

INTERNATIONAL STANDARD

NORME INTERNATIONALE



Railway applications – Fixed installations – Traction transformers

Applications ferroviaires – Installations fixes – Transformateurs de traction



THIS PUBLICATION IS COPYRIGHT PROTECTED

Copyright © 2014 IEC, Geneva, Switzerland

All rights reserved. Unless otherwise specified, no part of this publication may be reproduced or utilized in any form or by any means, electronic or mechanical, including photocopying and microfilm, without permission in writing from either IEC or IEC's member National Committee in the country of the requester. If you have any questions about IEC copyright or have an enquiry about obtaining additional rights to this publication, please contact the address below or your local IEC member National Committee for further information.

Droits de reproduction réservés. Sauf indication contraire, aucune partie de cette publication ne peut être reproduite ni utilisée sous quelque forme que ce soit et par aucun procédé, électronique ou mécanique, y compris la photocopie et les microfilms, sans l'accord écrit de l'IEC ou du Comité national de l'IEC du pays du demandeur. Si vous avez des questions sur le copyright de l'IEC ou si vous désirez obtenir des droits supplémentaires sur cette publication, utilisez les coordonnées ci-après ou contactez le Comité national de l'IEC de votre pays de résidence.

IEC Central Office
3, rue de Varembe
CH-1211 Geneva 20
Switzerland

Tel.: +41 22 919 02 11
Fax: +41 22 919 03 00
info@iec.ch
www.iec.ch

About the IEC

The International Electrotechnical Commission (IEC) is the leading global organization that prepares and publishes International Standards for all electrical, electronic and related technologies.

About IEC publications

The technical content of IEC publications is kept under constant review by the IEC. Please make sure that you have the latest edition, a corrigenda or an amendment might have been published.

IEC Catalogue - webstore.iec.ch/catalogue

The stand-alone application for consulting the entire bibliographical information on IEC International Standards, Technical Specifications, Technical Reports and other documents. Available for PC, Mac OS, Android Tablets and iPad.

IEC publications search - www.iec.ch/searchpub

The advanced search enables to find IEC publications by a variety of criteria (reference number, text, technical committee,...). It also gives information on projects, replaced and withdrawn publications.

IEC Just Published - webstore.iec.ch/justpublished

Stay up to date on all new IEC publications. Just Published details all new publications released. Available online and also once a month by email.

Electropedia - www.electropedia.org

The world's leading online dictionary of electronic and electrical terms containing more than 30 000 terms and definitions in English and French, with equivalent terms in 14 additional languages. Also known as the International Electrotechnical Vocabulary (IEV) online.

IEC Glossary - std.iec.ch/glossary

More than 55 000 electrotechnical terminology entries in English and French extracted from the Terms and Definitions clause of IEC publications issued since 2002. Some entries have been collected from earlier publications of IEC TC 37, 77, 86 and CISPR.

IEC Customer Service Centre - webstore.iec.ch/csc

If you wish to give us your feedback on this publication or need further assistance, please contact the Customer Service Centre: csc@iec.ch.

A propos de l'IEC

La Commission Electrotechnique Internationale (IEC) est la première organisation mondiale qui élabore et publie des Normes internationales pour tout ce qui a trait à l'électricité, à l'électronique et aux technologies apparentées.

A propos des publications IEC

Le contenu technique des publications IEC est constamment revu. Veuillez vous assurer que vous possédez l'édition la plus récente, un corrigendum ou amendement peut avoir été publié.

Catalogue IEC - webstore.iec.ch/catalogue

Application autonome pour consulter tous les renseignements bibliographiques sur les Normes internationales, Spécifications techniques, Rapports techniques et autres documents de l'IEC. Disponible pour PC, Mac OS, tablettes Android et iPad.

Recherche de publications IEC - www.iec.ch/searchpub

La recherche avancée permet de trouver des publications IEC en utilisant différents critères (numéro de référence, texte, comité d'études,...). Elle donne aussi des informations sur les projets et les publications remplacées ou retirées.

IEC Just Published - webstore.iec.ch/justpublished

Restez informé sur les nouvelles publications IEC. Just Published détaille les nouvelles publications parues. Disponible en ligne et aussi une fois par mois par email.

Electropedia - www.electropedia.org

Le premier dictionnaire en ligne de termes électroniques et électriques. Il contient plus de 30 000 termes et définitions en anglais et en français, ainsi que les termes équivalents dans 14 langues additionnelles. Egalement appelé Vocabulaire Electrotechnique International (IEV) en ligne.

Glossaire IEC - std.iec.ch/glossary

Plus de 55 000 entrées terminologiques électrotechniques, en anglais et en français, extraites des articles Termes et Définitions des publications IEC parues depuis 2002. Plus certaines entrées antérieures extraites des publications des CE 37, 77, 86 et CISPR de l'IEC.

Service Clients - webstore.iec.ch/csc

Si vous désirez nous donner des commentaires sur cette publication ou si vous avez des questions contactez-nous: csc@iec.ch.

INTERNATIONAL STANDARD

NORME INTERNATIONALE



Railway applications – Fixed installations – Traction transformers

Applications ferroviaires – Installations fixes – Transformateurs de traction

INTERNATIONAL
ELECTROTECHNICAL
COMMISSION

COMMISSION
ELECTROTECHNIQUE
INTERNATIONALE

PRICE CODE
CODE PRIX

XA

ICS 45.060

ISBN 978-2-8322-1645-3

Warning! Make sure that you obtained this publication from an authorized distributor.
Attention! Veuillez vous assurer que vous avez obtenu cette publication via un distributeur agréé.

CONTENTS

FOREWORD.....	5
INTRODUCTION.....	7
1 Scope.....	8
2 Normative references.....	8
3 Terms, definitions and symbols.....	9
3.1 Terms and definitions.....	9
3.2 Symbols.....	14
4 Service conditions.....	15
5 General requirements for a traction transformer.....	16
5.1 Loading.....	16
5.1.1 General.....	16
5.1.2 Rated current.....	17
5.1.3 Rated current of accessories.....	17
5.2 Checking of the capability of the transformer to sustain the stipulated load cycle.....	17
5.2.1 General.....	17
5.2.2 Temperature rise measurement for liquid immersed transformers.....	18
5.2.3 Temperature rise measurement for dry-type transformers.....	18
5.2.4 Alternative criteria for determining temperature rise limits.....	18
5.3 Transferred overvoltages.....	19
5.4 Short circuit stresses.....	19
5.4.1 General.....	19
5.4.2 Short circuit withstand (when applicable).....	19
5.5 Insulation characteristics and test values.....	20
5.6 Other particular features.....	20
5.7 Requirements for the simulation test.....	21
5.8 Rating plate.....	21
6 Directly-coupled traction transformer.....	22
6.1 General.....	22
6.2 Dielectric tests for windings with $U_m < 300$ kV.....	22
6.2.1 General.....	22
6.2.2 Applied voltage test (routine test).....	22
6.2.3 Lightning impulse test (type test).....	22
6.2.4 Induced overvoltage withstand test (routine test).....	23
6.3 Dielectric tests for windings with $U_m \geq 300$ kV.....	23
6.3.1 General.....	23
6.3.2 Applied voltage test (routine test).....	23
6.3.3 Lightning impulse test (routine test).....	23
6.3.4 Switching impulse test (routine test).....	23
6.3.5 Induced overvoltage withstand test (routine test).....	23
7 Traction converter transformers.....	24
7.1 General.....	24
7.2 Short-circuit impedance and load loss.....	25
7.2.1 Total load loss calculation.....	25
7.2.2 Impedance.....	25
7.3 Tolerances.....	26

8	Auxiliary transformers	27
9	Traction auto-transformers	27
9.1	General	27
9.2	Loading	29
9.3	Checking of the capability of the auto-transformer to sustain the stipulated load cycle	29
9.4	Short-circuit stresses	29
10	Three-phase to two-phase conversion transformers	29
10.1	General	29
10.2	Scott connection transformer	30
10.2.1	General	30
10.2.2	Loading	31
10.2.3	Checking of the capability of the Scott connection transformer to sustain the stipulated load cycle	31
10.2.4	Short-circuit stresses	31
10.3	Modified Woodbridge transformer	31
10.3.1	General	31
10.3.2	Loading	34
10.3.3	Checking of the capability of the modified Woodbridge transformer to sustain the stipulated load cycle	34
10.3.4	Short-circuit stresses	34
10.4	Roof-delta connection transformer	34
10.4.1	General	34
10.4.2	Loading	36
10.4.3	Checking of the capability of the roof-delta connection transformer to sustain the stipulated load cycle	36
10.4.4	Short-circuit stresses	36
11	Other traction transformers	37
11.1	General	37
11.2	Booster transformer	37
11.3	Scalene Scott connection transformer	37
	Annex A (informative) Preferred duty classes	39
	Annex B (normative) Insulation characteristics and test values	44
	Annex C (normative) Determination of losses and of equivalent current by means of alternative methods	45
C.1	General	45
C.2	Definition of symbols used in loss calculation	45
C.3	Ratios between rated current and rated service current for traction converter transformers	45
C.4	Calculation of load losses based on loss measurements at two different frequencies for oil immersed transformers	48
C.5	Calculation of load losses based on two frequencies for dry type transformers	49
	Annex D (informative) Evaluation of traction transformer behaviour	50
D.1	Evaluation of losses	50
D.2	Magnetic information	50
	Annex E (informative) Information for tenders and orders	51
E.1	Information to be provided in a tender enquiry	51
E.1.1	General	51
E.1.2	Characteristics	51
E.1.3	Service conditions	51

E.1.4	Auxiliaries	52
E.1.5	Operation and fitting.....	52
E.1.6	Tests	52
E.2	Information to be provided in a tender	52
Bibliography		53
Figure 1	– Example of scheme for connection Dd0y11 with earthed screen	22
Figure 2	– Typical arrangement of a traction auto-transformer	28
Figure 3	– Vector groups of traction auto-transformers	28
Figure 4	– Connection of Scott connection transformers	30
Figure 5	– Connection of modified Woodbridge transformers	32
Figure 6	– Phase A currents on modified Woodbridge transformer	33
Figure 7	– Phase B currents on modified Woodbridge transformer	33
Figure 8	– Connection of roof-delta connection transformers	35
Figure 9	– Phase currents on roof-delta connection transformer	36
Figure 10	– Booster transformer	37
Figure 11	– Scalene Scott connection transformer	38
Figure A.1	– Test cycle for duty classes IA to IF	40
Figure A.2	– Test cycle for duty classes V, VI, VII	41
Figure A.3	– Test cycle for duty classes VIII, IX and JP	42
Figure A.4	– Test cycle for duty class CN	43
Figure C.1	– Service current versus fundamental current	48
Table 1	– Tolerances for voltage ratio and impedances of traction converter transformers	26
Table A.1	– Preferred duty classes	39
Table B.1	– Insulation voltages and test values.....	44
Table C.1	– Connections of converter transformers	46
Table C.2	– Main harmonic contents for various converter connections.....	47
Table C.3	– Service current over rated current.....	47

INTERNATIONAL ELECTROTECHNICAL COMMISSION

**RAILWAY APPLICATIONS –
FIXED INSTALLATIONS –
TRACTION TRANSFORMERS**

FOREWORD

- 1) The International Electrotechnical Commission (IEC) is a worldwide organization for standardization comprising all national electrotechnical committees (IEC National Committees). The object of IEC is to promote international co-operation on all questions concerning standardization in the electrical and electronic fields. To this end and in addition to other activities, IEC publishes International Standards, Technical Specifications, Technical Reports, Publicly Available Specifications (PAS) and Guides (hereafter referred to as "IEC Publication(s)"). Their preparation is entrusted to technical committees; any IEC National Committee interested in the subject dealt with may participate in this preparatory work. International, governmental and non-governmental organizations liaising with the IEC also participate in this preparation. IEC collaborates closely with the International Organization for Standardization (ISO) in accordance with conditions determined by agreement between the two organizations.
- 2) The formal decisions or agreements of IEC on technical matters express, as nearly as possible, an international consensus of opinion on the relevant subjects since each technical committee has representation from all interested IEC National Committees.
- 3) IEC Publications have the form of recommendations for international use and are accepted by IEC National Committees in that sense. While all reasonable efforts are made to ensure that the technical content of IEC Publications is accurate, IEC cannot be held responsible for the way in which they are used or for any misinterpretation by any end user.
- 4) In order to promote international uniformity, IEC National Committees undertake to apply IEC Publications transparently to the maximum extent possible in their national and regional publications. Any divergence between any IEC Publication and the corresponding national or regional publication shall be clearly indicated in the latter.
- 5) IEC itself does not provide any attestation of conformity. Independent certification bodies provide conformity assessment services and, in some areas, access to IEC marks of conformity. IEC is not responsible for any services carried out by independent certification bodies.
- 6) All users should ensure that they have the latest edition of this publication.
- 7) No liability shall attach to IEC or its directors, employees, servants or agents including individual experts and members of its technical committees and IEC National Committees for any personal injury, property damage or other damage of any nature whatsoever, whether direct or indirect, or for costs (including legal fees) and expenses arising out of the publication, use of, or reliance upon, this IEC Publication or any other IEC Publications.
- 8) Attention is drawn to the Normative references cited in this publication. Use of the referenced publications is indispensable for the correct application of this publication.
- 9) Attention is drawn to the possibility that some of the elements of this IEC Publication may be the subject of patent rights. IEC shall not be held responsible for identifying any or all such patent rights.

International Standard IEC 62695 has been prepared by IEC technical committee 9: Electrical equipment and systems for railways.

This standard is derived from EN 50329:2003 and its amendment 1(2010).

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

FDIS	Report on voting
9/1916FDIS	9/1943/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.

The committee has decided that the contents of this publication will remain unchanged until the stability 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.

IMPORTANT – The 'colour inside' logo on the cover page of this publication indicates that it contains colours which are considered to be useful for the correct understanding of its contents. Users should therefore print this document using a colour printer.

INTRODUCTION

Transformers used in fixed installations of traction systems differ from other transformers. The transformer standards of IEC technical committee 14 deal mainly with three-phase transformers or single-phase units assembled to a three-phase bank.

Application of such standards to single- or bi-phase transformers as used in traction systems is not evident.

Moreover, IEC 61378-1 deals with converter transformers for industrial use which have loading characteristics different from traction transformers for converters.

Therefore, this standard is set up to clarify the particular aspects of traction transformers.

RAILWAY APPLICATIONS – FIXED INSTALLATIONS – TRACTION TRANSFORMERS

1 Scope

This International Standard covers specific characteristics of traction transformers as defined in 3.1.1, used in traction substations or along the track for the supply of power to a.c. and d.c. traction systems or to provide power to auxiliary services. Traction transformers are either

- single-phase traction transformers, or
- three-phase to two-phase traction transformers, or
- single-, three- or poly-phase rectifier-transformers or converter-/inverter-transformers for d.c. or a.c. traction systems, or
- single phase auto-transformers for traction power supply, or
- single-phase booster transformers, or
- single- or three-phase auxiliary transformers at traction supply voltage.

Traction transformers are generally covered by the Standards of the IEC 60076 series. The requirements given in IEC 60076 apply together with the additional requirements given in this standard.

Dependent on the selected technology specific parts of IEC 60076 apply:

- IEC 60076-1: Oil immersed transformers
- IEC 60076-11: Dry-type transformers
- IEC 60076-15: Gas-filled transformers

For transformers feeding contact lines through static converters IEC 61378-1 may assist, but modified or additional requirements are given in this standard.

Transformers mounted on-board traction vehicles are covered by IEC 60310 and are excluded from the scope of this standard.

Electromagnetic compatibility is ruled by IEC 60076-1, which states that a transformer may be considered a passive element in this respect. Some accessories, however, are subject to EMC requirements given in IEC 62236-5.

2 Normative references

The following documents, in whole or in part, are normatively referenced in this document and are indispensable for its application. 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 60076-2:2011, *Power transformers – Part 2: Temperature rise for liquid-immersed transformers*

IEC 60076-3:2013, *Power transformers – Part 3: Insulation levels, dielectric tests and external clearances in air*

IEC 60076-5:2006, *Power transformers – Part 5: Ability to withstand short circuit*

IEC 60076-7:2005, *Power transformers – Part 7: Loading guide for oil-immersed power transformers*

IEC 60076-11:2004, *Power transformers – Part 11: Dry-type transformers*

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

IEC 60076-14:2013, *Power transformers – Part 14: Liquid-immersed power transformers using high-temperature insulation materials*

IEC 60076-15:2008, *Power transformers – Part 15: Gas-filled power transformers*

IEC TR 60146-1-2:2011, *Semiconductor converters – General requirements and line commutated converters – Part 1-2: Application guide*

IEC 60850:2007, *Railway applications – Supply voltages of traction systems*

IEC 61000-2-12:2003, *Electromagnetic Compatibility (EMC) – Part 2-12: Environment – Compatibility levels for low-frequency conducted disturbances and signalling in public medium-voltage power supply systems*

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 62498-2:2010, *Railway applications – Environmental conditions for equipment – Part 2: Fixed electrical installations*

IEC 62505-1:2009, *Railway applications – Fixed installations – Particular requirements for a.c. switchgear – Part 1: Single-phase circuit-breakers with U_m above 1 kV*

IEC 62589:2010, *Railway applications – Fixed installations – Harmonisation of the rated values for converter groups and tests on converter groups*

IEC 62590:2010, *Railway applications – Fixed installations – Electronic power converters for substations*

3 Terms, definitions and symbols

3.1 Terms and definitions

For the purposes of this document, the terms and definitions given in IEC 60076-1 and IEC 62590, as well as the following apply.

3.1.1

traction transformer

transformer (with separate or auto-connected windings) connected to an a.c. or d.c. contact line, directly or through a converter, used in fixed installations of railway applications

Note 1 to entry: The above definition relates to the contents of this standard and is introduced to simplify the following definitions, which, in most cases, are not valid for all transformers and autotransformers.

3.1.2

traction converter transformer

traction transformer on the supply side of a converter group and supplying contact line(s) through static converter(s)

3.1.3

traction inverter transformer

traction transformer on the traction (contact) line side of a converter group and supplied by a static converter(s) (inverter)

3.1.4

directly-coupled traction transformer

traction transformer supplying contact line(s) without the interposition of static converter(s)

3.1.5

rated value

numerical value for the electrical, thermal, mechanical and environmental rating assigned to the quantities which define the operation of a traction transformer in the conditions specified in accordance with this International Standard and on which the manufacturer's guarantees and tests are based

3.1.6

rated frequency

f_N

frequency at which the traction transformer is designed to operate

3.1.7

rated voltage on the supply side of a traction transformer

U_{NL}

r.m.s. value of the sinusoidal no-load voltage assigned to be applied to the supply side terminals of a traction transformer (for traction converter transformers)

3.1.8

rated voltage of a traction autotransformer

U_{OHL}

r.m.s. value of the sinusoidal no-load voltage between the overhead contact line and the line feeder in a traction autotransformer

3.1.9

rated intermediate voltage of a traction autotransformer

U_{rail}

r.m.s. value of the sinusoidal no-load voltage between the overhead contact line and the connection to the rail

3.1.10

rated voltage on the converter side(s) of a traction converter transformer and on the traction side of a directly-coupled traction transformer

U_{NS}

r.m.s. value of the no-load voltage at the line-to-line terminals of the converter side(s) of a traction converter transformer or of the traction side of a directly-coupled traction transformer, at the rated voltage on the supply side of the traction transformer

3.1.11

rated voltage on the inverter side of a traction inverter transformer

U_{NP}

r.m.s. value of the sinusoidal no-load voltage resulting at the inverter side terminals of a traction transformer

3.1.12**rated voltage on the traction side(s) of an inverter transformer** U_{NV}

r.m.s. value of the no-load voltage at the line-to-line terminals of the traction side(s) of an inverter transformer at the rated voltage on its inverter side

3.1.13**rated power of a winding** $S_{NL}, S_{NP}, S_{NSn}, S_{NV}$

conventional value of apparent power assigned to a winding, which, together with the rated voltage of the winding, determines its rated current. It is based on the fundamental components of voltage and current (see 3.1.7, 3.1.10, 3.1.12 and 3.1.14)

Note 1 to entry: “primary” and “secondary” are referred to the normal flow of energy from the supply side to the traction side.

Note 2 to entry: In the suffix “ S_n ” for secondary windings “n” is the assigned order number of the secondary winding. In a formula where any winding is separately considered, S_N indicates the rated power of the winding considered.

3.1.14**rated current on the primary side of the traction transformer** I_{NL}, I_{NP}

r.m.s. value of the fundamental component of the current flowing through a line terminal of the primary winding which is derived from the rated power S_N and rated voltage U_N for the winding

Note 1 to entry: The generic r.m.s. of fundamental component of an a.c. current is indicated as I and the generic rated current as I_N .

3.1.15**rated current in the series winding of a traction autotransformer** I_{OHL}

r.m.s. value of the current flowing between the contact line terminal of a traction autotransformer and rail terminal

3.1.16**rated current in the common winding of a traction autotransformer** I_{feed}

r.m.s. value of the current flowing between the line feeder terminal of a traction autotransformer and rail

3.1.17**rated service current on the primary side of the traction converter transformer** I_{NGL}

r.m.s. value of the current flowing through a line terminal of the supply side winding of a traction converter transformer which contains all harmonic components and whose fundamental component is the rated current I_{NL}

Note 1 to entry: In case of traction inverter transformers it is assumed that the service current is not sensibly different from sinusoidal current in all windings.

Note 2 to entry: The generic r.m.s. value of the service current is indicated as I_G .

Note 3 to entry: The generic r.m.s. value of the harmonic current of order h of an a.c. current is indicated as I_h .

Note 4 to entry: In formulas where any winding is separately considered, I_N indicates the rated current of the winding considered and I_{NG} its rated service current.

3.1.18**rated current on the secondary side of a traction transformer** **I_{NS} , I_{NV}**

r.m.s value of the fundamental component of the current flowing at the terminals of the secondary winding(s) of a traction transformer, which is derived from the rated power S_N and rated voltage U_N for the winding

Note 1 to entry: When the secondary windings of a converter transformer are more than one, even if the secondaries are intended to feed a single conversion bridge, the rated secondary current of each winding may differ from that of other winding(s) by small quantities. The tolerances in any case should be observed.

Note 2 to entry: In some cases, the secondary current(s) of a traction converter transformer are not equal to the input current of the converter due to the presence of an auxiliary transformer (see Clause 3 of IEC 62589:2010).

3.1.19**rated service current on the converter (valve) side of a traction converter transformer** **I_{NGSn}**

r.m.s value of the current flowing at the terminals of the secondary winding(s) of a traction converter transformer which contains all harmonic components and whose fundamental component is the rated current I_{NS}

Note 1 to entry: I_{NGSn} differs from I_{NS} . The latter is taken into account to determine loadability of given accessories such as bushing insulators. Loss and temperature rise calculations are based on the rated service current, considering also the additional eddy losses in the windings and structural parts produced by the harmonics.

Note 2 to entry: In some cases, the secondary current(s) of a traction converter transformer are not equal to the input current of the converter due to the presence of an auxiliary transformer (see Clause 3 of IEC 62589:2010).

Note 3 to entry: In a formula where any winding is separately considered, I_N indicates the rated current of the winding considered and I_{NG} its rated service current.

3.1.20**basic current** **I_{BL} , I_{BP} , I_{BS} , I_{BV} , I_{BGL} , I_{BGS}**

current value in a winding which, according to a given duty class (see 3.1.31), is assumed to last for longer periods and represents the load carried out continuously by the traction transformer and on which the overloads are imposed.

3.1.21**basic current on the primary side of a traction transformer** **I_{BL} , I_{BP}**

r.m.s. value of the fundamental component of the current flowing through a line terminal of the primary winding which is derived from the basic power S_B and rated voltage U_N for the winding

3.1.22**basic service current on the primary side of the traction converter transformer** **I_{BGL}**

r.m.s. value of the current flowing through a line terminal of the supply side winding of a traction converter transformer which contains all harmonic components and whose fundamental component is the basic current I_{BL}

3.1.23**basic current on the secondary side of a traction transformer** **I_{BS} , I_{BV}**

r.m.s. value of the fundamental component of the current flowing at the terminals of the secondary winding(s) of a traction transformer, which is derived from the basic power S_B and rated voltage U_N for the winding

3.1.24**basic service current on the converter (valve) side of a traction converter transformer** I_{BGSn}

r.m.s value of the current flowing at the terminals of the secondary winding(s) of a traction converter transformer which contains all harmonic components and whose fundamental component is the basic current I_{BS}

3.1.25**leakage reactance related to the primary winding** X_p

<for three winding transformer> difference between the mean of the short circuit reactance values measured between the primary winding and each secondary winding and one half of the short circuit reactance measured between the two secondary windings

$$X_p = \frac{X_{ccP/S1} + X_{ccP/S2}}{2} - \frac{X_{ccS1/S2}}{2}$$

3.1.26**leakage reactance related to each of the secondary windings** X_{S1}, X_{S2}

<for three winding transformer> sum of the half difference of the short circuit reactance values measured between the primary winding and each secondary winding and one half of the short circuit reactance measured between the two secondary windings

$$X_{S1} = \frac{X_{ccP/S1} - X_{ccP/S2}}{2} + \frac{X_{ccS1/S2}}{2}$$

$$X_{S2} = \frac{X_{ccP/S2} - X_{ccP/S1}}{2} + \frac{X_{ccS1/S2}}{2}$$

3.1.27**reactance ratio
coupling factor** K

ratio between the leakage reactance from primary side and the sum of the leakage reactance from primary and secondary side

Note 1 to entry: In case of a traction transformer with two secondary windings, used for a twelve-pulse reaction converter, the reactance ratio is designed to have the same no-load secondary voltages and the same impedance between the primary and each secondary winding, in order to obtain an even sharing of the current on both bridges in case the d.c. outputs are paralleled. Then $X_{S1} = X_{S2} = X_S$ and

$$K = X_p / (X_S + X_p)$$

3.1.28**current demand**

actual or expected load variation of the current absorbed by a traction line, whose root mean square value is the rated current. It is expressed by a load diagram

3.1.29**load diagram**

true demand of current by the traction circuit in the worse expected condition

3.1.30**load cycle**

conventional representation of the current demand to a traction transformer expressed in per unit of the rated currents. It shows the repetitive variation of the loads with the time and, hence, the overloads and underloads the traction transformer is expected to carry, as well as the duration and intervals assumed

Note 1 to entry: Load cycles and duty classes are intended to allow testing of the traction transformers.

3.1.31**duty class**

conventional classification of the current capability of a traction transformer expressed in per unit of the basic currents I_B .

Note 1 to entry: The duty classes, associated with other rated values, define the characteristics of a traction transformer.

Note 2 to entry: Annex A indicates preferred duty classes and the corresponding basic and rated values.

Note 3 to entry: The indication of a duty class is not compulsory.

3.1.32**long time overload**

peak load in the load cycle lasting from 480 s up to 7 200 s

3.1.33**short time overload**

peak load in the load cycle lasting up to and including 480 s

3.1.34**additional winding**

winding required for connection of auxiliary devices such as harmonic filters

3.2 Symbols

See also Figure 1 of IEC 62589:2010.

f_N	rated frequency
I_B	basic current
I_{BL}	basic current on the supply side of a traction converter transformer
I_{BP}	basic current on the supply side of a traction inverter transformer
I_{BS}	basic current on the secondary side of a traction converter transformer
I_{BGL}	basic service current on the primary side of a traction converter transformer
I_{BGS}	basic service current on the converter (valve) side of a traction converter transformer
I_{BGSn}	basic service current on the converter (valve) side of a traction converter transformer
I_{BV}	basic current on the secondary side of a traction inverter transformer
I_{feed}	rated current in the common winding of a traction autotransformer
I_G	generic r.m.s. value of the service current
I_h	generic r.m.s. value of the harmonic current
I_{NG}	r.m.s. value of the rated service current
I_{NGL}	rated service current on the primary side of a traction converter transformer
I_{NGSn}	rated service current on the converter (valve) side of a traction converter transformer

I_{NL}	rated current on the supply side of a traction converter transformer
I_{NP}	rated current on the supply side of a traction inverter transformer
I_{NS}	rated current on the secondary side of a traction converter transformer
I_{NV}	rated current on the secondary side of a traction inverter transformer
I_{OHL}	rated current in the series winding of a traction autotransformer
K	coupling factor
q	continuous level of apparent charges
S_{NL}	rated power of the supply side winding of a traction transformer
S_{NP}	rated power on the inverter side winding of a traction inverter transformer
S_{NSn}	rated power of the converter side winding(s) of a traction converter transformer and on the traction side winding of a directly-coupled traction transformer
S_{NV}	rated power on the traction side winding(s) of an inverter transformer
U_m	highest voltage for equipment
U_{NL}	rated voltage on the supply side of a traction transformer
U_{NP}	rated voltage on the inverter side of a traction inverter transformer
U_{NS}	rated voltage of the converter side(s) of a traction converter transformer and on the traction side of a directly-coupled traction transformer
U_{NV}	rated voltage on the traction side(s) of an inverter transformer
U_{OHL}	rated voltage of a traction autotransformer
U_{rail}	rated intermediate voltage of a traction autotransformer
X_p	leakage reactance from primary side (for three winding transformer)
X_S	mean value of the leakage reactances from each of the secondary windings (for three winding transformer)
$X_{S1} X_{S2}$	leakage reactance from each of the secondary windings (for three winding transformer)
X_{ccPS1}	short circuit reactance between the primary winding and secondary winding 1 (for three winding transformer)
X_{ccPS2}	short circuit reactance between the primary winding and secondary winding 2 (for three winding transformer)

4 Service conditions

Depending on the type of transformer the normal service conditions given in the relevant part of IEC 60076 apply. However, in case the average yearly ambient temperature is considered to be equal to or lower + 10 °C and the maximum daily ambient temperature is considered to be + 30 °C, the temperature rise limits may be increased by 10 K. The ambient temperature shall then be indicated in the nameplate. For other requirements IEC 62498-2 applies.

For electrical service conditions the following operation ranges shall be considered:

- voltage variation in normal operation (steady state): $\pm 10 \%$;
- voltage variation which shall not cause harmful effects: $\pm 15 \%$; (short-time: 0,5 cycle to 30 cycles)
- frequency variations in normal operation: $\pm 1 \%$.

For directly-coupled substation transformers the voltage ranges according to IEC 60850 are not relevant as in a.c. contact line systems the minimum and maximum values of the contact line voltage apply only to the remote end of feeding sections.

5 General requirements for a traction transformer

5.1 Loading

5.1.1 General

The traction transformer is subject to loads with significant and rapid variations in amplitude and duration.

Therefore the expected load diagram shall in any case be determined by the purchaser before issuing a tender invitation for the traction transformer.

NOTE Depending on the variations during a daily cycle of the load, the quadratic mean value of the most severe load demand during a reasonable period is calculated. The load is given as apparent power or as current value at a fixed voltage

Thermal effects on the transformer resulting from high loads are compensated by low loads.

For testing purposes the use of a load diagram is not practicable. Therefore a conventional load cycle, equivalent to the load diagram, is determined. The quadratic mean of the load diagram and the load cycle are conceived to be the same as well as the effects of the overloads and underloads are concerned.

The representation of the load variation may be expressed either as a duty class or as a load cycle. When this conventional representation of the loading basically corresponds to one standardised duty class, this is preferable.

Annex A shows some conventional preferred duty classes. The purchaser, however, in case he is not in a position to accept one of the preferred duty classes given in Table A.1, is allowed to state his own load cycle.

The value of the long-time overloads, their duration, as well as the interval between successive peaks of this type shall be specified by the purchaser unless a duty class is specified. The time interval conventionally assumed is given in Annex A.

The value of short-time overloads, and their duration shall be specified by the purchaser, unless a duty class is specified. As specified by the duty class, they may occur when the traction transformer is either in any loading condition or is at its basic load. The time between two short-time peaks shall have a duration of at least 1 500 s. The purchaser is allowed to require shorter intervals, but without sufficient interval between two overloads, the loading has to be considered lasting for the sum of the adjacent overloads and the matter shall be object of consideration by the manufacturer.

Therefore is essential that the rated currents and power are considered along with the load cycle or duty class specified; being understood that the rated currents represent only the quadratic mean value of the currents flowing in the windings in order to assess a value for determining other rated values and to effect calculations on the life expectancies of the traction transformer.

The transformers under this standard are normally dimensioned from the duty class or load cycle specified by the purchaser.

In case the purchaser is in a position to take into account all phenomena related to the expected overloads, he is allowed, alternatively, to specify the rating of the traction transformer, without any further reference to the expected load cycle.

In traction converter transformers with connection 9 of the converter, the power of the converter side windings is increased, taking into account the current sharing between the two secondaries (see 6.7.3 of IEC 62590:2010).

Moreover, S_{NL} or S_{NP} may differ from the $\sum_1^n S_{NSn}$ (particularly in case of auxiliary windings) because the sum should be vectorial taking into account the $\cos \varphi_n$ of the secondary currents involved.

In case of tapped windings the rated values refer to the principal tapping.

5.1.2 Rated current

The rated current of the traction transformer shall be selected and specified not less than the quadratic mean of the fundamental component of the load current I over the load cycle:

$$I_N = \sqrt{\frac{1}{\Delta t} \int_{t_0}^{t_0 + \Delta t} I^2(t) dt}$$

where

I_N is the winding current = I_{NP} , I_{NL} , I_{NS} or I_{NV} ,

Δt is the duration of load cycle,

t_0 is the initial time.

It is to be noted that, unless specifically agreed between purchaser and supplier, the design of a traction transformer cannot be based only on the above rating (see 5.1.1).

5.1.3 Rated current of accessories

Bushing insulators, current transformers, connections, tap changers, if any, shall comply with the rated current, the overload requirements and the harmonic contribution, if any.

5.2 Checking of the capability of the transformer to sustain the stipulated load cycle

5.2.1 General

The temperature rise test shall be carried out in accordance with either IEC 60076-2 or IEC 60076-11 or IEC 60076-15 as applicable.

Basis for determining the temperature rises shall be the rated service current (the approximate relationship between the rated current and the rated service current is given in Table C.3).

Depending on the expected frequency and character of the overloads the resulting temperature rises after long-time overloads shall be within the limits of the temperature rises given in the relevant part of IEC 60076 under the stipulated ambient conditions and altitude.

The winding temperature rise after short-time overload conditions may exceed by 15 K the applicable temperature rise limits according to the relevant part of IEC 60076.

For transformers using high-temperature insulating material IEC 60076-14 may be used as a guideline and higher temperatures may be agreed between purchaser and supplier.

When determining the temperature rises the effect of the harmonics should be considered according to 5.2.2, 5.2.3 and 5.2.4.

5.2.2 Temperature rise measurement for liquid immersed transformers

The procedure of 7.3.2 of IEC 60076-2:2011 shall be applied with the exceptions mentioned here below. The specified duty class or load cycle shall be taken into account. For transformers designed according to a duty class recommended test cycles for the temperature rise tests are given in Annex A.

The transformer in short circuit conditions shall be injected with a current causing the total losses. In case of a traction converter transformer, the total losses are intended as the sum of the no-load loss and of the total load losses determined according to Annex C.

Total losses calculated on the service current in basic load condition (I_{BGL}) are injected until it reaches temperature steady-state conditions and then the long-term overload current is injected, for the specified duration of said overload according to the duty class or load cycle. The final top oil temperature rise shall be recorded.

For determining the temperature rises of windings, the transformer shall be subsequently loaded by service currents representing the basic load (including the effect of harmonics), for the time necessary to reach steady temperatures of the windings, and, for the respective durations, the service currents corresponding to long-time overloads, and, when practicable and agreed between purchaser and supplier, service currents corresponding to short-time overloads.

Measurements shall be taken at the end of the long-time overload duration and, when applicable, at the end of the short-time overload duration. When actual measurements are not possible, it may be agreed to carry out calculations on temperature variations along the short-time load duration, performed according to conventional methods.

IEC 60076-7 gives guidance for such a calculation.

5.2.3 Temperature rise measurement for dry-type transformers

The requirements given in Clause 23 of IEC 60076-11:2004 apply taking into account that in the second part of the test the losses attributable to the various stages of the current demand shall be calculated and successively applied and the overloads for the respective duration. Annex C allows determining total load losses.

Measurements shall be taken at the end of the long-time overload duration and, when applicable, at the end of the short-time overload duration. For transformers designed according to a duty class recommended test cycles for the temperature rise tests are given in Annex A.

When actual measurements are not possible, it may be agreed to carry out calculations on temperature variations along the short-time load duration, performed according to conventional methods.

IEC 60076-12 gives guidance for such a calculation.

5.2.4 Alternative criteria for determining temperature rise limits

On agreement between purchaser and manufacturer temperature limits and thermal ageing according to IEC 60076-7, IEC 60076-12 or IEC 60076-14 may be applied.

If the purchaser is able to define the load cycle in an extensive way as current demand, the capability of the transformer to sustain this current demand shall be checked as follows:

- temperature rise and loss measurements shall be performed at sinusoidal load with rated service current I_{NGL} ;

- based on these measurements, the top-oil temperature, the hot-spot temperatures of the windings and the relative loss of life for the given current demand shall be calculated. The loss of life calculation procedure of IEC 60076-7 may be used;
- the temperatures at the beginning of the load-cycle shall be set equal to those at the end of the load cycle to consider a steady state condition;
- the calculated relative loss of life for the load cycle based on the yearly average temperature shall be equal to or lower than 1;
- for conventional oil immersed transformers, the maximum occasional hot-spot- temperature shall be lower than 140 °C and the maximum top oil temperature shall be lower than 115 °C during the load cycle; for high-temperature insulation materials higher limits may be agreed;
- the influence of harmonics shall be considered as described in Annex C.

For transformers designed according to a duty class recommended test cycles for the temperature rise tests are given in Annex A.

5.3 Transferred overvoltages

The provisions of this subclause may be normally omitted in transformers supplying a.c. contact lines, especially if one of the LV terminals is connected to the return circuit.

Care shall be taken to avoid transmission of inadmissible voltage surges between primary and secondary windings and vice versa.

The manufacturer shall either give demonstration, if required by means of a type test with the recurrent impulse generator at low voltage or by means of high impedance device (e.g. oscilloscope probe), that phenomenon is negligible or agree with the purchaser the steps taken to minimise transferred overvoltages.

This protection can be achieved, for the transformers feeding semiconductor converters, either with an insulation level in excess of the expected overvoltages or by means of suitable screens. The latter solution should be used when the demonstration according to the previous paragraph is not possible. It should be considered that in some cases overvoltages can also be reduced with capacitors connected to the LV terminals.

5.4 Short circuit stresses

5.4.1 General

Traction transformers are subject to frequent short circuits and current shocks. The purchaser shall indicate the short circuit apparent power of the supply line at the transformer (in lack of such indication the regulations in IEC 60076-5 apply). The purchaser shall also inform the manufacturer regarding the reclosing procedure in use.

The manufacturer shall take particular care to these aspects in the mechanical design of the traction transformers.

Agreed calculations or the test procedure indicated in IEC 60076-5 (special test) may prove the suitability of the transformer to withstand such stresses. A short circuit type test may be agreed between purchaser and supplier at the time of ordering.

5.4.2 Short circuit withstand (when applicable)

Traction transformers shall be suitable to short circuit test carried out at the installation site and/or in a test laboratory.

For traction converter transformers the short circuit test should be carried out as combined transformer-converter test. The procedure for this test is given in 7.7 of IEC 62589:2010.

For directly coupled traction transformers, the following procedure may be agreed.

The transformer shall be fed by the rated voltage with a wave-shape as per IEC 61000-2-12. Its tap changer, if any, shall be placed in the principal tap position. Over-excitation of the transformer to ensure full short circuit current is not admitted in this case.

The reactance of the transformer before test shall be recorded. The short circuit shall be established on the low voltage side by a suitable short circuit maker, ensuring, when possible, an asymmetric short circuit, and cleared by the secondary circuit breaker. Other test connections such as switching in with an already short circuited winding may be required. The short circuit test may also be performed with a short circuit on the high voltage side.

In case an auto-reclose scheme is adopted for the said circuit breaker, a number of sequences (up to two) of opening and closing operations, in line with the requirements of IEC 62505-1 shall be agreed in the offering stage. The sequences of short circuits shall be carried out with an interval of 900 s.

The wave shape shall be exempted from distortions during breaking as far as applicable. For this reasons breakers introducing harmonics beyond the limits given in the fourth paragraph of 5.4.2 shall be avoided.

Oscillographic record shall be taken for voltage and current both on primary and secondary side.

The following measurements shall be normally taken:

- voltage and current during the fault;
- impedance at least before the test, just after the first short circuit sequence, immediately after the second sequence, one hour after the first measurement.

To show that the test object passed the test the impedance value measured after the second sequence shall not differ from that taken before the tests by more than 3 % of the impedance value.

5.5 Insulation characteristics and test values

Annex B gives the insulation levels (corresponding to highest voltage for equipment U_m according to IEC 60076-3) to be observed in the design of the insulation and test of the same.

These values are taken from IEC 60076-3 for voltages above 52 kV and from IEC 62497-1 for traction voltages.

For voltage values not covered in Annex B the values given in Table 2 or Table 3 of IEC 60076-3:2013 may be taken as applicable.

For clearances and creepage distances, refer to IEC 62497-1 for voltages up to 52 kV and to IEC 60076-3 for higher voltages.

5.6 Other particular features

Traction transformers may be required with a tertiary/additional winding, which may be used for ancillary services. In such cases the design of the said winding shall consider very carefully transfer of overvoltages and short circuit stresses.

The choice of the provision of particular accessories and features is left to the parties and are not covered in this standard.

5.7 Requirements for the simulation test

For assessment and for simulation works, the supplier shall, when required by the purchaser and stated in the enquiry specifications, give the information mentioned in Clause D.2 relating to the magnetic characteristics of the traction transformer.

5.8 Rating plate

Requirements of IEC 60076-1 (information to be given in all cases) and of IEC 60076-11 apply.

In addition the following information shall be given:

- a) kind of transformer:
 - traction converter transformer;
 - traction inverter transformer;
 - directly-coupled traction transformer;
 - traction auto-transformer;
 - traction auxiliary transformer;
- b) the number of this standard;
- c) duty class(es), referred to Annex A to this standard;
- d) cooling method;
- e) class of insulation material used;
- f) insulation levels of the windings, referred to Annex B to this standard;
- g) provision against transferred overvoltages (if any);
- h) no-load current;
- i) inrush current (peak and time constant);
- j) short circuit power factors;
- k) indoor/outdoor;
- l) service conditions which differ from standard conditions (i.e. lower ambient temperature);
- m) auxiliary power characteristics;
- n) scheme of connection with identification of terminals (typical example is given in Figure 1).

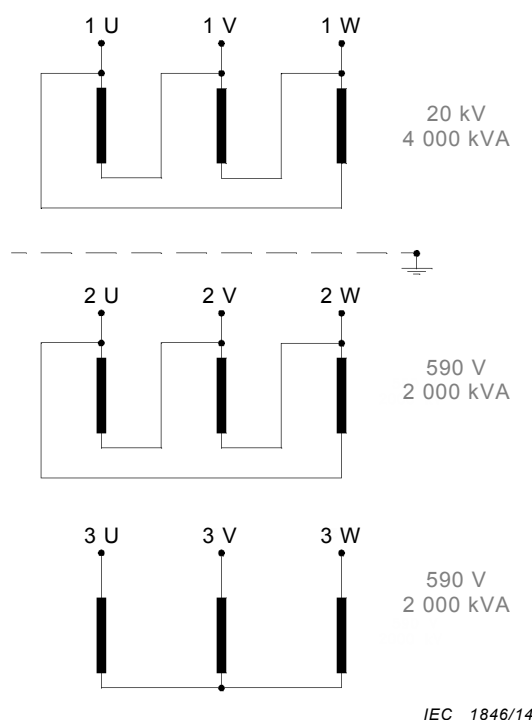


Figure 1 – Example of scheme for connection Dd0y11 with earthed screen

6 Directly-coupled traction transformer

6.1 General

This clause covers some specific testing procedures concerning single-phase traction transformers having both supply side terminals connected to two line conductors of a three-phase or single-phase system and unearthed.

Transformers with two traction side windings each having one terminal connected to contact line or to line feeder and the remaining one commonly connected to the running rails (in such cases the LV is designated $2 \times U_{ph}$) are considered for the voltage level U_m corresponding to U_{ph} if the rail is earthed.

6.2 Dielectric tests for windings with $U_m < 300$ kV

6.2.1 General

This subclause applies to transformers under 6.1 with $U_m < 300$ kV (see Clause 7 of IEC 60076-3:2013).

6.2.2 Applied voltage test (routine test)

Each winding shall be submitted to applied voltage test according to Clause 10 of IEC 60076-3:2013, but according to the insulation values given in Annex B.

6.2.3 Lightning impulse test (type test)

Each line terminal (both ends of each winding) shall be submitted to the lightning impulse test according to Clause 13 of IEC 60076-3:2013, but according to the insulation values given in Annex B. In case of tapped winding, the test shall be carried out on the principal tap, unless otherwise agreed between purchaser and manufacturer.

In addition, if agreed between purchaser and manufacturer, the lightning impulse test is carried out by impulsing the two line terminals connected together against the other winding(s), the core and the tank connected to earth.

6.2.4 Induced overvoltage withstand test (routine test)

The test voltage across the windings shall be twice the rated phase-to-phase voltage.

If in the HV winding the test voltage exceeds the value prescribed for the separate source withstand test, the voltage towards earth of the terminals may be limited by using appropriate devices connected between terminals and earth.

In case of tapped winding, the test shall be carried out on the principal tap, unless otherwise agreed between purchaser and manufacturer.

For remaining test modalities see Clause 11 of IEC 60076-3:2013.

NOTE In case of a three-phase winding, star connected, at $U_m = 245$ kV phase-to-phase, the winding is at 142 kV. The test voltage is, in any case not greater than 395 kV; the ratio between these voltages is 2,78. For single-phase transformers, connected between two line terminals, a voltage $U_m = 245$ kV is actually present across the winding. It is herein prescribed that a test voltage of 490 kV is induced to ensure a minimum test ratio of 2. Otherwise, according to IEC 60076-3, the test ratio would be only 1,61.

6.3 Dielectric tests for windings with $U_m \geq 300$ kV

6.3.1 General

This subclause applies to transformers according to 3.1 with $U_m \geq 300$ kV (see Clause 7 of IEC 60076-3:2013).

If agreed between purchaser and manufacturer, the applicability of 6.3 may be applied to transformers $U_n \geq 200$ kV.

6.3.2 Applied voltage test (routine test)

Each winding shall be submitted to applied voltage test according to IEC 60076-3:2013.

6.3.3 Lightning impulse test (routine test)

Each line terminal (both ends of each winding) shall be submitted to the lightning impulse test according to Annex B and Clause 13 of IEC 60076-3:2013.

In case of tapped winding, the test shall be carried out on the principal tap, unless otherwise agreed between purchaser and manufacturer.

6.3.4 Switching impulse test (routine test)

Each line terminal (both ends of each winding) shall be submitted to the switching impulse test according to Clause 14 of IEC 60076-3:2013. In case of tapped winding, the test shall be carried out on the principal tap, unless otherwise agreed between purchaser and manufacturer. The test may be required by the purchaser for transformer windings at voltages ≤ 300 kV U_m in case circuit breakers suitable to produce switching surges are used.

6.3.5 Induced overvoltage withstand test (routine test)

The test voltages across the windings shall be as follows:

- $U_1 = 1,7 \times U_m$ for $U_m < 200$ kV
 $2,0 \times U_m$ for $200 \text{ kV} \leq U_m < 300 \text{ kV}$
- $U_2 = 1,3 \times U_m$ with specified value of $q = 100$ pC.

If in the HV winding the test voltage exceeds the value prescribed for the separate source withstand test, the voltage towards earth of the terminals may be limited by using appropriate devices connected between terminals and earth.

In case of tapped winding, the test shall be carried out on the principal tap, unless otherwise agreed between purchaser and manufacturer.

For remaining test modalities see Clause 11 of IEC 60076-3:2013.

7 Traction converter transformers

7.1 General

The IEC 61378 series specifies requirements for converter transformers for industrial use. This clause specifies additional requirements for traction rectifier transformers of most common use in substations with semiconductor diode rectifiers. Traction converter transformers for controlled converters need additional considerations and shall be subject to special agreement between purchaser and supplier.

Transformers for 6-pulse three-phase bridge connections have one primary and one secondary winding.

Transformers for 12-pulse rectifier connections have one or two primary windings and two secondary windings with a 30° phase shift between the secondary windings. One secondary winding is commonly star connected and the other is delta connected. Three types of rectifier transformers are preferably used for 12-pulse traction rectifier groups:

- a) three-windings transformer with one primary winding and two closely coupled secondary windings: coupling factor $K \geq 0,9$;
- b) three-windings transformer with one primary winding and two loosely coupled secondary windings: coupling factor $0,2 \leq K < 0,9$;
- c) four-windings transformer with two primary windings and two uncoupled secondary windings: coupling factor $K < 0,2$.

Three-windings transformers with closely coupled secondary windings are the preferred type for 12-pulse series connections and they are also used for 12-pulse parallel connections. The 12-pulse parallel connection needs an interphase transformer between the two rectifier bridges.

NOTE At low secondary voltages as for example for series connected rectifier groups for nominal voltage 750 V d.c. it is practically impossible to reach a coupling factor $K \geq 0,9$ due to the inductance of busbars.

Three-windings transformers with loosely coupled secondary windings are used for 12-pulse parallel connections with interphase transformer where certain requirements regarding voltage characteristics and maximum short-circuit current exist.

Four-windings transformers are used for 12-pulse parallel connections without the need of an interphase transformer.

It is recommended that 12-pulse rectifier groups with uncoupled rectifier transformers are not used with interphase transformers. The impedance of the uncoupled transformer secondary windings performs a function similar to an interphase transformer.

Other types of traction rectifier transformers are

- transformers using zigzag connections for 24-pulse rectifier connections,
- transformers with compensating windings,
- transformers for six-phase double star connection with interphase transformer.

These transformers need additional considerations and the particular requirements are subject to agreement between purchaser and supplier.

It is assumed in IEC 60076 that transformers are tested in sinusoidal conditions of voltage and current, as applicable in the manufacturer's works or in a laboratory. The actual losses however are highly influenced by the harmonic contents of the current, which depends on the characteristics of the converter. To simplify, only the effect of the typical harmonics of each scheme is considered, without any reference to the voltage harmonics, due to external sources and to those harmonics, of negligible effect however, which appear in the actual operation of a converter. Refer to 7.6 of IEC 61378-1:2011 for testing methods to include such harmonic effects.

The neutral point of a secondary star winding feeding a converter shall not be earthed and normally needs not be brought out.

7.2 Short-circuit impedance and load loss

7.2.1 Total load loss calculation

The losses shall be guaranteed at rated service current (see 10.4 of IEC 60076-1:2011). On purchaser's request, as an alternative, the losses at basic service current may be guaranteed.

The load loss, which appears under normal service conditions, is considered composed of the loss in the winding resistance as measured by d.c. and the additional loss caused by eddy currents, as well as by the stray flux in the windings and in the constructive parts.

The additional stray losses caused by the harmonics depend on the construction of the transformer, on the firing angle and the commutation reactance and may vary in a wide range.

The calculation of total load loss of the traction transformer in converter operation (P_T) may be obtained through alternative methods; the purchaser shall state which method he intends to be applied at the tender invitation stage, otherwise the method will be stated by the manufacturer.

In Annex C alternative methods for the calculation of load loss in transformers during converter operation are given.

7.2.2 Impedance

NOTE For the definition of impedance see 3.7 of IEC 60076-1:2011.

The short-circuit impedance shall be measured and recorded between each pair of windings. The impedance values shall be within the tolerances stated in 7.3.

For three-windings transformers the percent impedance shall be measured and recorded

- for the whole transformer with the terminals of both secondary windings short-circuited, at rated current flowing in the primary winding, $z_{P/S}$
- between the primary winding and either secondary winding with the terminals of one secondary winding short-circuited and the terminals of the other secondary left open, at 50 % rated current flowing in the primary winding, $z_{P/S1}$ and $z_{P/S2}$
- between the two secondary windings with the terminals of one secondary winding short circuited and rated current flowing in the other secondary winding, $z_{S1/S2}$

For four-windings transformers the percent impedance shall be measured and recorded

- for the whole transformer with the terminals of both secondary windings short-circuited, and rated current flowing in the primary windings, $z_{P/S}$

- between either one primary winding and the relating secondary winding with the terminals of the secondary winding short-circuited and the terminals of the other secondary left open, at rated current of each primary winding, $Z_{P1/S1}$ and $Z_{P2/S2}$

In case of additional windings (for example for auxiliary supply) care shall be taken to avoid adverse effect of these windings on the impedance of the secondary windings.

7.3 Tolerances

For no-load loss and load loss the tolerances stated in Clause 9 of IEC 60076-1:2011 apply.

The permissible tolerances for voltage ratio and short circuit impedance of traction converter transformers depend on the connection of the converter group and on the requirements regarding inherent voltage regulation, short-circuit current and parallel working of converter groups.

For voltage ratio and short-circuit impedance the tolerances according to Table 1 apply.

NOTE The required tolerance values for voltage ratio and short-circuit impedances can be significantly lower than for distribution transformers.

Table 1 – Tolerances for voltage ratio and impedances of traction converter transformers

Item	Tolerance
1. Transformers with one primary and one secondary winding (three phase bridge connection no. 8) ^a	
Voltage ratio at no-load (on principal tapping)	± 0,5 % of the declared value
Short circuit impedance (on principal tapping)	± 10 % of the declared value ^b
2. Three-windings transformer with one primary and two secondary windings for 12-pulse parallel connection with interphase transformer (connection no. 9)	
Voltage ratio at no-load (on principal tapping)	
– between primary winding and either secondary winding	± 0,5 % of the declared value
– deviation of the two voltage ratios primary winding to either secondary winding from the mean value	± 0,2 % of the arithmetic mean value of both voltage ratios
Short-circuit impedance (on principal tapping) for:	
– primary winding and both secondary windings $Z_{P/S}$	± 10 % of the declared value ^b
– primary winding and each individual secondary winding $Z_{P/S1}$ and $Z_{P/S2}$	± 10 % of the declared value ^b
– deviation of the impedance values $Z_{P/S1}$ and $Z_{P/S2}$ from the mean value of both impedances	± 1,5 % of the arithmetic mean value of both impedances
– one secondary winding to the other $Z_{S1/S2}$	± 10 % of the declared value
3. Four-windings transformer with two primary and two secondary windings for 12-pulse parallel connection (connection no. 9 without interphase transformer) ^a	
Voltage ratio at no-load (on principal tapping)	
– between primary windings and secondary windings	± 0,5 % of the declared value
– deviation of the two voltage ratios primary winding to either secondary winding from the mean value	± 0,2 % of the arithmetic mean value of both voltage ratios
Short-circuit impedance (on principal tapping) for:	
– primary windings and both secondary windings $Z_{P/S}$	± 10 % of the declared value ^b
– individual primary and secondary winding pairs $Z_{P1/S1}$ and $Z_{P2/S2}$	± 10 % of the declared value ^b
– deviation of the impedance values $Z_{P1/S1}$ and $Z_{P2/S2}$ from the mean value of both impedances	± 2,5 % of the arithmetic mean value of both impedances

Item	Tolerance
4. Three-windings transformer with one primary and two secondary windings for 12-pulse series connection (connection no. 12)	
Voltage ratio at no-load (on principal tapping) – between primary winding and either secondary winding	$\pm 0,5$ % of the declared value
Short-circuit impedance (on principal tapping) for: – primary winding and both secondary windings $z_{P/S}$ ^c – primary winding and each individual secondary winding $z_{P/S1}$ and $z_{P/S2}$ – deviation of the impedance values $z_{P/S1}$ and $z_{P/S2}$ from the mean value – one secondary winding to the other $z_{S1/S2}$	± 10 % of the declared value ^b ± 10 % of the declared value $\pm 2,5$ % of the arithmetic mean value of both impedances ± 10 % of the declared value
^a The tolerances for four-windings transformers are also applicable to the transformers of two parallel connected three-phase bridge rectifier groups (connection no. 8) with 30°-phase displaced transformer connections, both together forming a twelve-pulse substation. ^b Depending on the requirements for the voltage regulation of rectifier groups, lower tolerance values for short circuit impedance may be agreed between purchaser and supplier. This applies in particular where a new rectifier group shall be connected in parallel with one or several existing group(s). ^c This value is only correct if the current in the secondary windings is balanced during the test as it is during operation with a series rectifier. The current balance should be checked during measurement.	

8 Auxiliary transformers

Auxiliary transformers used in traction plants may have to be designed taking into account particular requirements as follows:

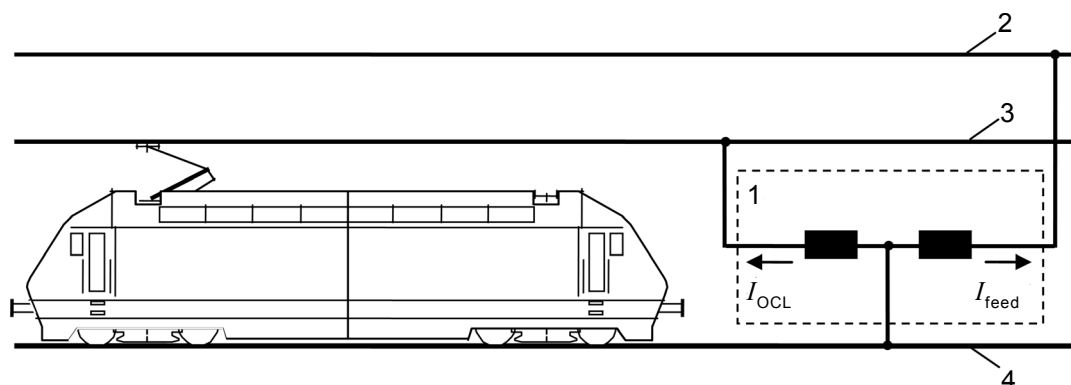
- the short circuit power upstream the transformer is in some cases higher than normal, because these transformers operate often close to supply sources of high power. This fact shall be brought by the purchaser to the attention of the supplier at the offer stage. The need of verifying short circuit withstand capability shall be considered;
- when the auxiliary transformers are subject to loads with high harmonic content this fact shall be brought by the purchaser to the attention of the supplier. In such cases it shall be agreed to follow either the provisions of Clause 4 or of IEC 61378-1:2011 (as applicable).

9 Traction auto-transformers

9.1 General

Traction auto-transformers are used in single-phase a.c. traction systems to reduce the voltage drop along the line with the possibility to increase traction power and the distance between substations (see Figure 2).

Because traction auto-transformers can also reduce the rail currents, reduction of inductive disturbance on telecommunication line may be possible.



IEC 1847/14

Key

- 1 Traction autotransformer
- 2 Feeder line (Feed)
- 3 Overhead contact line (OCL)
- 4 Running rails (Rail)

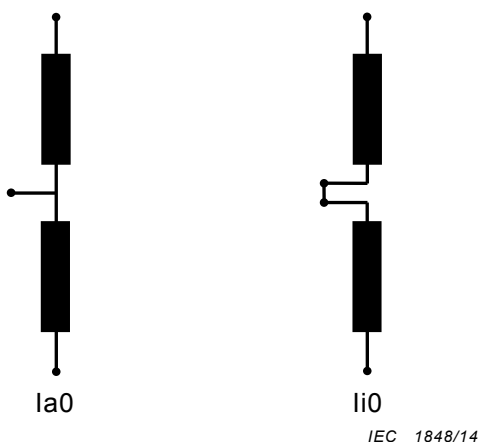
I_{OCL} Winding current through OCL-winding of the autotransformer

I_{feed} Winding current through Feeder-winding of the autotransformer

Figure 2 – Typical arrangement of a traction auto-transformer

Traction auto-transformers are connected between overhead contact line and feeder line with a mid point connection to the running rails (return circuit). The power from the feeder is transmitted with the voltage level defined by the voltage difference between overhead contact line and feeder line. Due to this higher voltage level smaller currents for the power transmission are necessary and the currents in the return circuit are reduced.

The centre tap connection can be made either internally or externally. The relating vector groups are Ia0 and Ii0 (see Figure 3).



IEC 1848/14

Figure 3 – Vector groups of traction auto-transformers

The most common voltage ratio is:

$$\frac{U_{\text{OCL-feed}}}{U_{\text{OCL-rail}}} = 2$$

where

$U_{\text{OCL-feed}}$ is the voltage between the overhead contact line and the line feeder,

$U_{\text{OCL-rail}}$ is the voltage between the overhead contact line and the return circuit.

Other voltage ratios are also in use.

The power of a traction auto-transformer is given as throughput power (rated power) S_N and as equivalent power S_E .

$$S_N = S_E \times \frac{U_{\text{OCL-feed}}}{U_{\text{OCL-feed}} - U_{\text{OCL-rail}}}$$

$$S_E = I_{\text{OCL}} \times U_{\text{OCL-rail}}$$

NOTE The equivalent power S_E is mainly of interest for the manufacturer of the traction auto-transformer.

The purchaser shall specify to the supplier

- the rated power S_N and/or the equivalent power S_E ,
- the voltages $U_{\text{OCL-feed}}$ and $U_{\text{OCL-rail}}$,
- the short circuit withstand currents for the windings and for the centre tap,
- the connection of the centre tap.

9.2 Loading

Subclause 5.1 applies.

9.3 Checking of the capability of the auto-transformer to sustain the stipulated load cycle

Subclause 5.2 applies.

9.4 Short-circuit stresses

Subclause 5.4 applies.

The short-circuit current level is defined by the system characteristics rather than by the auto-transformer impedance, therefore the short circuit current levels specified by the purchaser shall be applied.

10 Three-phase to two-phase conversion transformers

10.1 General

Three-phase to two-phase conversion transformers mentioned in this clause are used in a.c. traction systems for ensuring balanced load on the three-phase side.

10.2 Scott connection transformer

10.2.1 General

Scott connection transformers convert three-phase to two-phase using the connection seen in Figure 4.

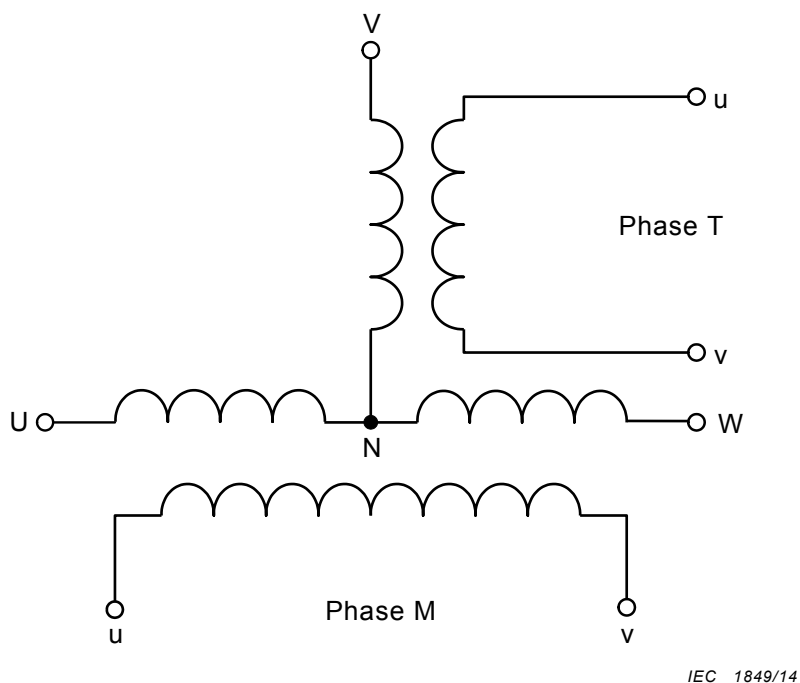


Figure 4 – Connection of Scott connection transformers

The ratio of voltages and currents between the primary side and the secondary side are given in the following formulas.

NOTE 1 Prerequisite conditions of leakage impedances or excitation impedances are omitted.

a) Voltage ratio

$$\text{Phase M} \quad \frac{\overline{U_{UW}}}{U_M} = \frac{U_1}{U_2} = m$$

$$\text{Phase T} \quad \frac{U_{VN}}{U_T} = \frac{(\sqrt{3}/2) \times U_1}{U_2} = \frac{\sqrt{3}}{2} \times m$$

where

U_1 is the primary voltage (line to line);

U_2 is the secondary voltage ($U_2 = |U_M| = |U_T|$);

U_M is the phase M secondary voltage;

U_T is the phase T secondary voltage.

b) Phase current (line voltage base)

$$I_U = I_W = \sqrt{I_{UM}^2 + I_{UT}^2}$$

$$I_V = I_{VT}$$

$$I_{UT} = \frac{1}{2} \times I_{VT} = \frac{1}{2} \times \frac{2}{\sqrt{3} \times m} \times I_T$$

$$I_{VT} = \frac{2}{\sqrt{3} \times m} \times I_T$$

where

I_U, I_V, I_W is the primary current;

I_M, I_T is the secondary current;

I_{UM} is the phase U primary current caused by loading on phase M;

I_{UT} is the phase U primary current caused by loading on phase T;

I_{VT} is the phase V primary current caused by loading on phase T.

NOTE 2 There are no phase V primary currents caused by loading on phase M.

10.2.2 Loading

Subclause 5.1 applies.

10.2.3 Checking of the capability of the Scott connection transformer to sustain the stipulated load cycle

Subclause 5.2 applies.

10.2.4 Short-circuit stresses

Subclause 5.4 applies.

The short-circuit current level is defined by the system characteristics rather than by the Scott connection transformer impedance. Therefore the short circuit current levels specified by the purchaser shall be applied.

10.3 Modified Woodbridge transformer

10.3.1 General

Because the neutral point of the primary winding of modified Woodbridge transformers can be earthed, modified Woodbridge transformers are used in ultra high voltage systems. Modified Woodbridge transformers are in particular used in high speed railways. The connection of modified Woodbridge transformers is shown in Figure 5.

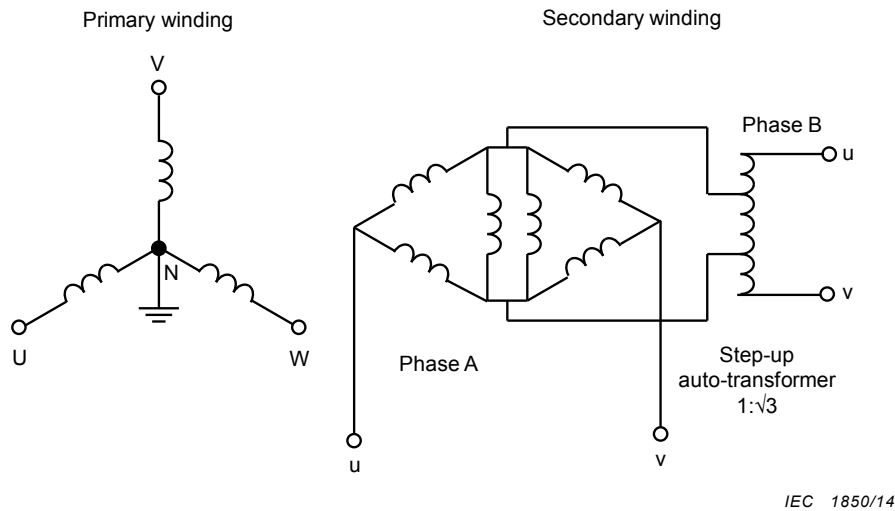


Figure 5 – Connection of modified Woodbridge transformers

The relationship of voltages and currents between the primary side and the secondary side are shown in the following formulas.

NOTE Prerequisite condition of leakage impedances or excitation impedances are omitted.

a) Voltage ratio

$$\text{Phase A} \quad \frac{\overline{U_{UW}}}{U_A} = \frac{U_1}{U_2} = m$$

$$\text{Phase B} \quad \frac{\overline{U_{VN}}}{U_B} = \frac{\frac{1}{\sqrt{3}} \times U_1}{U_2} = \frac{1}{\sqrt{3}} \times m$$

where

- U_1 is the primary voltage;
- U_2 is the secondary voltage ($U_2 = |U_A| = |U_B|$);
- U_A is the phase A secondary voltage;
- U_B is the phase B secondary voltage.

b) Phase current (line voltage base)

Phase A currents are shown in Figure 6.