BRITISH STANDARD

BS EN 60375:2003

Conventions concerning electric and magnetic circuits

The European Standard EN 60375:2003 has the status of a British Standard

ICS 17.220.01

British Standards

National foreword

This British Standard is the official English language version of EN 60375:2003. It is identical with EN 60375:2003.

The UK participation in its preparation was entrusted to Technical Committee SS/7, General metrology, quantities, units and symbols, which has the responsibility to:

— aid enquirers to understand the text;

— present to the responsible 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.

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Summary of pages

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EUROPEAN STANDARD **EN 60375**

NORME EUROPÉENNE

EUROPÄISCHE NORM September 2003

ICS 17.220.01

English version

Conventions concerning electric and magnetic circuits
(IEC 60375:2003)

Conventions concernant les circuits électriques et magnétiques
(CEI 60375:2003)

Vereinbarungen für Stromkreise und magnetische Kreise
(IEC 60375:2003)

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

This European Standard exists in three official versions (English, French, German). A version in any other language made by translation under the responsibility of a CENELEC member into its own language and notified to the Central Secretariat has the same status as the official versions.

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

Central Secretariat: rue de Stassart 35, B - 1050 Brussels

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Foreword

The text of document 25/261/FDIS, future edition 2 of IEC 60375, prepared by IEC TC 25, Quantities and units, and their letter symbols, was submitted to the IEC-CENELEC parallel vote and was approved by CENELEC as EN 60375 on 2003-09-01.

The following dates were fixed:

– latest date by which the EN has to be implemented at national level by publication of an identical national standard or by endorsement	(dop)	2004-06-01
– latest date by which the national standards conflicting with the EN have to be withdrawn	(dow)	2006-09-01

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

Endorsement notice

The text of the International Standard IEC 60375:2003 was approved by CENELEC as a European Standard without any modification.

CONTENTS

CONVENTIONS CONCERNING ELECTRIC AND MAGNETIC CIRCUITS

1 Scope

This International Standard lays down rules for signs and reference directions and reference polarities for electric currents and voltages in electric networks, as well as for the corresponding quantities in magnetic circuits.

In Clauses 3 to 9, the time dependence is arbitrary. Clause 10 details the rules and recommendations for complex notation.

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 60050-121:1998, *International Electrotechnical Vocabulary (IEV) – Part 121: Electromagnetism*

IEC 60050-131:2002, *International Electrotechnical Vocabulary (IEV) – Part 131: Circuit theory*

IEC 60617, *Graphical symbols for diagrams*

3 Terms and definitions

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

3.1
terminal
point of interconnection of an electric circuit element, an electric circuit or a network (IEC 60050-131:2002, 131-13-03) with other electric circuit elements, electric circuits or networks

[IEV-131-11-11]

NOTE 1 For an electric circuit element, the terminals are the points at which or between which the related integral quantities are defined. At each terminal, there is only one electric current from outside into the element.

NOTE 2 The term “terminal” has a related meaning in IEC 60050-151.

3.2
circuit element
in electromagnetism, mathematical model of a device characterized by one or more relations between integral quantities

[IEV-131-11-03]

3.3
two-terminal element
electric circuit element having two terminals

[IEV 131-11-16]

3.4
***n*-terminal circuit element**
electric circuit element having n terminals with generally $n > 2$

[IEV-131-11-13]

NOTE For an n-terminal electric circuit element:

1) the algebraic sum of the electric currents into the element through the terminals is zero at any instant;

2) there are $n - 1$ independent relations between integral quantities.

3.5
network
in network topology, set of ideal circuit elements and their interconnections, considered as a whole

[IEV-131-13-03]

NOTE 1 The term "electric network" is defined in IEC 60050-131-11-07 and in IEC 60050-151.

NOTE 2 In diagrams in this standard, a box, IEC 60617 symbol, represents any network, unless otherwise specified.

3.6
branch
subset of a network, considered as a two-terminal circuit, consisting of a circuit element or a combination of circuit elements

[IEV-131-13-06]

3.7
node, vertex (US)
end-point of a branch connected or not to one or more other branches

[IEV-131-13-07]

3.8
loop
closed path passing only once through any node

[IEV-131-13-12]

3.9
tree
connected set of branches joining all the nodes of a network without forming a loop

[IEV-131-13-13]

3.10
co-tree
set of the branches of a network not included in a chosen tree

[IEV-131-13-14]

3.11
link
branch of a co-tree

[IEV-131-13-15]

3.12
mesh
set of branches forming a loop and containing only one link of a given co-tree

[IEV-131-13-16]

Remark: The English terms *voltage, electric potential difference,* and *electric tension* have the same meaning in the area of electric circuits. In the English language version of the IEV *voltage* is the preferred term and *electric tension,* often shortened to *tension,* is an alternative. This standard uses the term *voltage*. The term *electric current* is often shortened to *current* according to IEC 60050-121.

For electric networks with lumped circuit elements (see IEC 60050-131), the Kirchhoff law for nodes (see 4.4) applies for the quantity *current*, and the Kirchhoff law for meshes (see 5.4) applies for the quantity *voltage.*

4 Direction rules for current

4.1 Physical direction of current

The net flow of electric charge through a surface is referred to as *electric current*. By convention, the *physical direction of the current* i is defined as the direction corresponding to the movement of positive charge. If the quasi-infinitesimal charge dq passes through a predetermined surface, for example the cross-section of a conductor, during the duration dt, the electric current is

$$i = \frac{\mathrm{d}q}{\mathrm{d}t}$$

4.2 Reference direction of current

The *reference direction* for the current in a branch or in a mesh is a direction fixed arbitrarily along the branch or around the mesh. A current is considered as positive when its physical direction corresponds to the reference direction.

4.3 Indication of the reference direction for currents

4.3.1 Indication of the reference direction for currents for a branch

An arrow having the direction corresponding to the reference direction for a current is placed on or near the line representing the branch element, or near the branch element. (See Figure 1.) The notations in Figures 1a and 1b are preferred.

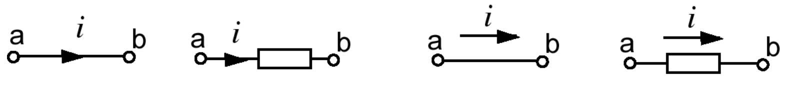


Figure 1a Figure 1b Figure 1c Figure 1d

Figure 1 − Indication of the reference direction for a current by an arrow

When there is only one branch between two nodes, it is clearer to use the notations for the nodes (a and b in Figure 2) to denote the direction of the current, in this case i_{ab}, which defines a current directed from a to b in a branch ab. It is useful to combine consistently the indication by an arrow and by using node designations as in Figure 2. The notations in Figures 2a and 2b are preferred.

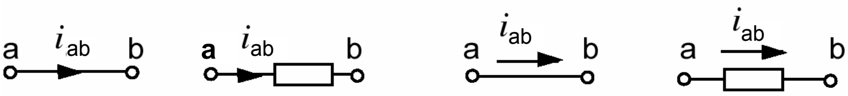
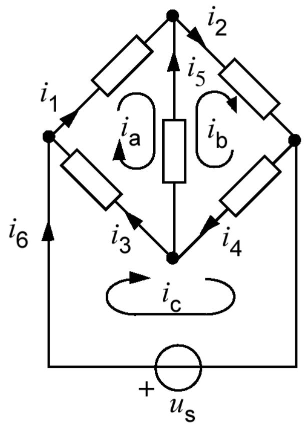


Figure 2a Figure 2b Figure 2c Figure 2d

Figure 2 − Indication of the reference direction for a current using the node names

4.3.2 Indication of the reference direction for mesh currents

To indicate in a diagram the reference direction for the current around a mesh, a curved arrow having a corresponding direction is placed in the mesh so as to follow its contour. In Figure 3, an example shows the connection between mesh currents and branch currents.



$i_1 = i_a$
$i_2 = i_b$
$i_3 = i_a - i_c$
$i_4 = i_b - i_c$
$i_5 = i_b - i_a$
$i_6 = i_c$

Figure 3 – Indication of the reference direction for mesh currents

4.4 Kirchhoff law for nodes

The Kirchhoff law for nodes states:

The algebraic sum of the branch currents towards any node of an electric network is zero (see IEC 60050-131:2002, 131-15-09). According to the currents defined in Figure 4a, this means that the Kirchhoff law for nodes applied to node e reads

$$i_{ae} + i_{be} + i_{ce} + i_{de} = 0$$

If the reference direction of a current, for example the current in branch between b and e in Figure 4b, is chosen as *away* from the node e, the corresponding current $i_{eb} = -i_{be}$, shall be taken with the opposite sign. In that case, the Kirchhoff law for nodes states:

$$i_{ae} - i_{eb} + i_{ce} + i_{de} = 0$$

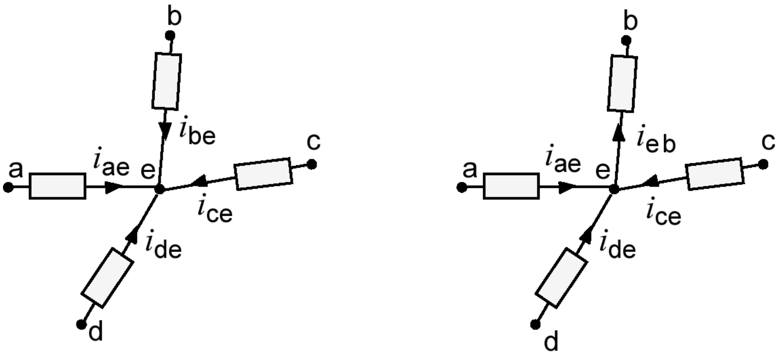


Figure 4a **Figure 4b**

Figure 4 − Examples of the Kirchhoff law for nodes

5 Polarity rules for voltage

5.1 Voltage

In an electric network, a voltage between two ordered nodes, a and b, is the difference of the electric potentials at node a and node b.

5.2 Reference polarity for a pair of nodes

The polarity of a pair of nodes is determined by the ordering of the nodes. The reference polarity may be chosen arbitrarily.

For two nodes, a and b, with the ordering ab, the voltage $u_{ab}$is defined as $u_{ab} = V_a - V_b$, where V_a and V_b are the electric potentials at the nodes a and b, respectively.

5.3 Indication of the reference polarity

First method:

The reference polarity for a voltage is indicated by a line, straight or curved, with a plus sign (+) at the node that comes first in the ordering of the nodes (a in ab). If wanted, a minus sign may be attached to the other end of the line. The letter symbol representing the voltage is placed close to the line (see Figure 5).

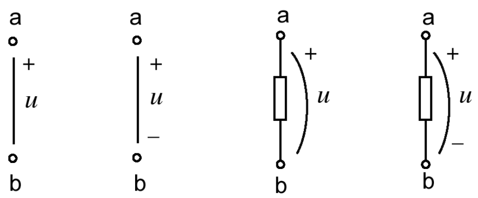


Figure 5a **Figure 5b** **Figure 5c** **Figure 5d**

Figure 5 − Indication of the reference polarity by means of plus and minus signs

The line may be omitted if there is no ambiguity in the grouping of nodes in terminal pairs. This is the case for indicating a voltage in a two-port network (see Figure 6).

Figure 6 − Simplified indication of the reference polarity by means of plus signs

Second method:

The reference polarity of the voltage $u = u_{ab} = V_a - V_b$ is indicated by an arrow with its tail at the node that comes first in the ordering of the nodes (a in ab). The letter symbol representing the voltage is placed close to the arrow. See Figure 7.

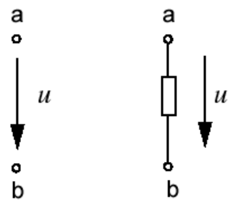


Figure 7 − Indication of the reference polarity by an arrow

Third method:

The reference polarity for a voltage is indicated by a double subscript attached to the letter symbol representing the voltage, the first subscript being understood to correspond to the node that comes first in the ordering (a in ab). This means that $u_{ab} = V_a - V_b$. As in the first method, the letter symbol is placed close to a straight or curved line between the two nodes (see Figure 8).

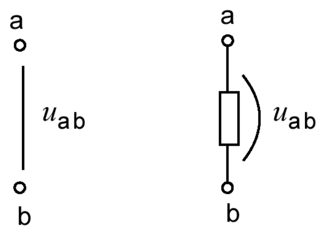


Figure 8 − Indication of the reference polarity using the node names

The line may be omitted if there is no ambiguity in the grouping of nodes in terminal pairs. This is the case for indicating a voltage in a two-port network (see Figure 9).

Figure 9 − Simplified indication of the reference polarity using the node names

NOTE The two subscripts attached to the letter symbol for voltage may also be used consistently in the first and the second methods. In doing so, the polarity is expressed with those two subscripts as well as with a plus sign in the first method and an arrow in the second case.

5.4 Kirchhoff law for meshes

The Kirchhoff law for meshes states:

Along any closed path in an electric network, the algebraic sum of the voltages at the terminals of the branches is zero. The voltages shall be taken with the sign corresponding to their reference polarities in relation to the direction in which the mesh is traversed.

This means that if all reference polarities are defined in the same direction around the mesh, as in Figure 10a, then $u_{ab} + u_{bc} + u_{cd} + u_{da} = 0$.

If some of the reference polarities are defined in the opposite direction, the corresponding voltages shall be taken with the opposite sign. In Figure 10b, the Kirchhoff law for meshes gives $u_{ab} - u_{cb} - u_{dc} + u_{da} = 0$.

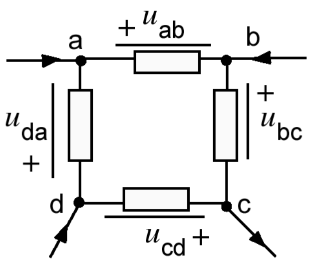


Figure 10a

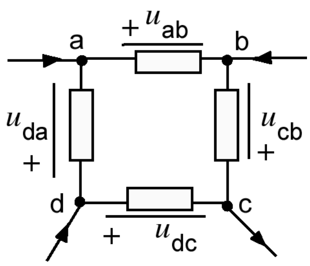


Figure 10b

Figure 10 − Examples of the Kirchhoff law for meshes

6 Conventions concerning two-terminal passive networks

6.1 General conventions

A passive network does not contain any voltage sources or current sources. For a passive two-terminal circuit element, the relation between the voltage across and the current through the element depends on the choice of the reference direction for the current and the reference polarity for the voltage. The reference direction for the current i_{ab} in a two-terminal network with terminals a and b is preferably related to the polarity of the voltage, defined as u_{ab} . This is shown for three ideal circuit elements, the ideal resistor, the ideal inductor and the ideal capacitor.

6.2 Resistive element

For an ideal resistor with constant positive resistance R, the relation between the voltage and the current is given by Ohm's law:

$$u_{ab} = Ri_{ab}$$

(The subscript ab is used to emphasize the coherent choice of the reference polarity for the voltage and the reference direction for the current. See Figure 11)

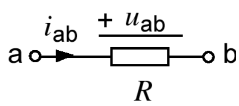


Figure 11

If, for some reason, it is desirable to alter the reference definition for one of the quantities, say the current (see Figure 12), which is then i_{ba} , the relation between voltage and current is

$$u_{ab} = -Ri_{ba}$$

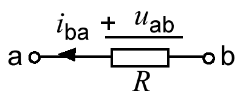


Figure 12

6.3 Inductive element

For an ideal inductor with constant positive inductance L, the relation between voltage and current is, with the reference polarity for the voltage and the reference direction for the current according to Figure 13,

$$u_{ab} = L\frac{di_{ab}}{dt}$$

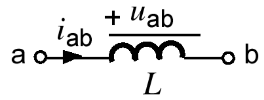


Figure 13

If, for some reason, it is desirable to alter the reference definition for one of the quantities, say the current (see Figure 14), which is then i_{ba} , the relation between voltage and current is

$$u_{ab} = -L\frac{di_{ba}}{dt}$$

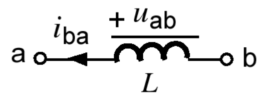


Figure 14

For an ideal inductor, the relation between linked flux and current is $\Psi_{ab} = Li_{ab}$.

For any inductive element, the relation between voltage and linked flux Ψ_{ab} is

$$u_{ab} = \frac{d\Psi_{ab}}{dt}$$

6.4 Capacitive element

For an ideal capacitor with constant positive capacitance C, the relation between voltage and current is, with the reference polarity for the voltage and the reference direction for the current according to Figure 15

$$i_{ab} = C\frac{du_{ab}}{dt}$$

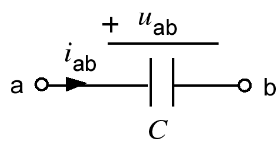


Figure 15

If, for some reason, it is desirable to alter the reference definition for one of the quantities, say the current (see Figure 16), which then is i_{ba}, the relation between voltage and current is

$$i_{ab} = -C\frac{du_{ba}}{dt}$$

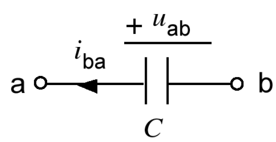


Figure 16

For an ideal capacitor, the relation between electric charge and voltage is $q_{ab} = Cu_{ab}$.

For any capacitive element the relation between current and electric charge is $i_{ab} = \frac{dq_{ab}}{dt}$.

6.5 Non-ideal two-terminal circuit elements

Two examples are given below. For an inductive two-terminal element (ab) with a resistance R in series with a self-inductance L and with no mutual coupling to other elements, the relation between voltage u_{ab} and current i_{ab} is

$$u_{ab} = Ri_{ab} + L\frac{di_{ab}}{dt}$$

Similarly, for a capacitive element (ab) with conductance G in parallel with capacitance C and with no coupling to other elements, the relation between voltage u_{ab} and current i_{ab} is

$$i_{ab} = Gu_{ab} + C\frac{du_{ab}}{dt}$$

7 Conventions for two-port networks

For a two-port network, the usual reference convention for associated voltages and currents is shown in Figure 17.

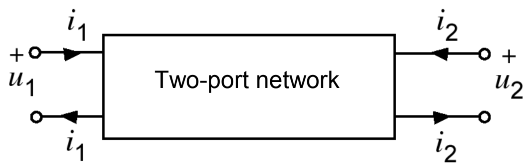


Figure 17 − Reference conventions for a two-port network

8 Conventions concerning sources

8.1 Conventions concerning voltage sources

8.1.1 Independent voltage sources

An *independent* voltage source is an active two-terminal network, for which the source voltage between its terminals (defined in 3.1) is independent of the current in the element and of any external voltage or electric current.

The letter symbol for the source voltage of an independent voltage source is u_s and two graphical symbols are shown in Figure 18. A plus sign at the voltage source defines the polarity of the terminals for the expression of the source voltage.

NOTE Only the graphical symbol shown in Figure 18a is standardized in IEC 60617-2.

Figure 18a **Figure 18b**

Figure 18 − Graphical symbols for an independent voltage source

8.1.2 Controlled voltage sources

The source voltage of a *controlled* voltage source depends on an external voltage or electric current. We can write the source voltage $u_s = \alpha(u_{cd})$ for a voltage source controlled by a voltage in a branch cd and $u_s = \beta(i_{cd})$ for a voltage source controlled by a current in a branch cd. In the following figures the sources are connected between nodes a and b, and the controlling current or voltage is in a branch cd.

The recommended graphical symbol for a voltage source controlled by voltage is shown in Figure 19.

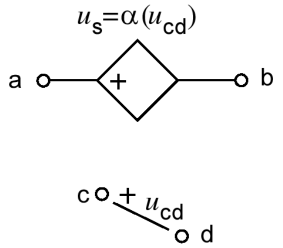


Figure 19 − Graphical symbol for a voltage source controlled by a voltage

The recommended graphical symbol for a voltage source controlled by a current is shown in Figure 20.

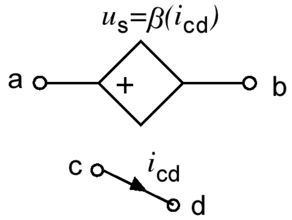


Figure 20 − Graphical symbol for a voltage source controlled by a current

8.2 Conventions concerning current sources

8.2.1 Independent current sources

An *independent* current source is an active two-terminal network, for which the source current is independent of the voltage between its terminals (defined in 3.1) and of any external voltage or electric current.

The letter symbol for the source current of an independent current source is i_s and two graphical symbols are shown in Figure 21. An arrow at the current source defines the reference direction for the current.

NOTE Only the graphical symbol shown in Figure 21a is standardized in IEC 60617-2.

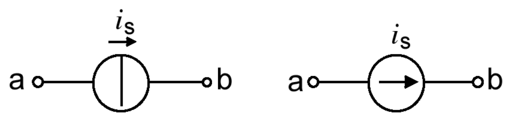


Figure 21a **Figure 21b**

Figure 21 − Graphical symbols for an independent current source

8.2.2 Controlled current sources

The source current of a *controlled* current source depends on an external voltage or electric current. We can write the source current $i_s = \gamma(u_{cd})$ for a current source controlled by a voltage in a branch cd, and $i_s = \delta(i_{cd})$ for a current source controlled by a current in a branch cd.

In the following figures the sources are connected between nodes a and b, and the controlling current or voltage is in a branch cd.

The recommended graphical symbol for a current source controlled by a voltage is shown in Figure 22.

$$i_s = \gamma(u_{cd})$$

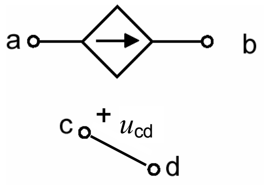


Figure 22 − Graphical symbol for a current source controlled by a voltage

The recommended graphical symbol for a current source controlled by a current is shown in Figure 23.

$$i_s = \delta(i_{cd})$$

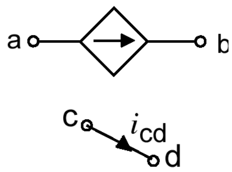


Figure 23 − Graphical symbol for a current source controlled by a current

9 Conventions concerning magnetic circuits

9.1 Magnetic flux

A combination of media through which a magnetic flux is channelled in a given region is called a *magnetic circuit*. A practical example of a magnetic circuit is the closed iron core associated with a coil. See Figure 24.

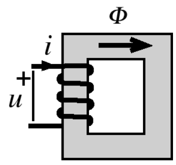


Figure 24

The magnetic flux in a magnetic circuit is defined by the expression

$$\Phi = \int_S \boldsymbol{B} \cdot \boldsymbol{e}_n \, dS$$

where the surface integral is to be taken over the cross section S of the magnetic circuit, $\boldsymbol{e}_n dS$ is the vector surface element and $\boldsymbol{e}_n$ is the unit vector, normal to the surface element.

The reference direction of the magnetic flux Φ in a magnetic circuit is a direction fixed arbitrarily in the circuit. A magnetic flux is considered as positive when its direction corresponds to the reference direction. To indicate in a diagram the reference direction of the magnetic flux, an arrow having a corresponding direction is placed in the magnetic circuit.

9.2 Linked flux

The linked flux Ψ for a closed path C is defined by the expression

$$\Psi = \oint_C \boldsymbol{A} \cdot \mathrm{d}\boldsymbol{r}$$

where $\boldsymbol{A}$ is the magnetic vector potential and $\mathrm{d}\boldsymbol{r}$ is the line element along path C.

For a coil with N turns wound around a closed iron core, where the points a and b are the end points of the coil and the magnetic flux $\Phi = \int_S \boldsymbol{B} \cdot \boldsymbol{e}_\mathrm{n}\, \mathrm{d}S$ is essentially the same along the magnetic circuit so that the stray flux can be neglected, the linked flux is

$$\Psi_\mathrm{ab} = \int_a^b \boldsymbol{A} \cdot \mathrm{d}\boldsymbol{r} \approx \int_S N\boldsymbol{B} \cdot \boldsymbol{e}_\mathrm{n} \mathrm{d}S = N\Phi \quad \text{(See Figure 25)}$$

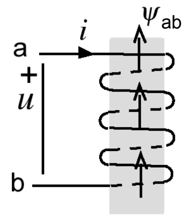


Figure 25

The relation between the direction of $\mathrm{d}\boldsymbol{r}$ along the path of integration and that of $\boldsymbol{e}_\mathrm{n}$ for the corresponding surface is fixed by the “right-handed trihedron”. The reference direction of Ψ_ab is the same as that of Φ.

The linked flux for a coil is related to the current i_ab in the coil and the inductance L of the coil by the expression

$$\Psi_\mathrm{ab} = L i_\mathrm{ab}$$

if the reference direction of the linked flux Ψ_ab is related to the reference direction of the current in such a way that a positive current is accompanied by a positive linked flux. The “right-handed trihedron” shall be applied.

9.3 Conventions concerning mutual inductance

The mutual inductance of two magnetically coupled electric circuit elements (1 and 2), $L_{12} = L_{21}$, for each of which the reference directions of the electric current and of the associated magnetic flux are so fixed that positive current produces positive flux, is considered as positive if the current in one of the elements produces a positive linked flux associated with the other circuit. The self-inductance of the coils 1 and 2 are denoted by L_{11} and L_{22} respectively.

The relations between induced voltage u, linked flux Ψ, electric current i, and self and mutual inductance L may be written

$$\begin{cases} u_1 = \dfrac{\mathrm{d}\Psi_1}{\mathrm{d}t} = \dfrac{\mathrm{d}\Psi_{11}}{\mathrm{d}t} + \dfrac{\mathrm{d}\Psi_{12}}{\mathrm{d}t} = L_{11}\dfrac{\mathrm{d}i_1}{\mathrm{d}t} + L_{12}\dfrac{\mathrm{d}i_2}{\mathrm{d}t} \\ u_2 = \dfrac{\mathrm{d}\Psi_2}{\mathrm{d}t} = \dfrac{\mathrm{d}\Psi_{21}}{\mathrm{d}t} + \dfrac{\mathrm{d}\Psi_{22}}{\mathrm{d}t} = L_{21}\dfrac{\mathrm{d}i_1}{\mathrm{d}t} + L_{22}\dfrac{\mathrm{d}i_2}{\mathrm{d}t} \end{cases}$$

$$L_{21} = L_{12}$$

If an increase of i_2 (i.e. $\frac{\mathrm{d}i_2}{\mathrm{d}t} > 0$) causes an increase of Ψ_{12}, then the mutual inductance L_{12} is positive (i.e. $L_{12} = |L_{12}|$).

NOTE When more than two coils are magnetically coupled, the expressions are generalized to

$$u_1 = \frac{\mathrm{d}\Psi_{11}}{\mathrm{d}t} + \frac{\mathrm{d}\Psi_{12}}{\mathrm{d}t} + \frac{\mathrm{d}\Psi_{13}}{\mathrm{d}t} = L_{11}\frac{\mathrm{d}i_1}{\mathrm{d}t} + L_{12}\frac{\mathrm{d}i_2}{\mathrm{d}t} + L_{13}\frac{\mathrm{d}i_3}{\mathrm{d}t}\text{, etc.}$$

For *two* coupled coils it is possible to use a dot representation to indicate the sign of L_{12}.

If the reference directions of the currents are such that each current *enters* the coil at the end where the dot is introduced, then the mutual inductance is positive (i.e. $L_{12} = |L_{12}|$). (See Figures 26a and 26b).

If the reference directions of the currents are such that one current *enters* the coil at the end where the dot is introduced and the other leaves the corresponding coil at the end where the dot is introduced, then the mutual inductance is negative (i.e. $L_{12} = -|L_{12}|$). (See Figure 26c).

The relations above between voltage, linked flux, electric current, and self and mutual inductance are not affected by moving the dot.

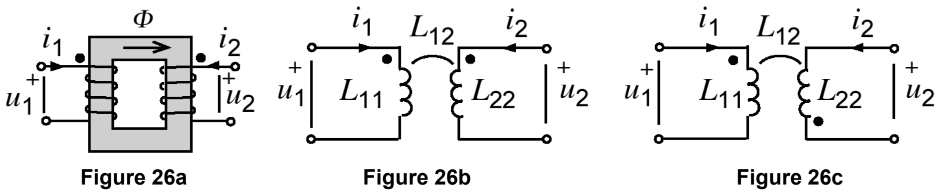


Figure 26 − Mutual induction of two magnetically coupled electric circuit elements

10 Complex notation

NOTE 1 In this clause, quantities whose time-dependence is sinusoidal are expressed in the form of cosines, but the use of sines, with obvious consequent modifications, is not debarred.

NOTE 2 Phasors, a complex representation of a time-harmonic quantity, and other complex quantities are denoted by capital letter symbols. The underlining of a letter symbol signifies that it is to be taken as complex. When there is no risk for confusion, the underlining may be omitted. For the sake of clarity, underlining of the symbols for complex quantities is used in this document.

10.1 Conventions concerning complex representation of sinusoidal quantities

The sinusoidal quantity

$$a(t) = \hat{A}\cos(\omega t + \vartheta_0)$$

with $\hat{A}$ and ω positive, can be represented:

a) when an indication of time-dependence is required, by:

1) the complex instantaneous value $\underline{a} = \hat{A}\mathrm{e}^{\mathrm{j}(\omega t+\vartheta_0)} = \underline{\hat{A}}\mathrm{e}^{\mathrm{j}\omega t} = \sqrt{2}\,\underline{A}\,\mathrm{e}^{\mathrm{j}\omega t}$;

b) when an indication of time dependence is not required, by:

2) the complex quantity in amplitude scale $\underline{\hat{A}} = \hat{A}\,\mathrm{e}^{\mathrm{j}\vartheta_0}$;

3) the complex quantity in root-mean-square scale $\underline{A} = (\hat{A}/\sqrt{2})\mathrm{e}^{\mathrm{j}\vartheta_0}$.

NOTE 1 The complex quantities in items 2) and 3) are called phasors. They are usually used when dealing with sinusoidal quantities, all of the same frequency.

NOTE 2 Note that the root-mean-square value of $a(t) = \hat{A}\cos(\omega t + \vartheta_0)$ is equal to $|\underline{A}|$, the modulus of the complex quantity in root-mean-square scale.

NOTE 3 A sinusoidal quantity can be derived from the corresponding complex quantity by means of the relations:

$$a(t) = \mathrm{Re}(\underline{a}) = \mathrm{Re}(\underline{\hat{A}}\,\mathrm{e}^{\mathrm{j}\omega t}) = \mathrm{Re}(\sqrt{2}\,\underline{A}\,\mathrm{e}^{\mathrm{j}\omega t})$$

10.2 Reference direction of a complex current

The reference direction of a complex current in a branch or in a mesh is a direction fixed arbitrarily along the branch or around the mesh. In circuit diagrams, the same notations are used as in 4.3, with the difference that the time-dependent current quantities are replaced by complex quantities.

Using reference directions, the Kirchhoff law for nodes states:

The sum of all complex currents directed towards a node is zero. According to the currents defined in Figure 27a, this means

$$\underline{I}_{\mathrm{ae}} + \underline{I}_{\mathrm{be}} + \underline{I}_{\mathrm{ce}} + \underline{I}_{\mathrm{de}} = 0$$

If the reference direction of a current, for example the current in branch b of Figure 27b, indicates that the current $\underline{I}_{\mathrm{eb}} = -\underline{I}_{\mathrm{be}}$ is directed away from the node, then

$$\underline{I}_{\mathrm{ae}} - \underline{I}_{\mathrm{eb}} + \underline{I}_{\mathrm{ce}} + \underline{I}_{\mathrm{de}} = 0$$

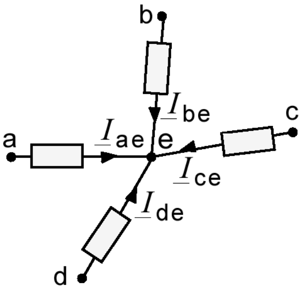


Figure 27a

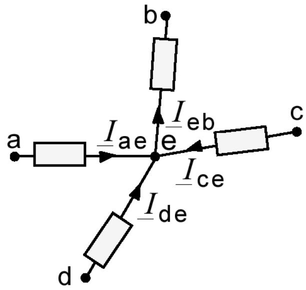


Figure 27b

Figure 27 − Example of the Kirchhoff law for nodes

10.3 Reference polarity for a complex voltage

A complex voltage between two nodes is the difference of the complex electric potentials at those nodes. The reference polarity is determined by the ordering of the nodes. The reference polarity may be chosen arbitrarily. For two nodes, a and b, with the ordering ab, the voltage is $\underline{U}_{\mathrm{ab}} = \underline{V}_{\mathrm{a}} - \underline{V}_{\mathrm{b}}$, where $\underline{V}_{\mathrm{a}}$ and $\underline{V}_{\mathrm{b}}$ are the complex electric potentials at the nodes a and b, respectively.

Rules for indication of the polarity for complex voltages correspond to those used for time-dependent quantities (see 5.3), with appropriate changes of symbols, $(u \rightarrow \underline{U})$, etc.

Using reference polarities, the Kirchhoff law for meshes states:

Along any closed path in an electric network, the algebraic sum of the complex voltages at the terminals of the branches is zero. The voltages shall be taken with the sign corresponding to their reference polarities in relation to the direction in which the mesh is traversed. This means that if all reference polarities are defined in the same direction around the mesh, as in Figure 28a, $\underline{U}_{\mathrm{ab}} + \underline{U}_{\mathrm{bc}} + \underline{U}_{\mathrm{cd}} + \underline{U}_{\mathrm{da}} = 0$.

If some of the reference polarities are defined in the opposite direction, as in Figure 28b, the corresponding voltages shall be taken with the opposite sign, i.e. $\underline{U}_{\mathrm{ab}} - \underline{U}_{\mathrm{cb}} - \underline{U}_{\mathrm{dc}} + \underline{U}_{\mathrm{da}} = 0$.

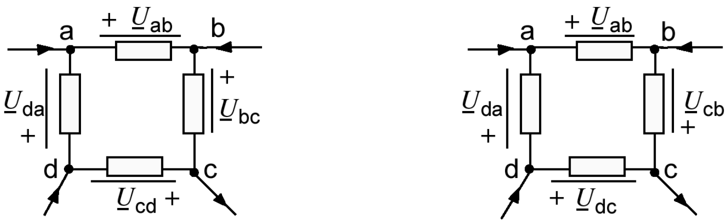


Figure 28a Figure 28b

Figure 28 − Example of the Kirchhoff law for meshes

10.4 Complex representation of Ohm's law

For networks with linear circuit elements (R, L, C), there is a linear relation between complex voltage and complex electric current. For a two-terminal network, the relation may be written $\underline{U} = \underline{Z}\,\underline{I}$. Here $\underline{Z}$ is the complex impedance.

For an ideal resistor, the impedance is real, $\underline{Z} = R$.

For an ideal inductor, the impedance is an imaginary positive quantity, $\underline{Z} = \mathrm{j}\omega L$.

For an ideal capacitor, the impedance is an imaginary negative quantity, $\underline{Z} = \frac{1}{\mathrm{j}\omega C} = -\mathrm{j}\frac{1}{\omega C}$.

Graphical symbols for an impedance are shown in Figure 29. Note that $\underline{Z}_{\mathrm{ab}} = \underline{Z}_{\mathrm{ba}}$.

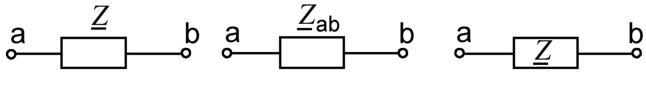


Figure 29 − Representation of an impedance

For an impedance $\underline{Z}$, Ohm's law assumes a specified relation between the reference direction for the current and the reference polarity for the voltage. By means of subscripts, the law may be expressed as $\underline{U}_{\mathrm{ab}} = \underline{Z}\,\underline{I}_{\mathrm{ab}}$. See Figure 30.

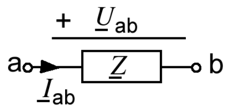


Figure 30 − Reference directions and polarities in Ohm's law

10.5 Conventions concerning the graphical representation of phasors

A phasor $\underline{A} = |\underline{A}|\mathrm{e}^{\mathrm{j}\vartheta_0}$ is represented in the complex plane by an arrow. The positive direction for angles is counterclockwise. See Figure 31.

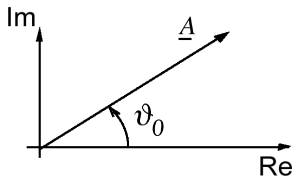


Figure 31 – Graphical representation of a phasor

NOTE As a consequence, an arrow representing a phasor with argument 0 rad is directed along the positive real semi-axis, and an arrow representing a phasor with argument $\pi/2$ rad is directed along the positive imaginary semi-axis.

10.6 Conventions concerning phase differences

The phase difference of the sinusoidal quantities $a(t)$ and $b(t)$ with $a(t) = \hat{A}\cos(\omega t + \vartheta_\mathrm{a})$ and $b(t) = \hat{B}\cos(\omega t + \vartheta_\mathrm{b})$ is expressed by the relation $\varphi_\mathrm{ab} = \vartheta_\mathrm{a} - \vartheta_\mathrm{b}$, and graphical representations for the time functions and the corresponding phasors are shown in Figure 32a and Figure 32b respectively.

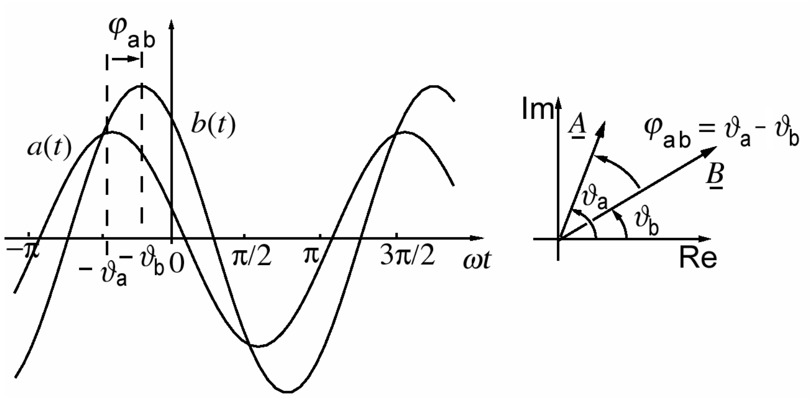


Figure 32a – **Time functions** $a(t)$ **and** $b(t)$ **Figure 32b** – **Phasors** $\underline{A}$ **and** $\underline{B}$

Figure 32 − Graphical representation of phase difference

Annex ZA
(normative)

Normative references to international publications with their corresponding European publications

This European Standard incorporates by dated or undated reference, provisions from other publications. These normative references are cited at the appropriate places in the text and the publications are listed hereafter. For dated references, subsequent amendments to or revisions of any of these publications apply to this European Standard only when incorporated in it by amendment or revision. For undated references the latest edition of the publication referred to applies (including amendments).

NOTE When an international publication has been modified by common modifications, indicated by (mod), the relevant EN/HD applies.

Publication	Year	Title	EN/HD	Year
IEC 60050-121	1998	International Electrotechnical Vocabulary (IEV) Part 121: Electromagnetism	-	-
IEC 60050-131	2002	Part 131: Circuit theory	-	-
IEC 60617	Series	Graphical symbols for diagrams	EN 60617	Series

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