

Short-circuit currents in three-phase a.c. systems

Part 0: Calculation of currents

The European Standard EN 60909-0:2001 has the status of a British Standard

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National foreword

This British Standard is the official English language version of EN 60909-0:2001. It is identical with IEC 60909-0:2001, including Corrigendum February 2002. It supersedes BS 7639:1993 which will be withdrawn on 2004-07-01.

The UK participation in its preparation was entrusted to Technical Committee PEL/73, Short circuit currents, which has the responsibility to:

- aid enquirers to understand the text;
- present to the responsible international/European committee any enquiries on the interpretation, or proposals for change, and keep the UK interests informed;
- monitor related international and European developments and promulgate them in the UK.

A list of organizations represented on this committee can be obtained on request to its secretary.

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Short-circuit currents in three-phase a.c. systems
Part 0: Calculation of currents
(IEC 60909-0:2001)

Courants de court-circuit dans les réseaux
triphasés à courant alternatif
Partie 0: Calcul des courants
(CEI 60909-0:2001)

Kurzschlussströme in Drehstromnetzen
Teil 0: Berechnung der Ströme
(IEC 60909-0:2001)

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European Committee for Electrotechnical Standardization
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Foreword

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- latest date by which the EN has to be implemented
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with the EN have to be withdrawn (dow) 2004-07-01

Annexes designated "normative" are part of the body of the standard.
In this standard, annexes A and ZA are normative.
Annex ZA has been added by CENELEC.

Endorsement notice

The text of the International Standard IEC 60909-0:2001 was approved by CENELEC as a European Standard without any modification.

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SHORT-CIRCUIT CURRENTS IN THREE-PHASE AC SYSTEMS –

Part 0: Calculation of currents

1 General

1.1 Scope

This part of IEC 60909 is applicable to the calculation of short-circuit currents:

- in low-voltage three-phase a.c. systems
- in high-voltage three-phase a.c. systems

operating at a nominal frequency of 50 Hz or 60 Hz.

Systems at highest voltages of 550 kV and above with long transmission lines need special consideration.

This part of IEC 60909 establishes a general, practicable and concise procedure leading to results, which are generally of acceptable accuracy. For this calculation method, an equivalent voltage source at the short-circuit location is introduced. This does not exclude the use of special methods, for example the superposition method, adjusted to particular circumstances, if they give at least the same precision. The superposition method gives the short-circuit current related to the one load flow presupposed. This method, therefore, does not necessarily lead to the maximum short-circuit current.

This part of IEC 60909 deals with the calculation of short-circuit currents in the case of balanced or unbalanced short circuits.

In case of an accidental or intentional conductive path between one line conductor and local earth, the following two cases must be clearly distinguished with regard to their different physical properties and effects (resulting in different requirements for their calculation):

- line-to-earth short circuit, occurring in a solidly earthed neutral system or an impedance earthed neutral system;
- a single line-to-earth fault, occurring in an isolated neutral earthed system or a resonance earthed neutral system. This fault is beyond the scope of, and is therefore not dealt with in, this standard.

For currents during two separate simultaneous single-phase line-to-earth short circuits in an isolated neutral system or a resonance earthed neutral system, see IEC 60909-3.

Short-circuit currents and short-circuit impedances may also be determined by system tests, by measurement on a network analyzer, or with a digital computer. In existing low-voltage systems it is possible to determine the short-circuit impedance on the basis of measurements at the location of the prospective short circuit considered.

The calculation of the short-circuit impedance is in general based on the rated data of the electrical equipment and the topological arrangement of the system and has the advantage of being possible both for existing systems and for systems at the planning stage.

In general, two short-circuit currents, which differ in their magnitude, are to be calculated:

- the maximum short-circuit current which determines the capacity or rating of electrical equipment; and
- the minimum short-circuit current which can be a basis, for example, for the selection of fuses, for the setting of protective devices, and for checking the run-up of motors.

NOTE The current in a three-phase short circuit is assumed to be made simultaneously in all poles. Investigations of non-simultaneous short circuits, which may lead to higher aperiodic components of short-circuit current, are beyond the scope of this standard.

This standard does not cover short-circuit currents deliberately created under controlled conditions (short-circuit testing stations).

This part of IEC 60909 does not deal with the calculation of short-circuit currents in installations on board ships and aeroplanes.

1.2 Normative references

The following normative documents contain provisions which, through reference in this text, constitute provisions of this part of IEC 60909. For dated references, subsequent amendments to, or revisions of, any of these publications do not apply. However, parties to agreements based on this part of IEC 60909 are encouraged to investigate the possibility of applying the most recent editions of the normative documents indicated below. For undated references, the latest edition of the normative document referred to applies. Members of IEC and ISO maintain registers of currently valid International Standards.

IEC 60038:1983, *IEC standard voltages*

IEC 60050(131):1978, *International Electrotechnical Vocabulary – Chapter 131: Electric and magnetic circuits*

IEC 60050(151):1978, *International Electrotechnical Vocabulary – Chapter 151: Electric and magnetic devices*

IEC 60050-195:1998, *International Electrotechnical Vocabulary – Part 195: Earthing and protection against electric shock*

IEC 60056:1987, *High-voltage alternating-current circuit-breakers*

IEC 60071-1:1993, *Insulation coordination – Part 1: Definitions, principles and rules*

IEC 60781:1989, *Application guide for calculation of short-circuit currents in low-voltage radial systems*

IEC 60865-1:1993, *Short-circuit currents – Calculation of effects – Part 1: Definitions and calculation methods*

IEC TR 60909-1,— *Short-circuit currents calculation in three-phase a.c. systems – Part 1: Factors for the calculation of short-circuit currents in three-phase a.c. systems according to IEC 60909-0* ¹⁾

IEC TR3 60909-2:1992, *Electrical equipment – Data for short-circuit current calculations in accordance with IEC 60909*

IEC 60909-3:1995, *Short-circuit current calculation in three-phase a.c. systems – Part 3: Currents during two separate simultaneous single phase line-to-earth short circuits and partial short-circuit currents flowing through earth*

IEC TR 60909-4:2000, *Short-circuit current calculation in three-phase a.c. systems – Part 4: Examples for the calculation of short-circuit currents*¹⁾

IEC 60949:1988, *Calculation of thermally permissible short-circuit currents, taking into account non-adiabatic heating effects*

IEC 60986:1989, *Guide to the short-circuit temperature limits of electrical cables with a rated voltage from 1,8/3 (3,6) kV to 18/30 (36) kV*

1.3 Definitions

For the purposes of this part of IEC 60909, the definitions given in IEC 60050(131) and the following definitions apply.

1.3.1

short circuit

accidental or intentional conductive path between two or more conductive parts forcing the electric potential differences between these conductive parts to be equal or close to zero

1.3.1.1

line-to-line short circuit

accidental or intentional conductive path between two or more line conductors with or without earth connection

1.3.1.2

line-to-earth short circuit

accidental or intentional conductive path in a solidly earthed neutral system or an impedance earthed neutral system between a line conductor and local earth

1.3.2

short-circuit current

over-current resulting from a short circuit in an electric system

NOTE It is necessary to distinguish between the short-circuit current at the short-circuit location and partial short-circuit currents in the network branches (see figure 3) at any point of the network.

¹⁾ To be published.

1.3.3

prospective (available) short-circuit current

current that would flow if the short circuit were replaced by an ideal connection of negligible impedance without any change of the supply (see note of 1.1)

1.3.4

symmetrical short-circuit current

r.m.s. value of the a.c. symmetrical component of a prospective (available) short-circuit current (see 1.3.3), the aperiodic component of current, if any, being neglected

1.3.5

initial symmetrical short-circuit current I_k''

r.m.s. value of the a.c. symmetrical component of a prospective (available) short-circuit current (see 1.3.3), applicable at the instant of short circuit if the impedance remains at zero-time value (see figures 1 and 2)

1.3.6

initial symmetrical short-circuit power S_k''

fictitious value determined as a product of the initial symmetrical short-circuit current I_k'' (see 1.3.5), the nominal system voltage U_n (see 1.3.13) and the factor $\sqrt{3}$: $S_k'' = \sqrt{3} U_n I_k''$

NOTE The initial symmetrical short-circuit power S_k'' is not used for the calculation procedure in this standard. If S_k'' is used in spite of this in connection with short-circuit calculations, for instance to calculate the internal impedance of a network feeder at the connection point Q, then the definition given should be used in the following form: $S_{kQ}'' = \sqrt{3} U_{nQ} I_{kQ}''$ or $Z_Q = c U_{nQ}^2 / S_{kQ}''$.

1.3.7

decaying (aperiodic) component $i_{d.c.}$ of short-circuit current

mean value between the top and bottom envelope of a short-circuit current decaying from an initial value to zero according to figures 1 and 2

1.3.8

peak short-circuit current i_p

maximum possible instantaneous value of the prospective (available) short-circuit current (see figures 1 and 2)

NOTE The magnitude of the peak short-circuit current varies in accordance with the moment at which the short circuit occurs. The calculation of the three-phase peak short-circuit current i_p applies to the line conductor and to the instant at which the greatest possible short-circuit current exists. Sequential short circuits are not considered.

1.3.9

symmetrical short-circuit breaking current I_b

r.m.s. value of an integral cycle of the symmetrical a.c. component of the prospective short-circuit current at the instant of contact separation of the first pole to open of a switching device

1.3.10

steady-state short-circuit current I_k

r.m.s. value of the short-circuit current which remains after the decay of the transient phenomena (see figures 1 and 2)

1.3.11**symmetrical locked-rotor current I_{LR}**

highest symmetrical r.m.s. current of an asynchronous motor with locked rotor fed with rated voltage U_{rM} at rated frequency

1.3.12**equivalent electric circuit**

model to describe the behaviour of a circuit by means of a network of ideal elements [IEV 131-01-33]

1.3.13**nominal system voltage U_n**

voltage (line-to-line) by which a system is designated, and to which certain operating characteristics are referred

NOTE Values are given in IEC 60038.

1.3.14**equivalent voltage source $cU_n / \sqrt{3}$**

voltage of an ideal source applied at the short-circuit location in the positive-sequence system for calculating the short-circuit current according to 2.3. This is the only active voltage of the network

1.3.15**voltage factor c**

ratio between the equivalent voltage source and the nominal system voltage U_n divided by $\sqrt{3}$. The values are given in table 1

NOTE The introduction of a voltage factor c is necessary for various reasons. These are:

- voltage variations depending on time and place,
- changing of transformer taps,
- neglecting loads and capacitances by calculations according to 2.3.1,
- the subtransient behaviour of generators and motors.

1.3.16**subtransient voltage E'' of a synchronous machine**

r.m.s. value of the symmetrical internal voltage of a synchronous machine which is active behind the subtransient reactance X_d'' at the moment of short circuit

1.3.17**far-from-generator short circuit**

short circuit during which the magnitude of the symmetrical a.c. component of the prospective (available) short-circuit current remains essentially constant (see figure 1)

1.3.18**near-to-generator short circuit**

short circuit to which at least one synchronous machine contributes a prospective initial symmetrical short-circuit current which is more than twice the machine's rated current, or a short circuit to which asynchronous motors contribute more than 5 % of the initial symmetrical short-circuit current I_k'' without motors (see figure 2)

1.3.19 short-circuit impedances at the short-circuit location F

1.3.19.1

positive-sequence short-circuit impedance $\underline{Z}_{(1)}$ of a three-phase a.c. system

impedance of the positive-sequence system as viewed from the short-circuit location (see 2.3.2 and figure 5a)

1.3.19.2

negative-sequence short-circuit impedance $\underline{Z}_{(2)}$ of a three-phase a.c. system

impedance of the negative-sequence system as viewed from the short-circuit location (see 2.3.2 and figure 5b)

1.3.19.3

zero-sequence short-circuit impedance $\underline{Z}_{(0)}$ of a three-phase a.c. system

impedance of the zero-sequence system as viewed from the short-circuit location (see 2.3.2 and figure 5c). It includes three times the neutral-to-earth impedance $\underline{Z}_N$

1.3.19.4

short-circuit impedance $\underline{Z}_k$ of a three-phase a.c. system

abbreviated expression for the positive-sequence short-circuit impedance $\underline{Z}_{(1)}$ according to 1.3.19.1 for the calculation of three-phase short-circuit currents

1.3.20

short-circuit impedances of electrical equipment

1.3.20.1

positive-sequence short-circuit impedance $\underline{Z}_{(1)}$ of electrical equipment

ratio of the line-to-neutral voltage to the short-circuit current of the corresponding line conductor of electrical equipment when fed by a symmetrical positive-sequence system of voltages (see clause 2 and IEC 60909-4)

NOTE The index of symbol $\underline{Z}_{(1)}$ may be omitted if there is no possibility of confusion with the negative-sequence and the zero-sequence short-circuit impedances.

1.3.20.2

negative-sequence short-circuit impedance $\underline{Z}_{(2)}$ of electrical equipment

ratio of the line-to-neutral voltage to the short-circuit current of the corresponding line conductor of electrical equipment when fed by a symmetrical negative-sequence system of voltages (see clause 2 and IEC 60909-4).

1.3.20.3

zero-sequence short-circuit impedance $\underline{Z}_{(0)}$ of electrical equipment

ratio of the line-to-earth voltage to the short-circuit current of one line conductor of electrical equipment when fed by an a.c. voltage source, if the three paralleled line conductors are used for the outgoing current and a fourth line and/or earth as a joint return (see clause 2 and IEC 60909-4)

1.3.21

subtransient reactance X''_d of a synchronous machine

effective reactance at the moment of short circuit. For the calculation of short-circuit currents the saturated value of X''_d is taken

NOTE When the reactance X''_d in ohms is divided by the rated impedance $Z_{rG} = U_{rG}^2 / S_{rG}$ of the synchronous machine, the result in per unit is represented by a small letter $x''_d = X''_d / Z_{rG}$.

1.3.22**minimum time delay $t_{\min}$**

shortest time between the beginning of the short-circuit current and the contact separation of the first pole to open of the switching device

NOTE The time $t_{\min}$ is the sum of the shortest possible operating time of a protective relay and the shortest opening time of a circuit-breaker. It does not take into account adjustable time delays of tripping devices.

1.3.23**thermal equivalent short-circuit current I_{th}**

the r.m.s. value of a current having the same thermal effect and the same duration as the actual short-circuit current, which may contain a d.c. component and may subside in time

1.4 Symbols, subscripts and superscripts

The equations given in this standard are written without specifying units. The symbols represent physical quantities possessing both numerical values and dimensions that are independent of units, provided a consistent unit system is chosen, for example the international system of units (SI). Symbols of complex quantities are underlined, for example $\underline{Z} = R + jX$.

1.4.1 Symbols

A	Initial value of the d.c. component $i_{\text{d.c.}}$
$\underline{a}$	Complex operator
a	A ratio between unbalanced short-circuit current and three phase short-circuit current
c	Voltage factor
$cU_n / \sqrt{3}$	Equivalent voltage source (r.m.s.)
E''	Subtransient voltage of a synchronous machine
f	Frequency (50 Hz or 60 Hz)
I_b	Symmetrical short-circuit breaking current (r.m.s.)
I_k	Steady-state short-circuit current (r.m.s.)
I_{kP}	Steady-state short-circuit current at the terminals (poles) of a generator with compound excitation
I_k''	Initial symmetrical short-circuit current (r.m.s.)
I_{LR}	Symmetrical locked-rotor current of an asynchronous motor
I_r	Rated current of electrical equipment
I_{th}	Thermal equivalent short-circuit current
$i_{\text{d.c.}}$	d.c. component of short-circuit current
i_p	Peak short-circuit current
K	Correction factor for impedances
m	Factor for the heat effect of the d.c. component
n	Factor for the heat effect of the a.c. component
p	Pair of poles of an asynchronous motor
p_G	Range of generator voltage regulation
p_T	Range of transformer voltage adjustment
P_{krT}	Total loss in transformer windings at rated current
P_{rM}	Rated active power of an asynchronous motor ($P_{\text{rM}} = S_{\text{rM}} \cos \varphi_{\text{rM}} \eta_{\text{rM}}$)
q	Factor for the calculation of breaking current of asynchronous motors
q_n	Nominal cross-section

R resp. r	Resistance, absolute respectively relative value
R_G	Resistance of a synchronous machine
R_{Gf}	Fictitious resistance of a synchronous machine when calculating i_p
S_k''	Initial symmetrical short-circuit power (see 1.3.6)
S_r	Rated apparent power of electrical equipment
$t_{\min}$	Minimum time delay
t_r	Rated transformation ratio (tap-changer in main position); $t_r \geq 1$
T_k	Duration of the short-circuit current
U_m	Highest voltage for equipment, line-to-line (r.m.s.)
U_n	Nominal system voltage, line-to-line (r.m.s.)
U_r	Rated voltage, line-to-line (r.m.s.)
u_{kr}	Rated short-circuit voltage of a transformer in per cent
u_{kR}	Short-circuit voltage of a short-circuit limiting reactor in per cent
u_{Rr}	Rated resistive component of the short-circuit voltage of a transformer in per cent
u_{Xr}	Rated reactive component of the short-circuit voltage of a transformer in per cent
$U_{(1)}, U_{(2)}, U_{(0)}$	Positive-, negative-, zero-sequence voltage
X resp. x	Reactance, absolute respectively relative value
X_d resp. X_q	Synchronous reactance, direct axis respectively quadrature axis
X_{dp}	Fictitious reactance of a generator with compound excitation in the case of steady-state short circuit at the terminals (poles)
X_d'' resp. X_q''	Subtransient reactance of a synchronous machine (saturated value), direct axis respectively quadrature axis
x_d	Unsaturated synchronous reactance, relative value
$x_{d \text{ sat}}$	Saturated synchronous reactance, relative value, reciprocal of the saturated no-load short-circuit ratio
Z resp. z	Impedance, absolute respectively relative value
Z_k	Short-circuit impedance of a three-phase a.c. system
$Z_{(1)}$	Positive-sequence short-circuit impedance
$Z_{(2)}$	Negative-sequence short-circuit impedance
$Z_{(0)}$	Zero-sequence short-circuit impedance
η	Efficiency of asynchronous motors
κ	Factor for the calculation of the peak short-circuit current
λ	Factor for the calculation of the steady-state short-circuit current
μ	Factor for the calculation of the symmetrical short-circuit breaking current
μ_0	Absolute permeability of vacuum, $\mu_0 = 4\pi \cdot 10^{-7}$ H/m
ρ	Resistivity
φ	Phase angle
θ_e	Conductor temperature at the end of the short circuit
01	Positive-sequence neutral reference
02	Negative-sequence neutral reference
00	Zero-sequence neutral reference

1.4.2 Subscripts

(1)	Positive-sequence component
(2)	Negative-sequence component
(0)	Zero-sequence component
a.c	Alternating current
d.c	Direct current
f	Fictitious
k or k3	Three-phase short circuit (see figure 3a)
k1	Line-to-earth short circuit, line-to-neutral short circuit (see figure 3d)
k2	Line-to-line short circuit (see figure 3b)
k2E resp. kE2E	Line-to-line short circuit with earth connection (see figure 3c)
K	Impedances or reactances calculated with an impedance correction factor K_T , K_G or K_S respectively K_{SO}
max	Maximum
min	Minimum
n	Nominal value (IEV 151-04-01)
r	Rated value (IEV 151-04-03)
rs1	Resulting
t	Transferred value
AT	Auxiliary transformer
B	Busbar
E	Earth
F	Short-circuit location
G	Generator
HV	High-voltage, high-voltage side of a transformer
LV	Low-voltage, low-voltage side of a transformer
L	Line
LR	Locked rotor
L1, L2, L3	Line conductors of a three-phase a.c. system
M	Asynchronous motor or group of asynchronous motors
~~M~~	Without motor
MV	Medium-voltage, medium-voltage side of a transformer
N	Neutral of a three-phase a.c. system, starpoint of a generator or a transformer
P	Terminal, pole
Q	Feeder connection point
R	Short-circuit limiting reactor
S	Power station unit (generator and unit transformer with on-load tap-changer)
SO	Power station unit (generator and unit transformer with constant transformation ratio or off-load taps)
T	Transformer

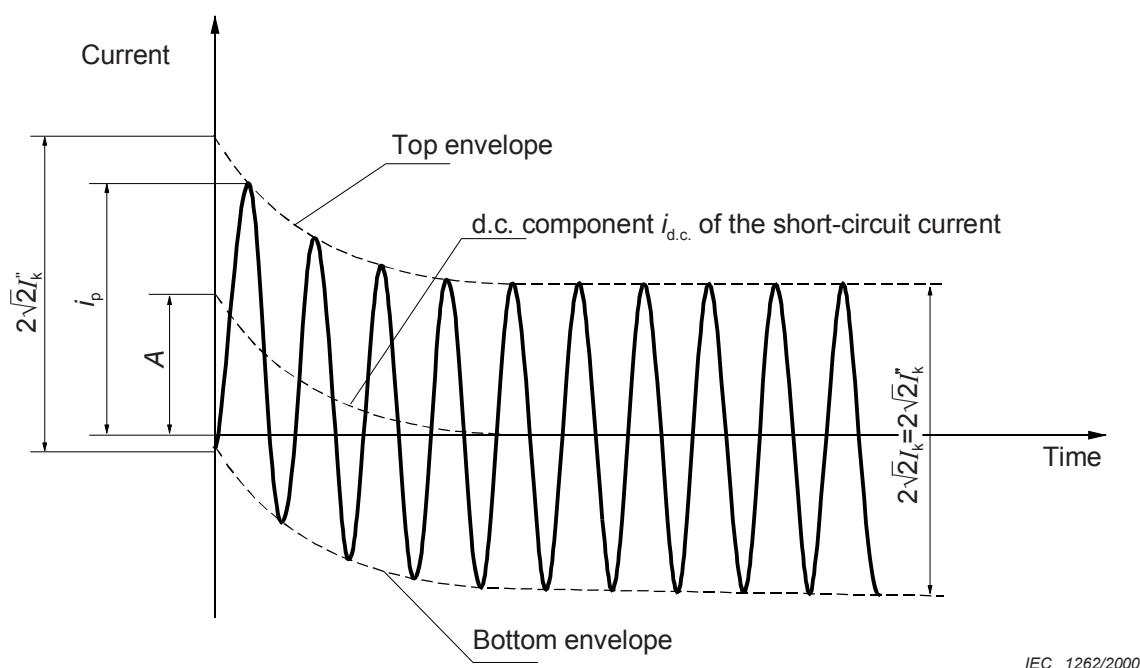
1.4.3 Superscripts

- " Subtransient (initial) value
- ' Resistance or reactance per unit length
- b Before the short circuit

2 Characteristics of short-circuit currents: calculating method

2.1 General

A complete calculation of short-circuit currents should give the currents as a function of time at the short-circuit location from the initiation of the short circuit up to its end, corresponding to the instantaneous value of the voltage at the beginning of the short circuit (see figures 1 and 2).



I_k'' = initial symmetrical short-circuit current

i_p = peak short-circuit current

I_k = steady-state short-circuit current

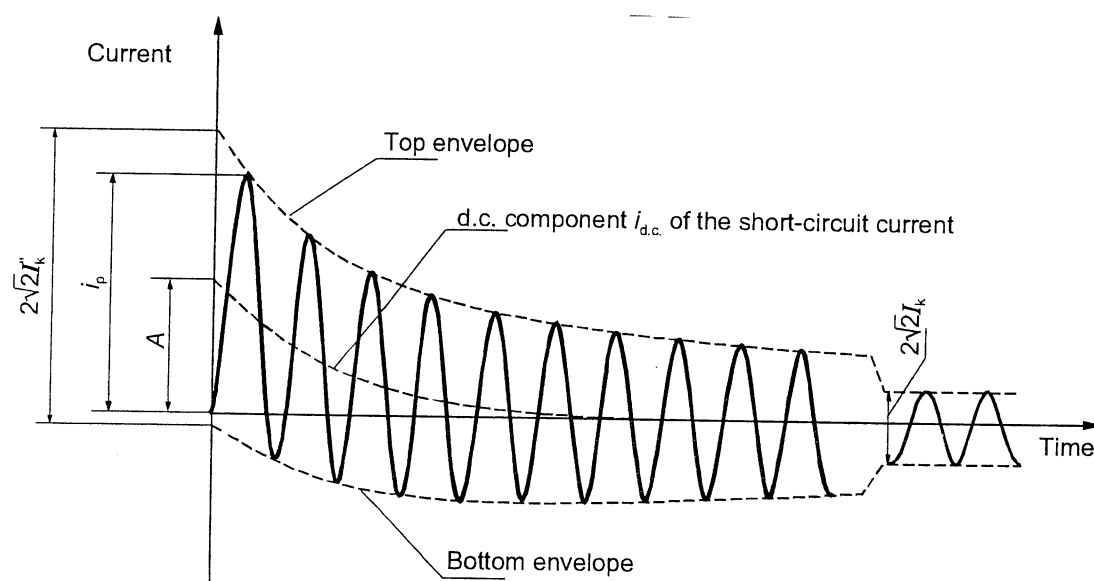
$i_{d.c.}$ = d.c. component of short-circuit current

A = initial value of the d.c. component $i_{d.c.}$

Figure 1 – Short-circuit current of a far-from-generator short circuit with constant a.c. component (schematic diagram)

In most practical cases a determination like this is not necessary. Depending on the application of the results, it is of interest to know the r.m.s. value of the symmetrical a.c. component and the peak value i_p of the short-circuit current following the occurrence of a short circuit. The highest value i_p depends on the time constant of the decaying aperiodic component and the frequency f , that is on the ratio R/X or X/R of the short-circuit impedance $\underline{Z}_k$, and is reached if the short circuit starts at zero voltage. i_p also depends on the decay of the symmetrical a.c. component of the short-circuit current.

In meshed networks there are several direct-current time constants. That is why it is not possible to give an easy method of calculating i_p and $i_{d.c.}$. Special methods to calculate i_p with sufficient accuracy are given in 4.3.



I_k'' = initial symmetrical short-circuit current

i_p = peak short-circuit current

I_k = steady-state short-circuit current

$i_{d.c.}$ = d.c. component of short-circuit current

A = initial value of the d.c. component $i_{d.c.}$

Figure 2 – Short-circuit current of a near-to-generator short circuit with decaying a.c. component (schematic diagram)

2.2 Calculation assumptions

The calculation of maximum and minimum short-circuit currents is based on the following simplifications.

- a) For the duration of the short circuit there is no change in the type of short circuit involved, that is, a three-phase short circuit remains three-phase and a line-to-earth short circuit remains line-to-earth during the time of short circuit.
- b) For the duration of the short circuit, there is no change in the network involved.
- c) The impedance of the transformers is referred to the tap-changer in main position. This is admissible, because the impedance correction factor K_T for network transformers is introduced.
- d) Arc resistances are not taken into account.
- e) All line capacitances and shunt admittances and non-rotating loads, except those of the zero-sequence system, are neglected.

Despite these assumptions being not strictly true for the power systems considered, the result of the calculation does fulfil the objective to give results which are generally of acceptable accuracy.

For balanced and unbalanced short circuits as shown in figure 3, it is useful to calculate the short-circuit currents by application of symmetrical components (see 2.3.2).

When calculating short-circuit currents in systems with different voltage levels, it is necessary to transfer impedance values from one voltage level to another, usually to that voltage level at which the short-circuit current is to be calculated. For per unit or other similar unit systems, no transformation is necessary if these systems are coherent, i.e. $U_{rTHV}/U_{rTLV} = U_{nHV}/U_{nLV}$ for each transformer in the system with partial short-circuit currents. U_{rTHV}/U_{rTLV} is normally not equal to U_{nHV}/U_{nLV} (see IEC 60909-2 and the examples given in IEC 60909-4).

The impedances of the equipment in superimposed or subordinated networks are to be divided or multiplied by the square of the rated transformation ratio t_r . Voltages and currents are to be converted by the rated transformation ratio t_r .

2.3 Method of calculation

2.3.1 Equivalent voltage source at the short-circuit location

The method used for calculation is based on the introduction of an equivalent voltage source at the short-circuit location. The equivalent voltage source is the only active voltage of the system. All network feeders, synchronous and asynchronous machines are replaced by their internal impedances (see clause 3).

In all cases it is possible to determine the short-circuit current at the short-circuit location F with the help of an equivalent voltage source. Operational data and the load of consumers, tap-changer position of transformers, excitation of generators, and so on, are dispensable; additional calculations about all the different possible load flows at the moment of short circuit are superfluous.

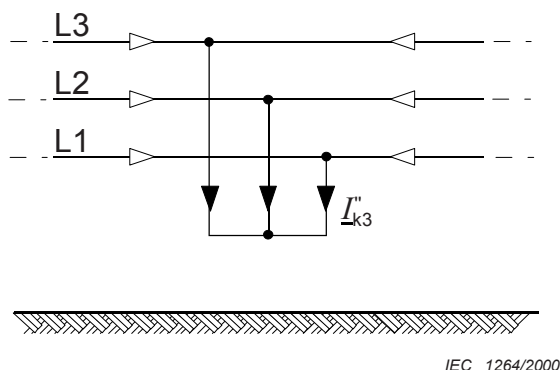


Figure 3a – Three-phase short circuit

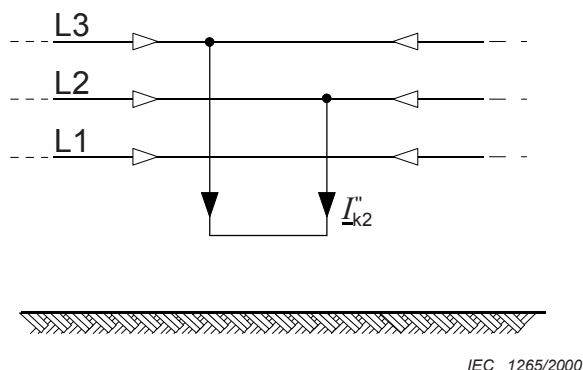


Figure 3b – Line-to-line short circuit

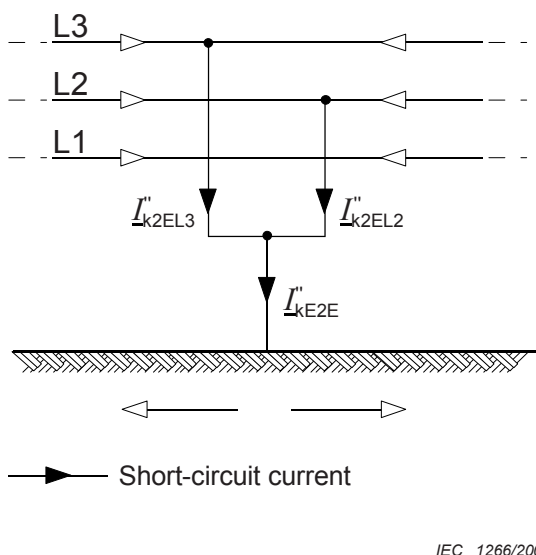


Figure 3c – Line-to-line short circuit with earth connection

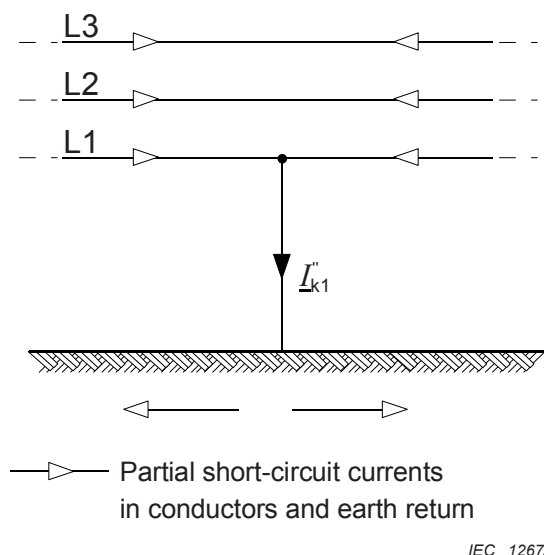


Figure 3d – Line-to-earth short circuit

NOTE The direction of current arrows is chosen arbitrarily.

Figure 3 – Characterization of short circuits and their currents

Figure 4 shows an example of the equivalent voltage source at the short-circuit location F as the only active voltage of the system fed by a transformer without or with on-load tap-changer. All other active voltages in the system are assumed to be zero. Thus the network feeder in figure 4a is represented by its internal impedance Z_{Qt} , transferred to the LV-side of the transformer (see 3.2) and the transformer by its impedance referred to the LV-side (see 3.3). Shunt admittances (for example, line capacitances and passive loads) are not to be considered when calculating short-circuit currents in accordance with figure 4b.

If there are no national standards, it seems adequate to choose a voltage factor c according to table 1, considering that the highest voltage in a normal (undisturbed) system does not differ, on average, by more than approximately +5 % (some LV systems) or +10 % (some HV systems) from the nominal system voltage U_n .

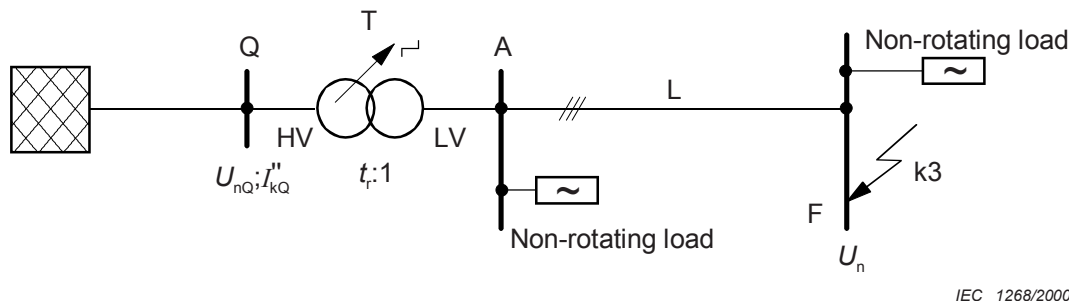


Figure 4a – System diagram

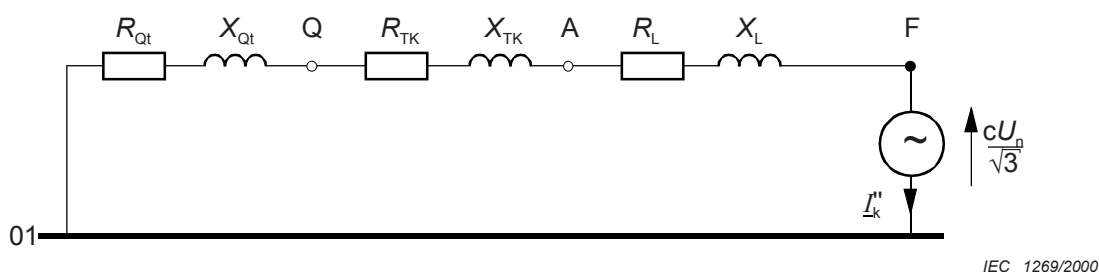


Figure 4b – Equivalent circuit diagram of the positive-sequence system

NOTE The index (1) for the impedances of the positive-sequence system is omitted. 01 marks the positive-sequence neutral reference. The impedance of the network feeder and the transformer are related to the LV-side and the last one is also corrected with K_T (see 3.3.3).

Figure 4 – Illustration for calculating the initial symmetrical short-circuit current I_k'' in compliance with the procedure for the equivalent voltage source

Table 1 – Voltage factor c

Nominal voltage U_n	Voltage factor c for the calculation of	
	maximum short-circuit currents $c_{\max}^{1)}$	minimum short-circuit currents $c_{\min}$
Low voltage 100 V to 1 000 V (IEC 60038, table I)	1,05 ³⁾ 1,10 ⁴⁾	0,95
Medium voltage >1 kV to 35 kV (IEC 60038, table III)	1,10	1,00
High voltage²⁾ >35 kV (IEC 60038, table IV)		
¹⁾ $c_{\max}U_n$ should not exceed the highest voltage U_m for equipment of power systems. ²⁾ If no nominal voltage is defined $c_{\max}U_n = U_m$ or $c_{\min}U_n = 0,90 \times U_m$ should be applied. ³⁾ For low-voltage systems with a tolerance of +6 %, for example systems renamed from 380 V to 400 V. ⁴⁾ For low-voltage systems with a tolerance of +10 %.		

2.3.2 Application of symmetrical components

In three-phase a.c. systems the calculation of the current values resulting from balanced and unbalanced short circuits is simplified by the use of symmetrical components. This postulates that the electrical equipment has a balanced structure, for example in the case of transposed overhead lines. The results of the short-circuit current calculation have an acceptable accuracy also in the case of untransposed overhead lines.

Using this method, the currents in each line conductor are found by superposing the currents of the three symmetrical component systems:

- positive-sequence current $\underline{I}_{(1)}$;
- negative-sequence current $\underline{I}_{(2)}$;
- zero-sequence current $\underline{I}_{(0)}$.

Taking the line conductor L1 as reference, the currents $\underline{I}_{L1}$, $\underline{I}_{L2}$, and $\underline{I}_{L3}$ are given by

$$\underline{I}_{L1} = \underline{I}_{(1)} + \underline{I}_{(2)} + \underline{I}_{(0)} \quad (1a)$$

$$\underline{I}_{L2} = \underline{a}^2 \underline{I}_{(1)} + \underline{a} \underline{I}_{(2)} + \underline{I}_{(0)} \quad (1b)$$

$$\underline{I}_{L3} = \underline{a} \underline{I}_{(1)} + \underline{a}^2 \underline{I}_{(2)} + \underline{I}_{(0)} \quad (1c)$$

$$\underline{a} = -\frac{1}{2} + j\frac{1}{2}\sqrt{3}; \quad \underline{a}^2 = -\frac{1}{2} - j\frac{1}{2}\sqrt{3} \quad (2)$$



Figure 5a – Positive-sequence short-circuit impedance $\underline{Z}_{(1)}$

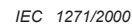


Figure 5b – Negative-sequence short-circuit impedance $\underline{Z}_{(2)}$



Figure 5c – Zero-sequence short-circuit impedance $\underline{Z}_{(0)}$

Figure 5 – Short-circuit impedances of a three-phase a.c. system at the short-circuit location F