# IEC TR 60909-4

Edition 2.0 2021-06

# TECHNICAL REPORT

colour inside

## Short-circuit currents in three-phase AC systems – Part 4: Examples for the calculation of short-circuit currents



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CONTENTS

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# SHORT-CIRCUIT CURRENTS IN THREE-PHASE AC SYSTEMS –

# Part 4: Examples for the calculation of short-circuit currents

## FOREWORD

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IEC TR 60909-4 has been prepared by IEC technical committee 73: Short-circuit currents. It is a Technical Report.

This second edition cancels and replaces the first edition published in 2000. This edition constitutes a technical revision.

This edition includes the following significant technical changes with respect to the previous edition:

a) adaption to IEC 60909-0:2016;
b) addition of an example for the calculation of short-circuit currents of wind power station units;
c) correction of errors.

The text of this Technical Report is based on the following documents:

| Draft | Report on voting |
|---|---|
| 73/187/DTR | 73/193/RVDTR |

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

The language used for the development of this Technical Report is English.

This document was drafted in accordance with ISO/IEC Directives, Part 2, and developed in accordance with ISO/IEC Directives, Part 1 and ISO/IEC Directives, IEC Supplement, available at www.iec.ch/members_experts/refdocs. The main document types developed by IEC are described in greater detail at www.iec.ch/standardsdev/publications.

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

The committee has decided that the contents of this document will remain unchanged until the stability date indicated on the IEC website under webstore.iec.ch in the data related to the specific document. At this date, the document will be

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- withdrawn,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



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# SHORT-CIRCUIT CURRENTS IN THREE-PHASE AC SYSTEMS –

# Part 4: Examples for the calculation of short-circuit currents

## 1 Scope

This part of IEC 60909, which is a Technical Report, is intended to give help for the application of IEC 60909-0 for the calculation of short-circuit currents in 50 Hz or 60 Hz three-phase AC systems.

This document does not include additional requirements but gives support for the modelling of electrical equipment in the positive-sequence, the negative-sequence and the zero-sequence system (Clause 4), the practical execution of calculations in a low-voltage system (Clause 5), a medium-voltage system with asynchronous motors (Clause 6) and a power station unit with its auxiliary network feeding a large number of medium-voltage asynchronous motors and low-voltage motor groups (Clause 7).

The three examples given in Clauses 5, 6 and 7 are similar to those given in IEC TR 60909-4:2000 but they are revised in accordance with IEC 60909-0, which replaces it. The example given in Clause 8 is new and mirrors the introduction of the new 6.8 of IEC 60909-0:2016.

Clause 9 gives the circuit diagram and the data of a test network and the results for a calculation carried out in accordance with IEC 60909-0, to offer the possibility for a comparison between the results found with a digital program for the calculation of short-circuit currents and the given results for $I''_{k}$, $i_{p}$, $I_{b}$, $I_{k}$, $I''_{k1}$ and $i_{p1}$ in a high-voltage network with power station units, generators, asynchronous motors and lines in four different voltage levels 380 kV, 110 kV, 30 kV and 10 kV.



## 2 Normative references

IEC 60038:2009, *IEC standard voltages*

IEC 60909-0:2016, *Short-circuit currents in three-phase a.c. systems – Part 0: Calculation of currents*

## 3 Terms and definitions, symbols and indices, and formulae

For the purposes of this document, the terms and definitions, symbols and indices, and formulae given in IEC 60909-0 apply.

ISO and IEC maintain terminological databases for use in standardization at the following addresses:

- IEC Electropedia: available at http://www.electropedia.org/
- ISO Online browsing platform: available at http://www.iso.org/obp

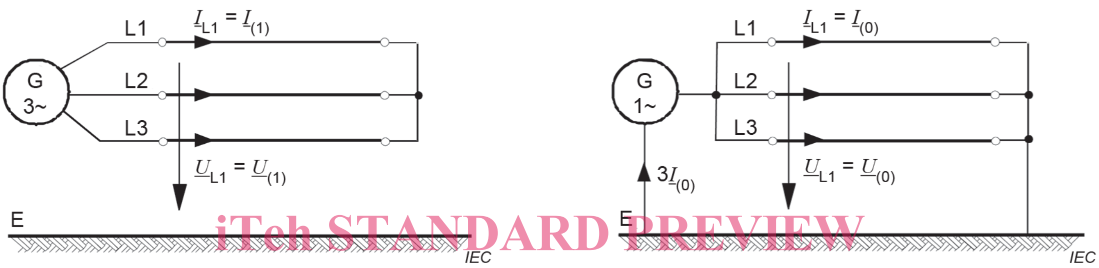
## 4 Positive-sequence, negative-sequence and zero-sequence impedances of electrical equipment

### 4.1 General

In addition to Clause 6 of IEC 60909-0:2016, modelling and calculation of the positive-sequence and the zero-sequence impedances of electrical equipment is given. In most cases, the negative-sequence impedances are equal to the positive-sequence impedances when calculating the initial symmetrical short-circuit currents, but see 6.6.1 of IEC 60909-0:2016 and IEC TR 60909-2.

### 4.2 Overhead lines, cables and short-circuit current-limiting reactors

Figure 1 demonstrates the meaning and the principal measurement of the positive-sequence [Figure 1 a)] and the zero-sequence [Figure 1 b)] impedances of lines with one circuit L1, L2, L3.






a) **Positive-sequence** b) **Zero-sequence**



NOTE Positive-sequence:

$\underline{Z}_{(1)} = \underline{U}_{L1}/\underline{I}_{L1} = \underline{U}_{(1)}/\underline{I}_{(1)}$ with $\underline{U}_{L1} + \underline{U}_{L2} + \underline{U}_{L3} = 0$ and $U_{L1} = U_{L2} = U_{L3}$

Zero-sequence:

$\underline{Z}_{(0)} = \underline{U}_{L1}/\underline{I}_{L1} = \underline{U}_{(0)}/\underline{I}_{(0)}$ with $\underline{U}_{L1} = \underline{U}_{L2} = \underline{U}_{L3} = \underline{U}_{(0)}$ and $\underline{I}_{L1} = \underline{I}_{L2} = \underline{I}_{L3} = \underline{I}_{(0)}$

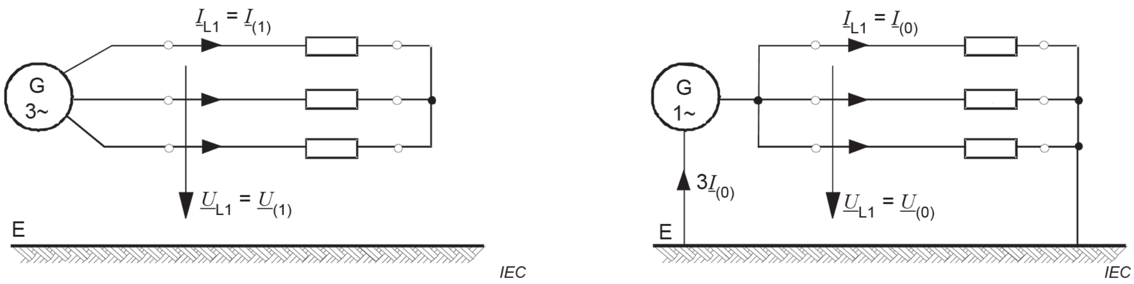
**Figure 1 – Positive-sequence and zero-sequence impedances of an overhead line (one circuit) and cable (cross-bonded)**

In practice, the measurement of voltage $U_{L1}$ and current $I_{L1}$ leads to the absolute value $Z$ of the impedance. Together with the measurement of the total loss $P_V$ at the current $I_{L1}$, it is possible to find the complex value $\underline{Z}$ of the impedance:

$$Z = \frac{U_{L1}}{I_{L1}} \qquad R = \frac{P_V}{3I_{L1}^2} \qquad X = \sqrt{Z^2 - R^2} \qquad \underline{Z} = R + jX$$

Formulae for the calculation of the positive-sequence and the zero-sequence system impedances of overhead lines with one or two parallel circuits (double circuit line) and without or with one or two earth wires are given in IEC TR 60909-2. The negative-sequence impedance is equal to the positive-sequence impedance assuming transposed lines and cross-bonded cables, respectively. The measurements to find the positive-sequence and the zero-sequence impedances of cables with sheath, shielding and armouring are similar to those given in Figure 1. Examples are given in IEC TR 60909-2. In the case of the zero-sequence impedance, the earthing of the sheath or the shielding or the armouring is important as well as the number of parallel cables. In the case of low-voltage four-core cables, the cross-section of the earthed core has an influence on the zero-sequence impedance.

Figure 2 demonstrates the meaning and the principal measurement of the positive-sequence [Figure 2 a)] and the zero-sequence impedance [Figure 2 b)] of a three-phase AC short-circuit current-limiting reactor.




a) **Positive-sequence** b) **Zero-sequence**

NOTE Positive-sequence:

$$\underline{Z}_{(1)} = \underline{U}_{L1}/\underline{I}_{L1} = \underline{U}_{(1)}/\underline{I}_{(1)} \text{ with } \underline{U}_{L1} + \underline{U}_{L2} + \underline{U}_{L3} = 0 \text{ and } U_{L1} = U_{L2} = U_{L3}$$

Zero-sequence:

$$\underline{Z}_{(0)} = \underline{U}_{L1}/\underline{I}_{L1} = \underline{U}_{(0)}/\underline{I}_{(0)} \text{ with } \underline{U}_{L1} = \underline{U}_{L2} = \underline{U}_{L3} = \underline{U}_{(0)} \text{ and } \underline{I}_{L1} = \underline{I}_{L2} = \underline{I}_{L3} = \underline{I}_{(0)}$$

**Figure 2 – Positive-sequence and zero-sequence impedance of a short-circuit current-limiting reactor**



If the magnetic coupling between the three coils without or with iron core is small, the zero-sequence impedance $\underline{Z}_{(0)}$ is approximately equal to the positive-sequence impedance $\underline{Z}_{(1)}$. When calculating short-circuit currents in high-voltage systems, it is generally sufficient to use the reactance only.



## 4.3 Transformers

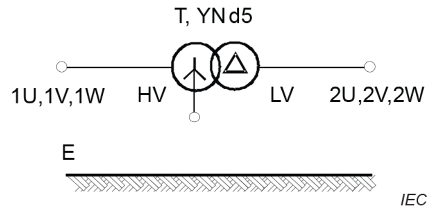
### 4.3.1 General

Unit transformers of power station units are also dealt with in 4.4.

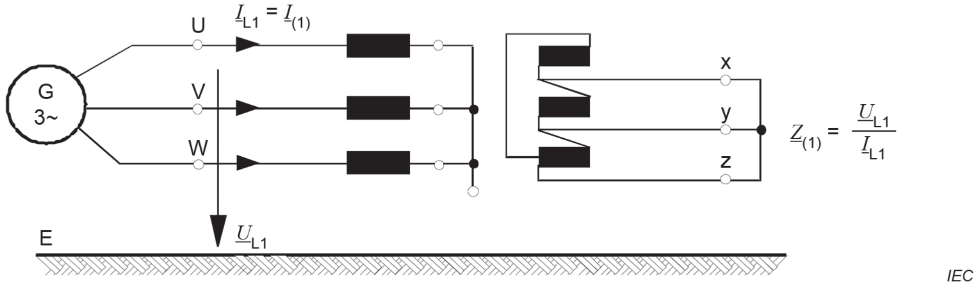
Network transformers have two, or three or even more three-phase windings. Figure 3 gives an example for the positive-sequence [Figure 3 b)] and the zero-sequence system impedances [Figure 3 c)] of a two-winding transformer with the vector group YNd5 [Figure 3 a)].

In the case of three-winding transformers (examples are given in Table 3 of IEC TR 60909-2:2008), it is necessary to measure three different impedances and then to calculate the three impedances of the equivalent circuit in the positive-sequence or the zero-sequence system of the transformer (see 6.3.2 of IEC 60909-0:2016 and the example in 4.3.2 of this document).

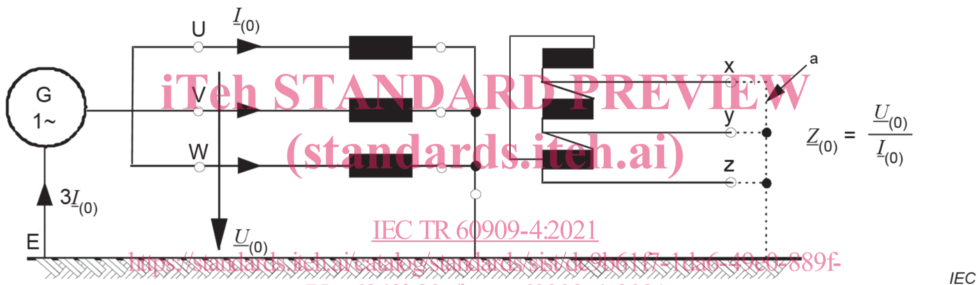
Table 1 gives examples for the equivalent circuits in the positive-sequence and the zero-sequence system of two- and three-winding transformers with different earthing conditions on the HV- and the LV-side. The impedances of Table 1 are related to side A, which may be the HV-side or the LV-side of the transformer.




**a) Two-winding transformer with the terminals 1U,1V,1W at the high-voltage side and 2U,2V,2W at the low-voltage side**




**b) Positive-sequence and negative-sequence impedance $\underline{Z}_{(1)} = \underline{Z}_{(2)}$**






**c) Zero-sequence impedance $\underline{Z}_{(0)}$**

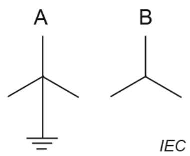
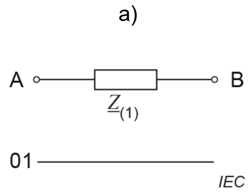
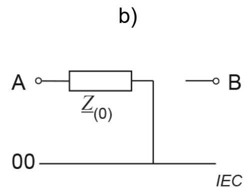
[a] In the case of a delta winding, it is not necessary to introduce the short circuit and the earth connection.

**Figure 3 – Positive-sequence and zero-sequence system impedances of a two-winding transformer YNd5**

As shown in Table 2, transformers with the vector group Yy should not be used in low-voltage systems with low-impedance earthing on the LV-side (TN-network), because $Z_{(0)}$ may be very high, so that short-circuit protection may fail. For feeding TN-networks, transformers of no. 2 or 3 in Table 1 should be used.

Transformers with the vector group YNyn,d are typical in high-voltage networks, with neutral point earthing normally only on one side (A or B). The examples no. 4b and 6 of Table 1 show that the zero-sequence system of both networks are coupled, if both the neutral points A and B are earthed (earthing switch ES in case no. 4b closed). In these cases, additional considerations are necessary, especially if the transformation ratio is high, to find out if this coupling is admissible. Case no. 5 of Table 1 gives an example how to avoid this coupling in the zero-sequence system. Case no. 9 of Table 1 gives a further example to avoid the coupling in the zero-sequence system if two parallel transformers at the same place or at different places are present.

**Table 1 – Examples for equivalent circuit-diagrams of transformers in the positive-sequence and the zero-sequence system**

<table>
<tr><th>No.</th><th>Vector group</th><th>Transformer</th><th>Positive-sequence system</th><th>Zero-sequence system</th></tr>
<tr><td>1a</td><td>YNy</td><td>
</td><td>
</td><td>
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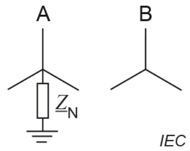
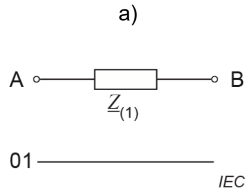
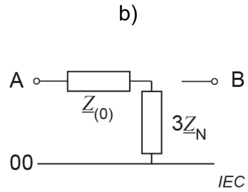
<tr><td>1b</td><td>YNy</td><td>
</td><td>
</td><td>
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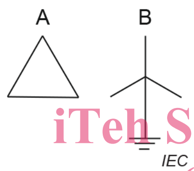
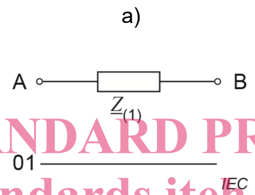
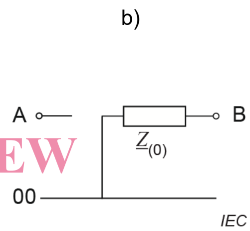
<tr><td>2</td><td>Dyn</td><td>
</td><td>
</td><td>
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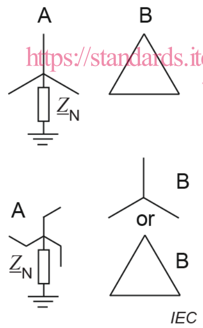
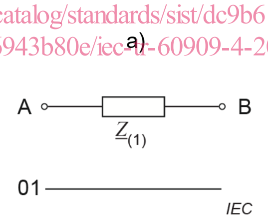
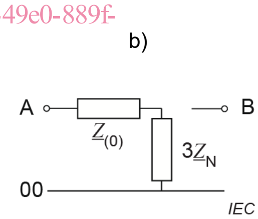
<tr><td>3</td><td>YNd<br>ZNy<br>ZNd</td><td>
</td><td>
</td><td>
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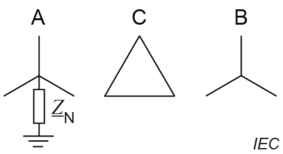
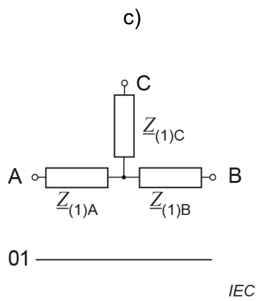
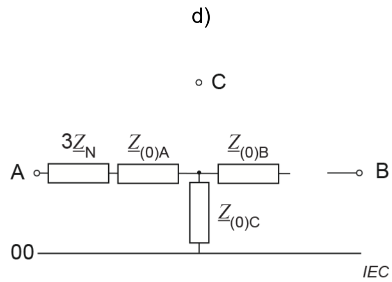
<tr><td>4a</td><td>YNdy</td><td>
</td><td>
</td><td>
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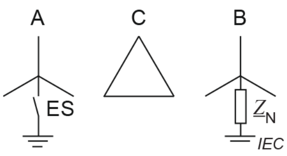
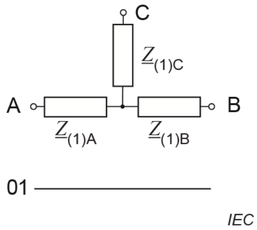
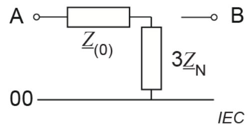
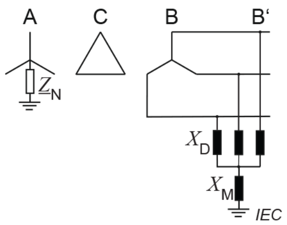
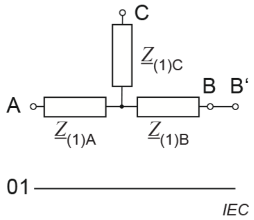
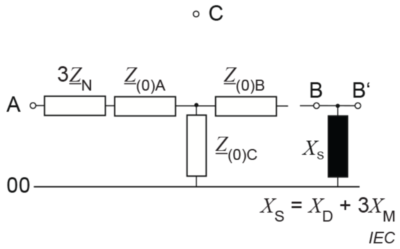
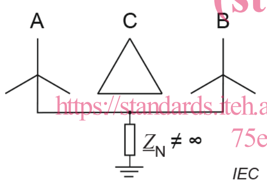
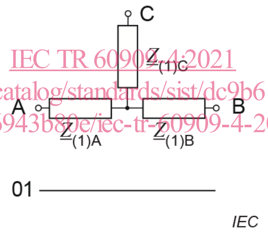
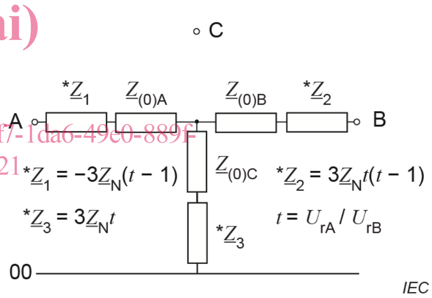
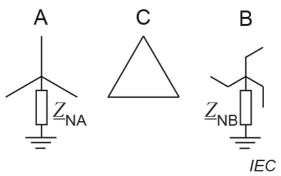
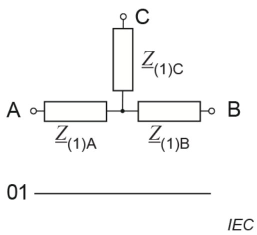
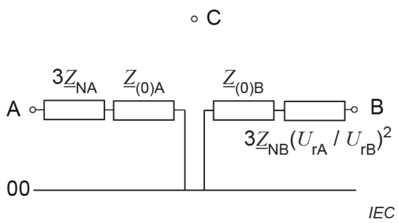
| No. | Vector group | Transformer | Positive-sequence system | Zero-sequence system |
|---|---|---|---|---|
| 4b | YNdyn | e)   | c)   | d)   |
| 5 | YNdz |   | c)   | d)   |
| 6 | YNdyn |   | f)   | g)   |
| 7 | YNdzn |   | f)   | g)   |