecting leads (iii) insulation fault (natural tear and wear) (iv) carelessness (v) water immersion and (vi) unintentional touching. This rapid tripping device identify the residual currents to the earth and detach the power supply automatically in order to protect human or animal lives.

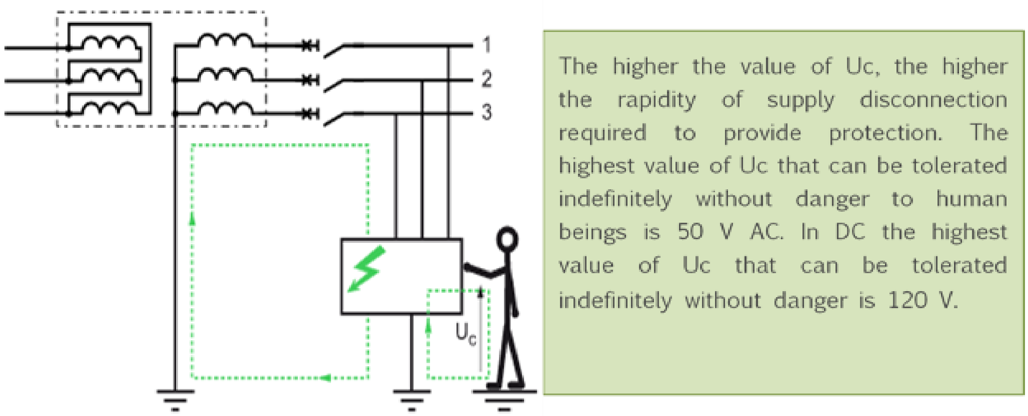
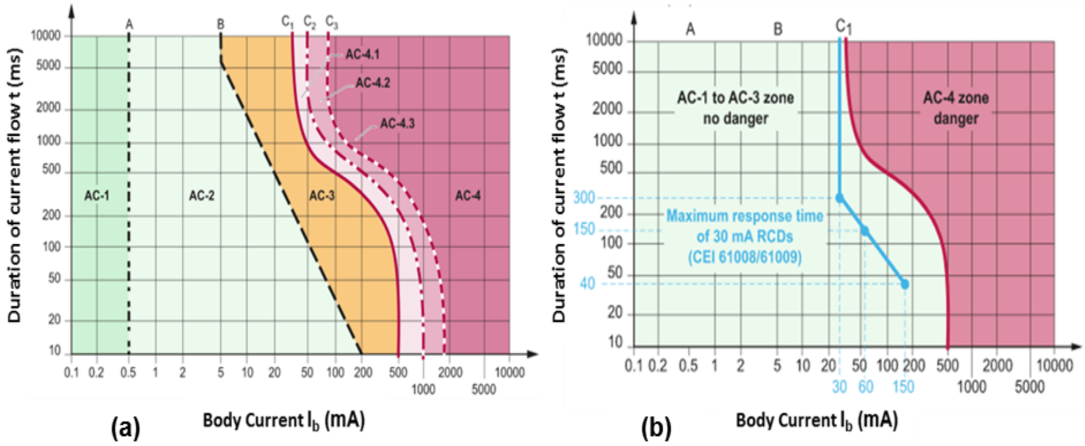


Figure 6: Illustration of dangerous touch voltage Uc

RCD devices calculates the residual current and identify the difference in the input current and output current leaving the system with earthed source. To provide the rapid security, it follows the IEC 61008 and IEC 61009 standard. Therefore, it offers extra protection where standard protection entails failures like human error, damaged or old insulation etc. It can interrupt the current even in the device failure and terms as ultimate protection device. For instance, in the case of greenhouse possibility of proportion of electrocutions is high, wherein the people are in contact with earth. A low track of resistance can be deployed by damp ground for the passage of electric shock through the body. In other way, RCD can be attached with the fuse box to have in the existing system. Moreover, there are plug-in RCDs available that are cost-effective, and can literally save lives. Residual current instruments (RCDs) are usually used to protect against over direct and indirect interactions.

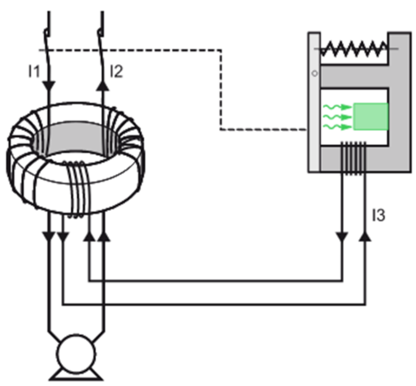


AC-1 zone: Imperceptible, AC-2 zone: Perceptible, AC-3 zone: Reversible effects: muscular contraction, AC-4 zone: Possibility of irreversible effects, AC-4-1 zone: Up to 5% probability of heart fibrillation, AC-4-2 zone: Up to 50% probability of heart fibrillation, AC-4-3 zone: More than 50% probability of heart fibrillation, A curve: Threshold of perception of current, B curve: Threshold of muscular reactions, Ci curve: Ventricular fibrillation unlikely to happen, C2 curve: Threshold of 5% probability of ventricular fibrillation, C3 curve: Threshold of 50% probability of ventricular fibrillation

Figure 7: (a) Body sensitivity curve and (b) High sensitivity RCD tripping curve

3.1 Principle of Residual Current Device

The flux produced in the toroidal magnetic core at any moment depends on the sum of the vector currents, if one path of current (I_1) moment is considered positive, then the other direction of current (I_2) will be negative. The detailed explanation is shown in Figure 8.



In a normally healthy circuit, there will be no flux in the magnetic core, and zero e.m.f. in its coil. An earth-fault current Id will pass through the core to the fault, but will return to the source via the earth, or via protective conductors in a TN-earthed system. The current balance in the conductors passing through the magnetic core therefore no longer exists, and the difference gives rise to a magnetic flux in the core. The difference current is known as the “residual” current and the principle is referred to as the “residual current” principle.

Figure 8: Working principle of RCD

3.2 Technologies of Residual Current Device

Two technologies such as voltage Independent (VI) technology and voltage dependent (VD) technology are implemented by the RCDs. In which technology, whatever the line voltage may, but the voltage drop is < 50 V, the RCD will migrate in the event that the residual current exceeds the

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operating value. Using these technologies, When the voltage of the line is too low, the RCD would be able to sense but not to move, because the electrical circuit and the tripping devices must be driven. The supply line's minimum voltage is 50 V, to allow for tripping as shown in Figure 9.

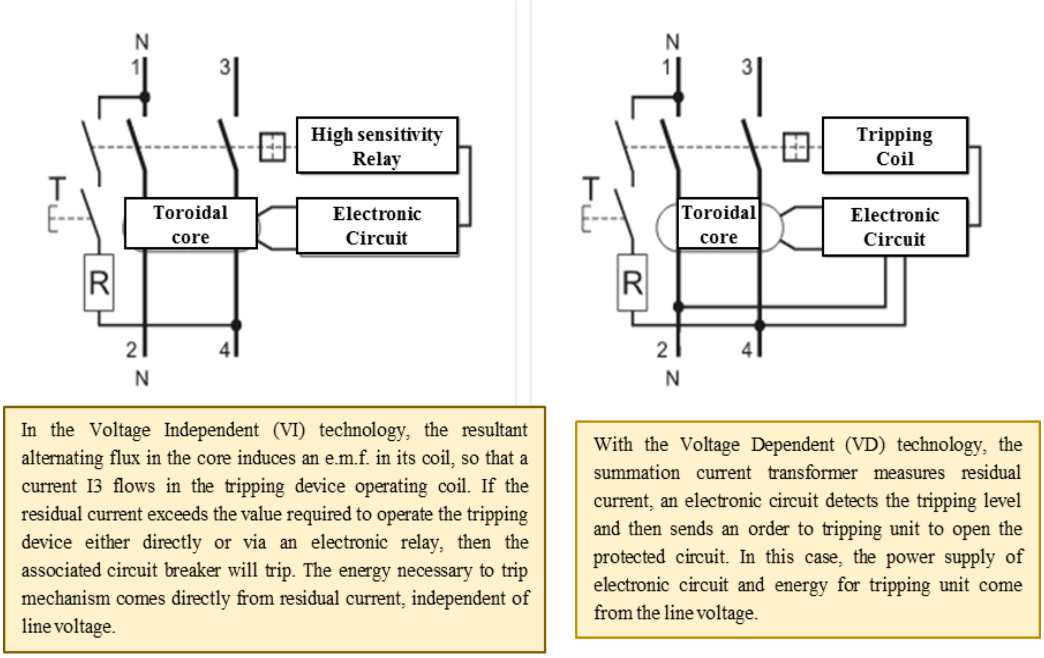


Figure 9: Voltage Independent and Voltage Dependant Technology

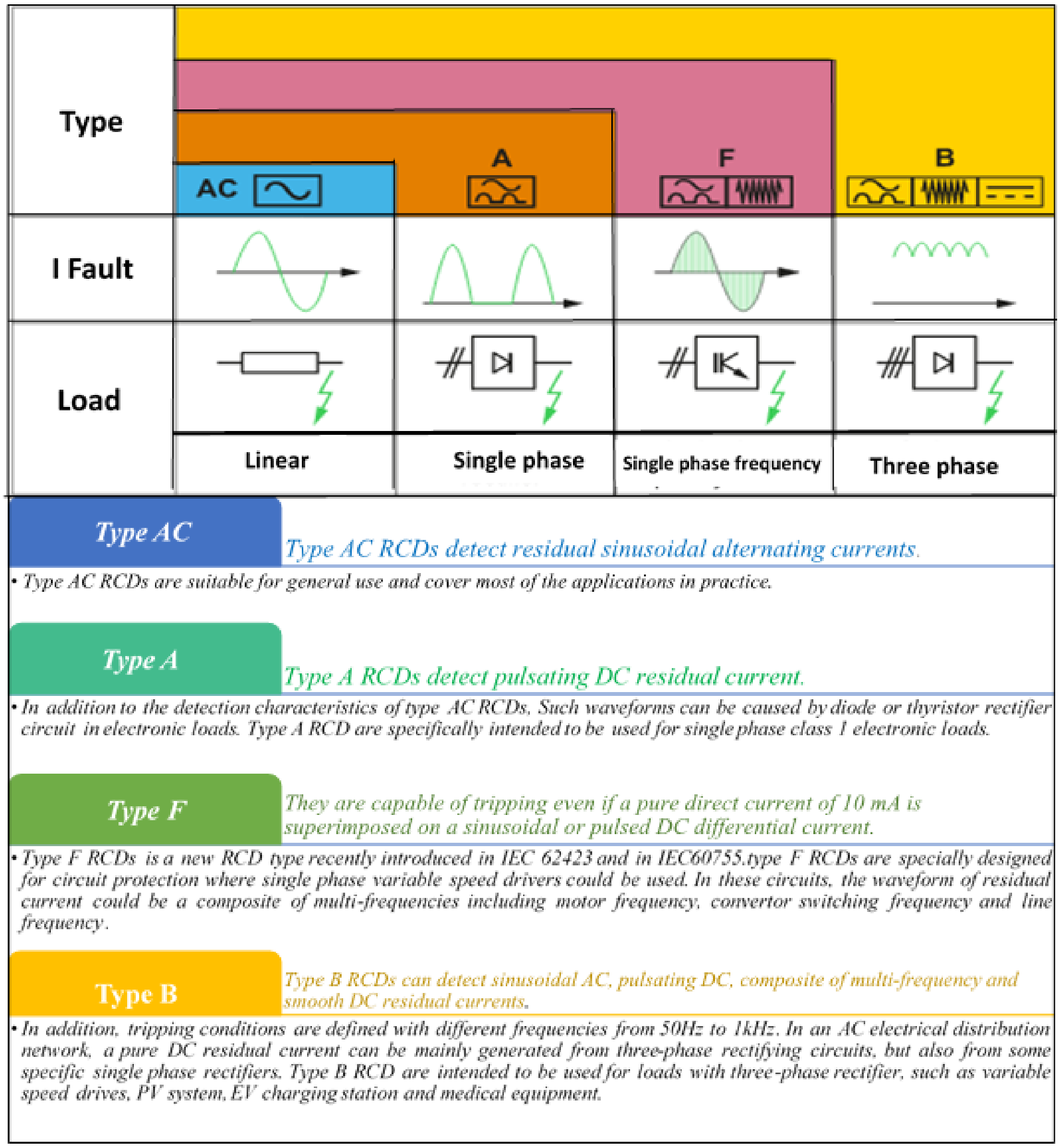
3.3 Types of RCDs

An appropriate safety device with a suitable level of sensitivity should be introduced and applied to identify a line to earth fault and insulation fault which may leads to fire hazard or electrical shock. The operating algorithm of the protective system depends on the power network, special signals, detection of nonlinear sinusoidal alternating earth faulty current, DC current, distorted voltages, current comprising component of low frequency system, detection of an arc failure, higher order harmonics, power electronic converter circuits [7] – [23]. Different types and its description is depicted in Figure 10.

The international standards [24] – [26] consider the following types of RCDs in accordance of their sensitivity and the shape of waveform:

- AC-type: only intended for residual sinusoidal currents of 50/60 Hz,
- A-type: intended for waveforms similar to AC-type RCDs and residual DC-pulsing currents with a smooth DC portion up to 6 mA;
- F-type: designed for waveforms, the same as for A-type RCDs (but the smooth DC portion can be increased up to 10 mA) and mixed-frequency residual currents; the RCD must be provided from one single phase.
- B-type: designed for residual currents: designed for sinusoidal waveforms up to 1000 Hz, pulsating DC, smooth DC, and also mixed frequency. It can be concluded that nowadays A-type RCDs are the most common RCDs used in low voltage systems [27, 28].

Figure 10: Different types of RCDs



3.4 Selectivity of residual current device

Selectivity of residual current device is accomplished either by delaying time or by splitting circuits which are then separately or jointly protected, or by combining the two methods together. Such selectivity protects any RCD tripping, rather than the one instantly upstream of a fault detection. With the device presently offered, selectivity at different distribution levels is achievable, systems for automated disconnection in case of indirect contact danger are placed on distribution panel boards and on security of electrical appliances, along with added safety against direct interaction hazards.

3.4.1 Selectivity among RCDs

RCD selection is accomplished by leveraging the different levels of uniform sensitivity: 30 mA, 100 mA, 300 mA and 1 A as shown in Figure 11.

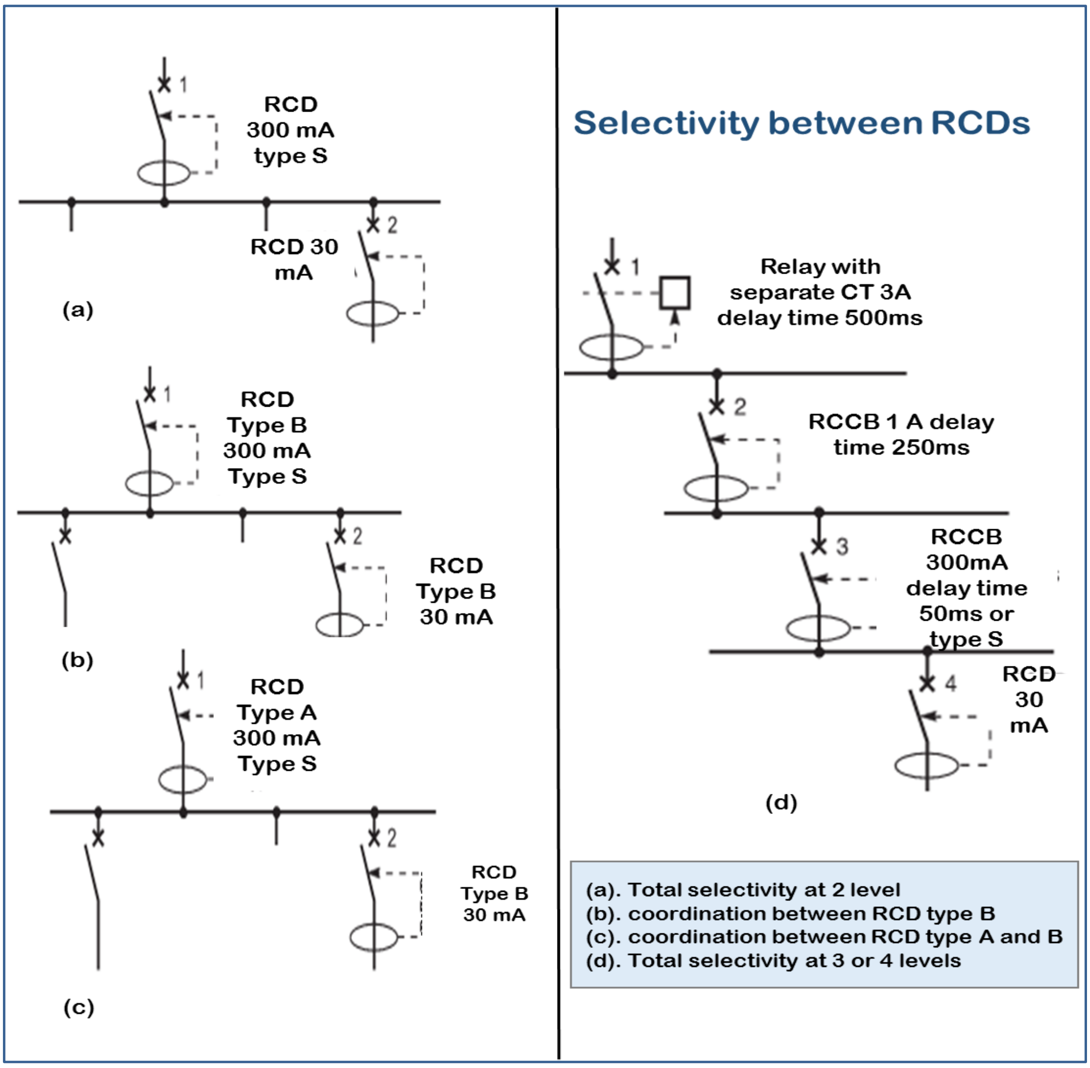


Figure 11: Different levels of selectivity with RCDs

a) *Selectivity at 2 levels (Figure 10a.)*: Level-1: RCD time delayed configuration of either I (industrial devices) or S (domestic devices) for defect safety. Level-2: High sensitivity RCD on at-risk outlet socket products (washing machines, heater, etc.).

b) *Selectivity at 2 levels (Coordination with RCDs type B Figure 10b):* If earth-leakage DC fault current is present, an RCD type B must be used to protect against electric shock. The upstream RCD should not be blinded by the possible DC residual current in this case and should have its usual protection when any residual fault current exists in some other part of the circuits. For instance, in Figure 10(b), the 30mA RCD type B at level-2 might have had a maximum DC tripping threshold of (2*I), according RCD brand standard IEC 62423. This ensures that type B 30mA RCD should require residual current to pass through nearly 60mA DC before tripping and the upstream RCD will not lack any of those output with both the existence of this significantly high DC level. Therefore, it is always suggested using a level-1 RCD type B to prevent any blinding effect from DC current, as shown in Figure 10(b).

c) *Selectivity at 2 levels (another possibility Figure 10c.)*: Many class A RCDs are eligible in the industry to never be susceptible to residual DC current of up to 60mA. A 30 mA RCD type B could be used upstream, but with no risk of ignorance, as seen in Figure 10c. Its type

AC and type A prevention traits are guaranteed though in the existence of 60 mA smooth DC residual current.

d) *Selectivity at 3 or 4 levels (Figure 10d.)*: Level 1: RCD time-delayed (setting III), level-2: RCD time-delayed (setting II), level-3: RCD time-delayed (setting I), or type S, level-4: RCD instantaneous. The upstream RCCB architecture must abide by the selectivity laws and take into consideration all downstream ground leakage currents.

4. Advanced Trends in RCD Type B for Frequency Converter

Safety is the important aspects in VSD, the design and development of USD has various factor including protection, site, rating, cooling, emc filter, etc., among them the protection of VSD is the important as it could same the VSD from power interruption and the same for the other systems connected to it intentionally or un intentionally from electrical hazard. Also consideration should be taken to reducing hazards arising from fairly predictable mishandling of the variable velocity drives that may occur during their lifetime. And the other is defect safety that safeguards the user from an electrical shock in coarse of simple fault. Usually, in the variable speed drives the protections are provided by protective connection in earth or by the use of plastic enclosure.

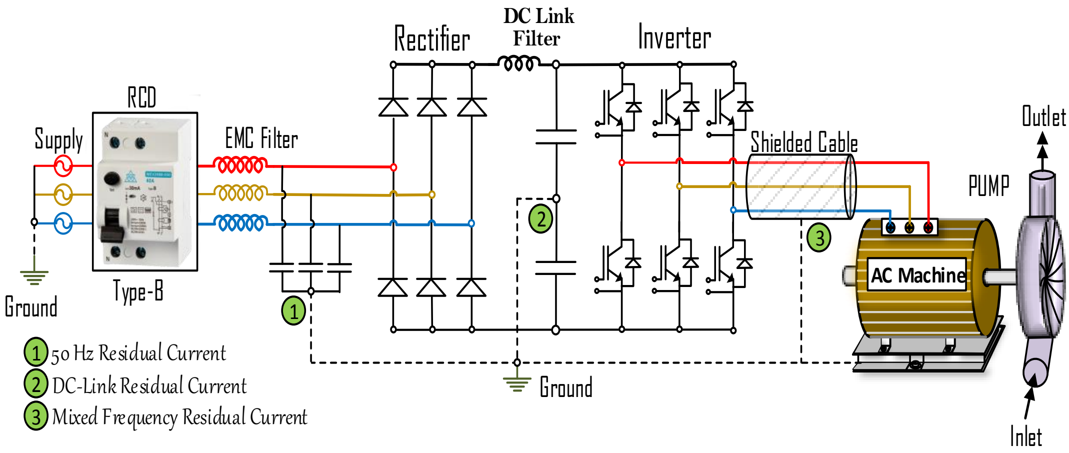


Figure 12: RCD for Frequency Converter

Additionally, protective galvanic insulation is provided for variable sped drives of the power circuit components and attainable control components. It is to ensure that no harmful voltage will appear on the control lines. This would potentially cause lethal contact with the control lines, and also destroy the equipment. The IEC / EN61800-5-1 international / European standard describes the electric shock protection to variable speed drives. Enclosure rating of FC offers protection from damage or loss to the contact. A better cage rating than IP-21 avoids personal injury associated with the contact. Compliance FC's enclosure rating provides protection from contact damage or injury. A better enclosure ranking than IP-21 avoids contact-related personal injury. In order to protect against contact hazards, compliance with national accident prevention regulations (such as BGV-A3, which is mandatory for electrical equipment in Germany) [29] is also essential.

The noise source in inverter voltage that produces a pulse-shaped output voltage with very quick acceleration and deceleration periods. This voltage is fed to motor, and the motor results in a common-mode current through parasite ground capacity. The current of common mode will return to its source after closing, the DC-link, shown in figure 12. One main element in keeping electromagnetic interference under control is through regulating the return path of the common-mode current. There are common mode condensers inside the VSD This includes VSD condensers and ground / earth loops. Common-mode capacitors can be used as decoupling condensers in the RFI circuit, or in the DC-link. By using a shielded motor wire and attaching the motor end of the power cord to the motor frame and attaching the VSD end to the VSD frame, the standard mode current is preferably returned to the DC link by the common mode capacitor. The common-mode current that passes from the supply of the mains is unwanted because it can create interference on other devices attached to the mains. Therefore, this current needs to be limited e.g. by using RFI filters. When utilizing unshielded motor cables, just a part of the common-mode current passes via the variable speed drives' frames and common-mode condensers, creating pressure on main grid.

The variable-speed drive systems are the most controversial from the perspective of RCD spectrum and operation. Such circuits produce complex nonlinear earth fault currents [30], the range of which depends on the pulse width modulation (PWM) frequency and individual motor velocities. For practical applications, the PWM frequency may be within the range of a few to more than 20 kHz. The larger the PWM frequency, the weaker the RCD-operation situation. Such currents comprising the frequency domain differentiate tripping properties of the most typical RCDs from those for the nominal 50/60 Hz [31]. The outcome of the easiest RCD style test described in [32] indicates that their threshold for tripping depends entirely on the magnetic properties of the tripping circuit configuration and current sensor. The elevated tripping frequency of RCDs, which can be harmful for the efficiency of electrical shock protection [33], and the authors recommend a redesign of the RCD structure. Upon correction the correct function of the evaluated RCD is achieved but only for a frequency not much higher than the central wavelength. The problem of RCD operation in the existence of harmonic currents is demonstrated in the guide [34]; it illustrates strongly that the selection of RCDs for circuits with skewed earth fault current needs a detailed review of the existing earth fault shapes. The selected RCD should be capable of responding to them, while at the same time being resistant to natural earth-leakage currents. For these circuits the manufacturer [34] also recommends different RCD types. An advanced RCD sort (B-type) is studied in [35], but is a fairly costly RCD and is used mainly for limited applications. The standard related to RCD is shown in Figure 13.

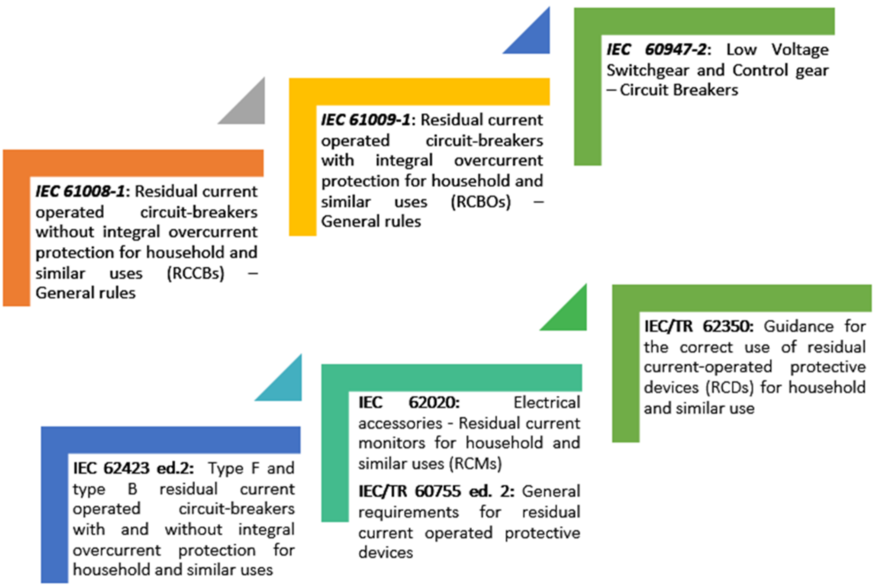


Figure 13: Standards related to residual current device.

An RCD is the only solution on a TT system to protect against indirect contacts because the dangerous fault current is too low for overcurrent protection devices to detect. The TN-S and IT systems are also an easy solution. RCD applications are briefly shown in Figure 14.

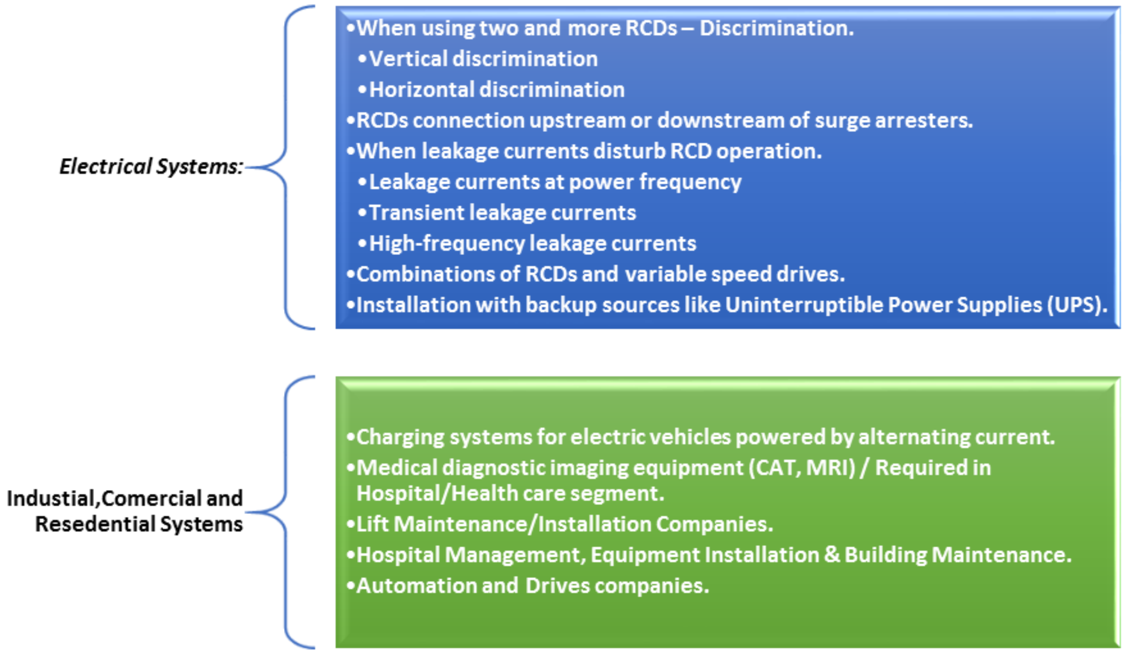


Figure 14: Special application of RCD

5. Conclusions

Electrical devices are frequently handled with currents and voltages which is inherently harmful to animals, humans and structures. Those dangers can be caused by physical interaction, overloading, short circuiting, and loss of component, or impact of heat or moisture. An RCD can sense low currents of leakage that can pass through a person's body. The paper has studied on RCD for electrical safety as well electrical hazards and its caused that are also described in detail. Moreover, during the electrical faults, the paper studies the function and importance of highly sensitive residual current device (RCD) and its defensive techniques. These residual current device is a protective device, which detect the electrical faults and switch off the electricity automatically. The ensuing possible dangers have to be eliminated by precautionary planning and architecture combined to fault analysis and detection system. Therefore, the study helps the readers to understand the importance of electrical safety and give awareness about the electrical hazards.

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