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Short-circuit current calculation in three-phase a.c. systems (IEC 60909:1988, modified)

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HARMONIZATION DOCUMENT

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HARMONISIERUNGSDOKUMENT

HD 533 S1

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ENGLISH VERSION

SHORT-CIRCUIT CURRENT CALCULATION IN THREE-PHASE A.C. SYSTEMS
(IEC 909:1988, modified)

Calcul des courants de court-circuit dans les réseaux triphasés à courant alternatif
(CEI 909:1988, modifiée)

Berechnung von Kurzschlußströmen in Drehstromnetzen
(IEC 909, modifiziert)

This Harmonization Document was approved by CENELEC on 1990-03-05. CENELEC members are bound to comply with the CEN/CENELEC Internal Regulations which stipulate the conditions for implementation of this Harmonization Document on a national level.

Up-to-date lists and bibliographical references concerning national implementation may be obtained on application to the Central Secretariat or to any CENELEC member.

This Harmonization Document exists in three official versions (English, French, German).

CENELEC members are the national electrotechnical committees of Austria, Belgium, Denmark, Finland, France, Germany, Greece, Iceland, Ireland, Italy, Luxembourg, Netherlands, Norway, Portugal, Spain, Sweden, Switzerland and United Kingdom.

CENELEC

European Committee for Electrotechnical Standardization
Comité Européen de Normalisation Electrotechnique
Europäisches Komitee für Elektrotechnische Normung

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Ref. No. HD 533 S1:1991 E

FOREWORD

The CENELEC questionnaire procedure, performed for finding out whether or not the International Standard IEC 909:1988 could be accepted without textual changes, has shown that some CENELEC common modifications were necessary for the acceptance as Harmonization Document.
The reference document, together with the common modifications prepared by the CENELEC Reporting Secretariat SR 73, was submitted to the CENELEC members for formal vote.

The text of the draft was approved by all CENELEC members, **with the exception of** Austria, Finland and Norway, as HD 533 S1 on 5 March 1990.

The following dates were fixed:

- latest date of announcement of the HD at national level	(doa)	1990-09-01
- latest date of publication of a new harmonized national standard	(dop)	1991-11-01
- latest date of withdrawal of conflicting national standards	(dow)	1991-11-01

ENDORSEMENT NOTICE

The text of the International Standard IEC 909:1988 was approved by CENELEC as a Harmonization Document with agreed common modifications as given below.

COMMON MODIFICATIONS

1	**Scope**
	In the third line change "230 kV" into "380 kV".
6	**Equivalent voltage source at the short-circuit location**
Table I	In the last box of column 1, change "230 KV" into "380 kV".
9.3.1	At the end of the subclause add:
	For lines in low-voltage systems it is sufficient to take 0 = 80°C.
Appendix A	Replace "Appendix A" by "Appendix A (informative)".

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Calcul des courants de court-circuit dans les réseaux triphasés à courant alternatif

Short-circuit current calculation in three-phase a.c. systems

Publication
909: 1988

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INTERNATIONAL ELECTROTECHNICAL COMMISSION

SHORT-CIRCUIT CURRENT CALCULATION IN THREE-PHASE A.C. SYSTEMS

FOREWORD

1) The formal decisions or agreements of the IEC on technical matters, prepared by Technical Committees on which all the National Committees having a special interest therein are represented, express, as nearly as possible, an international consensus of opinion on the subjects dealt with.
2) They have the form of recommendations for international use and they are accepted by the National Committees in that sense.
3) In order to promote international unification, the IEC expresses the wish that all National Committees should adopt the text of the IEC recommendation for their national rules in so far as national conditions will permit. Any divergence between the IEC recommendation and the corresponding national rules should, as far as possible, be clearly indicated in the latter.

PREFACE

This standard has been prepared by IEC Technical Committee No. 73: Short-circuit currents.

The text of this standard is based on the following documents:

Six Months' Rule	Report on Voting
73(CO)5	73(CO)7

Full information on the voting for the approval of this standard can be found in the Voting Report indicated in the above table.

The following IEC publications are quoted in this standard:

Publication Nos. 38 (1983): IEC standard voltages.
50: International Electrotechnical Vocabulary (IEV).
50 (131) (1978): Chapter 131: Electric and magnetic circuits.
50 (151) (1978): Chapter 151: Electrical and magnetic devices.
50 (441) (1984): Chapter 441: Switchgear, controlgear and fuses.
865 (1986): Calculation of the effects of short-circuit currents.

SHORT-CIRCUIT CURRENT CALCULATION IN THREE-PHASE A.C. SYSTEMS

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1. Scope

This standard 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 with nominal voltages up to 230 kV operating at nominal frequency (50 Hz or 60 Hz).

This standardized procedure is given in such a form as to facilitate as far as possible its use by non-specialist engineers.

2. Object

The object of this standard is to establish a general, practicable and concise procedure leading to conservative results with sufficient accuracy. For this purpose, an equivalent voltage source at the short-circuit location is considered, as described under Clause 6. 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.

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 based on the rated data of the electrical equipment and the topological arrangement of the system has the advantage of being possible both for existing systems and for systems at the planning stage.

There are two different short-circuit currents to be calculated which differ in their magnitude:

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

One has to distinguish between:

- systems with short-circuit currents having no a.c. component decay (far-from-generator short circuit), treated in Section One,
- systems with short-circuit currents having decaying a.c. components (near-to-generator short circuit), treated in Section Two. This section also includes the influence of motors.

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

This standard does not deal with installations on board ships and areoplanes.

For the calculation of the thermal equivalent short-circuit currents see Section Two of IEC Publication 865.

An application guide, dealing with non-meshed low-voltage three-phase a.c. systems and a technical report on the derivation of the parameters and various calculation factors of this standard are under consideration.

3. Definitions

For the purpose of this standard, the following definitions apply. Reference is made to the International Electrotechnical Vocabulary (IEV) [IEC Publication 50] when applicable.

3.1 *Short circuit*

The accidental or intentional connection, by a relatively low resistance or impedance, of two or more points in a circuit which are normally at different voltages (IEV 151-03-41).

3.2 *Short-circuit current*

An over-current resulting from a short circuit due to a fault or an incorrect connection in an electric circuit (IEV 441-11-07).

Note. – It is necessary to distinguish between the short-circuit current at the short-circuit location and in the network branches.

3.3 *Prospective (available) short-circuit current*

The current that would flow if the short circuit were replaced by an ideal connection of negligible impedance without any change of the supply.

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 can lead to higher aperiodic components of short-circuit current, are beyond the scope of this standard.

3.4 *Symmetrical short-circuit current*

The r.m.s. value of the a.c. symmetrical component of a prospective (available) short-circuit current (see Sub-clause 3.3), the aperiodic component of current, if any, being neglected.

3.5 *Initial symmetrical short-circuit current* I''_k

The r.m.s. value of the a.c. symmetrical component of a prospective (available) short-circuit current (see Sub-clause 3.3) applicable at the instant of short circuit if the impedance remains at zero-time value (see Figures 1 and 12, pages 19 and 63).

3.6 *Initial symmetrical short-circuit (apparent) power* S''_k

The fictive value determined as a product of the initial symmetrical short-circuit current I''_k (see Sub-clause 3.5), the nominal system voltage U_n (see Sub-clause 3.14), and the factor $\sqrt{3}$:

$$S''_k = \sqrt{3}\ U_n\ I''_k$$

3.7 *D.C. (aperiodic) component* i_{DC} *of short-circuit current*

The 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 12.

3.8 *Peak short-circuit current* i_p

The maximum possible instantaneous value of the prospective (available) short-circuit current (see Figures 1 and 12).

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 peak three-phase short-circuit current i_p applies for the phase conductor and moment at which the greatest possible short-circuit current exists. Sequential faults are not considered. For three-phase short circuits it is assumed that the short circuit occurs simultaneously in all phase conductors.

3.9 *Symmetrical short-circuit breaking current* I_b

The 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 of a switching device.

3.10 *Steady-state short-circuit current* I_k

The r.m.s. value of the short-circuit current which remains after the decay of the transient phenomena (see Figures 1 and 12, pages 19 and 63).

3.11 *Symmetrical locked-rotor current* I_{LR}

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

3.12 *Equivalent electric circuit*

A model to describe the behaviour of a circuit by means of a network of ideal elements (IEV 131-01-33).

3.13 *(Independent) voltage source*

An active element which can be represented by an ideal voltage source independent of all currents and voltages in the circuit, in series with a passive circuit element (IEV 131-01-37).

3.14 *Nominal system voltage* U_n

Voltage (line-to-line) by which a system is designated and to which certain operating characteristics are referred. Values are given in IEC Publication 38.

3.15 *Equivalent voltage source* $cU_n/\sqrt{3}$

The voltage of an ideal source applied at the short-circuit location in the positive-sequence system for calculating the short-circuit current according to Clause 6. This is the only active voltage of the network.

3.16 *Voltage factor c*

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

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 Clause 6,
- the subtransient behaviour of generators and motors.

3.17 *Subtransient voltage E″ of a synchronous machine*

The 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.

3.18 *Far-from-generator short circuit*

A short circuit during which the magnitude of the symmetrical a.c. component of prospective (available) short-circuit current remains essentially constant (see Clause 7).

3.19 *Near-to-generator short circuit*

A short circuit to which at least one synchronous machine contributes a prospective initial symmetrical short-circuit current which is more than twice the generator's rated current, or a short circuit to which synchronous and asynchronous motors contribute more than 5% of the initial symmetrical short-circuit current I''_k without motors (see Clause 10).

3.20 *Short-circuit impedances at the short-circuit location F*

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

The impedance of the positive-sequence system as viewed from the short-circuit location (see Sub-clause 8.3.1 and Figure 4a, page 27).

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

The impedance of the negative-sequence system as viewed from the short-circuit location (see Sub-clause 8.3.1 and Figure 4b, page 27).

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

The impedance of the zero-sequence system as viewed from the short-circuit location (see Sub-clause 8.3.1 and Figure 4c, page 27). It includes three times the neutral-to-earth impedance 3 $\underline{Z}_{NE}$.

3.20.4 *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 Sub-clause 3.20.1 for the calculation of three-phase short-circuit currents.

3.21 *Short-circuit impedances of electrical equipment*

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

The ratio of the line-to-neutral voltage to the short-circuit current of the corresponding phase of electrical equipment when fed by a symmetrical positive-sequence system of voltages (see Sub-clause 8.3.2).

Note. – 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.

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

The ratio of the line-to-neutral voltage to the short-circuit current of the corresponding phase of electrical equipment when fed by a symmetrical negative-sequence system of voltages (see Sub-clause 8.3.2).

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

The ratio of the line-to-earth voltage to the short-circuit current of one phase of electrical equipment when fed by an a.c. voltage source, if the three parallel phase conductors are used for the outgoing current and a fourth line and/or earth is joint return (see Sub-clause 8.3.2).

3.22 *Subtransient reactance X''_d of a synchronous machine*

The 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 $Z_{rG} = U^2_{rG} / S_{rG}$ of the synchronous machine, the result in per unit is represented by a small letter $x''_d = X''_d / Z_{rG}$.

3.23 *Minimum time delay t_{min} of a circuit breaker*

The shortest time between the beginning of the short-circuit current and the first contact separation of one pole of the switching device.

Note. – The time t_{min} is the sum of the shortest possible operating time of an instantaneous relay and the shortest opening time of a circuit breaker. It does not take into account adjustable time delays of tripping devices.

4. Symbols, subscripts and superscripts

Symbols of complex quantities are underlined, for example: $\underline{Z} = R + jX$.

All equations are written without specifying units. The symbols represent quantities possessing both numerical values and dimensions that are independent of units, provided a coherent unit system is chosen, for example, the International System of Units (SI).

4.1 *Symbols*

A	Initial value of aperiodic component
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
$\underline{I}''_k$ or $\underline{I}''_{k3}$	Initial symmetrical short-circuit current (r.m.s.)
I_{LR}	Locked-rotor current of an asynchronous motor
i_{DC}	Decaying aperiodic component of short-circuit current
i_p	Peak short-circuit current
K	Correction factor for impedances
P_{krT}	Total loss in transformer windings at rated current
q	Factor for the calculation of breaking currents of asynchronous motors
q_n	Nominal cross section
R resp. r	Resistance, absolute respectively relative value
R_G	Fictitious resistance of a synchronous machine when calculating I''_k and i_p
S''_k	Initial symmetrical short-circuit power (apparent power)
S_r	Rated apparent power of electrical equipment
t_f	Fictitious transformation ratio
t_{min}	Minimum time delay
t_r	Rated transformation ratio (tap changer in main position); $t_r \geqslant 1$
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 in percent
u_{Rr}	Rated ohmic voltage in percent
$\underline{U}_{(1)}$, $\underline{U}_{(2)}$, $\underline{U}_{(0)}$	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) if the excitation is taken into account
X''_d resp. X''_q	Subtransient reactance of a synchronous machine (saturated value), direct axis respectively quadrature axis
$X_{d\,sat}$	Reciprocal of the short-circuit ratio
Z resp. z	Impedance, absolute respectively relative value
$\underline{Z}_k$	Short-circuit impedance of a three-phase a.c. system
$\underline{Z}_{(1)}$	Positive-sequence short-circuit impedance
$\underline{Z}_{(2)}$	Negative-sequence short-circuit impedance
$\underline{Z}_{(0)}$	Zero-sequence short-circuit impedance
η	Efficiency of asynchronous motors

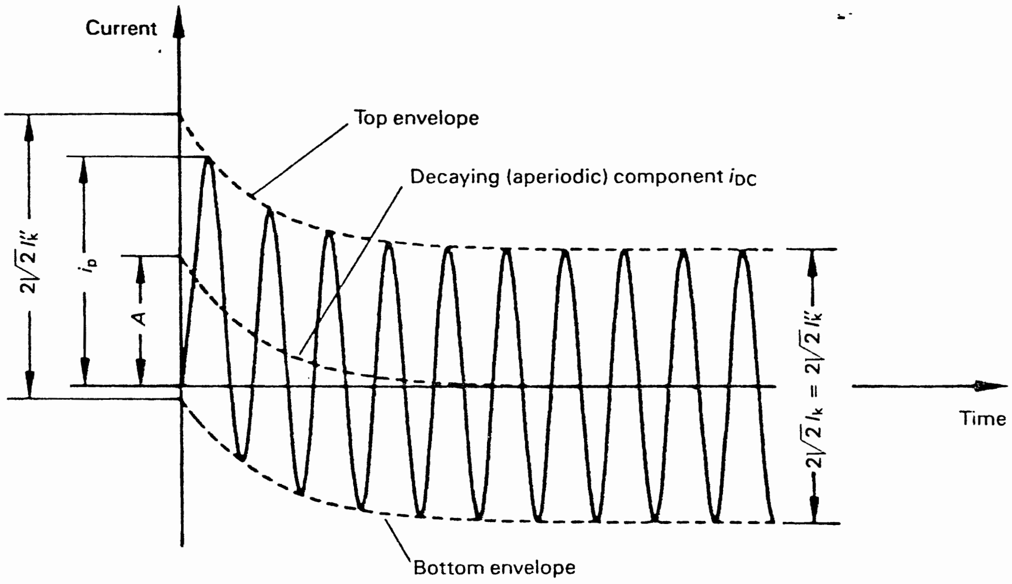
$\varkappa$	Factor for the calculation of the peak short-circuit current
λ	Factor for the calculation of the steady-state short-circuit current
μ	Factor for the calculation of the symmetrical short-circuit breaking current
μ_0	Absolute permeability of vacuum, $\mu_0 = 4\pi/10^{-7}$ H/m
ϱ	Resistivity
φ	Phase angle

4.2 *Subscripts*

(1)	Positive-sequence component
(2)	Negative-sequence component
(0)	Zero-sequence component
f	Fictitious
k or k3	Three-phase short circuit
k1	Line-to-earth short circuit, line-to-neutral short circuit
k2	Line-to-line short circuit without earth connection
k2E resp. kE2E	Line-to-line short circuit with earth connection, line current respectively earth current
max	Maximum
min	Minimum
n	Nominal value (IEV 151-04-01)
r	Rated value (IEV 151-04-03)
rsl	Resulting
t	Transformed value
AT	Auxiliary transformer
B	Busbar
E	Earth
F	Fault, short-circuit location
G	Generator
HV	High-voltage, high-voltage winding of a transformer
LV	Low-voltage, low-voltage winding of a transformer
L	Line
LR	Locked rotor
L1, L2, L3	Line 1, 2, 3 of a three-phase system
M	Asynchronous motor or group of asynchronous motors
M̸	Without motor
MV	Medium-voltage, medium-voltage winding of a transformer
N	Neutral of a three-phase a.c. system
P	Terminal, pole
PSU	Power-station unit (generator and transformer)
Q	Feeder connection point
T	Transformer

4.3 *Superscripts*

"	Initial (subtransient) value
'	Resistance or reactance per unit length



I''_k = initial symmetrical short-circuit current
i_p = peak short-circuit current
I_k = steady-state short-circuit current
i_{DC} = decaying (aperiodic) component of short-circuit current
A = initial value of the aperiodic component i_{DC}

FIG. 1. – Short-circuit current of a far-from-generator short circuit (schematic diagram).

5. Calculation assumptions

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 short circuit (see Figures 1 and 12, pages 19 and 63).

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 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 nearly reached if the short circuit starts at zero voltage.

In meshed networks there are several time constants. That is why it is not possible to give an easy exact method of calculating i_p and i_{DC}. Special methods to calculate i_p with sufficient accuracy are given in Sub-clause 9.1.3.2.

For the determination of the asymmetrical short-circuit breaking current the decaying aperiodic component i_{DC} of the short-circuit current as shown in Figures 1 or 12 may be calculated with sufficient accuracy by:

$$i_{DC} = \sqrt{2}\, I''_k\, e^{-2\pi f t\, R/X} \qquad (1)$$

where:

I''_k = initial symmetrical short-circuit current
f = nominal frequency 50 Hz or 60 Hz
t = time
R/X = ratio according to Sub-clause 9.1.1.2, 9.1.2.2 or 9.1.3.2

In meshed networks according to Sub-clause 9.1.3.2 – Method A – the right hand side of equation (1) should be multiplied by 1.15. According to Sub-clause 9.1.3.2 – Method B – the equivalent frequency should be selected as follows:

$2\pi ft$	$<2\pi$	$<5\pi$	$<10\pi$	$<25\pi$
f_c/f	0.27	0.15	0.092	0.055

where f = 50 Hz or 60 Hz.

Furthermore, the calculation of maximum and minimum short-circuit currents is based on the following simplifications:

1) For the duration of the short circuit there is no change in the number of circuits 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.
2) Tap changers of the transformers are assumed to be in main position.
3) Arc resistances are not taken into account.

While these assumptions are not strictly true for the power systems considered, the recommended short-circuit calculations have acceptable accuracy.

For balanced and unbalanced short circuits as shown in Figure 2, page 23, it is useful to calculate the short-circuit currents by the method of symmetrical components (see Sub-clause 8.2).

6. Equivalent voltage source at the short-circuit location

In all cases in Sections One and Two 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 on the static 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.

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 Sub-clause 8.3.1).

Furthermore, with this method all line capacitances and parallel admittances of non-rotating loads, except those of the zero-sequence system (see Sub-clauses 8.3.1 and 11.4), shall be neglected.