IEC/IEEE 60076-57-1202

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INTERNATIONAL STANDARD

NORME INTERNATIONALE

colour inside

Power transformers –
Part 57-1202: Liquid immersed phase-shifting transformers

Transformateurs de puissance –
Partie 57-1202: Transformateurs déphaseurs immergés dans un liquide

IEC/IEEE 60076-57-1202:2017-05(en-fr)

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CONTENTS

FOREWORD 5
1 Scope 7
2 Normative references 7
2.1 IEC references 7
2.2 IEEE references 7
3 Terms and definitions 8
4 Use of normative references 11
5 Service conditions 11
5.1 General 11
5.2 Usual service conditions 11
5.2.1 Switching arrangement 11
5.2.2 Power flow 11
5.2.3 Operation with two or more PSTs in series or parallel 11
5.2.4 Phase unbalance 12
5.2.5 Surge protection 12
6 Rating and general requirements 12
6.1 Rated power 12
6.2 Loading at other than rated conditions 12
6.3 Specification of buck capability 12
6.4 Cooling modes 13
6.5 Short circuit impedance and load phase angle capability 13
6.5.1 Specification 13
6.5.2 Short circuit impedance for asymmetric designs 13
6.6 Neutral earthing (grounding) 13
6.7 Rated voltage 13
6.8 Voltage variation and asymmetric design 13
6.9 Rated frequency 14
6.10 Operation at higher than rated voltage and/or at other than rated frequency 14
6.11 Highest voltage for equipment and dielectric test levels 14
6.12 Taps 14
6.13 Sound level 14
6.14 Transport 14
7 Construction 14
7.1 General 14
7.2 Liquid-filled connections between tanks 15
7.3 Liquid insulation and preservation system 15
7.4 Alignment between tanks 15
7.5 Core and core frame earthing arrangements 16
7.6 Test connections 16
8 Short circuit capability 16
9 Connection phase displacement symbols 16
9.1 General 16
9.2 Special symbols for PSTs 16
9.3 Clock number notation 17
9.4 Examples 17
9.4.1 Single core phase shifting transformers 17

AVA Documents
Document Sharing Hub
Full document details: IEC IEEE 60076-57-1202-2017

9.4.2 Two core phase shifting transformers 19
9.4.3 Transformers incorporating a phase shifting element 21
10 Rating plates (nameplates) 22
11 Terminal markings and phase rotation 23
12 Information to be provided by the manufacturer 23
13 Tests 24
13.1 General 24
13.2 Routine tests 24
13.3 Type (design) tests 24
13.4 Special tests 24
13.5 Winding resistance 25
13.6 Measurement of voltage ratio, phase angle and check of phase displacement 25
13.7 Measurement of short-circuit impedance and load loss 25
13.8 Temperature-rise test 26
13.9 Measurement of no-load loss and current 26
13.10 Determination of sound level 26
13.10.1 General 26
13.10.2 For PSTs with one combined cooling system 26
13.10.3 For PSTs with separate exciting and series unit cooling systems 27
13.11 Measurement of zero sequence impedance 27
13.12 Dielectric tests 27
13.12.1 General 27
13.12.2 Induced voltage test with partial discharge measurement (IVPD) 28
13.12.3 Switching impulse test (SI) 28
13.12.4 Lightning impulse test 28
13.12.5 Lightning impulses applied to multiple line terminals simultaneously (LIMT) 29
13.13 Tests on on-load tap-changers – operation test 29
13.14 Leak testing with pressure 30
13.15 Vacuum deflection test 30
13.16 Pressure deflection test 30
14 Tolerances 30
14.1 General 30
14.2 Tolerance for impedance and phase angle 30
Annex A (informative) Check list of information to be provided with enquiry and order 32
A.1 Rating and general data 32
A.1.1 Normal information 32
A.1.2 Special information 33
A.2 Parallel operation 34
Annex B (informative) Behaviour of a phase shifting transformer with non-symmetrical fault currents 35
Annex C (informative) Example specification of buck capability 37
Annex D (informative) Additional noise measurements 38
Annex E (informative) Calculation of phase angle under load 40
Annex F (informative) Additional information on advance-retard switch 44
F.1 Principle 44
F.2 Classification within the international standardization system 44

AVA Documents
Document Sharing Hub
Full document details: IEC IEEE 60076-57-1202-2017

F.3 Requirements according to IEC 60214-1 and IEEE Std C57.131 44
Bibliography 45

Figure 1 – Example A: DS0-3/9 18
Figure 2 – Example B: PS0-3/9 18
Figure 3 – Example C: DA0-3 19
Figure 4 – Example D: YNyn/IIId S0-3/9 20
Figure 5 – Example E: YNyn+d/IIId A0-3/9 20
Figure 6 – Example F: YNa0yn/dIII A0-3/9 21
Figure 7 – Example G: V A0-2/8 22
Figure B.1 – PST with single phase fault and surge protection 36
Figure E.1 – Phase angle diagram for a PST under load where $\alpha_0 > 0$ and $\varphi_L < 0$ 40
Figure E.2 – Phase angle diagram for a PST under load where $\alpha_0 < 0$ and $\varphi_L < 0$ 40
Figure E.3 – Phase angle diagram for a PST under load where $\alpha_0 > 0$ and $\varphi_L > 0$ 41
Figure E.4 – Phase angle diagram for a PST under load where $\alpha_0 < 0$ and $\varphi_L > 0$ 41

Table C.1 – Required PST capability in buck operation 37
Table D.1 – Combinations of sound level measurements needed to represent different loading conditions 39

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Document Sharing Hub
Full document details: IEC IEEE 60076-57-1202-2017

POWER TRANSFORMERS –

Part 57-1202: Liquid immersed phase-shifting transformers

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

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POWER TRANSFORMERS –

Part 57-1202: Liquid immersed phase-shifting transformers

1 Scope

This part of IEC 60076 covers the requirements for phase-shifting transformers of all types. The scope excludes transformers with an unregulated phase shift.

This document is limited to matters particular to phase-shifting transformers and does not include matters relating to general requirements for power transformers covered in existing standards in the IEC 60076 series or IEEE Std C57.12.00™ and IEEE Std C57.12.10™.

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.

2.1 IEC references

IEC 60050-421, *International Electrotechnical Vocabulary – Chapter 421: Power transformers and reactors* (available at: www.electropedia.org)

IEC 60076-1, *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 60076-10, *Power transformers – Part 10: Determination of sound levels*

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

ISO 2178, *Non-magnetic coatings on magnetic substrates – Measurement of coating thickness – Magnetic method*

ISO 2409, *Paints and varnishes – Cross-cut test*

2.2 IEEE references

IEEE Std C57.12.00™, *IEEE Standard for General Requirements for Liquid-Immersed Distribution, Power, and Regulating Transformers*

IEEE Std C57.12.10™, *IEEE Standard Requirements for Liquid-Immersed Power Transformers*

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IEEE Std C57.12.70™, *IEEE Standard for Standard Terminal Markings and Connections for Distribution and Power Transformers*

IEEE Std C57.12.80™, *IEEE Standard Terminology for Power and Distribution Transformers*

IEEE Std C57.12.90™, *IEEE Standard Test Code for Liquid-Immersed Distribution, Power, and Regulating Transformers*

3 Terms and definitions

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

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

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

For the purposes of this document, the terms and definitions given in IEC 60050-421 and IEC 60076-1 apply to IEC specified phase shifting transformers. For IEEE specified phase shifting transformers the terms and definitions given in IEEE Std C57.12.80 apply. For all phase shifting transformers the following apply and take precedence.

3.1
phase-shifting transformer
PST
transformer (or combination of transformers designed to work together) with two sets of line terminals (S and L) which is capable of varying the voltage phase-angle relationship between the S terminals and the L terminals

Note 1 to entry: The rated voltage of the S terminals and the L terminals may be the same or different. In addition the PST may also be capable of varying the in-phase voltage.

Note 2 to entry: This note applies to the French language only.

3.2
S terminal
terminal that is used as the fixed reference point when measuring the voltage phase angle of a phase-shifting transformer

3.3
L terminal
terminal that is used to measure the voltage phase angle when compared to the S terminal of the phase-shifting transformer

Note 1 to entry: The designations of S and L to the terminals do not imply any particular direction of power flow.

3.4
zero phase shift tap position
tap position at which the no-load voltage phase angle is zero

3.5
rated power
output power at rated voltage and rated frequency that can be delivered at the L terminal continuously without exceeding the specified temperature rise

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3.6
excitation winding
winding of a phase-shifting transformer (PST) that draws power from the source to energize the PST

3.7
excited winding
winding of the series unit that is excited from the exciting winding

3.8
quadrature booster
asymmetric design phase-shifting transformer with the excitation winding connected to the S terminal

3.9
symmetric design
phase-shifting transformer where the no-load voltage ratio between the S and L terminals is constant

3.10
asymmetric design
phase-shifting transformer where the no-load voltage ratio between the S and L terminals changes with the phase angle variation tap position

3.11
single-core PST
phase-shifting transformer that has all windings mounted on a single core

3.12
two-core PST
phase-shifting transformer consisting of a series unit and an exciting unit, located on two separate cores

3.13
extreme tap
tap for maximum absolute value of no-load phase angle in the advance or retard direction

3.14
phase angle
electrical phase angle expressed in degrees between the S and L terminals with a sign such that the angle is positive when the voltage at the L terminal leads the voltage at the S terminal

3.15
boost operation
operation when the PST is acting to increase the power flow in the circuit

3.16
buck operation
operation when the PST is acting to reduce or reverse the power flow in the circuit

Note 1 to entry: For example, in retard operation the load phase angle between the S and L terminals is made more negative in buck operation relative to the no-load phase angle at the same tap position because both the no-load phase angle and the phase angle change caused by the load are negative (see Annex E).

3.17
advance
mode of operation where the L terminal no-load voltage leads the S terminal no-load voltage, giving a positive no-load phase angle

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3.18
retard
mode of operation where the L terminal no-load voltage lags the S terminal no-load voltage, giving a negative no-load phase angle

3.19
rated voltage
no-load phase-to-phase voltage at zero phase shift tap position to which operating and performance characteristics are referred

3.20
tapping voltage of the S terminal
<for asymmetric designs> no-load phase-to-phase voltage based on turns ratio appearing at the S terminal when rated voltage is applied to the L terminal at a particular tap position

Note 1 to entry: For an asymmetric design, the voltage at taps other than at the zero phase shift tap position will be lower at the S terminal than the L terminal. This definition is used so that the series unit rated current is constant with tap position to be compatible with the rating of the attached power system circuits.

3.21
series winding
winding connected between the S and L terminals

Note 1 to entry: The term series winding refers to any winding or set of windings that can be connected between the S and L terminals. For example, this term refers to the tap winding of a single-core phase shifting transformer where this winding is connected between the S and L terminals. In the case of a PST combined with a transformer or autotransformer, the series winding of the PST may be connected to the S or L terminal indirectly through the transformer or autotransformer series winding (see example 9.4.3.1).

3.22
series unit
core and windings of a two-core PST containing the series winding

3.23
exciting unit
core and windings of a two-core PST that provides excitation to the series unit

3.24
exciting winding
winding of a single-core PST or of the exciting unit of a two-core PST which supplies the voltage required to change the phase angle

3.25
tap winding
winding in which taps are changed to vary the phase angle

Note 1 to entry: The tap winding is referred to as the regulating winding in some countries.

3.26
design value
expected value given by the number of turns in the design in the case of turns ratio and no-load phase angle or calculated from the design in the case of impedance, no-load current or other parameters

3.27
advance-retard switch
ARS
switch separate from any change-over selector associated with the on-load tap-changer that allows a change of operation from advance to retard or from retard to advance at zero no-load phase angle without interrupting the load current or de-energizing the PST

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Note 1 to entry: See Annex F.

Note 2 to entry: This note applies to the French language only.

4 Use of normative references

This standard can be used with either the IEC or IEEE normative references, but the references shall not be mixed. The purchaser shall include in the enquiry and order which normative references are to be used. If the choice of normative references is not specified, then IEC standards shall be used, except for PSTs intended for installation in North America where IEEE standards shall be used.

5 Service conditions

5.1 General

Unless otherwise specified by the purchaser, normal service conditions shall apply as stated in IEC 60076-1 or IEEE Std C57.12.00.

5.2 Usual service conditions

5.2.1 Switching arrangement

Unless otherwise specified, the PST shall be designed for use with an on-load bypass device connecting the respective L terminals and S terminals that will only be closed in service when the PST is on the zero phase shift tap position for the time taken to complete a switching sequence to place the PST into or out of service.

If the PST will never be used with the L and S terminals connected (no on-load bypass device), this can be specified and the double ended impulse test may be omitted (see 13.12.5).

If the PST is to be used in the condition where an on-load bypass is closed in service with the PST energized from both S and L terminals for longer than the time taken for switching, this shall be specified.

Unless otherwise specified, the PST shall not be energized or operated with the L and S terminals connected by a bypass unless it is on the zero phase shift tap position. If it is required that the PST can be bypassed at other than zero phase shift tap position, this shall be clearly stated by the purchaser in the enquiry.

The PST shall be suitable for energization from either the S or L terminals at any tap position.

5.2.2 Power flow

Unless otherwise specified, the PST shall be capable of transferring rated power in either direction provided that the phase angle between the S and L terminals does not exceed the maximum no-load phase angle.

NOTE If the PST is acting to reduce or reverse the power flow in the circuit, the phase angle will exceed the no-load phase angle and, unless otherwise specified, there will be no power flow capability at the extreme taps under these conditions. If this capability is required, see 6.3.

5.2.3 Operation with two or more PSTs in series or parallel

Unless otherwise specified, it may be assumed that the PST will not be installed in series or parallel with another PST connected to the same circuit. If series or parallel operation is required, this shall be stated by the purchaser in the enquiry and contract, and details of the PST which will be in series or parallel given.

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NOTE For parallel operation of PSTs it should be considered that if the PST has a low impedance at or close to the no-load zero phase shift tap position then a short circuit or an extremely high circulating current can occur during tap-change operations if no additional reactance is connected to the circuit. See IEC 62032 [1] or IEEE Std C57.135 [2].[2]

5.2.4 Phase unbalance

PSTs are intended to be used in a system where the voltages and currents in the three phases are essentially balanced under normal conditions (see IEC 60076-1 or IEEE Std C57.12.00 for normal levels of voltage balance). If the PST is to operate in a system that has current unbalance of more than 5 %, the expected unbalance shall be stated by the purchaser in the enquiry and order.

5.2.5 Surge protection

The PST shall be installed with adequate surge protection on both S and L terminals irrespective of the characteristics of the connected system. Unless otherwise specified, this is the responsibility of the purchaser.

NOTE A through fault short circuit condition on one phase is likely to produce induced voltages on the other phases higher than the test voltage levels, see Annex B.

6 Rating and general requirements

6.1 Rated power

The rated power shall be specified by the purchaser and shall apply to the zero phase shift tap and any tap in boost mode, but see 6.3 for rated power in buck mode.

6.2 Loading at other than rated conditions

Any requirements for loading beyond rated power or at other than rated conditions shall be specified by the purchaser. See IEC 60076-7 [3] or IEEE Std C57.12.00, and IEEE Std C57.91 [6]. See also 6.3.

NOTE PSTs have loading limitations due to thermal, magnetic induction and tap-changer considerations.

6.3 Specification of buck capability

If operation of the PST in buck mode is required, the minimum required power at each tap position under buck loading conditions including any overloads shall be specified. Unless otherwise specified, unity power factor, rated frequency and rated voltage at the L terminal shall be assumed when calculating the PST capability. An example of such a specification is given in Annex C.

If the minimum required power at each tap position under buck loading conditions is not specified, then according to 5.2.2 the PST will have no buck loading capability at the extreme tap position. Some buck capability (below rated power) at other tap positions will be available depending on the no-load phase angle and impedance at that tap, but any capability will be determined by the manufacturer.

The impedance used as the basis for the buck loading capability assessment shall become the maximum guaranteed value (without tolerance) at that particular tap position. This figure may be lower than the maximum impedance, but shall be higher than the minimum impedance specified by the purchaser.

[2] Numbers in square brackets refer to the Bibliography.

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6.4 Cooling modes

Requirements for cooling modes and minimum power under different cooling modes if any shall be stated in the enquiry and order. See IEC 60076-1 or IEEE Std C57.12.00.

6.5 Short circuit impedance and load phase angle capability

6.5.1 Specification

The purchaser shall specify the load phase angle capability of the PST in one of the following ways:

- the maximum and minimum impedance at the extreme taps and the minimum absolute no-load phase angle at the extreme taps;
- the minimum absolute boost and/or buck phase angle at rated power. In this case the manufacturer shall determine the no-load phase angle and impedance required to meet this requirement. The purchaser shall also specify either a maximum impedance or voltage drop (regulation) if required.

Unless otherwise specified, unity power factor, rated frequency and rated voltage at the L terminal shall be assumed when calculating the PST capability.

NOTE In the case of certain asymmetric designs with both voltage and phase angle variation, it can be more convenient by agreement to base the capability on the S terminal to avoid an apparent interaction between phase angle tap position and voltage variation range.

If there is a minimum impedance requirement at the zero phase shift tap position, this shall be specified by the purchaser. Otherwise the minimum impedance at the zero phase shift tap is at the discretion of the manufacturer.

If the purchaser requires any particular limits on zero sequence impedance, for example to avoid series resonance conditions, this shall be stated in the enquiry and order.

6.5.2 Short circuit impedance for asymmetric designs

In the case of an asymmetric design, the voltage ratio between the S terminal and the L terminal and consequently the tapping voltage of the S terminal will vary with tap position. Unless otherwise agreed, the impedance at each tap shall be based on the rated voltage and rated power at the L terminal.

6.6 Neutral earthing (grounding)

The purchaser shall specify the neutral earthing arrangement for each neutral terminal; whether directly connected to earth, earthed through an impedance or not earthed.

Any intermediate circuit or circuits that would otherwise have no galvanic connection to the S, L or neutral terminals shall be connected to earth. Unless otherwise specified, intermediate circuits shall be connected to earth externally to facilitate site testing. Unless otherwise agreed, the connection to the tank earth shall be provided by the manufacturer.

6.7 Rated voltage

The purchaser shall specify the rated voltage for the S and L terminals.

6.8 Voltage variation and asymmetric design

Unless otherwise specified, the PST shall be designed so that the voltage ratio between the S and L terminals does not vary with tap position. If an asymmetric design can be accepted by the purchaser, this should be stated in the enquiry together with any limits on the voltage variation at the L terminal.

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Any requirements for voltage variation separate to or combined with phase angle variation shall be specified.

6.9 Rated frequency

The rated frequency shall be specified by the purchaser to be the normal undisturbed frequency of the network

6.10 Operation at higher than rated voltage and/or at other than rated frequency

If the PST is to be operated at V/Hz in excess of the provisions given in IEC 60076-1 or IEEE Std C57.12.00, this shall be specified by the purchaser.

6.11 Highest voltage for equipment and dielectric test levels

The purchaser shall specify the highest voltage for equipment (maximum system voltage) and the dielectric test levels. See IEC 60076-1, IEC 60076-3 or IEEE Std C57.12.00.

6.12 Taps

The PST shall be provided with an on-load tap-changer to vary the phase angle, unless a de-energized tap-changer or other means of varying the phase angle is specified. The purchaser shall specify any particular requirements for taps, for example a maximum no-load phase angle step, a particular number of tap positions (for parallel operation), a maximum time for tap-changer operation from zero phase shift to extreme tap and the number of tap-changes required in a continuous sequence. Otherwise these parameters may be determined by the manufacturer.

6.13 Sound level

Where the purchaser has a specific requirement for guaranteed maximum sound level(s) under either the no-load condition or under both no-load and load conditions, this shall be stated in the enquiry and should preferably be expressed as a sound power level. It is recognized that it is not possible to directly measure the sound levels under loaded operating conditions in the factory and any guarantee will have to be based on a combination of no-load and load noise measurements (see Annex D).

Unless otherwise specified, the guaranteed maximum sound level shall be for the complete PST at either the extreme advance tap (or extreme retard tap if there is no advance capability) or the zero phase shift tap, whichever is higher, and no-load at rated voltage on the S terminal with the cooling equipment in operation.

6.14 Transport

If transport size or weight limits apply, this shall be stated in the enquiry.

The PST shall be designed and manufactured to withstand a constant acceleration of at least $1g$ in all directions (in addition to the acceleration due to gravity in the vertical direction) without damage. If higher limits are required, this shall be specified by the purchaser unless transport is the responsibility of the manufacturer.

NOTE Further information on transport can be found in IEEE Std C57.150 [3].

7 Construction

7.1 General

In general, construction requirements for PSTs shall be in accordance with the requirements for power transformers, as covered in IEC 60076-1 or IEEE Std C57.12.00 and other

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applicable ANSI/IEEE or IEC standards with the exceptions or additions given in the following subclauses.

7.2 Liquid-filled connections between tanks

Liquid-filled connections between tanks in multiple tank designs shall meet the pressure and vacuum requirements of IEC 60076-1 or IEEE Std C57.12.00 in the fully assembled condition.

If the design includes a barrier between a tank and a liquid-filled connection, any restrictions on the differential pressure that the barrier can withstand shall be clearly indicated by the manufacturer on the nameplate.

NOTE It is normally expected that a barrier will only withstand vacuum on one side when the pressure on the other side is limited to atmospheric pressure (adjacent enclosed connection is not full of liquid at the same time).

Connections between separate tanks shall accommodate thermal expansion and contraction. Unless otherwise agreed between manufacturer and purchaser, connections shall be designed for installation or removal without the need for jacking or moving the transformer tanks.

7.3 Liquid insulation and preservation system

Liquid insulation and preservation systems shall be in accordance with IEC 60076-1 or IEEE Std C57.12.10 with the following addition.

Liquid-filled connections between tanks may be either sealed by insulating barriers from each tank or open to the insulating liquid from one or both tanks.

If the liquid, in liquid-filled electrical connections between tanks, is isolated by insulating barriers from the liquid in both of the tanks, then either a separate conservator system for the connections or pressure equalizing pipes shall be provided to allow expansion into one of the main tanks or one of the main tank conservators.

If the purchaser has a particular requirement to be able to differentiate between faults in the different tanks and connections or to be able to drain the liquid in the connections or tanks separately, this shall be specified.

NOTE The use of oil and gas analysis to isolate problems will be complicated unless the liquid in the connections is separated from both main tanks.

For each isolated liquid-filled connection, the connection compartment shall be equipped with devices that perform the following functions:

- gas accumulation relay (for units equipped with a conservator system);
- pressure relief device/relay;
- liquid filling and draining valves;
- sudden pressure relay or liquid surge relay;
- liquid level gauge.

7.4 Alignment between tanks

The manufacturer of the PST shall make provisions for differential alignments that will occur when multiple tanks are connected due to for example, installation tolerances, foundation tolerances, application of vacuum, thermal expansion and, where applicable, seismic activity.

The alignment requirements between the foundations for multiple tanks and tolerances shall be defined by agreement between the purchaser and the manufacturer.

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Full document details: IEC IEEE 60076-57-1202-2017

If special provisions for anchoring the tanks to the foundations are required to meet seismic or other requirements, these shall be defined by the manufacturer and agreed between the purchaser and the manufacturer.

NOTE Information on design for seismic conditions can be found in IEEE Std 693 [5].

7.5 Core and core frame earthing arrangements

The earth connection to each core and core frame (if deliberately insulated from the tank) of the PST shall be brought out of the tank separately to a suitable bushing so that the core to frame, core to earth and frame to earth resistances can be measured without removing liquid from the tank or tanks.

7.6 Test connections

Where temporary bushings and connections are required to perform certain tests, then nothing may be changed or introduced into the PST after the dielectric test that could affect the dielectric performance of the PST. Temporary bushings and connections shall not materially affect the voltages and currents that would otherwise occur. For example a temporary bushing used for an induced voltage test shall not affect the lightning impulse voltage distribution.

Bushings required solely for test shall be removed for service unless otherwise agreed. Internal leads required only for the connection to a test bushing may be removed or not at the discretion of the manufacturer or by agreement, provided the other requirements of 7.6 are met.

Any requirements for test connections to be provided for site tests shall be specified by the purchaser.

8 Short circuit capability

The PST shall be capable of withstanding the mechanical and thermal stresses produced by an external short circuit. See IEC 60076-5 or IEEE Std C57.12.00.

Series windings at all tap positions shall be capable of withstanding the increased voltage that will be imposed across the windings when either the S or L terminals are at earth potential due to the external fault condition. Any non-linear resistors (surge arresters) incorporated in the design shall not become conducting under these conditions.

9 Connection phase displacement symbols

9.1 General

Phase shifting transformers have a large number of possible connections, but all of them are three phase arrangements.

As a general rule the principles of three phase transformers shall be followed with the additional symbols given in Clause 9 used as necessary.

9.2 Special symbols for PSTs

For the purposes of this standard, phase shifting transformers are characterized according to whether they have one or two cores and the displacement symbols of the windings:

– D for delta connection (see IEC 60076-1 or IEEE Std C57.12.70) including single core PSTs where the tap winding is ‘outside’ the delta;

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– P for polygon connection including single core PSTs where the tap winding is ‘inside’ the ‘delta’ as part of the polygon;
– Y for star connected as defined in IEC 60076-1 or IEEE Std C57.12.70;
– Z for zigzag connection as defined in IEC 60076-1 or IEEE Std C57.12.70;
– V for a connection where the phase winding consists of two parts each on a different limb of the core;
– K for a connection where the phase winding consists of three parts each on a different limb of the core.

For a two core PST the vector symbols of the exciting unit are given first followed by / and then the vector symbol for the series unit.

The vector group is followed by a space and then S for a symmetric design or A for an asymmetric design, depending on whether the S and L terminals have the same no-load voltage or different no-load voltages on the extreme tap.

The existence of a test, stabilizing or additional winding, which is not terminated for external loading, is indicated, after the symbols of loadable windings, with the symbol ‘+y’ or ‘+d’ according to its connection symbol.

NOTE These designations are not all in accordance with IEEE Std C57.12.70 or IEC 60076-1 in order to develop a single system of designation for PSTs.

9.3 Clock number notation

The winding connection letter for any winding is immediately followed by its phase displacement 'clock number' (see IEC 60076-1).

The clock number of phase shifting transformers is given in two parts: the first is determined as for three phase transformers as the clock number phase relationship between the S and L terminals at zero phase angle tap (usually zero); the second part separated by a "-" is the relative clock number of the injected voltage using the S terminal at zero phase shift tap position as the reference. If advance and retard capabilities are possible, the retard injection clock number is shown first followed by / and the advance injection clock number.

The injected voltage is the variable part of the voltage between the S and L terminals intended to cause a phase shift.

9.4 Examples

9.4.1 Single core phase shifting transformers

9.4.1.1 Example A: D S0-3/9

Example A is a single core symmetric design PST with a delta connected excitation winding and the tap winding outside the delta. This has the connection phase displacement symbol D S0-3/9. The connection diagram is shown in Figure 1.

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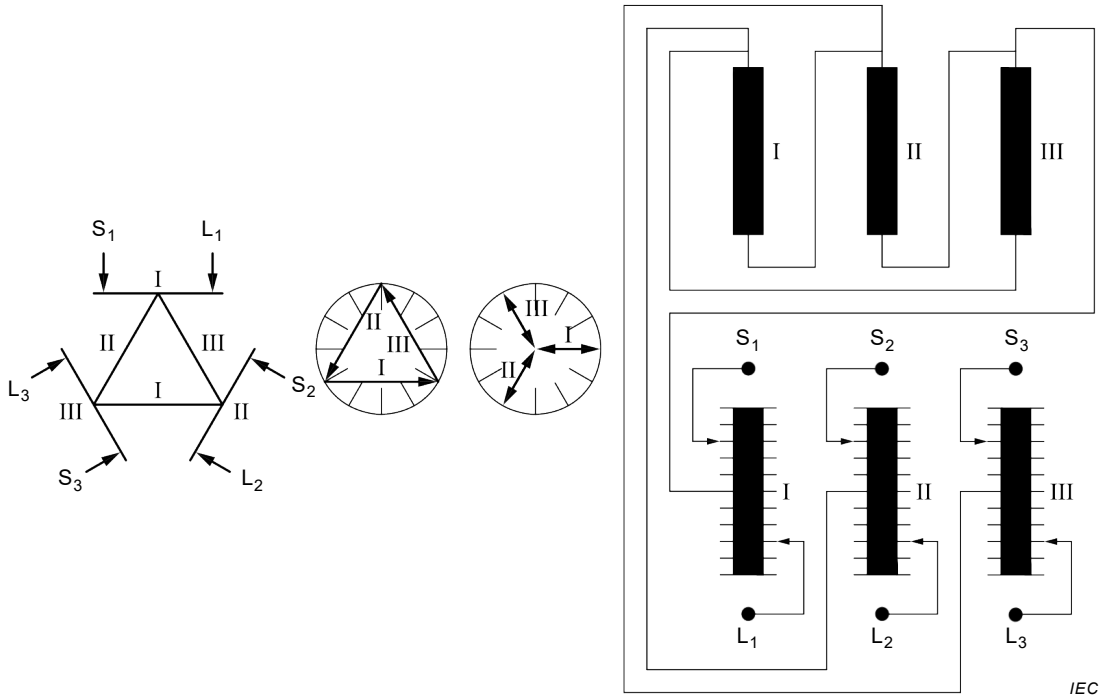

Figure 1 – Example A: D S0-3/9

9.4.1.2 Example B: P S0-3/9

Example B is a single-core symmetric design PST with the tap winding inside the delta (polygon design). This has the connection phase displacement symbol P S0-3/9. The connection diagram is shown in Figure 2.

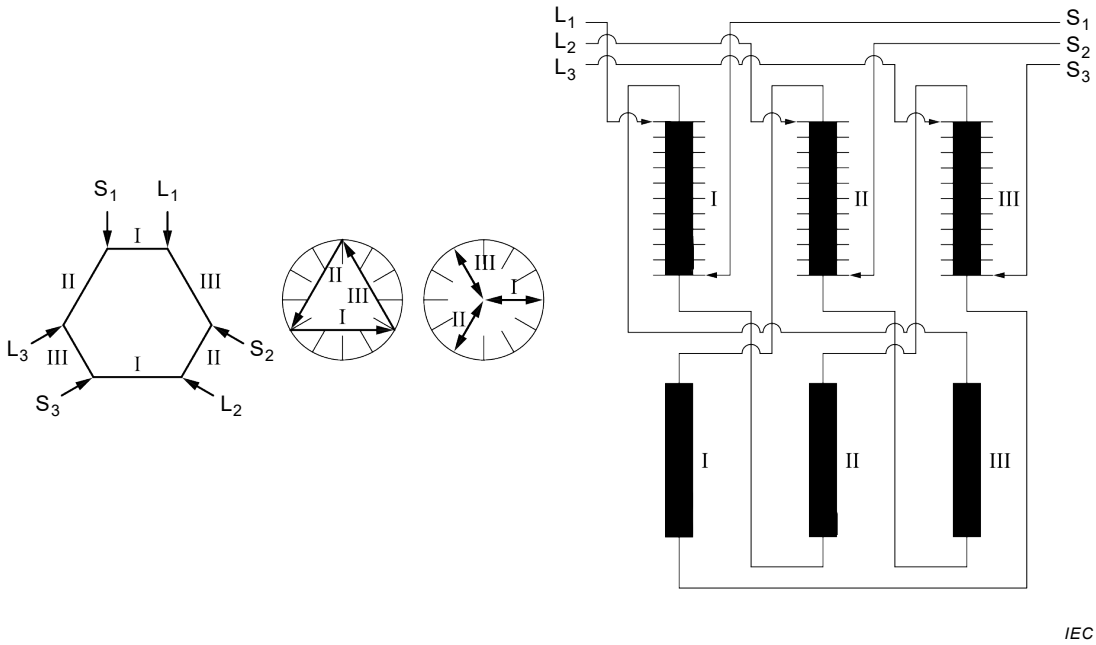

Figure 2 – Example B: P S0-3/9

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9.4.1.3 Example C: D A0-3

Example C is a single core asymmetric design PST with a delta connected excitation winding and the tap winding outside the delta. This has the connection phase displacement symbol D A0-3. The connection diagram is shown in Figure 3.

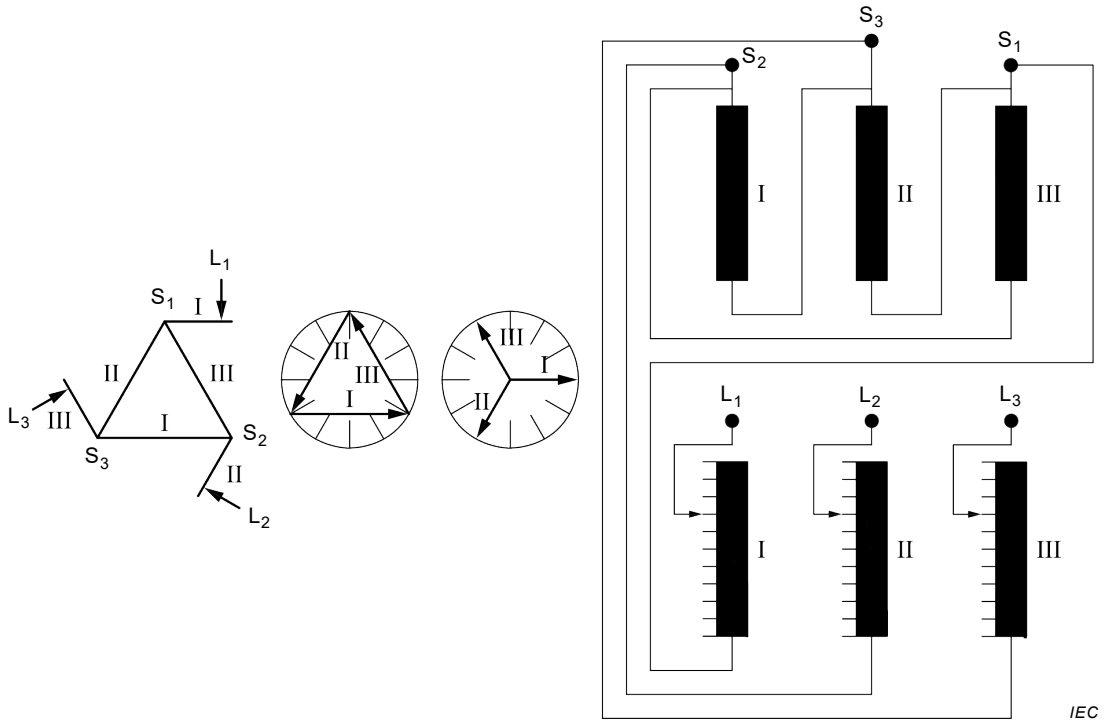

Figure 3 – Example C: D A0-3

9.4.2 Two core phase shifting transformers

9.4.2.1 Example D: YNyn/IIId S0-3/9

Example D is a two core symmetrical design PST with a star connected excitation winding and a star connected tap winding on the first core with a delta connected excited winding and series windings on the second core. This has the connection phase displacement symbol YNyn/IIId S0-3/9. The connection diagram is shown in Figure 4.

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Full document details: IEC IEEE 60076-57-1202-2017

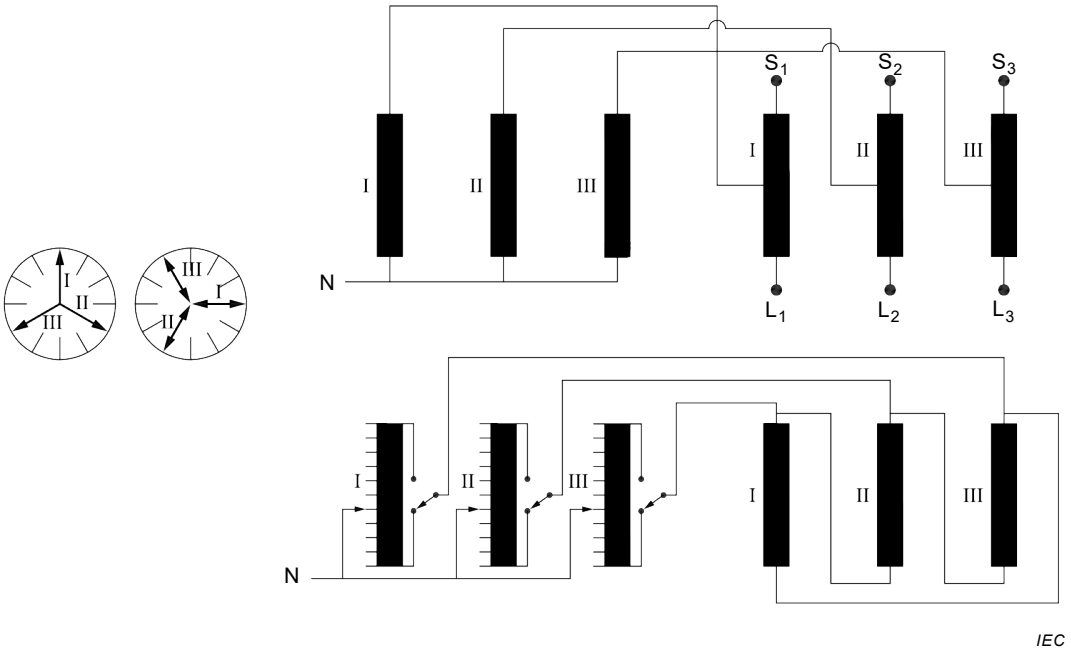

Figure 4 – Example D: YNyn/IIId S0-3/9

9.4.2.2 Example E: YNyn+d/IIId A0-3/9

Example E is a two core asymmetric design PST with a star connected excitation winding and a star connected tap winding and a delta connected stabilizing winding on the first core with a delta connected excited winding and series windings on the second core (a two-core quadrature booster). This has the connection phase displacement symbol YNyn+d/IIId A0-3/9. The connection diagram is shown in Figure 5.

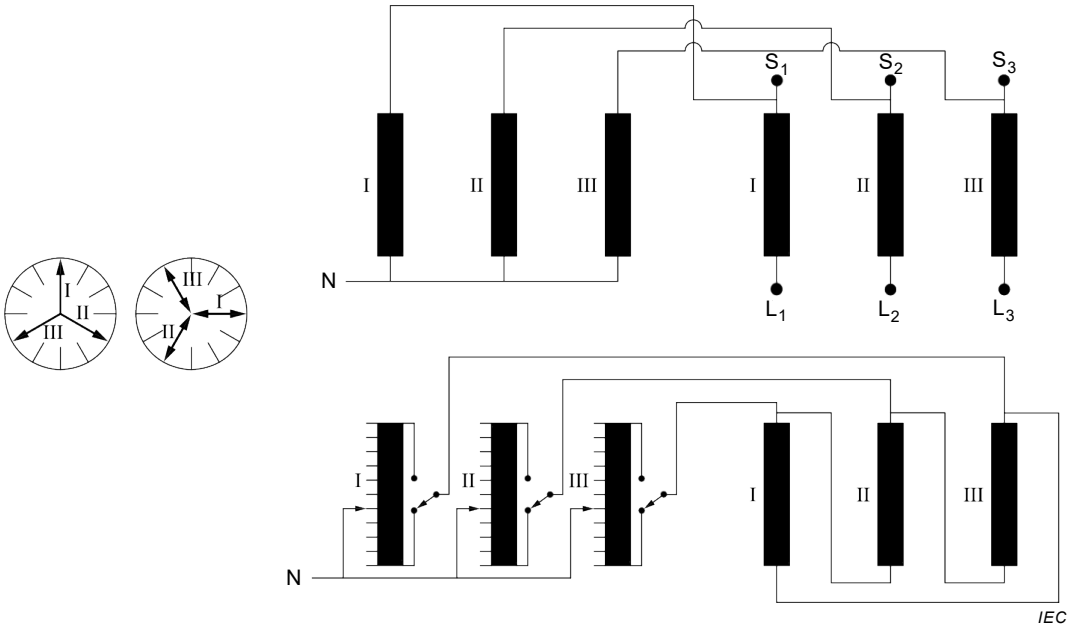

Figure 5 – Example E: YNyn+d/IIId A0-3/9

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9.4.3 Transformers incorporating a phase shifting element

9.4.3.1 Example F: YNa0yn/dIII A0-3/9

Example F is an autotransformer incorporating an asymmetric design phase shifting element on a second core. This has the connection phase displacement symbol YNa0yn/dIII A0-3/9. The connection diagram is shown in Figure 6.

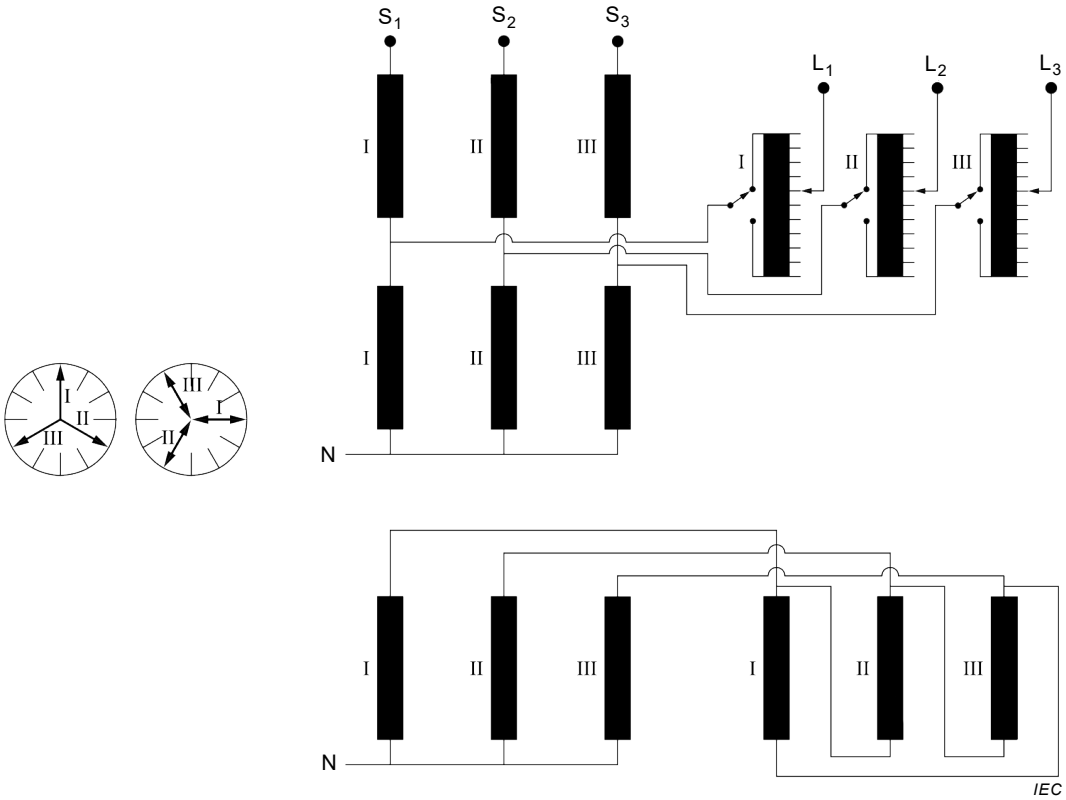

Figure 6 – Example F: YNa0yn/dIII A0-3/9

9.4.3.2 Example G: V A0-2/8

Example G is a transformer incorporating an asymmetric design phase shifting element on the same core. This has the connection phase displacement symbol V A0-2/8. The connection diagram is shown in Figure 7.

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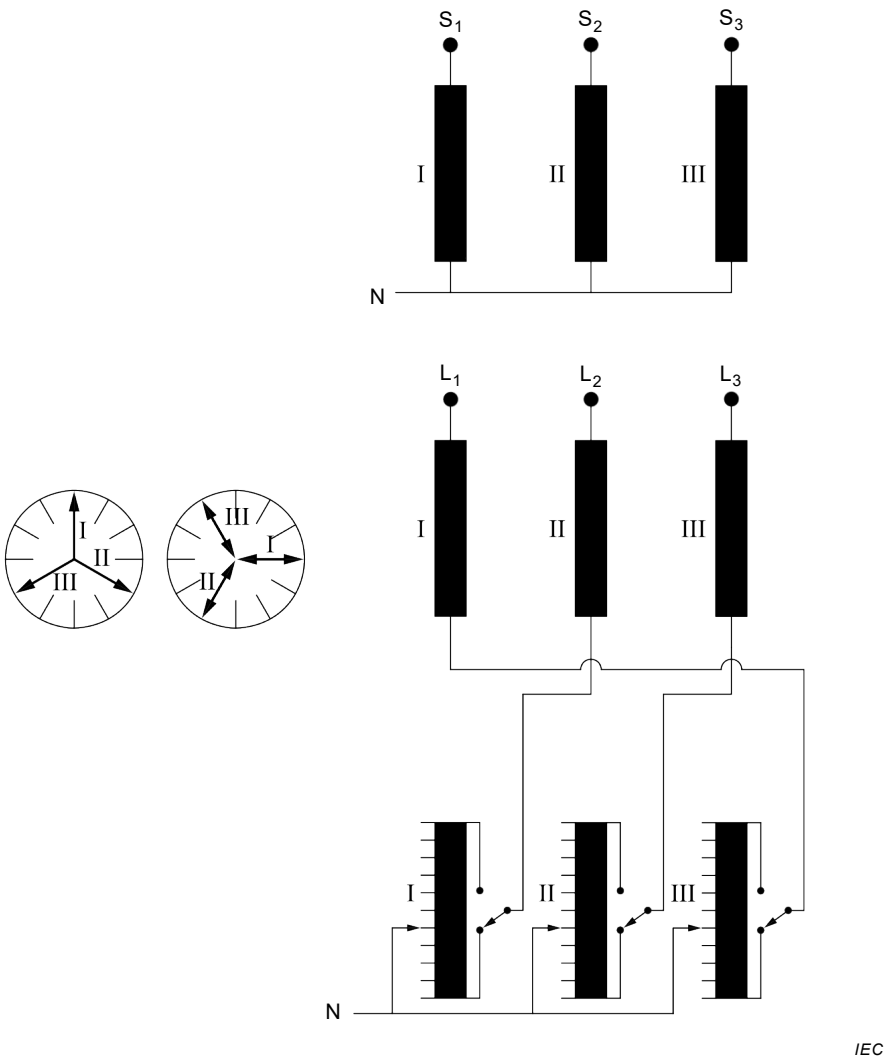

Figure 7 – Example G: V A0-2/8

10 Rating plates (nameplates)

The phase shifting transformer shall be provided with a rating plate in accordance with IEC 60076-1 or IEEE Std C57.12.00.

In addition, a table shall be provided with one row for each tap position with columns giving the following information at each tap position, either on the rating plate or on a separate plate:

a) Tap – the designation of the tap position, usually the tap number;

b) No-load phase shift – the phase shift in degrees from the S to the L terminals at no load with ‘a’ for advance and ‘r’ for retard;

c) Impedance – the measured short circuit impedance;

d) Power limit S to L – the maximum power at the L terminal (with unity power factor, rated voltage and frequency at the L terminal) when operating with power flowing from the S terminal to the L terminal that will not result in overfluxing of the core(s) or overstressing of other components such as the tap-changer, not counting thermal limits;

e) Power limit L to S – as d) above but for operation with power flowing from the L terminal to the S terminal.

The following legend shall be shown on the nameplate below the table:

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Full document details: IEC IEEE 60076-57-1202-2017

"Loading above these power limits is not permissible. Loading is also subject to normal thermal overload limits which may be lower."

If there are both voltage and phase angle taps, additional information may be required.

If additional information is required on the rating plate, this should be indicated by the purchaser in the enquiry.

In particular, if full load phase shift data is specified by the purchaser, the phase shift in degrees calculated from the measured impedance at rated power with power flowing from S to L (and L to S if required) at unity power factor at each tap position shall be given. If rated power is not available on some buck taps, the value should be denoted by *.

For PSTs with more than one separate liquid compartment, the liquid volume and vacuum withstand capability of each compartment (including connection chambers) shall be shown on the rating plate. If barriers between compartments are incorporated, the vacuum capability of each compartment shall indicate whether or not the adjacent chamber needs to be drained and be at atmospheric pressure.

The rating plate shall indicate whether the PST is suitable for operation with an on-load bypass, continuous in-service bypass or no bypass, depending on the lightning impulses applied to multiple line terminals simultaneously (LIMT) test performed.

11 Terminal markings and phase rotation

Unless otherwise specified by the purchaser, the following terminal markings shall be used:

- the S terminals: S with the phase designation 1, 2 and 3, for example S_1 S_2 S_3;
- the L terminals: L with the phase designation 1, 2 and 3, for example L_1 L_2 L_3;
- the neutral of the excitation winding (if present): S_0 or N_1 N_2 N_3 if the phase neutrals are separate;
- the neutral of the exciting winding (if present and brought out): n_0 or n_1 n_2 n_3 if the phase neutrals are separate;
- additional windings (if any brought out): Y, Z.

The phase connection to obtain the defined meaning of advance and retard between the S and L terminals see 3.17 and 3.18 (as recorded on the rating plate) shall be in the sequence 1, 2, 3. If this rotation is reversed, the sense of advance and retard is also reversed compared with the rating plate.

Unless otherwise specified, the terminals shall be in the sequence 1, 2, 3 from left to right facing the L terminals and right to left facing the S terminals.

12 Information to be provided by the manufacturer

The manufacturer shall provide details, at the tender stage, of the loading capability in buck mode with tap position voltage and frequency.

The manufacturer shall provide, at the design stage, sufficient details of the design to be able to model the transient operation of the PST in order to be able to properly specify the insulation coordination. See 5.2.5.

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Document Sharing Hub
Full document details: IEC IEEE 60076-57-1202-2017

13 Tests

13.1 General

Tests shall be carried out in accordance with the requirements of IEC 60076-1 or IEEE Std C57.12.00 (see Clause 4) except for the modifications introduced in Clause 13. For testing purposes, a complete PST shall be defined as a fully assembled and connected PST as it will be placed in-service, but without external surge arresters installed.

See 7.6 for test connections.

Where the phase shifting transformer consists of separate single phase units, tests may be carried out on each phase separately and type (design) tests are required on only one phase. The tests shall be arranged so that the test requirements are met. Dielectric tests on the interconnected windings are required at levels representative of those that would occur if the unit was tested completely assembled in the three phase configuration.

13.2 Routine tests

The following routine tests are required on all PSTs:

a) measurement of winding resistance (13.5);

b) measurement of voltage ratio, phase angle and check of phase displacement (13.6);

c) measurement of short-circuit impedance and load loss (13.7);

d) measurement of no-load loss and current (13.9);

e) dielectric routine tests (13.12);

f) tests on on-load tap-changers (13.13);

g) leak testing with pressure for liquid-immersed transformers (tightness test) (13.14);

h) check of the ratio and polarity of built-in current transformers;

i) check of core and frame insulation for liquid-immersed transformers with core or frame insulation (IEC 60076-1 or IEEE Std C57.12.00);

j) determination of capacitance between each winding and earth and where possible between windings;

k) measurement of DC insulation resistance between each winding and earth and where possible between windings;

l) measurement of dissipation factor (tan δ) of the insulation system capacitances;

m) measurement of dissolved gases in dielectric liquid from each separate oil compartment except diverter switch compartment.

13.3 Type (design) tests

The following type (design) tests are required on the first unit of each design:

a) temperature-rise test (13.8);

b) dielectric type (design) tests (13.12);

c) determination of sound level (13.10);

d) measurement of zero sequence impedance (13.11);

e) measurement of the power taken by the fan and liquid pump motors.

13.4 Special tests

The following special tests are to be carried out if individually specified by the purchaser in the enquiry and order:

a) dielectric special tests (13.12);

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Full document details: IEC IEEE 60076-57-1202-2017

b) short-circuit withstand test (IEC 60076-5 or IEEE Std C57.12.90);

c) vacuum deflection test (IEC 60076-1 or IEEE Std C57.12.90);

d) pressure deflection test (IEC 60076-1 or IEEE Std C57.12.90);

e) vacuum tightness test on site (IEC 60076-1 or IEEE Std C57.12.90);

f) measurement of frequency response (IEC 60076-18 or IEEE Std C57.149 [7]);

g) check of external coating (ISO 2178 and ISO 2409 or as specified);

h) mechanical test or assessment of tank for suitability for transport (to customer specification);

i) determination of the weight of each PST unit arranged for transport by calculation or, if required by the purchaser at the enquiry stage, by measurement;

j) transient voltage measurements, for example low voltage impulse [recurrent surge oscillograph (RSO)] and/or resonant frequency measurements.

13.5 Winding resistance

The resistance of each winding of the PST shall be measured individually including any tap winding at each tap position using temporary test bushings or before internal winding to winding connections are made if necessary.

By agreement, measurements at some tap positions may be omitted if no additional information is gained.

13.6 Measurement of voltage ratio, phase angle and check of phase displacement

The voltage ratio and phase angle between the S and L terminals shall be measured on each tap position and on both positions of the ARS (if fitted). See IEC 62032 [1] or IEEE Std C57.135 [2].

The voltage ratio of each individual transformer shall be measured using temporary test bushings or before internal winding to winding connections are made if necessary.

When additional windings are present, a check of phase displacement shall be made according to IEC 60076-1 or IEEE Std C57.12.90.

13.7 Measurement of short-circuit impedance and load loss

The short-circuit impedance and load loss shall be measured on the complete PST at each tap position. The short-circuit impedance and loss shall be measured at each extreme and zero phase shift tap positions, and any other tap positions where either of these values is guaranteed, at a current corresponding to rated power. Other tap positions may be measured at reduced current, in which case the measurement at each extreme and zero phase shift tap position shall be repeated at the same reduced current.

NOTE 1 These measurements are necessary because impedance is an important parameter for calculating the performance of the PST on each tap position. Impedance is not expected to vary significantly with current. Loss measurements are less important on tap positions other than extreme, zero phase shift and any other tap positions for which they are guaranteed, so errors associated with reduced current are usually acceptable.

By agreement, measurements on individual transformers may be combined to derive the PST impedance and loss if this approach has been validated on a previously supplied unit of the same design or at a reduced current if necessary due to test equipment limitations.

NOTE 2 Impedance and load loss are based on rated power and rated voltage, as defined in 3.5 and 3.19 (for asymmetric designs).

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13.8 Temperature-rise test

The temperature-rise test shall be carried out in accordance with IEC 60076-2 or IEEE Std C57.12.90.

Unless otherwise agreed, the test shall be carried out on the extreme tap position that has the maximum load loss. If under this condition any winding other than a tap winding receives less than 90 % of the maximum current that the winding will see at rated power on another tap position, an additional winding gradient measurement shall be made on the tap position for maximum current in this winding.

The temperature rise of all windings shall be determined. This may require the use of temporary test bushings.

Unless otherwise agreed between manufacturer and purchaser, the test shall be carried out on the completely assembled PST. If agreed, the test may be carried out on the exciting unit and the series unit separately if they are in separate tanks each with its own cooling system. In this case all the connections between the exciting and series units shall be tested with at least one of the units. Since the flux distribution in the series unit will be different from the combined condition in a separate test, a review of this difference shall be carried out and any necessary corrections applied.

If the exciting and series units have separate cooling systems and they are tested together, then in general it will not be possible to achieve the calculated total loss in each unit simultaneously. In this case the current for the determination of top liquid rise shall be chosen to give the correct total loss for both units summed together, and a correction made in the test results of each unit individually.

By agreement, the losses and currents achieved during the temperature-rise test may be reduced according to the provisions of IEC 60076-2 or IEEE Std C57.12.90. Any limitation on the achievable losses or currents imposed by the PST design or the manufacturer's test facility that would require this agreement shall be clearly stated by the manufacturer in the tender.

13.9 Measurement of no-load loss and current

The no-load loss and current shall be measured with 90 %, 100 % and 110 % of rated voltage appearing at the S terminals at each extreme and zero phase shift tap position. Temporary bushings connected to one of the windings may be used to perform this measurement.

13.10 Determination of sound level

13.10.1 General

Sound level measurements shall be made according to IEC 60076-10 or IEEE Std C57.12.90. If it is desired to be able to estimate the noise level of the PST for a wider range of operating conditions than is covered by the standard measurements set out below, additional measurements will be required. See Annex D.

13.10.2 For PSTs with one combined cooling system

Unless otherwise specified, the following measurements shall be made for PSTs with one combined cooling system:

a) with the PST energized at rated voltage no-load at zero phase shift tap position with only the cooling equipment that would be in operation at no-load;

b) with the PST energized at rated voltage no-load at zero phase shift tap position with all the cooling equipment in operation;

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c) with the PST energized at rated voltage no-load at the extreme advance tap (or extreme retard tap if there is no advance capability) with all the cooling equipment in operation.

13.10.3 For PSTs with separate exciting and series unit cooling systems

If the exciting and series units are in separate tanks with separate cooling systems, unless otherwise specified the following measurements shall be made:

a) with the PST energized at rated voltage no-load at zero phase shift tap position with only the cooling equipment that would be in operation at no-load;

b) with the PST energized at rated voltage no-load at zero phase shift tap position with only the cooling equipment that would be in operation at no-load on the exciting unit and all the cooling equipment in operation on the series unit;

c) with the PST energized at rated voltage no-load at the extreme advance tap (or extreme retard tap if there is no advance capability) with all the cooling equipment in operation.

The PST shall be in the service condition if possible; if this is not possible, separate measurements of each tank and cooling system may be made and the results combined.

13.11 Measurement of zero sequence impedance

The following zero sequence impedance measurements shall be made at each extreme and zero phase shift tap position:

a) between the S terminals connected together and neutral, with the L terminals open circuit;

b) between the S terminals connected together and neutral, with the L terminals connected to neutral;

c) between the L terminals connected together and neutral, with the S terminals open circuit.

For designs which do not have a neutral connection, the zero sequence measurement shall be made between the S terminals connected together and the L terminals connected together.

For designs with more than one neutral, all the neutrals connected to earth in service shall be connected together.

Additional zero sequence impedance measurements may be specified by the purchaser.

13.12 Dielectric tests

13.12.1 General

The classification of dielectric tests as routine, type (design) and special shall be as given in IEC 60076-3 or IEEE Std C57.12.00, except for the lightning impulses applied to multiple line terminals simultaneously (LIMT) test (see 13.12.5).

Dielectric tests shall be performed on the complete PST unless all the following conditions are fulfilled:

- it is unreasonable to perform the tests on the fully assembled PST;
- it can be shown that tests on separate parts of the PST completely represent the voltages that would occur on the fully assembled PST;
- all windings and connections are tested;
- the test arrangements are agreed between manufacturer and purchaser.

If the manufacturer cannot test the complete PST, this shall be stated in the tender together with the alternative arrangements.

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NOTE The application of a line terminal AC test (LTAC) according to IEC 60076-3 is complicated in the case of a phase shifting transformer because of the phase to phase connections and the specification of this test can lead to a higher insulation level.

13.12.2 Induced voltage test with partial discharge measurement (IVPD)

Induced voltage tests with partial discharge measurement shall be performed at both the extreme tap positions in accordance with IEC 60076-3 or IEEE Std C57.12.90.

If rated currents on particular taps in buck mode are specified, a test or tests shall be conducted at a level which accounts for the highest increase in internal voltage that occurs in operation in the buck mode at the specified rated powers and tap positions. This increased internal voltage shall be taken as the rated voltage for the purpose of determining the induced test voltage levels for that winding. In order to avoid overtesting the exciting unit, it may be necessary to conduct this test with the exciting winding to series unit connection disconnected when testing the series unit.

Additionally, the internal arrangement of the PST shall be analysed to ensure that the prescribed test voltage is achieved for all the windings and connections. Additional induced voltage tests may be required for some designs.

13.12.3 Switching impulse test (SI)

The switching impulse test shall be carried out on the complete PST on the zero phase shift tap with the required voltage on the S and L terminals of the tested phase connected together. If the design has a neutral connection, it shall be earthed; if not, the other end of the tested phase of the excitation winding shall be earthed. The other terminals may either be open circuit, connected together or earthed via an impedance.

NOTE 1 The zero phase shift tap is chosen to give the highest voltage on the excitation winding

For designs where a switching impulse test on the zero phase shift tap will not induce voltage in the series winding, an alternative or additional test at an extreme or other tap position may be specified by the purchaser. In this case the S and L terminals are not connected together. If this is an additional test and the voltage on one or more of the line terminals not connected to the impulse generator is higher than the voltage on the impulsed terminal, then the applied impulse voltage may be reduced provided that the required switching impulse voltage level and waveshape is achieved on the other terminal(s).

NOTE 2 For PSTs of a two core design it might be difficult to obtain the required time-to-zero; in this case, procedures such as pre-magnetizing the cores with DC or additional reduced impulses could be helpful.

NOTE 3 Short rise time waves might give rise to high oscillatory phase to phase voltages.

13.12.4 Lightning impulse test

The lightning impulse test shall be performed on each of the S and L terminals in turn, the other line terminal (S or L) of the same phase shall be earthed directly or, if needed to achieve the required waveshape, through an impedance. The impedance shall not exceed the surge impedance of the connected line if a value is supplied by the purchaser or 400 Ω if not.

If the surge impedance value is not specified, the voltage appearing during the impulse test at the other line terminal shall not be more than 75 % of the rated lightning impulse withstand voltage. In all circumstances, the lowest value of impedance needed to achieve the required waveshape shall be used.

All other terminals shall be earthed.

The manufacturer shall determine, either by calculation or by performing low voltage impulse measurements, the tap position or tap positions that give the highest internal voltages and voltage differences between windings and parts of windings. On request from the purchaser

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