A client requires to justify the choice of the despatched fuses...

This file must help you to answer.

**selection of fuses for the protection of transformers**

**KEEP IN MIND**

Generally, it is sufficient to use the selection tables.

For case not covered by the standard selection tables, you must know characteristics of:

- the transformer,
- the breaking system,
- the fuses.

We will make an example with SM6 fuses.
Medium voltage fuses used in MV/LV substations are coordinated with the output rating of the transformer.

Their time/current characteristics are designed to protect medium voltage distribution systems from transformer faults and low voltage faults upstream of LV protection devices.

The fuses may be simply connected in series with the switch-disconnector or equipped with strikers in a fuse-switch combination to automatically open the switch when a fuse blows, thereby preventing continued operation on one or two remaining phases.

In a “transformer protection” cubicle, the fuse-switch combination can be replaced by a circuit breaker.

1 - RULES GOVERNING FUSE SELECTION

Generally, to select the right fuse, it is sufficient to use the SM6 fuse selection tables (see page 11).

The fuse rating is determined for an ambient temperature not exceeding 40 °C maximum or a mean daily value of 35 °C.

If these values are exceeded, over-rated fuses must be used to avoid unnecessary fuse-blowing due to these temperatures.

For cases not covered by the standard selection tables, the applicable fuse selection rules and criteria must be respected according to the type of load and the environment (fuse-switch combination).
2 - SOME DEFINITIONS

**SYSTEM CHARACTERISTICS**

Rated voltage $U_r$  
The highest phase-to-phase voltage (in kV) of the system on which the fuse is installed

Short-circuit current $I_k$  
The maximum current in the event of a three-phase short-circuit on the system

**TRANSFORMER CHARACTERISTICS:**

- output power “P” expressed in kVA,
- short-circuit voltage “$U_k$ %”,
- service voltage “$U_s$” in kV,
- operation with or without overload.

*We write:*

Rms value of the rated current “$I_{rt}$”

$$I_{rt} = \frac{P}{U_s \cdot \sqrt{3}}$$

Short-circuit voltage “$U_k$ (%)”  
The supply voltage for which the short-circuit current is equal to $I_{rt}$, expressed as a percentage of the rated voltage.

Short-circuit current “$I_k$”  
The current corresponding to a solid short-circuit across the terminals of the secondary winding of the transformer.

$$I_k = \frac{I_{rt} \times 100}{U_k \%}$$

Transformer inrush current “$I_e$”  
$I_e = \text{the peak transient current when the transformer is energised.}$

“$X$” = \frac{I_e}{I_{rt}}

Time constant “$t_0$”  
The time constant for the damping of the transient conditions that occur when the transformer is energised.
2 - SOME DEFINITIONS

(cont’d)

**FUSE CHARACTERISTICS:**

- **rated current** \( I_{rf} \)
  The current that the fuse can withstand continuously without abnormal heating.

- **minimum interrupting current** \( I_3 \)
  The minimum current that can blow and interrupt the fuse. \( I_3 \) is the lower limit of the current zone within which the fuse is capable of interrupting. The value of \( I_3 \) is generally between 3 and 6 \( I_{rf} \) (4.5 \( I_{rf} \) according to standard UTE 64-210).

  **Remark:** A medium voltage fuse can blow without interrupting the flow of current. This is always the case for current values less than \( I_3 \). The arc is sustained, destroying the fuse and its environment. Fuses therefore must never be exposed to currents in the zone between \( I_{rf} \) and \( I_3 \).

- **time/current characteristics of the selected range of fuses**
  Given in the supplier documentation (see example on page 12 for the Merlin Gerin Fusarc CF range).

- **short-circuit breaking capacity** \( I_1 \)
  This is the maximum prospective current that the fuse can interrupt. It is the maximum fuse test value. This current is very high, generally between 20 kA and 63 kA.

- **resistance of a cold fuse** \( R_{\text{cold}} \)
  Supplied by the fuse manufacturer.
3 - CRITERIA APPLICABLE TO THE SELECTION OF FUSES FOR THE PROTECTION OF TRANSFORMERS

RULES GOVERNING FUSE SELECTION MUST RESPECT:

The rated voltage of the fuse $U_{rf}$ (in kV) must be greater than or equal to the rated voltage of the system.

$$U_{rf} \geq U_r$$

It must be respect the operating voltage tolerances specified by the fuse manufacturer (an excessively high rated fuse voltage could result in high overvoltages on the system when the fuse blows).

The short-circuit breaking capacity $I_1$ (in kAmp) must be greater than or equal to the short-circuit current of the system $I_{k\text{system}}$.

$$I_1 \geq I_k$$

The fault current on the transformer secondary to be interrupted must be greater than or equal to $I_3$.

$$I_k \geq I_3$$

The resistance of a cold fuse must be multiplied by a coefficient that depends on the cubicle characteristics.

To account for the increase in the resistance of the fuse when heated and for the installation of fuses in SM6 cubicles (higher air temperature), the resistance of the cold fuse must be multiplied by a coefficient that depends on the cubicle characteristics (volume, etc.).

$$P = 1.9 \times R_{\text{cold}} \times I_{rf}^2$$

$R_{\text{cold}}$ = the resistance of a cold fuse.

1.9 = coefficient obtained from tests.

Maximum power for fuses in SM6 cubicles:
- 100 W if ambient temperature < 40 °C
- 80 W if ambient temperature 40 °C < $\theta$ < 55 °C

Operating conditions must be considered.

- **brief transformer overloads**

  To account for these brief overloads, the following coefficient is applied to the rated current of the transformer.

  $$I_{rf} \geq I_{rt}$$

- **continuous transformer overloads**

  If the transformer is required to operate with a continuous overload, i.e. for a period of several hours or more, the fuse rating must be greater than or equal to $1.3 \times I_{\text{overload}}$.

  We choose:

  $$I_{rf} \geq 1.3 \times I_{\text{overload}}$$
3 - CRITERIA APPLICABLE TO THE SELECTION OF FUSES FOR THE PROTECTION OF TRANSFORMERS (cont’d)

### transient inrush currents

The transients produced when a transformer is energised vary according to the moment the voltage is applied (with respect to zero voltage) and the remanent flux density of the magnetic circuit.

The asymmetry and the magnitude of the current are maximum when energisation occurs at zero voltage and the remanent flux density on the same phase is maximum.

Before selecting a fuse, it is therefore necessary to determine the rms value of the inrush current and its duration.

In practice, it is possible to use a simple rule that takes these requirements into account to avoid premature ageing of fuses.

This rule consists in checking, on the fuse time/current curve, that the maximum current that blows the fuse at time $T$, corresponding to the time constant of the transformer, is always greater than the transformer inrush current.

$$ I_{\text{min. fuse blow}} > X \times I_{\text{rt}} $$

- $X$ and $T$ are coming from the transformer supplier’s characteristics table.
- If the transient characteristics of the transformer are unknown, an empirical rule may be used. This consists in checking that the fuse-blowing current at 0.15 s is greater than $X \times I_{\text{rt}}$ where:
  - $X = 12$ for transformers with low kVA ratings.
  - $X = 10$ for transformer with rating greater than 1,000 kVA

**Example from France Transfo documentation:**

$T$ transformer time constant

$$ X = \frac{I_e}{I_{\text{rt}}} $$

and $U_k$ % of the transformer as a function of its output $P$ (kVA rating).

| $P$ (kVA) | 25 | 50 | 100 | 125 | 160 | 200 | 250 | 315 | 400 | 500 | 630 | 800 | 1,000 | 1,250 | 1,600 | 2,000 | 2,500 |
|-----------|----|----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-------|-------|-------|-------|-------|-------|
| $T$ (s)   | 0.1| 0.1| 0.15| 0.2 | 0.2 | 0.22| 0.22| 0.25| 0.25| 0.3 | 0.3 | 0.35 | 0.35  | 0.4   | 0.45  | 0.45  |
| $X$       | 15 | 14 | 14   | 12  | 12  | 12  | 12  | 12  | 12  | 11  | 11  | 10   | 9     | 8     | 8     |       |
| $U_k$ %   | 4  | 4  | 4    | 4   | 4   | 4   | 4   | 4   | 4   | 4   | 4   | 4    | 4     | 4     | 6     | 6     | 6     | 6     | 6     | 6     | 6     |
4 - FUSE CHARACTERISTICS IN ACCORDANCE WITH THE TYPE OF CUBICLE

FUSED SWITCH, WITH THE FUSE AND SWITCH CONNECTED IN SERIES AND OPERATING INDEPENDENTLY (EX. PM CUBICLE)

The switch interrupts its rated current under normal operating conditions (100 interruptions at a power factor of 0.7).

The fuses protect against short-circuits.

The fuses are not equipped with striker releases and the switch is therefore not opened automatically when a fuse blows.

FUSE-SWITCH COMBINATIONS (EX. QM, QMB, QMC CUBICLES)

The operation of the switch and the fuses is linked.

The fuses are equipped with strikers that open the switch when a fuse blows to prevent continued operation on the remaining one or two phases.

The switch is capable of interrupting a fault current. It can be actuated by opening releases in the event of internal transformer fault (DGPT relays, Buchholz relays, etc.) or by indirect relays supplied by the current transformers or toroids for overload protection (QMC cubicle). The fuse ratings must satisfy the requirements of standards IEC 60 282-1 and IEC 62271-105

Type of fuses: Fusarc CF or Solefuse with strikers or other brands.

“Medium” type striker: minimum energy for fuse-blown tripping = 0.5 Joules.

The selection of fuses for fuse-switch combination units depends on the transition current $I_{40}$ and the short-circuit current seen from the primary.

Standard IEC 62 271-105 defines the conditions that ensure coordinated performance of the fuses and the switches used in combination units.

The transition current of the combination unit depends both on the time/current characteristics of the fuses and on the opening time of the switch.

Switch opening is initiated by the fuses near the transition point of a 3-phase fault. The fastest fuse blows, thereby interrupting one of the phases, and its striker commands the opening of the switch.

The two remaining phases are then faced with a lower current (87%) which will be interrupted either by the switch or by the remaining two fuses. The transition point is where the switch opens at the same time as the remaining two fuses blow. At this point, the switch takes over from the fuses, thereby defining the minimum breaking capacity required for the switch.
4 - FUSE CHARACTERISTICS IN ACCORDANCE WITH THE TYPE OF CUBICLE (cont’d)

From a practical standpoint, the transition current is determined by the plotting a time equal to 0.9 times the switch opening time by the fuses on the minimum time/current characteristic curve of the fuse (i.e. using a current tolerance of - 6.5 %).

The current corresponding to this point is the value of the 3-phase transition current ($I_{40}$)

This current must not be greater than the rated transition current, which is the current specified by the manufacturer of the combination unit and checked by series TD $I_{\text{transfer}}$ tests.

$$I_{40} < I_{\text{transfer}}$$

The rated transition current ($I_{\text{transfer}}$) corresponds to the breaking capacity of the switch (see page 9).

VARIOUS CURRENTS ARE DISPACHED BETWEEN EACH ITEMS OF THE SYSTEM:

Remark: all the currents are expressed as rms values except for the current $I_p$, which is expressed as a peak value.
4 - FUSE CHARACTERISTICS IN ACCORDANCE WITH THE TYPE OF CUBICLE (cont’d)

**BREAKING CAPACITY OF THE SM6 SWITCH AS A FUNCTION OF THE SERVICE VOLTAGE** (under transition current conditions).

\[ I_{\text{transfer}} = \text{breaking capacity} \]

**TRANSITION CURRENT OF THE FUSE-SWITCH COMBINATION** \(I_{40}\)

The transition current of the fuse-switch combination must be lower than the fault current observed on the primary during a solid short-circuit across the secondary terminals of a transformer.

A solid short-circuit across the secondary terminals of a transformer leads to high values of the TRV (Transient Recovery Voltage) which the switch may not be able to handle. Consequently the selected fuse must be able to clear such a fault by itself, without making use of the switch.

In practice, this condition makes it necessary to check that the transition current of the switch-fuse combination, calculated as indicated in paragraph 8.102-3 of IEC 62 271-105, is less than the current observed on the primary.

\[ I_{40} < I_k \]
5 - APPLICATION EXAMPLES

**LET US CHECK THAT THE FUSE 31.5 AMPS IS SITTING 20 KV/630 KVAMPS TRANSFORMER PROTECTION**

- determination of the transformer characteristics

  \[ l_f = 18 \text{ Amps} \quad l_e = 198 \text{ Amps} \quad l_k = 450 \text{ Amps} \]

- determination of the fuse characteristics

  \[ l_f > 1.4 l_t \text{ (see p. 5) so } l_f > 18 \times 1.4 = 25.2 \text{ Amps; the selected fuse is 31.5 Amps} \]

  On page 6, we find that for a 630 kVA transformer, \( T = 0.3 \text{ s} \)

  On the curve (see page 12), for 0.3 s and a 31.5 Amps fuse, we find \( I_z < 160 \text{ Amps < } l_e \), this fuse is not acceptable.

  So, we try with \( l_f = 40 \text{ Amps} \); \( I_z > 210 \text{ Amps > } l_e \), the 40 Amps fuse is OK.

  We find \( I_{40} \) on the curve page 12 for a time value of the SM6 0.036 s (0.9 time the opening time of the fuse; 0.04 for SM6; 0.06 for RM6).

  \[ I_{40} = 360 \text{ Amps} \quad I_3 = 135 \text{ Amps} \quad l_1 = 40 \text{ kA} \]
5 - APPLICATION EXAMPLES (cont’d)

These values meet the previous requirement.

Selection of fuses for the protection of transformers

Selection table for the SM6
Rating in A, no overload – 5 °C < \( \theta < 40 ^{\circ} C \)
Please consult us for overloads and operation over 40 °C.

<table>
<thead>
<tr>
<th>type of fuse</th>
<th>operating voltage (kV)</th>
<th>transformer output rating (kVA)</th>
<th>rated voltage (kV)</th>
</tr>
</thead>
<tbody>
<tr>
<td>UTE NFC standards: 13.100, 64.210</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Solefus</td>
<td>25 50 100 125 160 200 250 315 400 500 630 800 1,000 1,250 1,600 2,000 2,500</td>
<td></td>
<td></td>
</tr>
<tr>
<td>5.5</td>
<td>6.3</td>
<td>10 16 31.5</td>
<td>31.5</td>
</tr>
<tr>
<td>10</td>
<td>6.3</td>
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<td>15</td>
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<td>6.3</td>
<td>31.5</td>
<td>31.5</td>
</tr>
<tr>
<td>general case, UTE NFC standard: 13.200</td>
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<td></td>
<td></td>
</tr>
<tr>
<td>Solefus</td>
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<td>16</td>
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<td>13.8</td>
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<tr>
<td>22</td>
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<td>31.5</td>
</tr>
<tr>
<td>Fusarc CF</td>
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<td>6.3</td>
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<tr>
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<td>10</td>
<td>16</td>
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<tr>
<td>22</td>
<td>6.3</td>
<td>10</td>
<td>25</td>
</tr>
</tbody>
</table>

We find page 8 of the technical leaflet AC0479 about fuse for \( I_{rt} = 40 \text{ Amps} \) and \( L = 442 \text{ mm} \)}

\[ I_{b} = X \cdot I_{rt} \]

\( X = 11 \) (see page 6)

\[ I_{rt} \cdot \frac{100}{4} \]

See fuse documentation

in bold characters fuses from SIBA
Selection of fuses for the protection of transformers

5 - APPLICATION EXAMPLES (cont’d)

Time/current characteristics of a fuse from the Fusarc CF range (Merlin Gerin)

These curves are an average. The current accuracy is ± 10%
6 - IDENTIFICATION PLATE

**FUSE RATING PLATE ON THE FRONT OF THE CUBICLE (QM)**

In accordance with standard IEC 62271-105, the front plate of the cubicle indicates that the use of the fuses at a permanent service current must be in accordance with the reference list.

- **fuses**
  - see reference list
  - IEC 62271-105 :2002
  - 04 03 006 u
  - fixed indications
  - serial indication

**Remark:** if a customer does not use the fuses specified by the reference list, he must ensure with the technical department that the fuses installed are compatible with the requirements of IEC 62271-105, the performance of the SM6 switch and the cubicle environment (heat dissipation).

7 - SAFETY PRECAUTIONS

**SAFETY PRECAUTIONS FOR ON-SITE FUSE REPLACEMENT**

When a fault occurs downstream of the switch, one or two fuses generally “blow”, the other(s) remaining intact.

The characteristics of the remaining fuse or fuses are modified by the fault since they have been exposed to a current that may have been high enough to damage the fuse elements without actually blowing the fuse (the active part of a fuse is made up of a number of parallel elements).

It is therefore necessary, in the event of a downstream fault cleared by the protection cubicle, to change all three fuses and dispose of them immediately to avoid all possibility of subsequent use.

**IF YOU HAVE ANY TROUBLE...**

Please contact the MV Technical Department.
8 - BIBLIOGRAPHY

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  Current-limiting fuses.

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