IEC 62271-100 and ANSI C37-04, C37-06, C37-09 define on one hand the operating conditions, the rated characteristics, the design and the manufacture; and on the other hand the testing, the selection of controls and installation.

## Introduction

The circuit breaker is a device that ensures the control and protection on a network. It is capable of making, withstanding and interrupting operating currents as well as short-circuit currents.

The main circuit must be able to withstand without damage:
- The thermal stress caused by the short-circuit current during 1 or 3 s
- The electrodynamic stress caused by the peak of short-circuit current:
  - $2.5 \cdot I_{sc}$ for 50 Hz (standard time constant of 45 ms)
  - $2.6 \cdot I_{sc}$ for 60 Hz (standard time constant of 45 ms)
  - $2.7 \cdot I_{sc}$ (for longer time constant)
- The constant load current.

Since a circuit breaker is mostly in the "closed" position, the load current must pass through it without the temperature running away throughout the equipment’s life.
Switchgear definition

Medium voltage circuit breaker

Characteristics

Compulsory rated characteristics (cf § 4 IEC 62271-100)

a) Rated voltage
b) Rated insulation level
c) Rated frequency
d) Rated normal current
e) Rated short-time withstand current
f) Rated peak withstand current
g) Rated duration of short-circuit
h) Rated supply voltage of closing and opening devices
i) Rated supply frequency of closing and opening devices
j) Rated pressures of compressed gas supply and/or of hydraulic supply
   for operation, interruption and insulation, as applicable
k) Rated short-circuit breaking current
l) Transient recovery voltage related to the rated short-circuit breaking
   current
m) Rated short-circuit making current
n) Rated operating sequence
o) Rated time quantities.

Special rated characteristics

Rated characteristics to be given in the specific cases indicated below

p) Characteristics for short-line faults related to the rated short-circuit
   breaking current, for circuit breakers designed for direct connection to
   overhead lines, irrespective of the type of network on the source side,
   and rated at 15 kV and above and at more than 12.5 kA rated short-circuit
   breaking current
q) Rated line-charging breaking current, for three-pole circuit breakers
   intended for switching overhead transmission lines (mandatory for circuit
   breakers of rated voltages equal to or greater than 72.5 kV).
r) Rated cable-charging breaking current, for three-pole circuit breakers
   intended for switching cables (mandatory for circuit breakers of rated
   voltages equal to or less than 52 kV).

Rated characteristics to be given on request

s) Rated out-of-phase making and breaking current
t) Rated single capacitor bank breaking current
u) Rated back-to-back capacitor bank breaking current
v) Rated capacitor bank inrush making current
w) Rated back-to-back capacitor bank inrush making current.

The rated characteristics of the circuit breaker are referred to the rated
operating sequence.

Rated voltage (cf. § 4.1 IEC 62271-1)

The rated voltage is the maximum rms value of the voltage that
the equipment can withstand in normal service. It is always greater than
the operating voltage.

- Standardised values for $U_r$ (kV) : 3.6 - 7.2 -12 - 17.5 - 24 - 36 kV.
Rated insulation level (cf. § 4.2 IEC 62271-1)
- The insulation level is characterised by two values:
  - the lightning impulse wave (1.2/50 µs) withstand voltage
  - the power frequency withstand voltage for 1 minute.

<table>
<thead>
<tr>
<th>Rated voltage</th>
<th>Impulse withstand voltage</th>
<th>Power frequency withstand voltage</th>
</tr>
</thead>
<tbody>
<tr>
<td>(Ur in kV)</td>
<td>(Up in kV)</td>
<td>(Ud in kV)</td>
</tr>
<tr>
<td>7.2</td>
<td>60</td>
<td>20</td>
</tr>
<tr>
<td>12</td>
<td>75</td>
<td>28</td>
</tr>
<tr>
<td>17.5</td>
<td>95</td>
<td>38</td>
</tr>
<tr>
<td>24</td>
<td>125</td>
<td>50</td>
</tr>
<tr>
<td>36</td>
<td>170</td>
<td>70</td>
</tr>
</tbody>
</table>

Rated normal current (cf. § 4.4 IEC 62271-1)
With the circuit breaker always closed, the load current must pass through it in compliance with a maximum temperature value as a function of the materials and the type of connections.
IEC sets the maximum permissible temperature rise of various materials used for an ambient air temperature not exceeding 40°C (cf. § 4.4.2 table 3 IEC 62271-1).

Rated short-time withstand current (cf. § 4.5 IEC 62271-1)

\[
I_{sc} = \frac{S_{sc}}{\sqrt{3} \cdot U}
\]

- **Ssc** Short-circuit power in MVA
- **U** Operating voltage in kV
- **Isc** Short-circuit current in kA

This is the standardised rms value of the maximum permissible short-circuit current on a network for the rated duration of short-circuit.

- Values of rated breaking current under maximum short-circuit (kA):
  - 6.3 - 8 - 10 - 12.5 - 16 - 20 - 25 - 31.5 - 40 - 50 - 63 kA.

Rated peak withstand current (cf. § 4.6 IEC 62271-1) and making current (cf. § 4.103 IEC 62271-100)
The making current is the maximum value that a circuit breaker is capable of making and maintaining on an installation in short-circuit. It must be greater than or equal to the rated short-time withstand peak current.

- \( I_{sc} \) is the maximum value of the rated short-circuit current for the circuit breakers’ rated voltage. The peak value of the short-time withstand current is equal to:
  - 2.5 \( I_{sc} \) for 50 Hz
  - 2.6 \( I_{sc} \) for 60 Hz
  - 2.7 \( I_{sc} \) for special time constants greater than 45 ms.

Rated short-circuit duration (cf. § 4.7 IEC 62271-1)
The standard value of rated duration of short-circuit is 1 s. Other recommended values are 0.5 s, 2 s and 3 s.
Switchgear definition

Medium voltage circuit breaker

**Rated supply voltage for closing and opening devices and auxiliary circuits** (cf. § 4.8 IEC 62271-1)

- Values of supply voltage for auxiliary circuits:
  - for direct current (dc): 24 - 48 - 60 - 110 or 125 - 220 or 250 volts,
  - for alternating current (ac): 120 - 230 volts.
- The operating voltages must lie within the following ranges (cf. § 5.6.4 and 5.8 of IEC 62271-1):
  - motor and closing release units:
    - 85% to 110% of \( U_r \) in dc and ac
  - opening release units:
    - 70% to 110% of \( U_r \) in dc
    - 85% to 110% of \( U_r \) in ac
  - undervoltage opening release unit:

<table>
<thead>
<tr>
<th>Voltage Range</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>DC</td>
<td>24 - 48 - 60 - 110 - 125 - 220 - 250 volts</td>
</tr>
<tr>
<td>AC</td>
<td>120 - 230 volts</td>
</tr>
</tbody>
</table>

The release unit gives the command and forbids closing (at 85%, the release unit must enable the device to close)

<table>
<thead>
<tr>
<th>DC</th>
<th>0% - 35% - 70% - 100%</th>
</tr>
</thead>
<tbody>
<tr>
<td>AC</td>
<td>0% - 35% - 70% - 100%</td>
</tr>
</tbody>
</table>

**Rated frequency** (cf. § 4.3 and 4.9 IEC 62271-1)

Two frequencies are currently used throughout the world: 50 Hz in Europe and 60 Hz in America, a few countries use both frequencies. The rated frequency is either 50 Hz or 60 Hz.

**Rated operating sequence** (cf. § 4.104 IEC 62271-100)

- Rated switching sequence according to IEC, O - t - CO - t' - CO.
  (cf. opposite diagram)

<table>
<thead>
<tr>
<th>Sequence</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>O</td>
<td>Represents opening operation</td>
</tr>
<tr>
<td>CO</td>
<td>Represents closing operation followed immediately by an opening operation</td>
</tr>
</tbody>
</table>

- Three rated operating sequences exist:
  - slow: O - 3 min - CO - 3 min - CO
  - fast 1: O - 0.3 s - CO - 3 min - CO
  - fast 2: O - 0.3 s - CO - 15 s - CO

**N.B.:** other sequences can be requested.

**Close/Open cycle**

Assumption: O order as soon as the circuit breaker is closed.
Switchgear definition

Medium voltage circuit breaker

- **Automatic reclosing cycle**
  Assumption: C order as soon as the circuit breaker is open, (with time delay to achieve 0.3 s or 15 s or 3 min).

![Diagram](https://example.com/diagram.png)

---

**Rated short-circuit breaking current**
(cf. § 4.101 IEC 62271-100)

The rated short-circuit breaking current is the highest value of current that the circuit breaker must be capable of breaking at its rated voltage.

- **It is characterised by two values:**
  - the rms value of its periodic component, given by the term: “rated short-circuit breaking current”
  - the percentage of the aperiodic component corresponding to the circuit breaker’s opening time, to which we add a half-period of the rated frequency.

- The half-period corresponds to the minimum activation time of an overcurrent protection device, this being 10 ms at 50 Hz.

According to IEC, the circuit breaker must break the rms value of the periodic component of the short-circuit (= its rated breaking current) with the percentage of asymmetry defined by the graphs below.

**Percentage of the aperiodic component (%)**
as a function of the time interval (t)

<table>
<thead>
<tr>
<th>%DC (%)</th>
<th>t (ms)</th>
</tr>
</thead>
<tbody>
<tr>
<td>100</td>
<td>0</td>
</tr>
<tr>
<td>90</td>
<td>10</td>
</tr>
<tr>
<td>80</td>
<td>20</td>
</tr>
<tr>
<td>70</td>
<td>30</td>
</tr>
<tr>
<td>60</td>
<td>40</td>
</tr>
<tr>
<td>50</td>
<td>50</td>
</tr>
<tr>
<td>40</td>
<td>60</td>
</tr>
<tr>
<td>30</td>
<td>70</td>
</tr>
<tr>
<td>20</td>
<td>80</td>
</tr>
<tr>
<td>10</td>
<td>90</td>
</tr>
</tbody>
</table>

**Example 1:**
- For a circuit breaker with a minimum opening time of 45 ms (\(T_{op}\)) to which we add 10 ms (\(T_r\)) due to relaying, the graph gives a percentage of the aperiodic component of around 30% for a time constant \(\tau_1 = 45\) ms:

\[
\%_{DC} = e^{\frac{-t}{45}} = 29.5\%
\]

**Example 2:**
- Supposing that \(\%_{DC}\) of a MV circuit breaker is equal to 65% and that the symmetric short-circuit current that is calculated \(I_{sym}\) is equal to 27 kA.

**What does \(I_{sym}\) equal?**

\[
I_{sym} = I_{sym} \sqrt{1 + 2 \left(\frac{\%_{DC}}{100}\right)^2} \text{ [A]}
\]

\[
= 27 \text{kA} \sqrt{1 + 2 \left(0.65\right)^2}
\]

\[
= 36.7 \text{kA}
\]

- Using the equation [A], this is equivalent to a symmetric short-circuit current at a rating of:

\[
\frac{36.7 \text{kA}}{1.086} = 33.8 \text{kA} \text{ for a } \%_{DC} \text{ of 30%}.
\]

- The circuit breaker rating is greater than 33.8 kA. According to the IEC, the nearest standard rating is 40 kA.

- As standard the IEC defines MV equipment for a time constant of 45 ms, for a peak value of maximum current equal to 2.5 \(I_{sc}\) at 50 Hz or 2.6 \(I_{sc}\) at 60 Hz. In this case use the \(\tau_1\) graph.
For low resistive circuits such as generator incomers, $\tau$ can be higher, with a peak value of maximum current equal to $2.7 \cdot I_{sc}$.

In this case use the $\tau_4$ graph. For all time constants $\tau$ between $\tau_1$ and $\tau_4$, use the equation:

$$\%_{DC} = 100 \cdot e^{-\frac{(T_{op} + T_r)}{\tau_{1, \ldots, 4}}}$$

Values of rated short-circuit breaking current:
6.3 - 8 - 10 - 12.5 - 16 - 20 - 25 - 31.5 - 40 - 50 - 63 kA.

Short-circuit breaking tests must meet the five following test sequences:

<table>
<thead>
<tr>
<th>Sequence</th>
<th>$% I_{sym}$</th>
<th>$%$ aperiodic component</th>
<th>$%_{DC}$</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>10</td>
<td>≤ 20</td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>20</td>
<td>≤ 20</td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>60</td>
<td>≤ 20</td>
<td></td>
</tr>
<tr>
<td>4</td>
<td>100</td>
<td>≤ 20</td>
<td></td>
</tr>
<tr>
<td>5*</td>
<td>100</td>
<td>According to equation</td>
<td></td>
</tr>
</tbody>
</table>

*For circuit breakers opening in less than 80 ms.

% Symmetric short-circuit current (in kA):

$$I_{sym} = \frac{I_{AC}}{\sqrt{2}}$$

% Asymmetric short-circuit current (in kA):

$$I_{asym}^2 = I_{sym}^2 \cdot I_{DC}^2$$

$$I_{asym} = I_{sym} \sqrt{1 + 2 \left(\frac{\%_{DC}}{100}\right)^2}$$

Rated Transient Recovery Voltage (TRV)
(cf. § 4.102 IEC 62271-100)

This is the voltage that appears across the terminals of a circuit breaker pole after the current has been interrupted. The recovery voltage wave form varies according to the real circuit configuration. A circuit breaker must be able to break a given current for all transient recovery voltages whose value remains below the rated TRV.

First pole-to-clear factor

For three-phase circuits, the TRV refers to the pole that breaks the circuit initially, in other words the voltage across the terminals of the first open pole. The ratio of this voltage to a single phase circuit voltage is called the first pole-to-clear factor, it is equal to 1.5 for voltages up to 72.5 kV (isolated neutral of the supply circuit).
Switchgear definition

Medium voltage circuit breaker

- Value of rated TRV for class S1 circuit breaker (intended to be used in cable systems)
  - the TRV is a function of the asymmetry, it is given for an asymmetry of 0%.

<table>
<thead>
<tr>
<th>Rated voltage (Ur in kV)</th>
<th>TRV peak value (Uc in kV)</th>
<th>Time (t3 in µs)</th>
<th>Delay (td in µs)</th>
<th>Rate of rise of TRV (Uc/t3 in kV/µs)</th>
</tr>
</thead>
<tbody>
<tr>
<td>7.2</td>
<td>12.3</td>
<td>51</td>
<td>8</td>
<td>0.24</td>
</tr>
<tr>
<td>12</td>
<td>20.6</td>
<td>61</td>
<td>9</td>
<td>0.34</td>
</tr>
<tr>
<td>17.5</td>
<td>30</td>
<td>71</td>
<td>11</td>
<td>0.42</td>
</tr>
<tr>
<td>24</td>
<td>41.2</td>
<td>87</td>
<td>13</td>
<td>0.47</td>
</tr>
<tr>
<td>36</td>
<td>61.7</td>
<td>109</td>
<td>16</td>
<td>0.57</td>
</tr>
</tbody>
</table>

\[ U_C = 1.4 \times 1.5 \times \sqrt[3]{2} \times U_r = 1.715 U_r \]

\[ t_d = 0.15 t_3 \]

- a specified TRV is represented by a reference plot with two parameters and by a segment of straight line defining a time delay.

<table>
<thead>
<tr>
<th>td</th>
<th>Time delay</th>
</tr>
</thead>
<tbody>
<tr>
<td>t3</td>
<td>Time defined to reach Uc</td>
</tr>
<tr>
<td>Uc</td>
<td>Peak TRV voltage in kV</td>
</tr>
<tr>
<td>TRV rate of rise</td>
<td>Uc/t3 in kV/µs</td>
</tr>
</tbody>
</table>

Rated out-of-phase breaking current
(cf. § 4.106 IEC 62271-100)

When a circuit breaker is open and the conductors are not synchronous, the voltage across the terminals can increase up to the sum of voltages in the conductors (phase opposition).

- In practice, standards require the circuit breaker to break a current equal to 25% of the fault current across the terminals, at a voltage equal to twice the voltage relative to earth.

- If Ur is the rated circuit breaker voltage, the power frequency recovery voltage is equal to:
  - 2 / \sqrt{3} Ur for networks with an effectively earthed neutral system
  - 2.5 / \sqrt{3} Ur for other networks.

- Peak value of TRV for class S1 circuit breaker, for networks other than those with effectively earthed neutral system:

\[ U_C = 1.25 \times 2.5 \times \sqrt[3]{2} \times U_r \]

<table>
<thead>
<tr>
<th>Rated voltage (Ur in kV)</th>
<th>TRV value (Uc in kV)</th>
<th>Time (t3 in µs)</th>
<th>Rate of increase (Uc/t3 in kV/µs)</th>
</tr>
</thead>
<tbody>
<tr>
<td>7.2</td>
<td>18.4</td>
<td>102</td>
<td>0.18</td>
</tr>
<tr>
<td>12</td>
<td>30.6</td>
<td>122</td>
<td>0.25</td>
</tr>
<tr>
<td>17.5</td>
<td>44.7</td>
<td>142</td>
<td>0.31</td>
</tr>
<tr>
<td>24</td>
<td>61.2</td>
<td>174</td>
<td>0.35</td>
</tr>
<tr>
<td>36</td>
<td>91.9</td>
<td>218</td>
<td>0.42</td>
</tr>
</tbody>
</table>
Switchgear definition

Medium voltage circuit breaker

Rated cable-charging breaking current
(cf. § 4.107 IEC 62271-100)

The specification of a rated breaking current for a circuit breaker switching unloaded cables is mandatory for circuit breakers of rated voltage lower than 52 kV.

- Normal rated breaking current values for a circuit breaker switching unloaded cables:

<table>
<thead>
<tr>
<th>Rated voltage (U_r in kV)</th>
<th>Rated breaking current for no-load cables (I_c in kA)</th>
</tr>
</thead>
<tbody>
<tr>
<td>7.2</td>
<td>10</td>
</tr>
<tr>
<td>12</td>
<td>25</td>
</tr>
<tr>
<td>17.5</td>
<td>31.5</td>
</tr>
<tr>
<td>24</td>
<td>31.5</td>
</tr>
<tr>
<td>36</td>
<td>50</td>
</tr>
</tbody>
</table>

Rated line-charging breaking current
(cf. § 4.107 IEC 62271-100)

The specification of a rated breaking current for a circuit breaker intended for switching unloaded overhead lines is mandatory for circuit breakers of rated voltage ≥ 72.5 kV.

Rated single capacitor bank breaking current
(cf. § 4.107 IEC 62271-100)

The specification of a capacitor bank breaking current for a circuit breaker is not compulsory. Due to the presence of harmonics, the breaking current for capacitors is lower or equal to 0.7 times the device’s rated current.

<table>
<thead>
<tr>
<th>Rated current (A)</th>
<th>Breaking current for capacitors (max) (A)</th>
</tr>
</thead>
<tbody>
<tr>
<td>400</td>
<td>280</td>
</tr>
<tr>
<td>630</td>
<td>440</td>
</tr>
<tr>
<td>1250</td>
<td>875</td>
</tr>
<tr>
<td>2500</td>
<td>1750</td>
</tr>
<tr>
<td>3150</td>
<td>2200</td>
</tr>
</tbody>
</table>

- Two classes of circuit breakers are defined according to their restrike performances:
  - class C1: low probability of restrike during capacitive current breaking
  - class C2: very low probability of restrike during capacitive current breaking.

Rated back-to-back capacitor bank breaking current
(cf. § 4.107 IEC 62271-100)

The specification of a breaking current for multi-stage capacitor banks is not compulsory.
Switchgear definition

Medium voltage circuit breaker

Rated capacitor bank inrush making current
(cf. § 4.107 IEC 62271-100)

The rated making current for capacitor banks is the peak current value that the circuit breaker must be capable of making at the rated voltage. The value of the circuit breaker's rated making current must be greater than the inrush current for the capacitor bank. Formulas for calculation of inrush currents for single and back-to-back capacitor banks can be found in Annex H of IEC 62271-100. Typically the values of peak current and frequency for inrush currents are in the order of a few kA and some 100 Hz for single capacitor banks, and in the order of a few 10 kA and some 100 kHz for back-to-back capacitor banks.

Switching of small inductive current
(no rating assigned, cf. § 4.108 IEC 62271-100 and IEC 62271-110)

The breaking of low inductive currents (several amperes to several hundreds of amperes) may cause overvoltages. Surge protection should be applied in some cases according to the type of circuit breaker in order to ensure that the overvoltages do not damage the insulation of the inductive loads (unloaded transformers, motors).

The figure shows the various voltages on the load side

- \( u_0 \) - Power frequency voltage crest value to earth
- \( u_x \) - Neutral voltage shift at first-pole interruption
- \( u_a \) - Circuit breaker arc voltage drop
- \( u_{in} = u_0 + u_a + u_c \) - Initial voltage at the moment of current chopping
- \( u_{ma} \) - Suppression peak voltage to earth
- \( u_{mr} \) - Load side voltage peak to earth
- \( u_w \) - Voltage across the circuit breaker at re-ignition
- \( u_p \) - Maximum overvoltage to earth (could be equal to \( u_{ma} \) or \( u_{mr} \) if no re-ignitions occur)
- \( u_s \) - Maximum peak-to-peak overvoltage excursion at re-ignition
Insulation level of motors

IEC 60034 stipulates the insulation level of motors.

Power frequency and impulse withstand testing is given in the table below (rated insulation levels for rotary sets).

<table>
<thead>
<tr>
<th>Insulation</th>
<th>Test at 50 (60) Hz rms value</th>
<th>Impulse test</th>
</tr>
</thead>
<tbody>
<tr>
<td>Between turns</td>
<td>(4 ( U_r ) + 5) kV</td>
<td>4.9 pu + 5 = 31 kV at 6.6 kV</td>
</tr>
<tr>
<td></td>
<td></td>
<td>(50% on the sample)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>front time 0.5 µs</td>
</tr>
<tr>
<td>Relative to earth</td>
<td>(2 ( U_r ) + 1) kV</td>
<td>4.9 pu + 5 = 31 kV at 6.6 kV</td>
</tr>
<tr>
<td></td>
<td>2( U_r ) + 1 ( \Rightarrow 2(2( U_r ) + 1) \Rightarrow 0</td>
<td></td>
</tr>
<tr>
<td></td>
<td>14 kV ( \Rightarrow 28 kV \Rightarrow 0</td>
<td></td>
</tr>
</tbody>
</table>

Normal operating conditions (cf. § 2 IEC 62271-1)

For all equipment functioning under more severe conditions than those described below, derating should be applied (see derating chapter).

Equipment is designed for normal operation under the following conditions:

- **Temperature**
  - °C Installation
    - Instantaneous ambient
      - Indoor: –5°C
      - Outdoor: –25°C
    - Maximal
      - Indoor: +40°C
      - Outdoor: +40°C

- **Humidity**
  - Average relative humidity for a period (max value)
    - Indoor equipment
      - 24 hours: 95%
      - 1 month: 90%

- **Altitude**
  - The altitude does not exceed 1000 metres.

**Electrical endurance**

Two classes are defined (cf. § 3.4 IEC 62271-100):
- Class E1 with basic electrical endurance
- Class E2 with extended electrical endurance, for circuit breakers which do not require maintenance of the interrupting parts of the main circuit during their expected operating life. Schneider Electric circuit breakers are tested according to class E2.

**Mechanical endurance**

Two classes are defined (cf. § 3.4 IEC 62271-100):
- Class M1 with normal mechanical endurance (2000 operations)
- Class M2 with extended mechanical endurance (10 000 operations). Schneider Electric circuit breakers are tested according to class M2.