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Railway applications - Transformers and inductors on board rolling stock

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IEC Secretariat
3, rue de Varembé
CH-1211 Geneva 20
Switzerland

Tel.: +41 22 919 02 11
info@iec.ch
www.iec.ch

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CONTENTS

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IEC 60310 has been prepared by IEC technical committee 9: Electrical equipment and systems for railways. It is an International Standard.

This fifth edition cancels and replaces the fourth edition published in 2016. This edition constitutes a technical revision.

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

a) typical circuits for transformer and inductors are added;
b) letter symbols for cooling methods are added;
c) dielectric test table is modified;
d) subclauses for the tests of transformers and inductors are restructured;

e) temperature test for dry type transformer and dry type inductors are separated in different subclauses;

f) requirements for shock and vibration tests are updated according to IEC 61373:20—.

The text of this International Standard is based on the following documents:

Draft	Report on voting
9/3296/FDIS	9/3322/RVD

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 International Standard 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/publications.

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– withdrawn, or
– revised.

1 Scope

This document specifies the terms and definitions, classification, service conditions, characteristics and test methods for transformers and inductors on board rolling stock.

This document is applicable to traction and auxiliary power transformers installed on board rolling stock and to the various types of power inductors inserted in the traction and auxiliary circuits of rolling stock, of dry or liquid-immersed design.

This document is also applicable to the traction transformers of three-phase AC line-side powered vehicles and to the transformers inserted in the single-phase or polyphase auxiliary circuits of vehicles, after agreement between purchaser and manufacturer.

This document does not apply to instrument transformers, transformers of a rated output below 1 kVA single-phase or 5 kVA poly-phase, and inductors of a rated output below 1 kVAR single-phase or 5 kVAR poly-phase on board rolling stock.

This document does not cover accessories such as tap changers, resistors, heat exchangers, fans, etc., intended for mounting on transformers or inductors, which are tested separately according to the relevant rules.

NOTE Items requiring agreement between the delivery parties and items of supplementary information and specification particulars to be provided by the ordering party or manufacturer are given in Annex A.

2 Normative references

The following documents are referred to in the text in such a way that some or all of their content constitutes requirements 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 60076-1:2011, *Power transformers - Part 1: General*

IEC 60076-2, *Power transformers - Part 2: Temperature rise for liquid-immersed transformers*

IEC 60076-3, *Power transformers - Part 3: Insulation levels, dielectric tests and external clearances in air*

IEC 60076-5, *Power transformers - Part 5: Ability to withstand short circuit*

IEC 60076-6:2007, *Power transformers - Part 6: Reactors*

IEC 60076-10, *Power transformers - Part 10: Determination of sound levels*

IEC 60076-12:2008, *Power transformers - Part 12: Loading guide for dry-type transformers*

IEC 60076-18, *Power transformers - Part 18: Measurement of frequency response*

IEC 60296, *Fluids for electrotechnical applications - Mineral insulating oils for electrical equipment*

IEC 60836, *Specifications for unused silicone insulating liquids for electrotechnical purposes*

IEC 60850, *Railway applications - Supply voltages of traction systems*

IEC 61039, *Classification of insulating liquids*

IEC 61099, *Insulating liquids - Specifications for unused synthetic organic esters for electrical purposes*

IEC 61373:20—, *Railway applications - Rolling stock equipment - Shock and vibration tests*[1]

IEC 61378-1:2011, *Converter transformers - Part 1: Transformers for industrial applications*

IEC 62497-1:2010, *Railway applications - Insulation coordination - Part 1: Basic requirements - Clearances and creepage distances for all electrical and electronic equipment*
IEC 62497-1:2010/AMD1:2013

IEC 62498-1, *Railway applications - Environmental conditions for equipment - Part 1: Equipment on board rolling stock*

ISO 3746, *Acoustics - Determination of sound power levels and sound energy levels of noise sources using sound pressure - Survey method using an enveloping measurement surface over a reflecting plane*

ISO 9614-1, *Acoustics - Determination of sound power levels of noise sources using sound intensity - Part 1: Measurement at discrete points*

ISO 9614-2, *Acoustics - Determination of sound power levels of noise sources using sound intensity - Part 2: Measurement by scanning*

3 Terms, definitions and abbreviated terms

For the purposes of this document, the terms and definitions given in IEC 60076-1, IEC 62497-1 and the following apply.

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

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

NOTE 1 When the term "transformer" is used alone, it applies to both traction and auxiliary transformers.

NOTE 2 The term "transformer(s)/inductor(s)" appears in clauses applicable to both transformers and inductors to avoid duplication of text.

NOTE 3 The term "inductor" is used in this document with the same meaning as the term "reactor" mentioned in IEC 60050-421, IEC 60050-811 and IEC 60076-6.

[1] Under preparation. Stage at the time of publication: IEC FDIS 61373:2024.

3.1 Terms and definitions

3.1.1 General definitions

3.1.1.1
traction transformer
transformer intended to supply the traction circuits, and optionally other equipment

3.1.1.2
auxiliary transformer
<on-board power supply system> transformer intended to supply electrical equipment except traction circuits

Note 1 to entry: In the energy storage system, the transformer that supplies power to the traction circuit(s) is called a traction transformer, and that supplying power to the electrical equipment except traction circuit(s) is called an auxiliary transformer.

3.1.1.3
inductor
two-terminal device characterized essentially by its inductance

[SOURCE: IEC 60050-151:2001, 151-13-25, modified – The notes to entry have been omitted.]

3.1.1.4
load profile
<component> component output power or current versus time under specified conditions including voltage, rectifier, configuration, harmonic content, etc.

Note 1 to entry: Efficiency for the transformer is agreed between the manufacturer and purchaser.

3.1.1.5
short time emergency loading
unusually heavy loading of a transient nature (less than one time constant of the transformer) occurring during degraded mode, such as a loss of one traction converter, etc.

[SOURCE: IEC 60076-12:2008, 3.2, modified – ”(less than one time constant of the coil)” replaced with “(less than one time constant of the transformer)”, “ the occurrence of one or more unlikely events which seriously disturb normal system loading” replaced with “occurring during degraded mode”]

3.1.1.6
cooling medium
medium used to extract the heat out of the transformer or inductor e.g. air, water, oil, heat sink, etc.

3.1.1.7
rated insulation voltage
U_{Nm}
RMS withstand voltage value assigned by the manufacturer to the equipment or a part of it, characterising the specified permanent (over 5 min) withstand capability of its insulation

Note 1 to entry: U_{Nm} is a voltage between a live part of equipment and earth or another live part. For rolling stock, earth refers to the car body.

Note 2 to entry: For circuits, systems and sub-systems in railway applications, this definition is preferred to "highest voltage for equipment" which is widely used in international standards.

Note 3 to entry: U_{Nm} is higher than or equal to the working voltage. As a consequence, for circuits directly connected to the contact line, U_{Nm} is equal to or higher than U_{max1} as specified in IEC 60850. For circuits connected to electronic converter U_{Nm} is higher than or equal to the DC link voltage.

Note 4 to entry: U_{Nm} is not necessarily equal to the rated voltage which is primarily related to functional performance.

[SOURCE: IEC 62497-1:2010, 3.4.4, modified – Addition of the second sentence in Note 3 to etnry.]

3.1.1.8
nominal voltage
U_n
suitable approximate voltage used to designate or identify a given supply system

3.1.1.9
rated voltage
U_r
value of voltage assigned for a specific operating condition

3.1.1.10
rated impulse voltage
U_{Ni}
impulse voltage value, characterizing the specified withstand capability of its insulation against transient over-voltages

3.1.1.11
test voltage
U_a
RMS value derived from U_{Nm} used for separate source voltage, induced voltage, voltage between terminals withstand, depending on test carried out

3.1.1.12
recurring peak voltage
U_{mT}
U_{mG}
maximum peak value of periodic excursions of the voltage waveform between terminals (U_{mT}) or between terminals and ground (U_{mG})

3.1.2 Definitions for transformers

3.1.2.1
voltage transmission ratio
VTR
ratio between the secondary voltage and the primary voltage when a specified impulse or AC square voltage is applied on the primary

Note 1 to entry: The VTR is expressed as a percentage of this applied voltage.

3.1.2.2
impedance voltage
voltage applied to reach the rated current in short-circuit

Note 1 to entry: This is expressed as a percentage of this applied voltage to the rated voltage at reference temperature.

Note 2 to entry: When expressed as a percentage or per unit, this is equal to the short circuit impedance referred in IEC 60076-1:2011, 3.7.1.

3.1.2.3
tolerance
permitted deviation between the declared value of a quantity and the measured value

[SOURCE: IEC 60050-411:2007, 411-36-19]

3.1.3 Definitions for inductors

NOTE Values of inductance for inductors are related to the different classes of utilization and are defined as follows, with the understanding that they include an indication of the nature and value of the current used in their measurement.

3.1.3.1
AC inductance
inductance derived from the measurement of the alternating current carried by the inductor when it is supplied by a sinusoidal alternating voltage of specified value and frequency

[SOURCE: IEC 60050-811:2017, 811-26-36]

3.1.3.2
differential inductance
inductance defined from the derivative of the linked flux as a function of current (equal to the slope of the magnetic characteristic)

Note 1 to entry: It is derived from the transient record of instantaneous voltage and current in the inductor or from the measurement of the variation of magnetic flux.

3.1.3.3
incremental inductance
inductance seen by the AC current of a particular value and frequency superimposed on a DC current through the inductor

Note 1 to entry: The ripple factor of a pulsating current, expressed as a percentage, is conventionally defined by the formula:

$$\frac{I_{max} - I_{min}}{I_{max} + I_{min}} \times 100$$

where I_{max} and I_{min} respectively represent the maximum and minimum values of the current wave.

Note 2 to entry: It is derived from a record of the terminal voltage.

3.1.4 Definitions of thermal endurance

3.1.4.1
thermal endurance
time taken for the deterioration of a selected property (electrical, mechanical, etc.) to reach a specified end-point at a given temperature

Note 1 to entry: An insulation material mainly ensures the electric performance (dielectric strength) of the conductor insulation, while the impregnation, casting, sealing, coating, etc., materials mainly ensure the mechanical performance of the windings (water tightness, resistance to thermal cycling and shock, resistance to vibration or shocks, thermal conduction, etc.).

Note 2 to entry: An end-point of 50 % of the initial value of the property is used (unless otherwise specified).

3.1.4.2
temperature index
TI
numerical value of the temperature (in degrees Celsius) derived from the thermal endurance relationship at a time of 20 000 h (unless otherwise specified)

Note 1 to entry: TI is referring to the RTE (Relative Thermal Endurance) or ATE (Assessed Thermal Endurance) indexes used in IEC 60216-5.

3.1.4.3
halving interval
HIC
numerical value of the temperature interval (in Kelvins) which expresses the halving of the time to end-point taken at the temperature equal to TI

[SOURCE: IEC 60050-212:2010, 212-12-13, modified – "corresponding to the temperature index or the relative temperature index" has been replaced with "equal to TI".]

3.1.5 Definitions of thermal endurance calculations

NOTE As far as thermal endurance calculations are concerned, IEC 60076-12 provides an explanation of ageing fundamentals and the means to estimate ageing rate and consumption of lifetime of the transformer or inductor insulation as a function of operating temperature, time and loading. The hot-spot temperature is used to estimate the number of hours of lifetime consumed during a particular time period of loading.

3.1.5.1
thermal endurance in continuous operation
ECO
value derived from the simplified equation of the Arrhenius plot (based on TI and HIC) for a given hotspot temperature θ_{HS} (°C)

$$ECO(h) = 20\ 000 \times 2^{\frac{TI-\theta_{\mathrm{HS}}}{HIC}}$$

Note 1 to entry: This simplified formula is very convenient to understand the concept of TI and HIC. However, this formula yields slightly pessimistic results compared to the exact formula.

Note 2 to entry: Whenever possible, the exact Arrhenius formula derived from the endurance graph (constants A and B) is used, where $E(h)$ is the thermal endurance and T_{HS}(K) = θ_{HS} (°C) + 273,15 is the thermodynamic (absolute) hot-spot temperature:

$$\log E(h) = \log A + \frac{B}{T_{\mathrm{HS}}(K)}$$

which represents the thermal endurance graph, or

$$E(h) = a \times \exp\left(\frac{b}{T_{\mathrm{HS}}}\right)$$

which expresses directly the thermal endurance value.

3.1.5.2
actual operating time
AOT
actual time (in hours) the insulating system will operate at the given hotspot temperature

3.1.5.3
consumed endurance potential
CEP
ratio of actual operating time by consumed endurance potential for a given hotspot temperature

$$CEP(\%) = \frac{AOT}{ECO} \times 100$$

3.2 Abbreviated terms

For the purposes of this document, the following abbreviations apply:

AC	alternating current
AOT	actual operating time
ATE	assessed thermal endurance
CEP	consumed endurance potential
DC	direct current
ECO	thermal endurance in continuous operation
EIM	electrical insulating material
EIS	electrical insulating system
FEA	finite element analysis
FRA	frequency response analysis
HIC	halving interval
HV	high voltage
RMS	root mean square
RTE	relative thermal endurance
TI	thermal index
VTR	voltage transmission ratio

4 Classification

4.1 General

The traction transformer and auxiliary transformer could be integrated, i.e. the traction transformers could have several secondary windings, such as traction windings, auxiliary windings. Traction windings supply power to traction circuits. Auxiliary windings supply power to auxiliary equipment.

NOTE In this document, the load side windings that feed the traction circuit or the auxiliary circuit used for other purposes or both are collectively called "secondary windings".

The typical circuits are described in this document to show the functions of each component. Figure 1 shows the typical circuit diagram for traction transformer with auxiliary windings, and Figure 2 shows that of separated traction and auxiliary transformers, while the traction transformer is fed by AC power supply system, and the auxiliary transformer is fed by an inverter connected to DC intermediate link. Figure 3 shows the typical circuit diagram for auxiliary transformer fed by DC power supply system. Figure 4 shows the typical circuit diagram for traction transformer (Medium Frequency Transformer) fed by Energy Storage System such as fuel cell battery system.