IEC 60909-3

Edition 3.0 2009-03

INTERNATIONAL STANDARD

NORME INTERNATIONALE

**Short-circuit currents in three-phase AC systems –
Part 3: Currents during two separate simultaneous line-to-earth short circuits and partial short-circuit currents flowing through earth**

**Courants de court-circuit dans les réseaux triphasés à courant alternatif –
Partie 3: Courants durant deux courts-circuits monophasés simultanés séparés à la terre et courants de court-circuit partiels s'écoulant à travers la terre**

IEC 60909-3:2009

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IEC 60909-3

Edition 3.0 2009-02

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INTERNATIONAL ELECTROTECHNICAL COMMISSION

COMMISSION ELECTROTECHNIQUE INTERNATIONALE

PRICE CODE
CODE PRIX XA

ICS 17.220.01; 29.240.20

ISBN 978-2-88910-328-7

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INTERNATIONAL ELECTROTECHNICAL COMMISSION

SHORT-CIRCUIT CURRENTS IN THREE-PHASE AC SYSTEMS –

Part 3: Currents during two separate simultaneous line-to-earth short circuits and partial short-circuit currents flowing through earth

FOREWORD

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International Standard IEC 60909-3 has been prepared by IEC technical committee 73: Short-circuit currents.

This International Standard is to be read in conjunction with IEC 60909-0.

This third edition cancels and replaces the second edition published in 2003. This edition constitutes a technical revision.

The main changes with respect to the previous edition are listed below:

– New procedures are introduced for the calculation of reduction factors of the sheaths or shields and in addition the current distribution through earth and the sheaths or shields of three-core cables or of three single-core cables with metallic non-magnetic sheaths or shields earthed at both ends;
– The information for the calculation of the reduction factor of overhead lines with earth wires are corrected and given in the new Clause 7;

– A new Clause 8 is introduced for the calculation of current distribution and reduction factor of three-core cables with metallic sheath or shield earthed at both ends;
– The new Annexes C and D provide examples for the calculation of reduction factors and current distribution in case of cables with metallic sheath and shield earthed at both ends.

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

FDIS	Report on voting
73/148/FDIS	73/149/RVD

Full information on the voting for the approval of this standard 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 2.

A list of all parts of the IEC 60909 series, published under the general title *Short-circuit currents in three-phase a.c. systems*, can be found on the IEC website.

The committee has decided that the contents of this publication will remain unchanged until the maintenance result date indicated on the IEC web site under "http://webstore.iec.ch" in the data related to the specific publication. At this date, the publication will be

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

The contents of the corrigendum of September 2013 have been included in this copy.

SHORT-CIRCUIT CURRENTS IN THREE-PHASE AC SYSTEMS –

Part 3: Currents during two separate simultaneous line-to-earth short circuits and partial short-circuit currents flowing through earth

1 Scope and object

This part of IEC 60909 specifies procedures for calculation of the prospective short-circuit currents with an unbalanced short circuit in high-voltage three-phase a.c. systems operating at nominal frequency 50 Hz or 60 Hz, i. e.:

a) currents during two separate simultaneous line-to-earth short circuits in isolated neutral or resonant earthed neutral systems;

b) partial short-circuit currents flowing through earth in case of single line-to-earth short circuit in solidly earthed or low-impedance earthed neutral systems.

The currents calculated by these procedures are used when determining induced voltages or touch or step voltages and rise of earth potential at a station (power station or substation) and the towers of overhead lines.

Procedures are given for the calculation of reduction factors of overhead lines with one or two earth wires.

The standard does not cover:

a) short-circuit currents deliberately created under controlled conditions as in short circuit testing stations, or

b) short-circuit currents in the electrical installations on board ships or aeroplanes, or

c) single line-to-earth fault currents in isolated or resonant earthed systems.

The object of this standard is to establish practical and concise procedures for the calculation of line-to-earth short-circuit currents during two separate simultaneous line-to-earth short circuits and partial short-circuit currents through earth, earth wires of overhead lines and sheaths or shields of cables leading to conservative results with sufficient accuracy. For this purpose, the short-circuit currents are determined by considering an equivalent voltage source at the short-circuit location with all other voltage sources set to zero. Resistances of earth grids in stations or footing resistances of overhead line towers are neglected, when calculating the short-circuit currents at the short-circuit location.

This standard is an addition to IEC 60909-0. General definitions, symbols and calculation assumptions refer to that publication. Special items only are defined or specified in this standard.

The calculation of the short-circuit currents 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. The procedure is suitable for determination by manual methods or digital computation. This does not exclude the use of special methods, for example the super-position method, adjusted to particular circumstances, if they give at least the same precision.

As stated in IEC 60909-0, short-circuit currents and their parameters may also be determined by system tests.

2 Normative references

The following referenced documents are indispensable for the application of this document. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

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

IEC/TR 60909-2:2008, *Short-circuit currents in three-phase a.c. systems – Part 2: Data of electrical equipment for short-circuit current calculations*

3 Terms and definitions

For the purposes of this document, the following terms and definitions apply.

3.1
two separate simultaneous line-to earth short circuits
line-to-earth short circuits at different locations at the same time on different conductors of a three-phase a.c. network having a resonant earthed or an isolated neutral

3.2
initial short-circuit currents during two separate simultaneous line-to-earth short circuits I''_{kEE}
r.m.s value of the initial short-circuit currents flowing at both short-circuit locations with the same magnitude

3.3
partial short-circuit current through earth $I_{\mathrm{E}\delta}$
r.m.s. value of the current flowing through earth in a fictive line in the equivalent earth penetration depth δ

NOTE In case of overhead lines remote from the short-circuit location and the earthing system of a station, where the distribution of the current between earthed conductors and earth is nearly constant, the current through earth depends on the reduction factor of the overhead line (Figures 4 and 5). In case of cables with metallic sheaths or shields, earthed at both ends in the stations A and B, current through earth between the stations A and B (Figures 9a) and 10a)), respectively between the short-circuit location and the stations A or B (Figures 9b) and 10b)).

3.4
total current to earth I_{ETtot} **at the short-circuit location on the tower T of an overhead line**
r. m. s. value of the current flowing to earth through the footing resistance of an overhead line tower far away from a station connected with the driving point impedances of the overhead line at both sides, see Figure 5

3.5
total current to earth I_{EBtot} **at the short-circuit location in the station B**
r.m.s. value of the current flowing to earth through the earthing system of a station B (power station or substation) with connected earthed conductors (earth wires of overhead lines or sheaths or shields or armouring of cables or other earthed conductors as for instance metallic water pipes), see Figure 4

3.6
current to earth $I_{\mathrm{ET}n}$
r.m.s. value of the current flowing to earth causing the potential rise at an overhead line tower n in the vicinity of a station

3.7
current to earth $I_{\mathrm{EB}n}$
r.m.s. value of the current flowing to earth causing the potential rise $U_{\mathrm{EB}n}$ of a station B, in case of a line-to-earth short circuit at an overhead line tower n in the vicinity of the station B

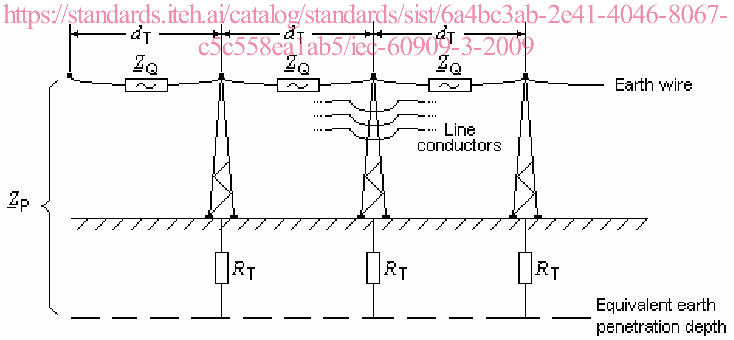
3.8
reduction factor r
for overhead lines, which determines the part of the line-to-earth short-circuit current flowing through the earth remote from the short-circuit location and the earthing systems of the stations

3.9
reduction factor r_1
for three-core cables with metallic sheath or shield earthed at both ends

3.10
reduction factor r_3
for three single-core cables with metallic sheaths or shields earthed at both ends

3.11
driving point impedance Z_{P} of an infinite chain
composed of the earth-wire impedance $\underline{Z}_{\mathrm{Q}}$ between two towers with earth return and the footing resistance R_{T} of the overhead line towers (Figure 1):

$$\underline{Z}_{\mathrm{P}} = 0{,}5\underline{Z}_{\mathrm{Q}} + \sqrt{(0{,}5\underline{Z}_{\mathrm{Q}})^2 + R_{\mathrm{T}}\underline{Z}_{\mathrm{Q}}} \qquad (1)$$



IEC 160/09

Figure 1 – Driving point impedance $\underline{Z}_{\mathrm{P}}$ of an infinite chain, composed of the earth wire impedance $\underline{Z}_{\mathrm{Q}} = \underline{Z}'_{\mathrm{Q}} d_{\mathrm{T}}$ and the footing resistance R_{T} of the towers, with equal distances d_{T} between the towers

The driving point impedance $\underline{Z}_{\mathrm{P}}$ can be assumed constant at a distance from the short-circuit location F longer than the far-from-station distance D_{F} defined by Equation (19).

3.12
driving point impedance $Z_{\mathrm{P}n}$ of a finite chain
with n towers of an overhead line as given in Figure 2 and with the impedance $\underline{Z}_{\mathrm{EB}}$ at the end, calculated according to Equation (2).

$$\underline{Z}_{\mathrm{P}n} = \frac{\underline{Z}_{\mathrm{P}}(\underline{Z}_{\mathrm{EB}} + \underline{Z}_{\mathrm{P}})\underline{k}^{n} + (\underline{Z}_{\mathrm{P}} - \underline{Z}_{\mathrm{Q}})(\underline{Z}_{\mathrm{EB}} - \underline{Z}_{\mathrm{P}} + \underline{Z}_{\mathrm{Q}})\underline{k}^{-n}}{(\underline{Z}_{\mathrm{EB}} + \underline{Z}_{\mathrm{P}})\underline{k}^{n} - (\underline{Z}_{\mathrm{EB}} - \underline{Z}_{\mathrm{P}} + \underline{Z}_{\mathrm{Q}})\underline{k}^{-n}} \qquad (2)$$

with

$$\underline{k} = 1 + \frac{\underline{Z}_P}{R_T} \tag{3}$$

NOTE For $n \to \infty$, Equation (2) is leading to Equation (1). In practical cases, this is true already for $n \approx 10 \dots 15$.

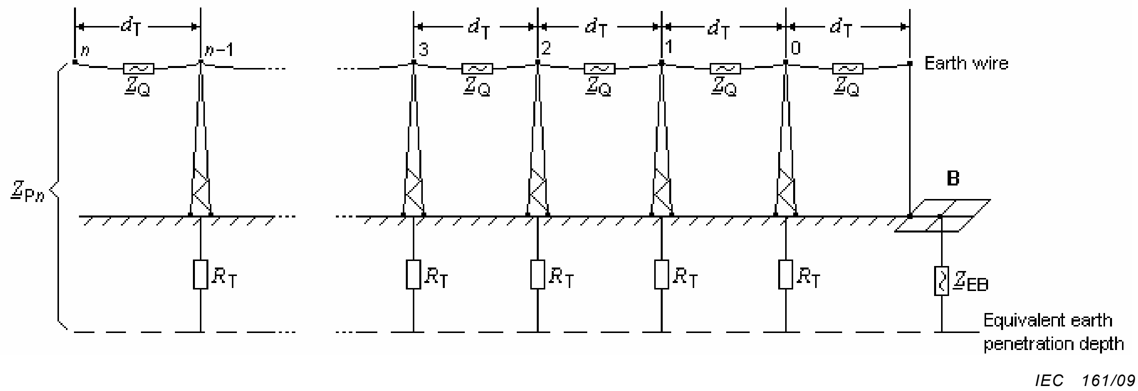


Figure 2 – Driving point impedance $\underline{Z}_{Pn}$ of a finite chain with n towers, composed of the earth wire impedance $\underline{Z}_Q = \underline{Z}'_Q d_T$, the footing resistance R_T of the towers, with equal distances d_T between the towers and the earthing impedance $\underline{Z}_{EB}$ of station B from Equation (29)

4 Symbols

All equations are written as quantity equations, in which the symbols represent physical quantities possessing both numerical values and dimensions. Symbols of complex quantities are underlined in the text and equations of this standard.

$cU_n / \sqrt{3}$	Equivalent voltage source (IEC 60909-0)
D_F	Far-from-station distance (Equation (19))
d_T	Distance between two towers
d_{L1L2}	Distance between the line conductors L1 and L2
d_{Q1Q2}	Distance between the earth wires Q1 and Q2
I_{bEE}	Short circuit breaking current in case of two separate simultaneous line-to-earth short circuits
$\underline{I}_E$	Current flowing to earth ($\underline{I}_{EA}$, $\underline{I}_{EB}$, $\underline{I}_{EC}$ and $\underline{I}_{ET}$ in the Figures 4, 5, 7)
$\underline{I}_{EBn}$	Current to earth in station B with a short-circuited tower n in the vicinity of station B (Figure 7)
$\underline{I}_{EBtot}$	Total current to earth in the station B if a short circuit with earth connection occurs in station B (Figure 4)
$\underline{I}_{ETn}$	Current to earth at the short-circuited tower n in the vicinity of a station (Figure 7)
$\underline{I}_{ETtot}$	Total current to earth at a short-circuited tower T far away from stations (see Figure 5)
I''_{kEE}	Initial symmetrical short-circuit current in case of two separate simultaneous line-to-earth short circuits
$\underline{I}''_{kE2E}$	Initial symmetrical short-circuit current flowing to earth in the case of a line-to-line short circuit with earth connection (IEC 60909-0)

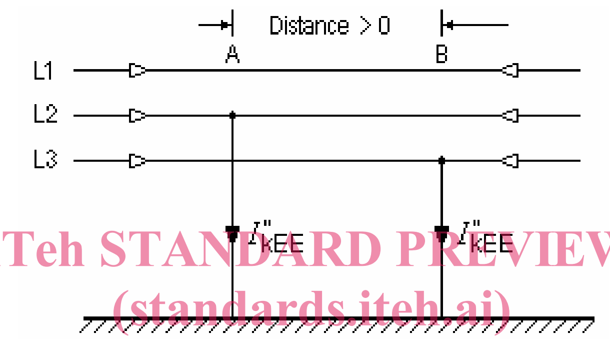
$I_{E\delta}$	Partial short-circuit current flowing through earth (for instance in Figure 4: $\underline{I}_{E\delta A} = \underline{r}_A \times 3\underline{I}_{(0)A}$ or in Figure 9b): Current $\underline{I}_{E\delta A}$ flowing back to the station A according to Equation (45))
I_Q	Earth wire current
I_S	Current in the sheath or shield of a cable (in case of three single-core cables: I_{S1}, I_{S2} and I_{S3})
I_T	Partial short-circuit current through the footing resistance R_T of an overhead line tower
i_{pEE}	Peak short-circuit current in case of two separate simultaneous line-to-earth short circuits
$M_{(1)}, M_{(2)}$	Coupling impedances in the positive- and the negative-sequence system
R_{EA}, R_{EB}	Resistance of the earth grid in the station A or B
R_{EF}	Resistance to earth at the short-circuit location of a cable (Figure 9b) or 10b))
R_T	Footing resistance of an overhead line tower
r	Reduction factor for overhead line with earth wires
r_1	Reduction factor of the sheath or shield of a three-core cable (Figure 9a))
r_3	Reduction factor of the sheaths or shields of three single core cables (Figure 10a))
r_Q	Earth wire radius
r_S	Radius of the metallic sheath or shield of a cable (medium value)
$Z_{(1)A}, Z_{(1)B}$	Positive-sequence short-circuit impedance of a three-phase a.c. system at the connection point A, B (Annex B)
$Z_{(0)}$	Zero-sequence short-circuit impedance of the entire network between the short-circuit locations A and B (admittances between line conductors and earth are disregarded)
Z_{EB}	Earthing impedance of a station B according to Equation (29)
Z_{EBtot}	Total earthing impedance of a station B according to Equation (17)
Z_{ET}	Earthing impedance of the short-circuited tower according to Equation (28)
Z_{ETtot}	Total earthing impedance of the short-circuited tower according to Equation (23)
Z_P	Driving point impedance of an infinite chain (Equation (1) and Figure 1)
Z_{Pn}	Driving point impedance of a finite chain (Equation (2) and Figure 2)
$Z_Q = Z_Q' d_T$	Earth-wire impedance between two towers with earth return
Z_Q'	Earth-wire impedance per unit length with earth return
Z_{QL}'	Mutual impedance per unit length between earth wire and line conductors with earth return
Z_S'	Impedance per unit length of a metallic sheath or shield with earth return
Z_{SL}'	Mutual impedance per unit length between the sheath (or the shield) and a core inside the sheath (or the shield) of a cable with earth return
Z_U	Input impedance of sheaths, shields or armouring of cables or other metallic pipes or pipelines (Equation (17))

δ	Equivalent earth penetration depth (Equation (36))
μ_0	Magnetic constant, $\mu_0 = 4\pi \times 10^{-7}$ Vs/Am
ρ	Resistivity of the soil
ω	Angular frequency, $\omega = 2\pi f$ (f = 50 Hz or 60 Hz)

5 Calculation of currents during two separate simultaneous line-to-earth short circuits

5.1 Initial symmetrical short-circuit current

Figure 3 shows the short-circuit current I''_{kEE} during two separate simultaneous line-to-earth short circuits on different line conductors at the locations A and B with a finite distance between them. It is assumed that the locations A and B are far from stations.



IEC 162/09

NOTE The direction of current arrows is chosen arbitrarily.

Figure 3 – Characterisation of two separate simultaneous line-to earth short circuits and the currents I''_{kEE}

In networks with isolated or with resonant earthed neutral the initial symmetrical short-circuit current I''_{kEE} is calculated with

$$I''_{\text{kEE}} = \frac{3cU_{\text{n}}}{\left|\underline{Z}_{(1)\text{A}} + \underline{Z}_{(2)\text{A}} + \underline{Z}_{(1)\text{B}} + \underline{Z}_{(2)\text{B}} + \underline{M}_{(1)} + \underline{M}_{(2)} + \underline{Z}_{(0)}\right|} \tag{4}$$

NOTE For derivation of Equation (4) see ITU-T – *Directives concerning protection of telecommunication lines against harmful effects from electric power and electrified railway lines, Volume V: Inducing currents and voltages in power transmission and distribution systems*, 1999.

In case of a far-from-generator short circuit, where $\underline{Z}_{(1)} = \underline{Z}_{(2)}$ and $\underline{M}_{(1)} = \underline{M}_{(2)}$, the initial short-circuit current becomes

$$I''_{\text{kEE}} = \frac{3cU_{\text{n}}}{\left|2\underline{Z}_{(1)\text{A}} + 2\underline{Z}_{(1)\text{B}} + 2\underline{M}_{(1)} + \underline{Z}_{(0)}\right|} \tag{5}$$

5.1.1 Determination of $\underline{M}_{(1)}$ and $\underline{M}_{(2)}$

The positive- and the negative-sequence coupling impedances $\underline{M}_{(1)}$ and $\underline{M}_{(2)}$ are determined as follows:

A voltage source is introduced at the short-circuit location A as the only active voltage of the network. If $\underline{I}_{(1)\mathrm{A}}$ and $\underline{I}_{(2)\mathrm{A}}$ are the currents due to this voltage source in the positive- and the negative-sequence system at the short-circuit location A, and if $\underline{U}_{(1)\mathrm{B}}$ and $\underline{U}_{(2)\mathrm{B}}$ are the resulting voltages in the positive- and negative-sequence system at the location B, then

$$\underline{M}_{(1)} = \frac{\underline{U}_{(1)\mathrm{B}}}{\underline{I}_{(1)\mathrm{A}}} \qquad \underline{M}_{(2)} = \frac{\underline{U}_{(2)\mathrm{B}}}{\underline{I}_{(2)\mathrm{A}}} \tag{6}$$

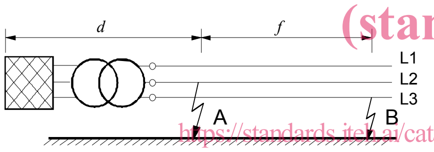
The coupling impedances may also be determined at the short-circuit location B instead of A

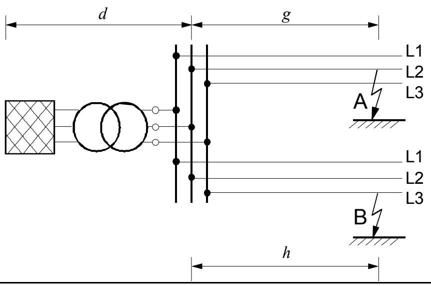
$$\underline{M}_{(1)} = \frac{\underline{U}_{(1)\mathrm{A}}}{\underline{I}_{(1)\mathrm{B}}} \qquad \underline{M}_{(2)} = \frac{\underline{U}_{(2)\mathrm{A}}}{\underline{I}_{(2)\mathrm{B}}} \tag{7}$$

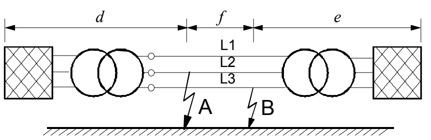
5.1.2 Simple cases of two separate simultaneous line-to-earth short circuits

In simple cases, the current I''_{kEE} can be calculated as shown in Table 1, if $\underline{Z}_{(1)}$ = $\underline{Z}_{(2)}$ and $\underline{M}_{(1)}$ = $\underline{M}_{(2)}$ (far-from-generator short circuit). Equations (8) to (10) are derived from Equation (5). The indices in these equations refer to the relevant impedances in the respective network.

Table 1 – Calculation of initial line-to-earth short-circuit currents in simple cases

<table>
<tr><td>a)</td><td>
</td><td>Single-fed radial line

$$I''_{\mathrm{kEE}} = \frac{3cU_{\mathrm{n}}}{\left|6\underline{Z}_{(1)\mathrm{d}} + 2\underline{Z}_{(1)\mathrm{f}} + \underline{Z}_{(0)\mathrm{f}}\right|} \tag{8}$$</td></tr>
<tr><td>b)</td><td>
</td><td>Two single-fed radial lines

$$I''_{\mathrm{kEE}} = \frac{3cU_{\mathrm{n}}}{\left|6\underline{Z}_{(1)\mathrm{d}} + 2(\underline{Z}_{(1)\mathrm{g}} + \underline{Z}_{(1)\mathrm{h}}) + \underline{Z}_{(0)\mathrm{g}} + \underline{Z}_{(0)\mathrm{h}}\right|} \tag{9}$$</td></tr>
<tr><td>c)</td><td>
</td><td>Double-fed single line

$$I''_{\mathrm{kEE}} = \frac{3cU_{\mathrm{n}}}{\left|\dfrac{6\underline{Z}_{(1)\mathrm{d}}\underline{Z}_{(1)\mathrm{e}} + 2\underline{Z}_{(1)\mathrm{f}}(\underline{Z}_{(1)\mathrm{d}} + \underline{Z}_{(1)\mathrm{e}})}{\underline{Z}_{(1)\mathrm{d}} + \underline{Z}_{(1)\mathrm{f}} + \underline{Z}_{(1)\mathrm{e}}} + \underline{Z}_{(0)\mathrm{f}}\right|} \tag{10}$$</td></tr>
<tr><td colspan="3">The voltage factor, c, shall be taken from Table 1 of IEC 60909-0.</td></tr>
</table>

5.2 Peak short-circuit current, symmetrical short circuit breaking current and steady-state short-circuit current

The peak short-circuit current is calculated according to IEC 60909-0: