# Aspects of the earthing and short-circuit device's safety quality

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**Abstract.** Earthing and short-circuit devices are part of the category of equipment and means of electric shock protection, and their purpose is to protect workers in the event of an accidental voltage in the work area while doing electrical installation work. The purpose of this study is to convey the findings of research into the level of safety that these devices must provide, not only in terms of electrodynamic and electro thermal consequences that occur during a short-circuit, but also in terms of mechanical, chemical, and environmental aspects. The study's risk analysis of safety performance provides critical information for earthing and short-circuiting device manufacturers to ensure the safety function throughout their use, as well as for workers to pick, use, and maintain.

## 1 Introduction

For user safety and installation protection when working on electrical installations, earthing and short-circuiting devices are crucial components. It would help if you also had equipment that satisfies the highest standards for quality and dependability for earthing and creating a temporary short-circuit-proof link to various components of the installation [1-3].

Maintenance of energized high voltage networks is driven by the need to ensure continuity of supply to users. In this sense, power supply quality standards impose obligations for transmission operators during scheduled interruptions, which cannot exceed a certain number of hours. Working on energized high voltage networks has several advantages, by increasing reliability indicators and the use of networks and ensuring continuity of supply to the users [4, 5].

Electric power systems in industrial plants and commercial and institutional buildings are designed to serve loads safely and reliably. One of the major considerations in designing a power system is adequate to control short circuits or faults as they are commonly called. Uncontrolled short-circuits can cause service outage with accompanying production downtime and associated inconvenience, interruption of essential facilities or

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vital services, extensive equipment damage, personnel injury or fatality, and possible fire damage.

To study the dynamic regimes, static stability analysis conditions, drawing of computing equivalent scheme, analysis and judicious choice of characteristics and setting the distance protection, differential protection phase etc. are necessary to conduct an exact short-circuit calculation.

Portable earthing and short-circuiting devices fall under the category of tools and safety measures that serve to protect workers and work areas from the dangers of electricity by establishing a regulated short-circuit current route for a predetermined amount of time.

In general, portable equipment for earthing or earthing and short-circuiting devices consists of the following: a grounding clamp, a phase/short-circuit clamp, a short-circuit cable, and an earthing cable, and, where necessary, a connection component, depending on the design.

A wide variety of earthing and short-circuiting devices have appeared on the market due to the variety of electrical installations and customer requests for reliable protective equipment that complies with technical requirements and occupational safety and health and is simple to handle and assemble/disassemble, and transport. They can therefore be classified after [6-9]:

- Type of electrical installation in which it is used / destination of use:
  - earthing and short-circuiting devices for power stations;
  - earthing and short-circuit devices for overhead power lines (transmission, distribution, electricity supply; with insulated conductors, twisted, with non-insulated conductors);
  - earthing and short-circuiting devices for underground power lines;
  - earthing and short-circuiting devices for transformer substations / power supply points;
  - earthing and short-circuiting devices for low voltage electrical installations;
  - earthing and short-circuit devices for railway, subway electrical installations;
- By type of phase connection clamp:
  - mobile earthing and short-circuiting devices with manual phase connection clamp;
  - mobile earthing and short-circuiting devices with automatic phase connection clamp;
  - mobile earthing and short-circuiting devices with a semi-automatic phase connection clamp;
- According to the dimensions and constructive characteristics of the connection point (with application on: flat or round bus bars, multiwire cables, round couplings, T-shaped)
- According to the grounding clamp:
  - mobile earthing and short-circuit devices with earthing clamp;
  - mobile earthing and short-circuit devices with earthing terminal;
  - mobile earthing and short-circuit devices with earthing electrode.

The project: "Partnership for the transfer of knowledge and the development of research on the assessment and prevention of occupational risks that can lead to disasters (PROC)" conducts research on the identification and analysis of risk to work equipment, with a protective role, useful in electrical installations [8].

## 2 Short circuit calculation

Wherever there is an electrical discontinuity, electrical systems nearly always need protection against short-circuits. This typically correlates to locations when the conductor cross-section changes. To determine the properties of the equipment needed to sustain or break the fault current, the short-circuit current must be computed at each level of the installation [4].

When short-circuits occur suddenly, high voltage transmission lines run the risk of “short-circuit currents” or “fault currents” circulating through the network.

A short–circuit fault is one of the most constraining situations in a circuit; since it can lead to a failure of the devices if suitable provisions for the protection are not adopted [2, 3].

This short-circuits current’s strength is so great that it might rampage through a network, wiping out everything in its path. All components are put to thermal, magnetic, and mechanical stress by short-circuit current [1-3].

This tension varies according to the square of the current and the length of its propagation. Additionally, it raises the risk of equipment damage, worker harm or death, and unintentional fire ignition.

Unwanted short-circuits can happen for a variety of causes. Natural occurrences including lightning strikes, storms and tree branches brushing up against power lines, animals gnawing on electrical insulation, and animals coming into simultaneous contact with two conductors are some of the causes of faults. Additionally, short-circuits can occasionally be brought on by people [3].

The growing demand for more power results in the construction of new power stations and transmission lines, making it even more susceptible to short-circuit occurrence. Currents from separate power stations concentrate near the fault, resulting in a total short-circuit current that can be many times higher than usual [3].

In an attempt to have any control over short-circuits, power systems and equipment are designed carefully, as well as proper installation and maintenance are done to deliver power to the end-users in a safe manner. Unfortunately, even after all these precautions short-circuit does occur.

Short-circuits must be detected and removed from the system as quickly as possible. This is achieved through protective circuit devices – circuit breakers and feeder protection relays [1].

Due to the potential for several faults to occur simultaneously, these devices must be able to interrupt large currents promptly and repeatedly. The devices should restart the system after the current value has decreased to a safe level. The protective devices must also be able to halt and sustain the maximum short-circuit current that can pass through the circuit; otherwise, they would become damaged and would need to be replaced frequently, which would be expensive and impractical. Therefore, to choose and install the appropriate devices, it is crucial to be able to compute the maximum short-circuit current at each point in the system [4].

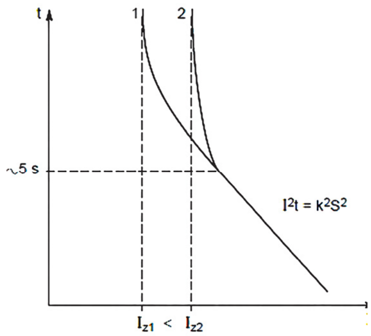
The research in this study concentrated on calculating and preventing short-circuit current in overhead transmission lines. It will cover the many kinds of short-circuits, the characteristics of short circuit current, and how to calculate them along with certain detection techniques and will describe the mathematical model.

Note that, under the least severe operating conditions (fault at the end of a feeder and not where A is the cross-sectional area of the conductors and k is a constant calculated based on different correction factors for the cable installation method, contiguous circuits, etc.), the minimum short-circuit current corresponds to a short-circuit at the end of the protected line, generally phase-to-earth for LV and phase-to-phase for HV (neutral not distributed) [4].

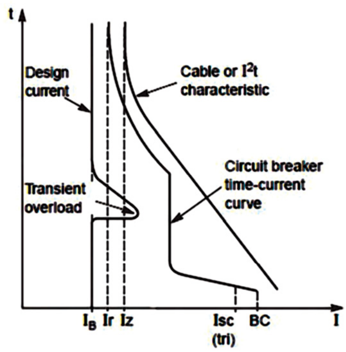
Also keep in mind that, regardless of the circumstance, the protection device must terminate the short-circuit within a period that is consistent with the thermal stresses that the protected cable can withstand, regardless of the type of short-circuit current (minimal or maximum) (see fig 1) [1-4]:

$$\int i^2 dt \leq k^2 A^2 \quad (1)$$

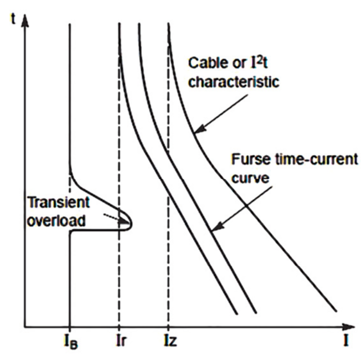
Where A is the cross-sectional area of the conductors and k is a constant calculated on the basis of different correction factors for the cable installation method, contiguous circuits, etc.




a. The $I^2t$ characteristics of a conductor depending on the ambient temperature (1 and 2 represent the rms value of the current in the conductor at different temperatures $\theta_1$ and $\theta_2$, with $\theta_1 > \theta_2$; $I_z$ being the limit of the permissible current under steady-state conditions).




b. Circuit protection using an aM fuse.




c. Circuit protection using a fuse.

**Fig. 1.** Types of circuit protection.

## 2.1 The main types of short-circuits

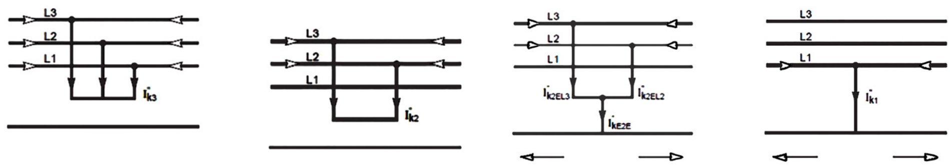
Electrical installations are susceptible to several different types of short-circuits [4]. The primary characteristics are:

- Duration (self-extinguishing, transient and steady-state);
- Origin:
  - mechanical (break in a conductor, accidental electrical contact between two conductors via a foreign conducting body such as a tool or an animal);
  - internal or atmospheric over voltages;
  - insulation breakdown due to heat, humidity or a corrosive environment.
- Location (inside or outside a machine or an electrical switchboard)

Short-circuits can be:

- Phase-to-earth (80% of faults);
- Phase-to-phase (15% of faults). This type of fault often degenerates into a three phase fault;
- Three-phase (only 5% of initial faults),

These different short-circuit currents are presented in Fig. 2 [18].




a) Three-phase short-circuit

b) Phase-to-phase short-circuit clear of earth

c) Phase-to-phase-to-earth short-circuit

d) Phase-to-earth short-circuit

Short-circuit current
Partial short-circuit currents in conductors and earth

**Fig. 2.** Different types of short-circuits and their currents. The direction of current is chosen arbitrarily.

## 2.2 Short-circuit current development

A switch, an impedance $Z_{sc}$ that represents all the impedances upstream of the switch, a load impedance $Z_s$, and a source of continuous AC power make up a simple network.

The numerous networks with varying voltages (HV, LV) and the series-connected wire systems with variable cross-sectional areas (A) and lengths make up the source impedance in a real network, which includes everything upstream of the short-circuit.
The design current flows across the network in Fig. 3 while the switch is closed and there is no fault [4, 10-18].

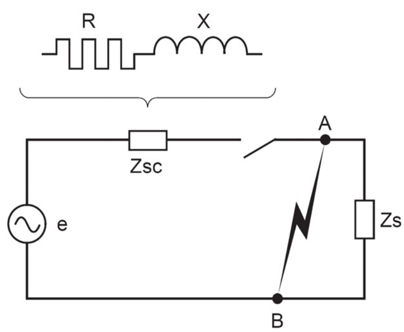



**Fig. 3.** Simplified network diagram.

The R / X ratio is between 0.1 and 0.3. The ratio is virtually equals cos ϕ for low values:

$$\cos\varphi = \frac{R}{\sqrt{R^2 + X^2}} \tag{2}$$

However, depending on the distance between the fault location and the generator, different transient circumstances apply when the short-circuit current develops. This separation, which need not be physical, simply indicates that the generating impedances are lower than the elements' impedances between the generator and the fault location.

### 2.3 Short-circuit far from generator

The most typical fault is the fault far from the generator. The transient conditions are those resulting from the application of a voltage to a reactor-resistance circuit. This voltage is [4, 10 - 18]:

$$e = E\sqrt{2}\sin(t + \omega\alpha) \tag{3}$$

Current i is then the sum of the two components:

$$i = i_{ac} + i_{dc} \tag{4}$$

where $i_{ac}$ is alternating and sinusoidal

$$i_{ac} = I\sqrt{2}(\sin t - \omega\alpha - \phi) \tag{5}$$

$$I = \frac{E}{Z_c} \tag{6}$$

and α = angle characterising the difference between the initiation of the fault and zero voltage. $i_{dc}$ is an aperiodic component, that depends on a and its decay rate is proportional to R / L.

$$i_{dc} = -I\sqrt{2}\sin(\alpha - \phi)e^{\frac{R}{L}t} \tag{7}$$

At the initiation of the short-circuit, i is equal to zero by definition (the design current Is is negligible), hence:

$$i = i_{ac} + i_{dc} = 0 \tag{8}$$

Figure 4 shows the graphical composition of i as the algebraic sum of its two components $i_{ac}$ and $i_{dc}$.

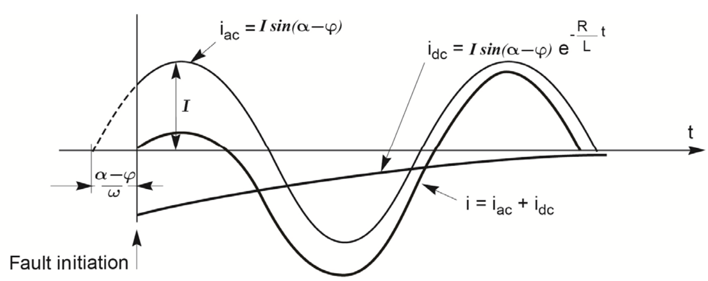
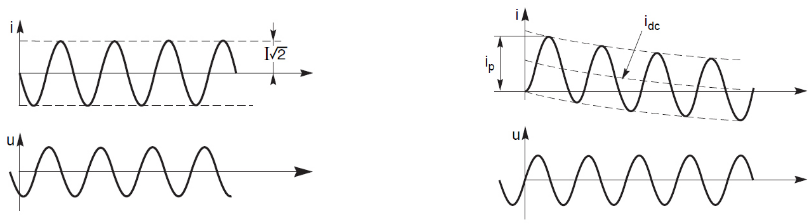



**Fig. 4.** Graphical presentation and decomposition of a short-circuit current occurring far from the generator.

For simplicity, Figure 5 presents the two extreme scenarios for the emergence of a short-circuit current using a single-phase, alternating voltage.




a) Symmetrical short-circuit b) Asymmetrical short-circuit

**Fig. 5.** Graphical presentation of the two extreme cases (symmetrical and asymmetrical) for a short-circuit current.

The factor is inversely proportional to the reactance of the machine variable. The aperiodic component damping, determined by the R / L or R / X ratios.

Therefore, the value of $i_p$ must be determined in order to establish the electrodynamic pressures that the installation as a whole must be able to withstand.

Its value can be calculated using the following equation from the symmetrical short-circuit current's rms value [4, 10 - 18]:

$$i_p = k\sqrt{2} \tag{9}$$

Where

$$k = 1.02 + 0.98 e^{-3\frac{R}{X}} \tag{10}$$

In Figure 6, coefficient *k* is indicated as a function of the ratio R / X or R / L.

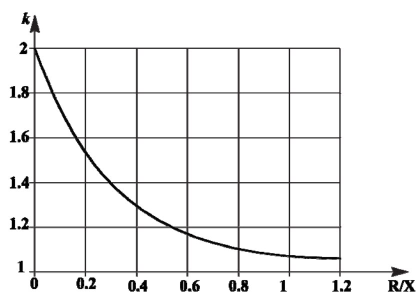



**Fig. 6.** Variation of coefficient *k* depending on *R / X* or *R / L*.

## 3 Test methodology

Based on the findings of the studies conducted on the currently in use earthing and short-circuit devices, the procedures for risk analysis, testing, and certification were developed.

A technical analysis of the equipment and means of protection used in electrical installations for the distribution and supply of electricity was performed as part of the papers “Study on the Identification of Occupational Hazards in Electrical Installations in order to Ensure the Safety and Health of Workers for 35 Workplaces” and “Partnership for knowledge transfer and research development on occupational risk assessment and prevention that can lead to disasters (PROC)” in order to identify and correct any non-conformities found and to ensure the safety and health of workers [8, 9].

On the basis of periodic verification reports and a visual inspection, the equipment and means of protection in use were assessed in respect to the relevant safety and health regulations.

A number of technical non-conformities were found with the earthing and short-circuiting devices, which were caused by wear over time and flaws from improper use. Figure 7 shows the percentage of detected non-conformities.

A technique was utilized to investigate 108 examples of earthing and short-circuit earthing devices used in 110 kV, 20 kV, 6 kV, and low voltage electrical facilities (power plants, overhead lines, cable line, transmission post). The investigated samples ranged in age from one to two years to twenty-five years. Nine devices with damaged or missing grounding clamps or grounding clamps, five devices with damaged insulation, and three devices with damaged grounding slipper cables (3) were taken out of service during the inspection. more than 10% of the cable's strands are broken or coming out of the earthing terminal [8, 9].

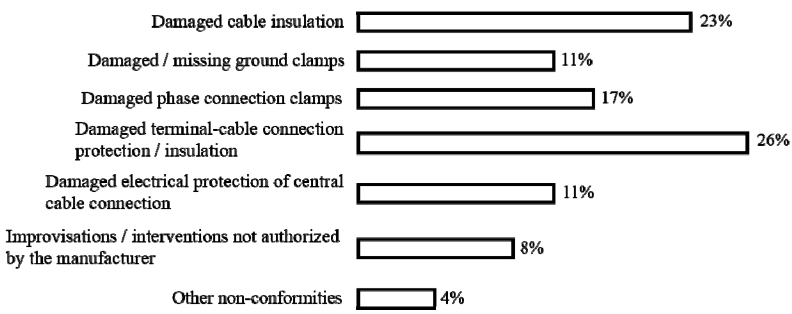



**Fig. 7.** Share of non-conformities identified for earthing and short-circuit devices in use (in 35 workplaces in electrical installations for the distribution and supply of electricity).

The professional risks and the technical, safety, and health requirements applicable to earthing and in short circuit devices, fundamental components in the development of risk analysis, testing, and certification methodologies, were identified within the research works elaborated at the level of the Electrical and Mechanical Risks Laboratory in collaboration with the ICSPM - CS Certification Body.

To cover the use in electrical installations for the production, transmission, distribution, supply, and use of electricity, both single-phase and polyphase, various configurations and various types of phase connection clamps (with automatic, semi-automatic, and manual application) and ground, 25 models of new earthing and short-circuiting devices were studied.

The order and process of carrying out safety tests required to assess their conformity were established and processed after the devices were examined, the risks associated with their use were analysed, the results of the tests and the function, and the level of the registered defects and non-conformities.

The methodology requires the short-circuit current "capability test" before the earthing and short-circuiting devices can pass it. The test is carried out on single-phase specimens (phase-ground) and two-phase specimens (phase-phase), as well as on the whole, as necessary, on application point configurations that are identical to those for which the corresponding devices—phase clamps and connection clamps—are intended to be used.

This study, it was tested two portable earthing and short-circuiting devices. The specimens were tested at thermal and dynamic short-circuit currents,

Using the assembly shown in figure 10, the thermal and dynamic stability were tested

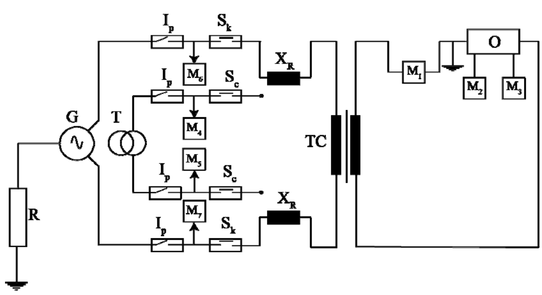
Technical data of the devices are indicated in table 1 [8, 9].

**Table 1.** Technical data.

| Technical data | First device | Second device |
|---|---|---|
| Cable cross-section | 35 $mm^2$ | 16 $mm^2$ |
| Peak short-circuit value | 20 kA | 10 kA |
| RMS short-circuit value | 8 kA | 4 kA |
| Short-circuit duration | 1 s | 1s |
| Short-circuit cable length ($l_f$) | 4 m | 4 m |
| Earthing cable length ($l_p$) | 15 m | 15 m |

To test the dynamic and thermal stability, both devices were tested at phase to phase short-circuit. The first device was tested with 23 kA dynamic short-circuit current ($I_{sd}$), short-circuit current ($I_{sc}$) of 9.2 kA and 1 s duration. The second device was tested with 11.5 kA dynamic short-circuit current ($I_{sd}$), short-circuit current ($I_{sc}$) of 4.6 kA and 1 s duration [7, 9, 10].

Using the assembly shown in the figure 8, the thermal and dynamic stability was tested.




T- power transformer
G – short-circuit generator
$I_K$ – 6kV circuit breaker
$I_p$ – 12 kV safety breaker
$S_c$ – 6kV shunt
$S_K$ – 12kV shunt
$X_R$ – reactance coils
TC – step down transformer
$M_1$ – $M_7$ – measure points
O – test object

**Fig. 8.** Test arrangement.

The required test currents are determined by the manufacturer's declared rated current, multiplied by the peak current factor 1.15 [6, 7, 10].

The short-circuit current test is a destructive test and is considered a major nonconformity if the test fails. Five specimens out of the total tested devices showed significant non-conformities caused by the model/design of the clamps (phase and grounding) and by the technique of execution (ex: clamp casting defect, execution errors).

For a three-phase grounding and short-circuiting device with automatic phase-connection clamps, the short-circuit current graphs for single-phase and two-phase tests are shown in Figure 9 and 10 [8, 9].

The grounding cable has $S_p$ cross-section, and the short-circuit cables have $S_f$ cross-section ($S_p = S_f$) of 16, 25, and 35 $mm^2$.

In power plants, transformer stations, round bars, and overhead lines, three-phase earthing and short-circuiting devices can be employed. It can be mounted from the ground or heights (pole, ladder, nacelle).

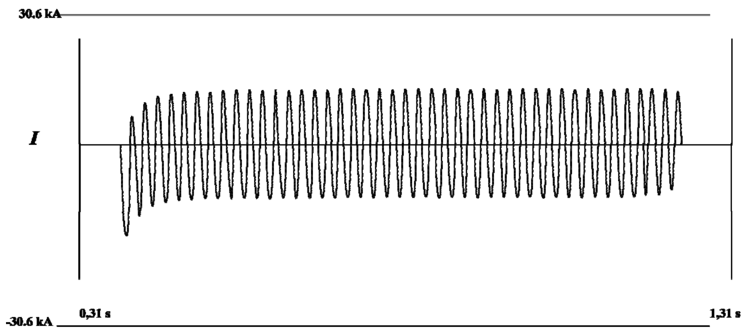



**Fig. 9.** Variation of short-circuit current for first device.

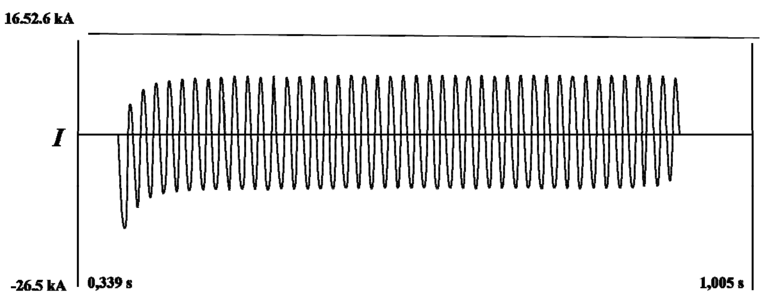



**Fig. 10.** Variation of short-circuit current for second device.

The next series of testing had to be mechanical tests to confirm each terminal/cable combination due to many non-conformities found in the earthing and short-circuiting devices in use regarding the connection of the earthing cable and/or the phase's cable. The purpose of these tests is to determine whether the terminal-cable connection can sustain over time the bending and twisting traction pressures, which can be coupled in service. Three non-conformities were recorded from a total of 40 examined specimens (strands more than 10 per cent torn from the terminal).

The following series of tests examines the dielectric properties of the materials and the electrical insulation components (rods, electrical insulating handles, electrical insulating sleeves, and cable insulation).

An analysis of chemical risk is necessary because electrical insulating materials can release toxic fumes and/or corrosive by-products in the case of a short circuit, which can irritate the eyes and respiratory system [19].

In terms of insulation deterioration, microclimate circumstances have a significant impact on the safety of electrical insulation equipment and raise worker danger [20 - 21].

According to research investigations, various kinds of work equipment necessitate the development of safety and health criteria as well as particular conformity evaluation and verification procedures.

The safety quality of the earthing and short circuit devices are guaranteed to comply with the safety and health requirements established based on the identification of occupational risks thanks to the conformity assessment and verification methodology created in the research study.

Risk workplace assessments allow for the elimination of risk factors through proper working conditions, limited risk exposure, appropriate personal safety equipment, medical surveys, and ergonomic workplace design. When eliminating the risks is not possible, it is mandatory to reduce them up to the level of residual risks, which must be adequately controlled to ensure healthy workplaces for all workers [22, 23].

Workplace risk assessments do not offer a thorough understanding of the risks associated with tools and protective means. The outcomes of tests, trials, and/or periodic checks must support the risk analysis.

Following the risk analyzes, technical measures can be adopted (eg: choosing another material) which must be adopted by the manufacturer (durability, performance, electrical, mechanical, thermal and chemical stress, ergonomic construction, lower cost) of the earthing device and in short circuit cumulated with the organizational ones imposed on the user, but specified in the technical documentation accompanying each product [22, 24, 25].

To ensure the goal of ensuring safe equipment and methods of protection and to strike a balance between technical and safety needs, dependability and economic requirements, one can use the data produced from the application of risk analysis [26].

## 4 Conclusions

The most effective protection against electric shock is thought to be to earth or short-circuit the installation or the area of the installation where a task is to be conducted.

The safety and health of employees and exposed persons are at risk when earthing and short-circuiting devices fail, are damaged while in use, or are operated improperly.

Through proper working conditions, limited risk exposure, adequate personal safety equipment, medical inspections, and ergonomic workplace design, occupational risk assessments enable the elimination of risk factors. When eliminating risks is not possible, however, it is necessary to reduce them to the level of residual risks, which must be adequately controlled to ensure that all employees have healthy jobs.

When the conformity assessment and verification methodology is used for each piece of equipment and means of protection, it certifies that the technical requirements have been met while maintaining the operational indicator values within the bounds set by national and European regulations, applicable standards, and technical requirements.

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