The Fuse

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1 Summary

The aim of this paper is to present a basic introduction to the operation of the Fuse. This is a protection element often used in electrical industrial installations. The paper intends to explain, in a very simple manner, the following aspects related to the Fuse:

- Constituting elements and operation principles.
- Basic specifications.
- Characteristic curves.
- Types of Fuses.
- Advantages/disadvantages.

This work is devoted to students or professionals that are involved in electrical installations design and, more specifically, in the basic switchgear used in those installations.

2 Introduction

A Fuse is a switchgear device that interrupts the circuit in which it is installed, when the current flow causes, because of overheating, the melting of one or several of its elements.

The fuse is an *overcurrent protection* device. It interrupts excessive currents (blows), i.e. currents higher than the normal currents in the circuit (overload or short-circuit currents), so that further damage by overheating or fire is prevented.

It only enables the disconnection of the circuit, so it must be always accompanied by a connection device, e.g. a switch (leading to integrated devices such as Fusible-switches).

There are fuses both for Low Voltage (L.V.) and High Voltage (H.V.) installations. This document will be focused on L.V. fuses that are typically used in most industrial electrical installations.

Specific information on L.V. Fuses can be found in the norms UNE 21-103 (EN 20-269) and IEC 60269.

3 Objetives

The following learning objectives are pursued in this paper:

- To understand the operation of the basic elements of a fuse.
- To know the basic terms defining a fuse and enabling its specification.
- To understand the characteristic curves of a fuse.
- To be able to describe and compare the different types of fuses.
- To know the main advantages and drawbacks of the fuses.

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4 Development

4.1 Basic parts and operation principle

A Fuse is based on two main parts: the Fuse holder and the Cartridge Fuse. The Fuse holder is the part in charge of accommodating the cartridge fuse and connecting it to the rest of the installation.

The Cartridge Fuse (Figure 1) consists of a *metallic element* which is surrounded by the *filler* and enclosed by the *fuse body*. The element is welded to the fuse contacts (typically, blades or ferrules). The element is a calibrated conductor. Its configuration, mass and the materials employed (usually copper, silver or similar metals) are selected to achieve the desired electrical and thermal characteristics. The element provides the current path through the fuse. It generates heat at a rate dependent on its resistance and the load current [4].

The heat generated by the conducting element is absorbed by the filler and passed through the fuse body to the surrounding air. The filler material (typically, quartz sand), provides effective heat transfer and allows for the small element cross-section typical in modern fuses. The effective heat transfer allows the fuse to carry harmless overloads. The small element cross section melts quickly under short-circuit conditions. The filler also aids fuse performance by absorbing arc energy when the fuse clears an overload or short circuit.

When a sustained overload occurs, the element will generate heat at a faster rate than the heat can be passed to the filler. If the overload persists, the element will reach its melting point and open. Increasing the applied current will heat the element faster and cause the fuse to open sooner. Thus, fuses have an inverse time current characteristic: that is, the greater the overcurrent, the less time required for the fuse to open the circuit. This characteristic is desirable because it parallels the characteristics of conductors, motors, transformers, and other electrical apparatus. These components can carry low-level overloads for relatively long periods without damage. However, under high-current conditions, damage can occur quickly. Because of its inverse time current characteristic, a properly applied fuse can provide effective protection over a broad current range, from low-level overloads to high-level short circuits [4].

Some cartridge fuses have a *melting indicator* that melt due to the heat dissipation, informing the user on the actuation of the Fuse.

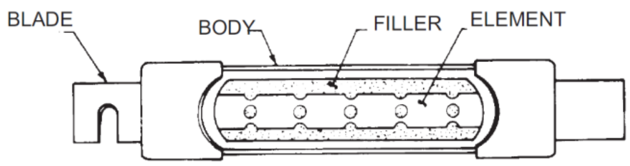


Figure 1. Main elements of a cartridge fuse (Source: [4])

4.2 Basic specifications

Some basic characteristics defining a Fuse are explained next [4]:

- **Ampere Rating or Rated Current (I_n)**: The continuous current carrying capability of a fuse under defined laboratory conditions. The ampere rating is marked on each fuse and it is also known as *size* of the fuse.
- **Available Fault Current**: The maximum short-circuit current that can flow in an unprotected circuit
- **Breaking capacity or Interrupting Rating (I_c):** The maximum level of fault current that the fuse has been tested to safely interrupt.
- **Clearing I^2t**: The total I^2t passed by a fuse as the fuse clears a fault, with t being equal to the time elapsed from the initiation of the fault to the instant the fault has been cleared.
- **Coordination:** The use of overcurrent protective devices that will isolate only that portion of an electrical system that has been overloaded or faulted.
- **Current-limiting Fuse:** A fuse that meets the following three conditions:
  1. Interrupts all available overcurrents within its interrupt rating.
  2. Within its current limiting range, limits the clearing time at rated voltage to an interval equal to, or less than, the first major or symmetrical current loop duration.
  3. Limits peak let-through current to a value less than the available peak current.
- **Current-Limiting Range:** The available fault currents a fuse will clear in less than ½ cycle, thus limiting the actual magnitude of current flow.
- **Element:** A calibrated conductor inside a fuse that melts when subjected to excessive current. The element is enclosed by the fuse body and may be surrounded by an arc-quenching medium such as silica sand. The element is sometimes referred to as a link.
- **Fast-Acting Fuse:** This is a fuse with no intentional time-delay designed into the overload range. It is sometimes referred to as a "single-element fuse" or "non-delay fuse."
- **Fault Current:** Short-circuit current that flows partially or entirely outside the intended normal load current path of a circuit component. Values may be from hundreds to any thousands of amperes.
- **Ferrule:** The cylindrical brass, bronze or copper mounting terminals of fuses with amp ratings up to 60 amperes. The cylindrical terminals at each end of a fuse fit into fuse clips.
- **I^2t (Ampere Squared seconds):** A measure of the thermal energy associated with current flow. I^2t is equal to $(I_{RMS})^2 \times t$, where t is the duration of current flow in seconds.
- **Melting I^2t**: The minimum I^2t required to melt the fuse element.
- **Total operating time:** The sum of the pre-arcing and the arcing time is the total operating time:
  - **Pre-arcing time:** The time taken from the initiation of the fault to the element melting.
  - **Arcing time:** the time taken from the appearance of the arc to its final extinction.

4.3 Characteristic curves

4.3.1 Time-current characteristic curves

These curves provide the pre-arcing time or the total operating time versus the current (RMS value) [1]. These curves show an inverse characteristic, i.e., the higher the current flow, the shorter the operating time. Figure 2 shows a basic representation of this curve and Figure 3 depicts the curves corresponding to a family of fuses, as they come in the catalog of a manufacturer [5].

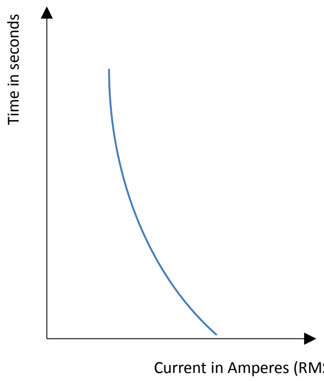


Figure 2. Time-current characteristic curve of a fuse

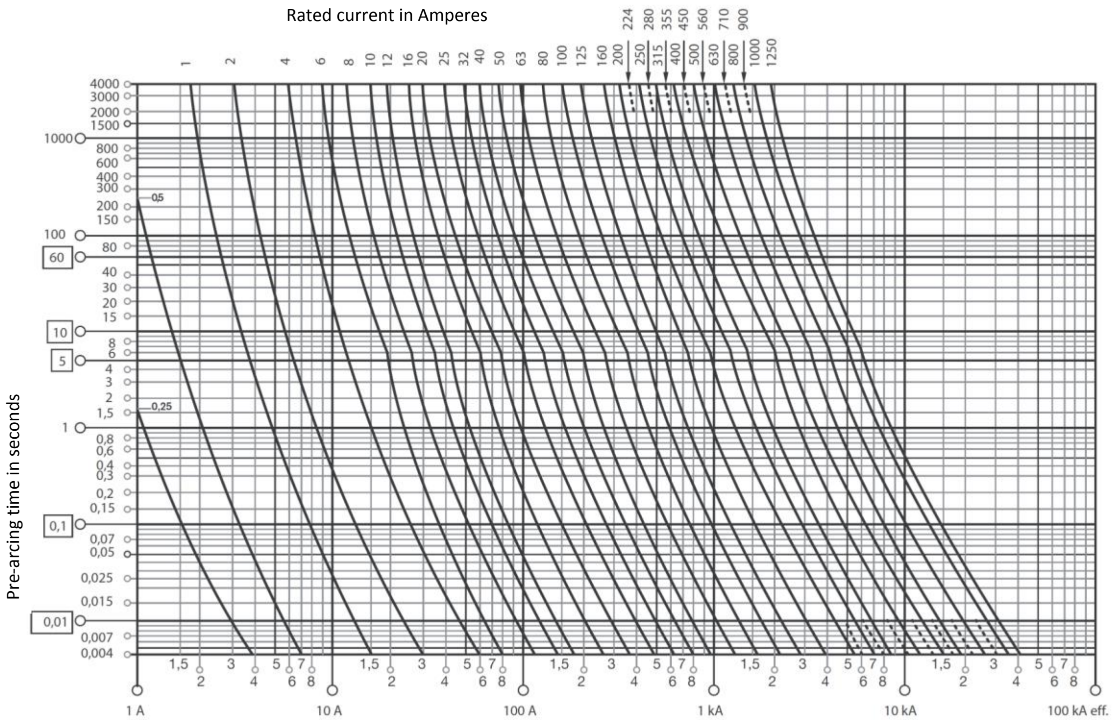
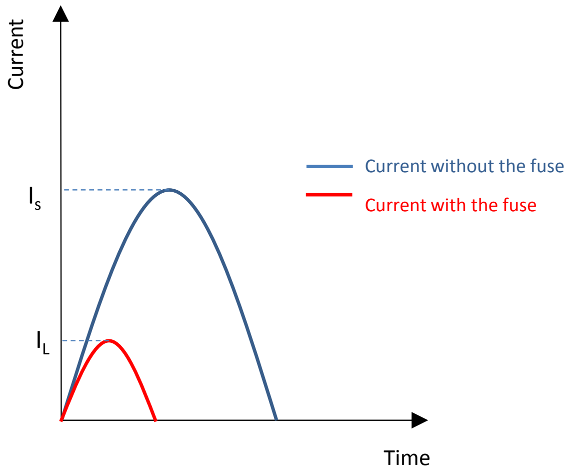
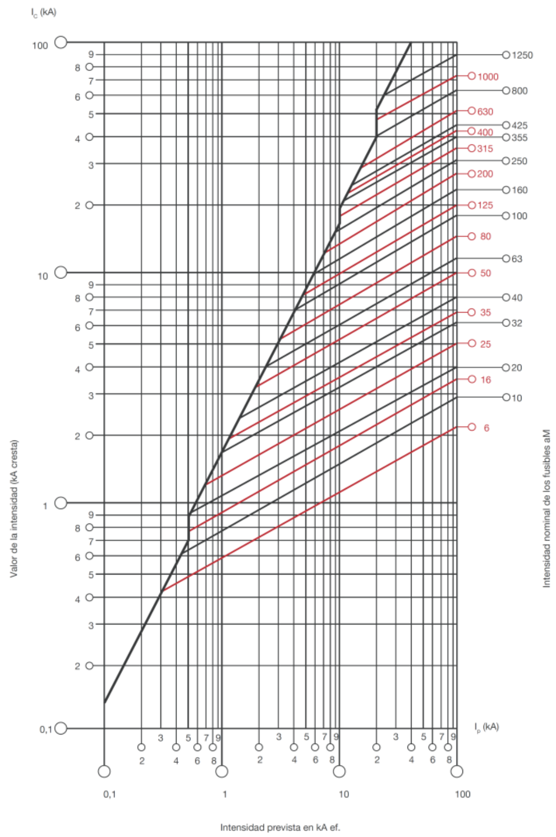


Figure 3. Time-current characteristics for NH family (Source: [5])

4.3.2. Current limiting curves

For current-limiting fuses, the manufacturers provide their current limiting curves. In these curves, the RMS symmetrical current is given in the x-axis, while the y-axis gives the Instantaneous peak let-thru current (I_L). Each curve has a number corresponding to the rated current (size) of the fuse; accessing with the RMS symmetrical current, the curves provide the peak value of the current limited by the device (I_L).





(a) (b)

Figure 4. (a) Short-circuit current waveforms with and without limiting fuse, (b) Time-current characteristics for NH family (Source: [5])

4.3.3. Fuse selectivity

The UNE norm provides different values to define, for each fuse size, two theoretical limit curves between which the real I/t curve of a fuse with that size should be placed [1]. To fulfill the regulation, the I/t characteristic of the fuse must be placed between the limit curves defined by the norm.

The selectivity condition implies that, given two fuses with different sizes, they will provide selectivity if their theoretical limit curves do not overlap. Figure 5 shows several families of fuses providing selectivity [6].

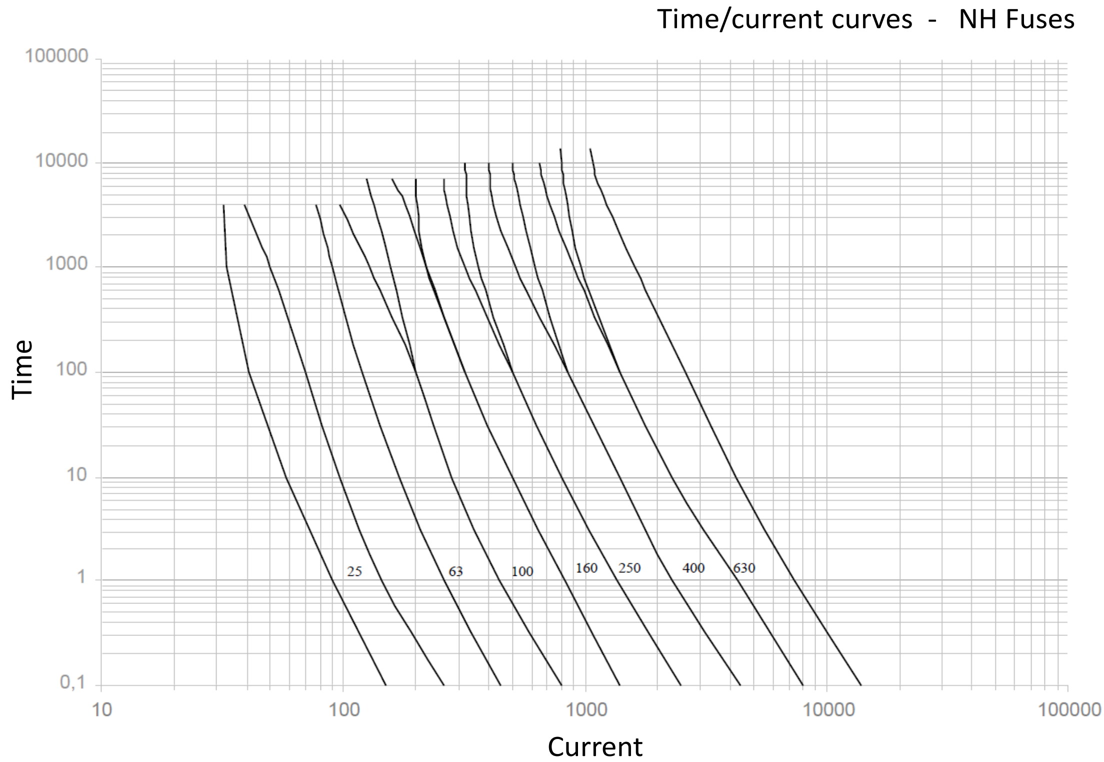


Figure 5. Curves of Fuses providing selectivity

4.4 Types of Fuses

According to IEC 60269, a possible classification of the L.V. fuses is the following one:

- **General Purpose fuses (type g)**: these fuses are intended to operate even with currents as low as those that cause it to blow in one hour. These are considered general-purpose fuses for protection of wires. So they are able to break, within a short time, all currents within a wide range (overload and short-circuit).
- **Time-delay fuses (type a)**: They are intended for short-circuit protection only; they have an intentional time-delay for overload currents; an associated device must provide overload protection. They withstand system switching surges, motor starting currents, and other harmless temporary overcurrents.

A second classification depends upon the type of protected element:

- **G**: protection of wires and cables
- **M**: protection of motors
- **R**: protection of semiconductors
- **Tr**: protection of transformers
- **PV**: Solar photovoltaic arrays
- …

The IEC 20269 norm designates the fuses with two letters; the first is in agreement of the first classification above (g or a), while the second letter is according to the second one (G, M, R, Tr, etc…)

4.5 Advantages/Drawbacks

Advantages:

- *Safety:* Overcurrent protective devices that have tripped are often reset without first investigating the cause of the fault. Electromechanical devices may not have the reserve capacity to open safely when a second or third fault occurs. When a fuse opens it is replaced with a new fuse, so the protection level is not degraded by previous faults.
- *Cost effective:* Fuses typically are the most cost effective means of providing overcurrent protection. This is especially true where high fault currents exist or where small components such as Control Transformers or DC power supplies need protection.
- *High interrupting rating:* With most low voltage current limiting fuses (< 600 volts) having a 200,000 amp interrupting rating, you are not paying a high premium for a high interrupting capacity.
- *Reliability:* Fuses have no moving parts to wear out or become contaminated by dust or oil.
- *Component protection:* The high current limiting action of a fuse minimizes or eliminates component damage.
- *Extended protection:* Devices with low interrupting ratings are often rendered obsolete by service upgrades or increases in available fault current. Updated NEC and UL standards are causing the need for potentially expensive system upgrades to non-fused systems.
- *Selectivity:* Fuses can be easily coordinated to provide selectivity under both overload and short circuit conditions.
- *Minimal maintenance:* Fuses do not require periodic recalibration as do some electromechanical overcurrent protective devices.
- *Long life:* As a fuse ages, the speed of response will not slow down or change. A fuse's ability to provide protection will not be adversely affected by the passing of time.

Drawbacks:

- *Protection against overload currents*: in some specific situations, it may be difficult to find a standardized fuse fulfilling the protection conditions against overloads.

- *False protection:* in maintenance operations, a fuse can be replaced by another one with higher size, obtaining a false protection
- *Phase overloading:* In three-phase systems, if only one phase melts, the machines can continue working overloading the rest of the phases.

5 Conclusions

This work constitutes a brief introduction to one of the most common elements in Low Voltage electric switchgear: the Fuse. The work explains the basic elements of a Fuse and its operation principles. Moreover, the basic quantities used for the specification of a Fuse are enumerated. The work describes the main characteristic curves of a Fuse, namely, the time-current characteristic and the current-limiting curves for fuses operating under this principle. The fuse typology is also analyzed in the paper. Finally, the main advantages and drawbacks of a fuse are described.

6 References

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