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Second edition
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Short-circuit currents in three-phase a.c. systems –

Part 1:
Factors for the calculation of short-circuit currents according to IEC 60909-0

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INTERNATIONAL ELECTROTECHNICAL COMMISSION

SHORT-CIRCUIT CURRENTS IN THREE-PHASE AC SYSTEMS –

Part 1: Factors for the calculation of short-circuit currents according to IEC 60909-0

FOREWORD

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Technical reports do not necessarily have to be reviewed until the data they provide are considered to be no longer valid or useful by the maintenance team.

IEC 60909-1, which is a technical report, has been prepared by IEC technical committee 73: Short-circuit currents.

This technical report shall be read in conjunction with IEC 60909-0.

The text of this technical report is based on the following documents:

Enquiry draft	Report on voting
73/120/DTR	73/125/RVC

Full information on the voting for the approval of this technical report can be found in the report on voting indicated in the above table.

This publication has been drafted in accordance with the ISO/IEC Directives, Part 3.

This document, which is purely informative, is not to be regarded as an International Standard.

The committee has decided that the contents of this publication will remain unchanged until 2010. At this date, the publication will be

- reconfirmed;
- withdrawn;
- replaced by a revised edition, or
- amended.

SHORT-CIRCUIT CURRENTS IN THREE-PHASE AC SYSTEMS –

Part 1: Factors for the calculation of short-circuit currents according to IEC 60909-0

1 General

1.1 Scope and object

This part of IEC 60909 is a technical report applicable to short-circuit currents in three-phase a.c. systems. This technical report aims at showing the origin and the application, as far as necessary, of the factors used to meet the demands of technical precision and simplicity when calculating short-circuit currents according to IEC 60909-0.

Thus this technical report is an addition to IEC 60909-0. It does not, however, change the basis for the standardized calculation procedure given in IEC 60909-0.

NOTE References are given in some cases to offer additional help, not to change the procedure laid down in the standard.

1.2 Reference documents

IEC 60038:1983, *IEC standard voltages*

IEC 60909-0:2001, *Short-circuit currents in three-phase a.c. systems – Part 0: Calculation of currents*

IEC/TR 60909-2:1992, *Electrical equipment – Data for short-circuit current calculations in accordance to IEC 60909 (1988)*

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

1.3 Application of the factors

1.3.1 Factor c

The voltage factors $c_{\max}$ and $c_{\min}$ are used together with the equivalent voltage source at the short-circuit location in order to calculate maximum and minimum initial short-circuit currents (see 2.1).

1.3.2 Factors K_G and K_S or K_{SO}

The impedance correction factors K_G and K_S or K_{SO} are introduced when calculating the short-circuit impedances of generators and power station units (with or without on-load tap changer) (see 2.2).

1.3.3 Factors $K_{G,S}$, $K_{T,S}$ or $K_{G,SO}$, $K_{T,SO}$

The impedance correction factors $K_{G,S}$, $K_{T,S}$ or $K_{G,SO}$, $K_{T,SO}$ are introduced when calculating the partial short-circuit currents in case of a short circuit between generator and unit transformer (with or without on-load tap changer) of a power station unit (see 2.2.3.2 or 2.2.4.2).

1.3.4 Factor K_T

The impedance correction factor K_T is used when calculating the short-circuit impedances of network transformers (see 2.3).

1.3.5 Factor κ

The peak short-circuit current is calculated by using this factor (see 2.4).

1.3.6 Factors μ, λ and q

Factors used when calculating the decay of the a.c. component of the short-circuit current of a near-to-generator or a near-to-asynchronous-motor short circuit (see 2.5, 2.6 and 2.7).

1.3.7 Factors m and n

The factors m and n are used for the calculation of the Joule integral or the thermal equivalent short-circuit current (see 2.8).

1.3.8 Contribution of asynchronous motors to the initial symmetrical short-circuit current

Derivation and validity of relevant equations for checking the contribution of asynchronous motors or groups of asynchronous motors to the initial symmetrical short-circuit current (see 2.9).

1.4 Symbols, subscripts and superscripts

The following symbols, subscripts and superscripts are used in addition to those already defined in IEC 60909-0.

1.4.1 Symbols

E	Voltage behind the synchronous direct axis reactance X_d of a synchronous machine
E'	Voltage behind the transient direct axis reactance X'_d of a synchronous machine
E''	Voltage behind the subtransient direct axis reactance X''_d of a synchronous machine
E''_Q	Subtransient voltage behind the impedance of a network feeder connected at Q
$E_0(I_\mathrm{f})$	Terminal voltage of a saturated synchronous machine at no-load (I_G = 0)
I^b	Branch current (load current) before the short circuit
I_f	Field current of a synchronous machine
$i_\mathrm{k}(t)$	Time-dependent short-circuit current
$I''_{\mathrm{kU}^\mathrm{b}}$	Initial symmetrical short-circuit current caused by the voltage $-U^\mathrm{b}$, when calculating short-circuit currents using the superposition method
p_G or p_T	Relative values to define the region for the variation of terminal voltages, for instance $U_\mathrm{G} = U_\mathrm{rG}\,(1 \pm p_\mathrm{G})$ or $U_\mathrm{THV} = U_\mathrm{rTHV}\,(1 \pm p_\mathrm{T})$
T_AC	AC time constant of an asynchronous motor
T''_N	Mean value of the time constants T''_dN and T''_qN
$T_{\mu q}$	Time constant calculated with the product μq (see 2.7.2)
t_p	Time duration from the beginning of a short circuit until the peak short-circuit current
U^b	Voltage at the short-circuit location before the short circuit
X_p	Potier reactance
Y	Admittance
γ	Impedance angle
Δ	Deviation
φ_U	Voltage angle

1.4.2 Subscripts

0	No load (T''_{d0})
a	Approximation
ad	Admissible
d	Direct axis
e	Exact
f	Field of the synchronous machine
IEC	according to IEC 60909-0, for example $K_{S(IEC)}$
i	Internal
L	Load
MAX	Maximum (short-circuit current at worst-case load flow)
N	Network
q	Quadrature axis
S	Superposition method
*	Per unit quantity

1.4.3 Superscripts

b	Before
'	Transient
"	Subtransient

2 Factors used in IEC 60909-0

2.1 Voltage factor *c* for the equivalent voltage source at the short-circuit location

2.1.1 General

The magnitude of a short-circuit current in a three-phase a.c. system (maximum or minimum short-circuit current) at any location depends primarily on the network configuration, the generators or power-station units and the motors in operation and secondarily on the operational stage of the network before the short circuit.

The variations during operation in a three-phase a.c. system are very large. Therefore, it is difficult to find the special load flow that leads either to a maximum or to a minimum short-circuit current at the different locations of the network. In a given system, there are as many different short-circuit current magnitudes as there are possible different load-flow conditions for every location. Normally, extreme load-flow cases are not empirically known.

IEC 60909-0 therefore recommends a calculation method with the equivalent voltage source $cU_n / \sqrt{3}$ at the short-circuit location. This method, described in IEC 60909-0, is an approximation method without special conditions of operation. The aim of this standard is to find the maximum short-circuit currents with sufficient accuracy, mainly taking into account safety aspects and as far as possible economical aspects.

During the planning stage of a network, the different future load-flow conditions are unknown. Therefore, the equivalent voltage source $cU_n / \sqrt{3}$ is based on the nominal system voltage U_n and the voltage factor $c = c_{max}$ or $c = c_{min}$ for the calculation of the maximum or the minimum short-circuit currents. These factors c are given in table 1 of IEC 60909-0. The introduction of a voltage factor c is necessary for various reasons (IEC 60909-0, 1.3.15). These are:

- voltage variation depending on time and place;
- changing of transformer taps;

- neglecting loads and capacitances by calculating according to IEC 60909-0 (see 2.3.1);
- the subtransient behaviour of generators, power-station units and motors.

The meaning of the voltage factor c is illustrated for a simple model of a radial network in 2.1.4. Furthermore, results of extended calculations given in 2.2.5 and 2.3.4 demonstrate the possible deviations of calculations with the equivalent voltage source at the short-circuit location against the worst-case values found with a special procedure using the superposition method.

2.1.2 Calculation methods

In principle, there are two methods for the calculation of the initial symmetrical short-circuit current at the short-circuit location (IEC 60909-0, figures 1 and 2):

- the superposition method, derived from Helmholtz´s or Thevenin´s principle;
- the method using the equivalent voltage source at the short-circuit location (see 2.1.3).

Examples for the superposition method are given in 2.2 and 2.3. There the results of the superposition method are compared with the results found with the method using the equivalent voltage source at the short-circuit location.

If a certain load flow in an existing network is known, then it is possible to calculate the initial symmetrical short-circuit current with the superposition method, but this method gives the short-circuit current only related to the load flow presupposed. Therefore, it does not necessarily lead to the maximum short-circuit current. The reason is that for one short-circuit location there are as many short-circuit currents as load-flow conditions without exceeding the boundary conditions of voltages and currents during normal operation, even if the same operational voltage at the short-circuit location is given.

To overcome this problem and to find the worst-case load flow that leads to the maximum short-circuit current at one short-circuit location, a special method was developed by varying the operation conditions [9], [13], [26][1]. Further information is given in 2.2.5 and 2.3.4.

2.1.3 Equivalent voltage source at the short-circuit location and voltage factor c

The procedure for the calculation of the initial symmetrical short-circuit current using the equivalent voltage source at the short-circuit location is described in IEC 60909-0. This method, which is normally based only on the rated data of electrical equipment, is an essential simplification compared to the superposition method or a transient calculation, because also in this case it is necessary to know the load-flow conditions before the short circuit.

Using this simplified procedure, the equivalent voltage source $cU_\mathrm{n}/\sqrt{3}$ at the short-circuit location is the only active voltage in the positive-sequence system. All network feeders, synchronous machines and asynchronous motors are short-circuited behind their internal (subtransient) reactances (IEC 60909-0, 3.6.1). All the shunt capacitances and the shunt admittances (loads), except those of the motors, are to be omitted in the positive- and the negative-sequence system (IEC 60909-0, 2.3). Capacitances of the zero-sequence system are to be considered in general. The zero-sequence capacitances are to be omitted in low-voltage systems and in high-voltage effectively grounded systems (i.e. earth fault factor $\delta \leq 1,4$). Special considerations are necessary in high-voltage networks with long-distance lines and, of course, in the case of isolated neutral or resonant earthed networks (IEC 60909-0, 1.1). An example for the application of the calculation using the equivalent voltage source at the short-circuit location F is given in IEC 60909-0, figure 4.

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[1] The figures in square brackets refer to the bibliography.

The factor $c_{\max}$ or $c_{\min}$ is introduced according to table 1 of IEC 60909-0. Corresponding to $c_{\max}$ or $c_{\min}$ special conditions are introduced for the calculation of the maximum and minimum short-circuit currents (see IEC 60909-0, 2.4 and 2.5). The introduction of the voltage factor c aims at finding a short-circuit current, for instance, a maximum short-circuit current, as near as possible to the real value. Using the impedance correction factors (IEC 60909-0, 3.3.3, 3.6.1, 3.7.1 and 3.7.2) together with the voltage factor c realistic values even for the partial short-circuit currents shall be obtained, even though compromises are necessary to a certain extent (see 2.2.5).

The following clause deals with the reliability of the method using the equivalent voltage source at the short-circuit location and gives the fundamental relation between the admissible or usual relative voltage drops Δu and the maximum possible deviation $\Delta i_{\mathrm{k}}''$ and furthermore the dependence of the factor $c_{\max}$ from the voltage U_{Qmax}.

2.1.4 A simple model illustrating the meaning of the voltage factor *c*

The following simple model in figure 1 illustrates the fundamental meaning of the voltage factor c in the case of a non-meshed radial network, for instance, in a distribution network. Complex models and their calculation results used to find the coherence between the relative voltage deviations Δu and the voltage factor c are given in [10] and [17].

The positive-sequence system of the model in figure 1a is given in figure 1b. It is presumed that the voltage U_{Q} at the beginning of the line is constant ($\underline{I}_{\mathrm{kQ}}'' \Rightarrow \infty$). The load is concentrated and simulated by the shunt impedance $\underline{Z}_{\mathrm{A}}$ at the variable location A between the line impedances $\alpha \underline{Z}_{\mathrm{L}}$ and $(1-\alpha)\underline{Z}_{\mathrm{L}}$ with $0 \le \alpha \le 1$.

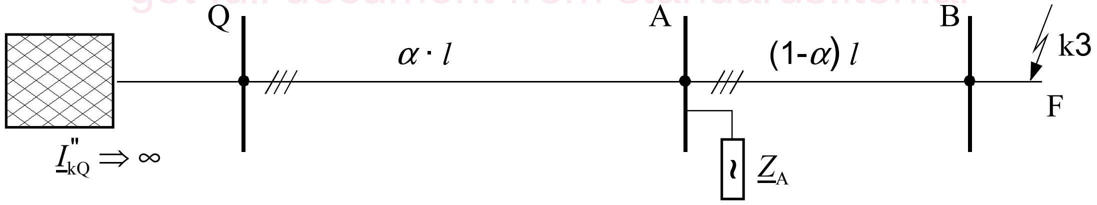

Figure 1a – Three-phase a.c. model (non-meshed radial network)

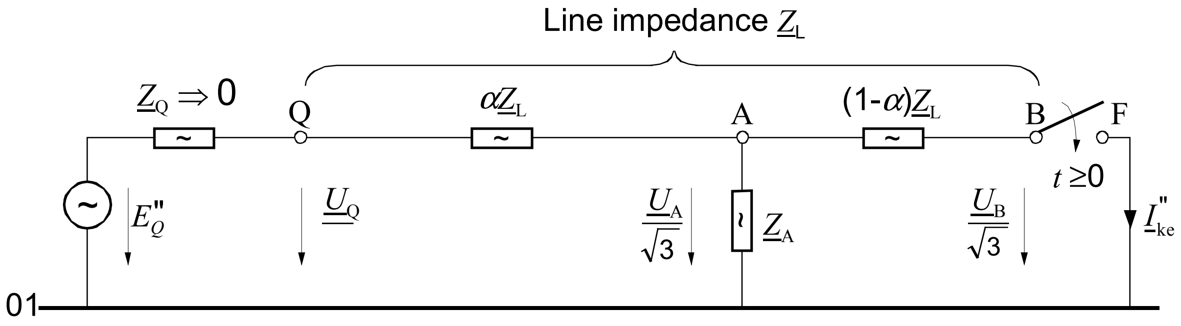

Figure 1b – Equivalent circuit diagram, positive-sequence system, before the short circuit at F

Figure 1 – Model for the calculation of the coherence between the voltage deviation Δu and the short-circuit current deviation $\Delta i_{\mathrm{k}}''$

It shall be shown that the short-circuit current deviation $\Delta i''_{\mathrm{k}}$ depends on the voltage deviation Δu. The following definitions are used:

$$\Delta u = \left| \frac{\underline{U}_{\mathrm{Q}}}{\underline{U}_{\mathrm{B}}} \right| - 1 \tag{1}$$

$$\Delta i''_{\mathrm{k}} = \left| \frac{\underline{I}''_{\mathrm{ka}}}{\underline{I}''_{\mathrm{ke}}} \right| - 1 \tag{2}$$

where

a is the subscript for the approximation of the short-circuit current when $\underline{Z}_{\mathrm{A}}$ is neglected;

e is the subscript for the exact value of the short-circuit current when $\underline{Z}_{\mathrm{A}}$ is taken into account.

The following equation, giving the voltage conditions before the short circuit, can be derived from figure 1b if $\underline{U}_{\mathrm{Q}}$ is taken as a constant value:

$$\underline{U}_{\mathrm{Q}} = \underline{U}_{\mathrm{A}}(1 + \alpha \underline{Z}_{\mathrm{L}} \underline{Y}_{\mathrm{A}}) = \underline{U}_{\mathrm{B}}(1 + \alpha \underline{Z}_{\mathrm{L}} \underline{Y}_{\mathrm{A}}) \tag{3}$$

with $\underline{U}_{\mathrm{A}} = \underline{U}_{\mathrm{B}}$ (see figure 1b) and $\underline{Y}_{\mathrm{A}} = 1/\underline{Z}_{\mathrm{A}}$.

Using equation (3) the voltage deviation can be expressed as follows:

$$\Delta u = \left| \frac{\underline{U}_{\mathrm{Q}}}{\underline{U}_{\mathrm{B}}} \right| - 1 = \left| 1 + \alpha \underline{Z}_{\mathrm{L}} \underline{Y}_{\mathrm{A}} \right| - 1 \tag{4}$$

The exact value of the initial symmetrical short-circuit current can be calculated with the help of figure 1b:

$$\underline{I}''_{\mathrm{ke}} = \underline{I}_{\mathrm{Q}} \cdot \frac{1}{1 + (1 - \alpha)\underline{Z}_{\mathrm{L}} \underline{Y}_{\mathrm{A}}} \tag{5a}$$

with

$$\underline{I}_{\mathrm{Q}} = \frac{\underline{U}_{\mathrm{Q}}}{\sqrt{3}\,\underline{Z}_{\mathrm{L}}} \cdot \frac{1}{\alpha + \dfrac{(1 - \alpha)}{1 + (1 - \alpha)\underline{Z}_{\mathrm{L}} \underline{Y}_{\mathrm{A}}}} \tag{5b}$$

Introducing $\underline{I}_{\mathrm{Q}}$ from equation (5b) to equation (5a) leads to

$$\underline{I}''_{\mathrm{ke}} = \frac{\underline{U}_{\mathrm{Q}}}{\sqrt{3}\,\underline{Z}_{\mathrm{L}}} \cdot \frac{1}{1 + \alpha(1 - \alpha)\underline{Z}_{\mathrm{L}} \underline{Y}_{\mathrm{A}}} \tag{6}$$

The approximation $\underline{I}''_{\mathrm{ka}}$ is found from figure 1b with $\underline{Z}_{\mathrm{A}} = \infty$ (or $\underline{Y}_{\mathrm{A}} = 0$) and the voltage $\underline{U}_{\mathrm{B}}$ at the prospective short-circuit location, using equation (3):

$$\underline{I}''_{\mathrm{ka}} = \frac{\underline{U}_{\mathrm{B}}}{\sqrt{3}\,\underline{Z}_{\mathrm{L}}} = \frac{\underline{U}_{\mathrm{Q}}}{\sqrt{3}\,\underline{Z}_{\mathrm{L}}} \cdot \frac{1}{1 + \alpha \underline{Z}_{\mathrm{L}} \underline{Y}_{\mathrm{A}}} \tag{7}$$