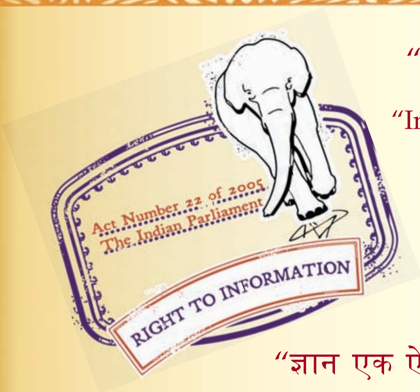
IS 2026-1 (2011): Power transformers, Part 1: General [ETD 16: Transformers]



BLANK PAGE

BRUTUM FULMEN

IGNORANTIA JURIS NON EXCUSAT

भारतीय मानक

पॉवर ट्रांसफार्मर

भाग 1 सामान्य

(दूसरा पुनरीक्षण)

Indian Standard

POWER TRANSFORMERS

PART 1 GENERAL

(Second Revision)

ICS 29.180

BUREAU OF INDIAN STANDARDS
MANAK BHAVAN, 9 BAHADUR SHAH ZAFAR MARG
NEW DELHI 110002

December 2011 **Price Group 10**

Power Transformers Sectional Committee, ETD 16

FOREWORD

This Indian Standard (Part 1) (Second Revision) was adopted by the Bureau of Indian Standards, after the draft finalized by the Power Transformers Sectional Committee had been approved by the Electrotechnical Division Council.

This standard was first published in 1962 and covered naturally cooled oil-immersed transformers. With subsequent amendments forced cooled transformers were included, use of synthetic liquids as cooling medium was permitted and requirements for aluminium windings were incorporated.

First revision was undertaken with a view to bringing it in line with the revision of IEC 76 : 1967 'Power transformers'.

This revision has been based on IEC 60076-1 : 2000 'Power transformers — Part 1: General', issued by the International Electrotechnical Commission with following modifications.

> The temperature of ambient air and cooling medium oil is as per Indian Environment and tests are conducted accordingly.

The requirements for power transformers are covered in eight parts. Other parts in the series are:

Part 2	Temperature-rise
Part 3	Insulation levels and dielectric tests
Part 4	Terminal markings, tappings and connections
Part 5	Ability to withstand short circuit
Part 7	Loading guide for oil-immersed power transformers
Part 8	Application guide
Part 10	Determination of sound levels

This standard shall be read in conjunction with the following standard:

IS No.	*Title*
2026	Power transformers:
(Part 2) : 2010	Temperature-rise (*first revision*)
(Part 3) : 2009	Insulation levels, dielectric tests and external clearances in air (*third revision*)
(Part 4) : 1977	Terminal markings, tappings and connectioins
(Part 5) : 2011	Ability to withstand short circuit (*first revision*)
5553 : 1989 (All parts)	Reactors
6600 : 1972	Guide for loading of oil immersed transformers
9001 : 2000	Quality management systems — Requirements
11171 : 1985	Specification for dry-type power tansformers
13964 : 1994	Methods of measurement of transformer and reactor sound levels

In addition assistance has also been derived from following IEC Standards:

IEC Standard	*Title*
60137 : 2008	Insulated bushings for alternating voltages above 1 000 V
60815 : 1986	Guide for the selection of insulators in respect of polluted conditions
60310 : 2004	Railway applications — Traction transformers and inductors on board rolling stock
60068-3-3 : 1991	Environmental testing — Part 3: Guidance, seismic test methods for equipment

For the purpose of deciding whether a particular requirement of this standard is complied with, the final value, observed or calculated, expressing the result of a test or analysis, shall be rounded off in accordance with IS 2 : 1960 'Rules for Rounding off numerical values (*revised*)'. The number of significant places retained in the rounded off value should be the same as that of the specified value in this standard.

Indian Standard

POWER TRANSFORMERS

PART 1 GENERAL

(Second Revision)

1 SCOPE

This standard (Part 1) applies to three-phase and single-phase power transformers (including auto-transformers) with the exception of certain categories of small and special transformers such as;

a) single-phase transformers with rated power less than 1 kVA and three-phase transformers less than 5 kVA;
b) instrument transformers;
c) transformers for static convertors;
d) traction transformers mounted on rolling stock;
e) starting transformers;
f) testing transformers; and
g) welding transformers.

Where Indian Standards do not exist for such categories of transformers, this part of IS 2026 may still be applicable either as a whole or in part.

For those categories of power transformers and reactors which have their own Indian Standards, this part is applicable only to the extent in which it is specifically called up by cross reference in the other standard.

NOTE — Such standards exist for dry-type tranformers (*see* IS 11171) and for reactors in general (*see* IS 5553). For traction transformers and reactors and for stastic convertor transformers, standards are under preparation.

At several places in this Part it is specified or recommended that an 'agreement' shall be reached concerning alternative or additional technical solutions or procedures. Such agreement is to be made between the manufacturer and the purchaser. The matters should preferably be raised at an early stage and the agreements included in the contract specification.

1.1 Service Conditions

1.1.1 *Normal Service Conditions*

This standard gives detailed requirements for transformers for use under the following conditions:

a) *Altitude* — A height above sea-level not exceeding 1 000 m (3 300 ft).
b) *Temperature of ambient air and cooling medium* — A temperature of ambient air not below –5 °C and not above +50 °C. For water-cooled transformers, a temperature of cooling water at the inlet not exceeding +30 °C.

   Further limitations, with regard to cooling are given for;

   1) oil-immersed transformers in IS 2026 (Part 2); and
   2) dry-type transformers in IS 11171.
c) *Wave shape of supply voltage* — A supply voltage of which the wave shape is approximately sinusoidal.

   NOTE — This requirement is normally not critical in public supply systems but may have to be considered in installations with considerable convertor loading. In such cases there is a conventional rule that the deformation shall neither exceed 5 percent total harmonic content nor 1 percent even harmonic content. Also note the importance of current harmonics for load loss and temperature-rise.
d) *Symmetry of three-phase supply voltage* — For three-phase transformers, a set of three-phase supply voltages which are approximately symmetrical.
e) *Installation environment* — An environment with a pollution rate that does not require special consideration regarding the external insulation of transformer bushings or of the transformer itself.

An environment not exposed to seismic disturbance which would otherwise require special consideration in the design. (This is assumed to be the case when the ground acceleration level a_g is below 2 m/s).

1.1.2 *Provision for Unusual Service Conditions*

Any unusual service conditions which may lead to special consideration in the design of a transformer shall be stated in the enquiry and the order. These may be factors such as high altitude, extreme high or low temperature, tropical humidity, seismic activity, severe contamination, unusual voltage or load current wave shapes and intermittent loading. They may also concern conditions for shipment, storage and installation, such as weight or space limitations (*see* Annex B).

Supplementary rules for rating and testing are given in other publications for:

a) temperature rise and cooling in high ambient temperature or at high altitude: IS 2026 (Part 2) for oil-immersed transformers, and IS 11171for dry-type transformers, and
b) external insulation at high altitude: IS 2026 (Part 3) for oil-immersed transformers, and IS 11171 for dry-type transformers.

2 REFERENCES

The standards given in Annex A are necessary adjuncts to this standard.

3 DEFINITIONS

For the purpose of this standard, the following definitions shall apply.

3.1 General

3.1.1 *Power Transformer* — A static piece of apparatus with two or more windings which, by electromagnetic induction, transforms a system of alternating voltage and current into another system of voltage and current usually of different values and at the same frequency for the purpose of transmitting electrical power.

3.1.2 *Auto-Transformer* — A transformer in which at least two windings have a common part.

NOTE — Where there is a need to express that a transformer is not auto-connected, use is made of terms such as separate winding transformer, or double-wound transformer

3.1.3 *Booster Transformer* — A transformer of which one winding is intended to be connected in series with a circuit in order to alter its voltage and/or shift its phase. The other winding is an energizing winding.

3.1.4 *Oil-Immersed Type Transformer* — A transformer of which the magnetic circuit and windings are immersed in oil.

NOTE — For the purpose of this part any insulating liquid, mineral oil or other product, is regarded as oil.

3.1.5 *Dry-Type Transformer* — A transformer of which the magnetic circuit and windings are not immersed in an insulating liquid.

3.1.6 *Oil Preservation System* — The system in an oil-immersed transformer by which the thermal expansion of the oil is accommodated. Contact between the oil and external air may sometimes be diminished or prevented.

3.2 Terminals and Neutral Point

3.2.1 *Terminal* — A conducting element intended for connecting a winding to external conductors.

3.2.2 *Line Terminal* — A terminal intended for connection to a line conductor of a network.

3.2.3 *Neutral Terminal*

a) *For three-phase transformers and three-phase banks of single-phase transformers:*

   The terminal or terminals connected to the common point (the neutral point) of a star-connected or zigzag connected winding.
b) *For single-phase transformers:*

   The terminal intended for connection to a neutral point of a network.

3.2.4 *Neutral Point* — The point of a symmetrical system of voltages which is normally at zero potential

3.2.5 *Corresponding Terminals* — Terminals of different windings of a transformer, marked with the same letter or corresponding symbol.

3.3 Windings

3.3.1 *Winding* — The assembly of turns forming an electrical circuit associated with one of the voltages assigned to the transformer.

NOTE — For a three-phase transformer, the 'winding' is the combination of the phase windings (*see* **3.3.3**).

3.3.2 *Tapped Winding* — A winding in which the effective number of turns can be changed in steps.

3.3.3 *Phase Winding* — The assembly of turns forming one phase of a three-phase winding.

NOTE — The term 'phase winding' should not be used for identifying the assembly of all coils on a specific leg.

3.3.4 *High-Voltage Winding* — The winding having the highest rated voltage.

3.3.5 *Low-Voltage Winding* — The winding having the lowest rated voltage.

NOTE — For a booster transformer, the winding having the lower rated voltage may be that having the higher insulation level.

3.3.6 *Intermediate-VoltageWinding* — A winding of a multi-winding transformer having a rated voltage intermediate between the highest and lowest winding rated voltages. The winding which receives active power from the supply source in service is referred to as a 'primary winding', and that which delivers active power to a load as a 'secondary winding'. These terms have no significance as to which of the windings has the higher rated voltage and should not be used except in the context of direction of active power flow. A further winding in the transformer, usually with lower value of rated power than the secondary winding, is then often referred to as 'tertiary winding' (*see also* **3.3.8**).

3.3.7 *Auxiliary Winding* — A winding intended only for a small load compared with the rated power of the transformer.

3.3.8 *Stabilizing Winding* — A supplementary delta-connected winding provided in a star-star-connected or star-zigzag-connected transformer to decrease its zero-sequence impedance (*see* **3.7.3**).

NOTE — A winding is referred to as a stabilizing winding only if it is not intended for three-phase connection to an external circuit.

3.3.9 *Common Winding* — The common part of the windings of an auto-transformer.

3.3.10 *Series Winding* — The part of the winding of an auto-transformer or the winding of a booster transformer which is intended to be connected in series with a circuit.

3.3.11 *Energizing Winding* — The winding of a booster transformer which is intended to supply power to the series winding.

3.4 Rating

3.4.1 *Rating* — Those numerical values assigned to the quantities which define the operation of the transformer in the conditions specified in IS 2026 (Part 2) and on which the manufacturer's guarantees and the tests are based.

3.4.2 *Rated Quantities* — Quantities (voltage, current, etc), the numerical values of which define the rating.

NOTES

1 For transformers having tappings, rated quantities are related to the principal tapping (*see* **3.5.2**), unless otherwise specified. Corresponding quantities with analogous meaning, related to other specific tappings, are called tapping quantities (*see* **3.5.10**).

2 Voltages and currents are always expressed by their r.m.s. values, unless otherwise specified.

3.4.3 *Rated Voltage of a Winding* (U_r) — The voltage assigned to be applied, or developed at no-load, between the terminals of an untapped winding, or of a tapped winding connected on the principal tapping (*see* **3.5.2**). For a three-phase winding it is the voltage between line terminals.

NOTES

1 The rated voltages of all windings appear simultaneously at no-load when the voltage applied to one of them has its rated value.

2 For single-phase transformers intended to be connected in star to form a three-phase bank, the rated voltage is indicated as phase-to-phase voltage, divided by $\sqrt{3}$, for example $U_r = 400\sqrt{3}$ kV.

3 For the series winding of a three-phase booster transformer which is designed as an open winding (*see* **3.10.5**) the rated voltage is indicated as if the winding were connected in star, for example $U_r = 23\sqrt{3}$ kV.

3.4.4 *Rated Voltage Ratio* — The ratio of the rated voltage of a winding to the rated voltage of another winding associated with a lower or equal rated voltage.

3.4.5 *Rated Frequency* (f_r) — The frequency at which the transformer is designed to operate.

3.4.6 *Rated Power* (S_r) — A conventional value of apparent power assigned to a winding which, together with the rated voltage of the winding, determines its rated current.

NOTES

1 Both windings of a two-winding transformer have the same rated power which by definition is the rated power of the whole transformer.

2 For a multi-winding transformer, half the arithmetic sum of the rated power values of all windings (separate windings, not auto-connected) gives a rough estimate of its physical size as compared with a two-winding transformer.

3.4.7 *Rated Current* (I_r) — The current flowing through a line terminal of a winding which is derived from rated power S_r and rated voltage U_r for the winding.

NOTES

1 For a three-phase winding the rated current I_r is given by:

$$I_r = \frac{S_r}{\sqrt{3} \times U_r} A$$

2 For single-phase transformer windings intended to be connected in delta to form a three-phase bank the rated current is indicated as line current divided by $\sqrt{3}$, for example:

$$I_r = \frac{500}{\sqrt{3}} A$$

3.5 Tappings

3.5.1 *Tapping* — In a transformer having a tapped winding, a specific connection of that winding, representing a definite effective number of turns in the tapped winding and, consequently, a definite turns ratio between this winding and any other winding with fixed number of turns.

NOTE — One of the tappings is the principal tapping, and other tappings are described in relation to the principal tapping by their respective tapping factors. See definitions of these terms below.

3.5.2 *Principal Tapping* — The tapping to which the rated quantities are related.

3.5.3 *Tapping Factor* (corresponding to a given tapping)

The ratio:

$\dfrac{U_d}{U_r}$ (tapping factor) or

$100\,\dfrac{U_d}{U_r}$ (tapping factor expressed as a percentage) where

U_r = rated voltage of the winding (*see* **3.4.3**); and

U_d = voltage which would be developed at no-load at the terminals of the winding, at the tapping concerned, by applying rated voltage to an untapped winding.

NOTE — This definition is not appropriate in relation to a series winding of a booster transformer (*see* **3.1.3**), and in that case the percentage notation would be referred to the voltage of the energizing winding or of the winding of an associated system transformer.

3.5.4 *Plus Tapping* — A tapping whose tapping factor is higher than 1.

3.5.5 *Minus Tapping* — A tapping whose tapping factor is lower than 1.

3.5.6 *Tapping Step* — The difference between the tapping factors, expressed as a percentage, of two adjacent tappings.

3.5.7 *Tapping Range* — The variation range of the tapping factor, expressed as a percentage, compared with the value '100'.

NOTE — If this factor ranges from 100 + a to 100 – b, the tapping range is said to be: +a percent, – b percent or ± a percent, if $a = b$.

3.5.8 *Tapping Voltage Ratio* (of a pair of windings) — The ratio which is equal to the rated voltage ratio:

a) multiplied by the tapping factor of the tapped winding, if this is the high-voltage winding; and
b) divided by the tapping factor of the tapped winding, if this is the low-voltage winding.

NOTE — While the rated voltage ratio is, by definition, at least equal to 1, the tapping voltage ratio can be lower than 1 for certain tappings when the rated voltage ratio is close to 1.

3.5.9 *Tapping Duty* — The numerical values assigned to the quantities, analogous to rated quantities, which refer to tappings other than the principal tapping.

3.5.10 *Tapping Quantities* — Those quantities the numerical values of which define the tapping duty of a particular tapping (other than the principal tapping).

The tapping quantities are:

a) Tapping voltage (analogous to rated voltage, *see* **3.4.3**);
b) Tapping power (analogous to rated power, *see* **3.4.6**); and
c) Tapping current (analogous to rated current, *see* **3.4.7**).

NOTE — Tapping quantities exist for any winding in the transformer, not only for the tapped winding (*see* **5.2** and **5.3**).

3.5.11 *Full-Power Tapping* — A tapping whose tapping power is equal to the rated power.

3.5.12 *Reduced-Power Tapping* — A tapping whose tapping power is lower than the rated power.

3.5.13 *On-load Tap-changer* — A device for changing the tapping connections of a winding, suitable for operation while the transformer is energized or on load.

3.6 Losses and No-load Current

NOTE — The values are related to the principal tapping, unless another tapping is specifically stated.

3.6.1 *No-load Loss* — The active power absorbed when rated voltage (tapping voltage) at rated frequency is applied to the terminals of one of the windings, the other winding or windings being open-circuited.

3.6.2 *No-load Current* — The r.m.s. value of the current flowing through a line terminal of a winding when rated voltage (tapping voltage) is applied at rated frequency, the other winding or windings being open-circuited.

NOTES

1 For a three-phase transformer, the value is the arithmetic mean of the values of current in the three phases.

2 The no-load current of a winding is often expressed as a percentage of the rated current of that winding. For a multi-winding transformer this percentage is referred to the winding with the highest rated power.

3.6.3 *Load Loss* — The absorbed active power at rated frequency and reference temperature (*see* **10.1**), associated with a pair of windings when rated current (tapping current) is flowing through the line terminals of one of the windings, and the terminals of the other winding are short-circuited. Further windings, if existing, are open-circuited.

NOTES

1 For a two-winding transformer there is only one winding combination and one value of load loss. For a multi-winding transformer there are several values of load loss corresponding to the different two-winding combinations. A combined load loss figure for the complete transformer is referred to a specified winding load combination. In general, it is usually not accessible for direct measurement in testing.

2 When the windings of the pair have different rated power values the load loss is referred to rated current in the winding with the lower rated power and the reference power should be mentioned.

3.6.4 *Total Losses* — The sum of the no-load loss and the load loss.

NOTE — The power consumption of the auxiliary plant is not included in the total losses and is stated separately.

3.7 Short-Circuit Impedance and Voltage Drop

3.7.1 Short-circuit impedance of a pair of windings — the equivalent series impedance $Z = R + jX$, in ohms, at rated frequency and reference temperature, across the terminals of one winding of a pair, when the terminals of the other winding are short-circuited and further windings, if existing, are open-circuited. For a three-phase transformer the impedance is expressed as phase impedance (equivalent star connection).

In a transformer having a tapped winding, the short-circuit impedance is referred to a particular tapping. Unless otherwise specified the principal tapping applies.

NOTE — This quantity may be expressed in relative, dimensionless form, as a fraction z of the reference impedance Z_{ref}, of the same winding of the pair. In percentage notation:

$$z = 100 \frac{Z}{Z_{ref}}$$

where

$Z_{ref} = \frac{u^2}{S_r}$ (Formula valid for both three-phase and single-phase transformers),

U = voltage (rated voltage or tapping voltage) of the winding to which Z and Z_{ref} belong, and

S_r = reference value of rated power.

The relative value is also equal to the ratio between the applied voltage during a short-circuit measurement which causes the relevant rated current (or tapping current) to flow, and rated voltage (or tapping voltage). This applied voltage is referred to as the short-circuit voltage of the pair of windings. It is normally expressed as a percentage.

3.7.2 *Voltage Drop or Rise for a Specified Load Condition* — The arithmetic difference between the no-load voltage of a winding and the voltage developed at the terminals of the same winding at a specified load and power factor, the voltage supplied to (one of) the other winding(s) being equal to,

a) its rated value if the transformer is connected on the principal tapping (the no-load voltage of the former winding is then equal to its rated value); and
b) the tapping voltage if the transformer is connected on another tapping.

This difference is generally expressed as a percentage of the no-load voltage of the former winding.

NOTE — For multi-winding transformers, the voltage drop or rise depends not only on the load and power factor of the winding itself, but also on the load and power factor of the other windings.

3.7.3 *Zero-Sequence Impedance* (of a three-phase winding) — The impedance, expressed in ohms per phase at rated frequency, between the line terminals of a three-phase star-connected or zigzag-connected winding, connected together, and its neutral terminal.

NOTES

1 The zero-sequence impedance may have several values because it depends on how the terminals of the other winding or windings are connected and loaded.

2 The zero-sequence impedance may be dependent on the value of the current and the temperature, particularly in transformers without any delta-connected winding.

3 The zero-sequence impedance may also be expressed as a relative value in the same way as the (positive sequence) short-circuit impedance (*see* **3.7.1**).

3.8 Temperature Rise — The difference between the temperature of the part under consideration and the temperature of the external cooling medium.

3.9 Insulation — For definitions relating to insulation, *see* IS 2026 (Part 3).

3.10 Connections

3.10.1 *Star Connection (Y-connection)* — The winding connection so arranged that each of the phase windings of a three-phase transformer, or of each of the windings for the same rated voltage of single-phase transformers associated in a three-phase bank, is connected to a common point (the neutral point) and the other end to its appropriate line terminal.

3.10.2 *Delta Connection (D-connection)* — The winding connection so arranged that the phase windings of a three-phase transformer, or the windings for the same rated voltage of single-phase transformers associated in a three-phase bank, are connected in series to form a closed circuit.

3.10.3 *Open-Delta Connection* — The winding connection in which the phase windings of a three-phase transformer, or the windings for the same rated voltage of single-phase transformers associated in a three-phase bank, are connected in series without closing one corner of the delta.

3.10.4 *Zigzag Connection (Z-connection)* — The winding connection in which one end of each phase winding of a three-phase transformer is connected to a common point (neutral point), and each phase winding consists of two parts in which phase-displaced voltages are induced.

NOTE — These two parts normally have the same number of turns.

3.10.5 *Open Windings* — Phase windings of a three-phase transformer which are not interconnected within the transformer.

3.10.6 *Phase Displacement of a Three-Phase Winding* — The angular difference between the phasors representing the voltages between the neutral point (real or imaginary) and the corresponding terminals of two windings, a positive-sequence voltage system being applied to the high-voltage terminals, following each other in alphabetical sequence if they are lettered, or in numerical sequence if they are numbered. The phasors are assumed to rotate in a counter-clockwise sense.

NOTE — The high-voltage winding phasor is taken as reference, and the displacement for any other winding is conventionally expressed by the 'clock notation', that is, the hour indicated by the winding phasor when the H.V. winding phasor is at 12 O'clock (rising numbers indicate increasing phase lag).

3.10.7 *Connection Symbol* — A conventional notation indicating the connections of the high-voltage, intermediate-voltage (if any), and low-voltage windings and their relative phase displacement(s) expressed as a combination of letters and clock-hour figure(s).

3.11 Kinds of Tests

3.11.1 *Routine Test* — A test to which each individual transformer is subjected

3.11.2 *Type Test* — A test made on a transformer which is representative of other transformers, to demonstrate that these transformers comply with specified requirements not covered by routine tests.

NOTE — A transformer is considered to be representative of others if it is fully identical in rating and construction, but the type test may also be considered valid if it is made on a transformer which has minor deviations of rating or other characteristics. These deviations should be subject to agreement between the manufacturer and the purchaser.

3.11.3 *Special Test* — A test other than a type test or a routine test, agreed by the manufacturer and the purchaser.

3.12 Meteorological Data with Respect to Cooling

3.12.1 *Monthly Average Temperature* — Half the sum of the average of the daily maxima and the average of the daily minima during a particular month — over many years.

3.12.2 *Yearly Average Temperature* — One-twelfth of the sum of the monthly average temperatures.

4 RATING

4.1 Rated Power

The transformer shall have an assigned rated power for each winding which shall be marked on the rating plate. The rated power refers to continuous loading. This is a reference value for guarantees and tests concerning load losses and temperature rises.

If different values of apparent power are assigned under different circumstances, for example, with different methods of cooling, the highest of these values is the rated power.

A two-winding transformer has only one value of rated power, identical for both windings.

When the transformer has rated voltage applied to a primary winding, and rated current flows through the terminals of a secondary winding, the transformer receives the relevant rated power for that pair of windings.

The transformer shall be capable of carrying, in continuous service, the rated power [for a multi-winding transformer: the specified combination(s) of winding rated powers] under conditions listed in **4.2** and without exceeding the temperature-rise limitations specified in IS 2026 (Part 2).

NOTE — The interpretation of rated power according to this subclause implies that it is a value of apparent power input to the transformer — including its own absorption of active and reactive power. The apparent power that the transformer delivers to the circuit connected to the terminals of the secondary winding under rated loading differs from the rated power. The voltage across the secondary terminals differs from rated voltage by the voltage drop (or rise) in the transformer. Allowance for voltage drop, with regard to load power factor, is made in the specification of the rated voltage and the tapping range.

This is different from the method used in transformer standards, where 'rated kVA' is 'the output that can be delivered at... rated secondary voltage...'. According to that method, allowance for voltage drop has to be made in the design so that the necessary primary voltage can be applied to the transformer.

4.2 Loading Cycle

If specified in the enquiry or the contract, the transformer may, in addition to its rated power for continuous loading, be assigned a temporary load cycle which it shall be capable of performing under conditions specified in IS 2026 (Part 2).

NOTE — This option is to be used in particular to give a basis for design and guarantees concerning temporary emergency loading of large power transformers.

In the absence of such specification, guidance on loading of transformers complying with this part may be found in IS 6600.

The bushings, tap-changers and other auxiliary equipment shall be selected so as not to restrict the loading capability of the transformer.

NOTE — These requirements do not apply to special purpose transformers, some of which do not need loading capability above rated power. For others, special requirements will be specified.

4.3 Preferred Values of Rated Power

For transformers up to 10 MVA, values of rated power should preferably be taken from the R10 series given in IS 1076 (Part 1)

(...100, 125, 160, 200, 250, 315, 400, 500, 630, 800, 1 000, etc)

4.4 Operation at Higher than Rated Voltage and/or at Disturbed Frequency

Methods for the specification of suitable rated voltage values and tapping range to cope with a set of loading cases (loading power and power factor, corresponding line-to-line service voltages) are described in as per requirement.

Within the prescribed value of U_m, a transformer shall be capable of continuous service without damage under conditions of 'overfluxing' where the ratio of voltage over frequency exceeds the corresponding ratio at rated voltage and rated frequency by no more than 5 percent.

NOTE — U_m is the highest voltage for equipment applicable to a transformer winding [*see* IS 2026 (Part 3)].

5 REQUIREMENTS FOR TRANSFORMERS HAVING A TAPPED WINDING

5.1 General — Notation of Tapping Range

The following clauses apply to transformers in which only one of the windings is a tapped winding.

In a multi-winding transformer, the statements apply to the combination of the tapped winding with either of the untapped windings.

In auto-connected transformers, tappings are sometimes arranged at the neutral which means that the effective number of turns is changed simultaneously in both windings. For such transformers, the tapping particulars are subject to agreement. The requirements of this clause should be used as far as applicable.

Unless otherwise specified, the principal tapping is located in the middle of the tapping range. Other tappings are identified by their tapping factors. The number of tappings and the range of variation of the transformer ratio may be expressed in short notation by the deviations of the tapping factor percentages from the value 100 (for definitions of terms, *see* **3.5**).

Example: A transformer with a tapped 160 kV winding having altogether 21 tappings, symmetrically placed, is designated:

$$(160 \pm 10 \times 1.5 \text{ percent})/66 \text{ kV}$$

If for some reason the tapping range is specified asymmetrically around the rated voltage, we may get:

$$\left(160^{+12\times1.5\%}_{-8\times1.5\%}\right)/\,66 \text{ kV}$$

NOTE — This way of short notation is only a description of the arrangement of the tapped winding and does not imply actual variations of applied voltage on that winding in service. This is dealt with in **5.2** and **5.3**.

Regarding the full presentation on the nameplate of data related to individual tappings (*see* **7**).

Some tappings may be 'reduced-power tappings' due to restrictions in either tapping voltage or tapping current. The boundary tappings where such limitations appear are called 'maximum voltage tapping' and 'maximum current tapping' (*see* Fig. 1).

5.2 Tapping Voltage — Tapping Current Standard Categories of Tapping Voltage Variation Maximum Voltage Tapping

The short notation of tapping range and tapping steps indicates the variation range of the ratio of the transformer. But the assigned values of tapping quantities are not fully defined by this alone. Additional information is necessary. This can be given either in tabular form with tapping power, tapping voltage and tapping current for each tapping, or as text, indicating 'category of voltage variation' and possible limitations of the range within which the tappings are 'full-power tappings'.

The extreme categories of tapping voltage variation are:

a) constant flux voltage variation (CFVV); and
b) variable flux voltage variation (VFVV).

They are defined as follows:

a) *CFVV*

   The tapping voltage in any untapped winding is constant from tapping to tapping. The tapping voltages in the tapped winding are proportional to the tapping factors.

b) *VFVV*

   The tapping voltage in the tapped winding is constant from tapping to tapping. The tapping voltages in any untapped winding are inversely proportional to the tapping factor.

c) *CbVV (Combined voltage variation)*

   In many applications and particularly with transformers having a large tapping range, a combination is specified using both principles applied to different parts of the range: combined voltage variation (CbVV). The change-over point is called 'maximum voltage tapping'. For this system the following applies:

   1) CFVV applies for tappings with tapping factors below the maximum voltage tapping factor.
   2) VFVV applies for tappings with tapping factors above the maximum voltage tapping factor.
   3) *Graphic presentation of tapping voltage variation categories:*

      CFVV (*see* Fig. 1A) — VFVV (*see* Fig. 1B) — CbVV (*see* Fig. 1C).

Symbols:

U_A, I_A : Tapping voltage and tapping current in the tapped winding.

U_B, I_B : Tapping voltage and tapping current in the untapped winding.

S_{AB} : Tapping power.

Abscissa : Tapping factor, percentage (indicating relative number of effective turns in tapped winding).

1 : Indicates full-power tappings throughout the tapping range.

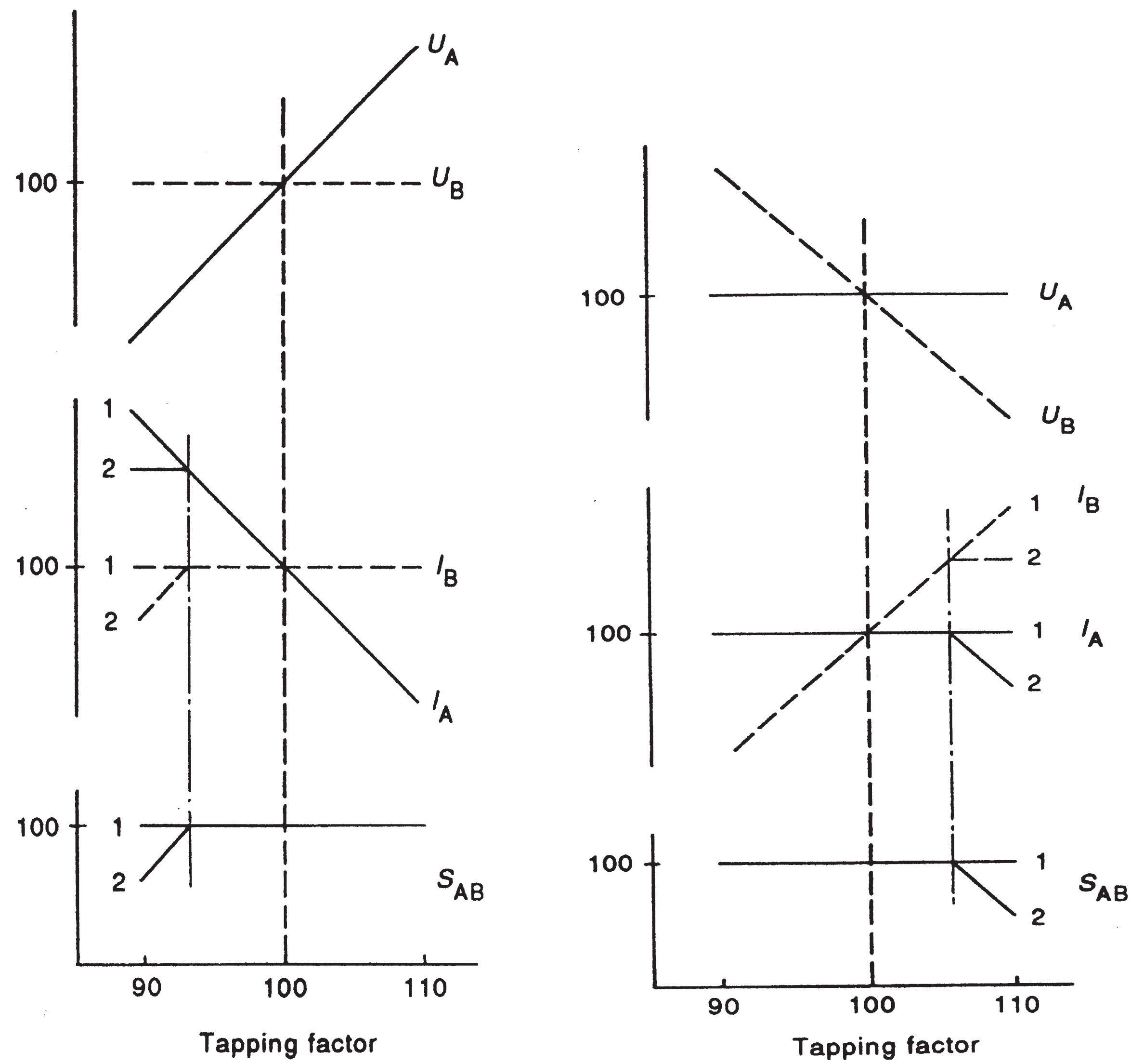
2 : Indicates 'maximum-voltage tapping', 'maximum current tapping' and range of reduced power tappings.

The change-over point is shown in the plus tapping range. It constitutes both a maximum voltage tapping (U_A) and a maximum current tapping (I_B constant, not rising above the change-over point). An additional, optional maximum current tapping (in the CFVV range) is also shown.

5.3 Tapping Power. Full-Power Tappings — Reduced-Power Tappings

All tappings shall be full-power tappings, except as specified below.

In separate-winding transformers up to and including 2 500 kVA with a tapping range not exceeding ±5 percent the tapping current in the tapped



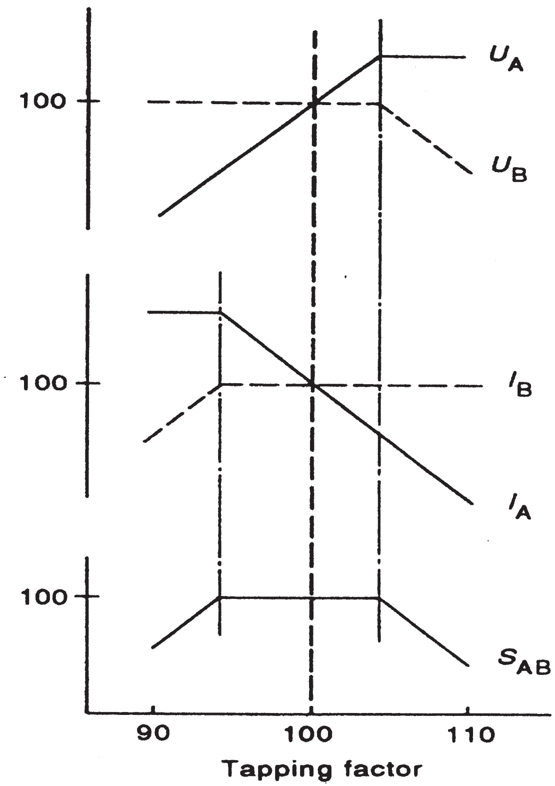
Optional maximum current tapping shown

1A Constant Flux Voltage Variation CFVV

Optional maximum current tapping shown

1B Variable Flux Voltage Variation VFVV

FIG. 1 TAPPING VOLTAGE VARIATION (*Continued*)



1C Combined Voltage Variation CbVV

FIG. 1 TAPPING VOLTAGE VARIATION

winding shall be equal to rated current at all minus tappings. This means that the principal tapping is a 'maximum current tapping'.

In transformers with a tapping range wider than ±5 percent, restrictions may be specified on values of tapping voltage or tapping current which would otherwise rise considerably above the rated values. When such restrictions are specified, the tappings concerned will be 'reduced-power tappings'. This subclause describes such arrangements.

When the tapping factor deviates from unity, the tapping current for full-power tappings may rise above rated current on one of the windings. As Fig. 1A illustrates, this applies for minus tappings, on the tapped winding, under CFVV, and for plus tappings on the untapped winding under VFVV (*see* Fig. 1B). In order to limit the corresponding reinforcement of the winding in question, it is possible to specify a maximum current tapping. From this tapping onwards the tapping current values for the winding are then specified to be constant. This means that the remaining tappings towards the extreme tapping are reduced-power tappings (*see* Fig. 1A, 1B and 1C).

Under CbVV, the 'maximum voltage tapping', the change-over point between CFVV and VFVV shall at the same time be a 'maximum current tapping' unless otherwise specified. This means that the untapped winding current stays constant up to the extreme plus tapping (*see* Fig. 1C).

5.4 Specification of Tappings in Enquiry and Order

The following data are necessary to define the design of the transformer:

a) Which winding shall be tapped;
b) The number of steps and the tapping step (or the tapping range and number of steps). Unless otherwise specified it shall be assumed that the range is symmetrical around the principal tapping and that the tapping steps in the tapped winding are equal. If for some reason the design has unequal steps, this shall be indicated in the tender;
c) The category of voltage variation and, if combined variation is applied, the change-over point ('maximum voltage tapping', *see* **5.2**); and
d) Whether maximum current limitation (reduced power tappings) shall apply, and if so, for which tappings.

Instead of **5.4** (c) and **5.4** (d), tabulation of the same type as used on the rating plate may be used to advantage (*see* example in Annex C).

The specification of these data may be accomplished in two different ways,

a) either the user may specify all data from the beginning, in his enquiry; and
b) alternatively, the user may submit a set of loading cases with values of active and reactive power (clearly indicating the direction of power flow), and corresponding on-load voltages.

These cases should indicate the extreme values of voltage ratio under full and reduced power. Based on this information the manufacturer will then select the tapped winding and specify rated quantities and tapping quantities in his tender proposal.

5.5 Specification of Short-Circuit Impedance

Unless otherwise specified, the short-circuit impedance of a pair of windings is referred to the principal tapping (*see* **3.7.1**). For transformers having a tapped winding with tapping range exceeding ±5 percent, impedance values are also to be given for the two extreme tappings. On such transformers these three values of impedance shall also be measured during the short-circuit test (*see* **10.4**).

When impedance values are given for several tappings, and particularly when the windings of the pair have dissimilar rated power values, it is recommended that the impedance values be submitted in ohms per phase, referred to either of the windings, rather than as percentage values. Percentage values may lead to confusion because of varying practices concerning reference values. Whenever percentage values are given it is advisable that the corresponding reference power and reference voltage values be explicitly indicated.

A way of specifying short-circuit impedance values in the enquiry which leaves some degree of freedom in the design, is to indicate an acceptable range between upper and lower boundaries, across the whole tapping range. This may be done with the aid of a graph or a table.

The boundaries shall be at least as far apart as to permit the double-sided tolerances of **9** to be applied on a median value between them. An example is shown in Annex D. The manufacturer shall select and guarantee impedance values for the principal tapping and for the extreme tappings which are between the boundaries. Measured values may deviate from guaranteed values within the tolerances according to **9**, but shall not fall outside the boundaries, which are limits without tolerance.

NOTE — The selection of an impedance value by the user is subject to conflicting demands: limitation of voltage drop versus limitation of overcurrent under system fault conditions. Economic optimization of the design, bearing in mind loss, leads towards a certain range of impedance values. Parallel operation with an existing transformer requires matching impedance.

If an enquiry contains a specification of not only the impedance at the principal tapping but also its variation across the tapping range, this means a quite important restriction on the design (placing of windings in relation to each other). Such a detailed specification should therefore not be issued without good reason.

5.6 Load Loss and Temperature Rise

a) If the tapping range is within ±5 percent, and the rated power not above 2 500 kVA, load loss guarantees and temperature rise refer to the principal tapping only, and the temperature rise test is run on that tapping.
b) If the tapping range exceeds ±5 percent or the rated power is above 2 500 kVA, it shall be stated for which tappings, in addition to the principal tapping, the load losses are to be guaranteed by the manufacturer. These load losses are referred to the relevant tapping current values. The temperature-rise limits are valid for all tappings, at the appropriate tapping power, tapping voltage and tapping current.

A temperature-rise type test, if specified, shall be carried out on one tapping only. It will, unless otherwise agreed, be the 'maximum current tapping' (which is usually the tapping with the highest load loss). The total loss for the selected tapping is the test power for determination of oil temperature-rise during the temperature-rise test, and the tapping current for that tapping is the reference current for determination of winding temperature-rise above oil. For information about rules and tests regarding the temperature rise of oil-immersed transformers [*see* IS 2026 (Part 2)].

In principle, the temperature-rise type test shall demonstrate that the cooling equipment is sufficient for dissipation of maximum total loss on any tapping, and that the temperature-rise over ambient of any winding, at any tapping, does not exceed the specified maximum value.

The second purpose normally requires the 'maximum current tapping' to be selected for the test. But the amount of total loss to be injected in order to determine maximum oil temperature-rise shall correspond to the highest value for any tapping, even if this is other than the tapping connected for the test [*see also* **5.2** in IS 2026 (Part 2)].

6 CONNECTION AND PHASE DISPLACEMENT SYMBOLS FOR THREE-PHASE TRANSFORMERS

The star, delta, or zigzag connection of a set of phase windings of a three-phase transformer or of windings of the same voltage of single-phase transformers associated in a three-phase bank shall be indicated by the capital letters Y, D or Z for the high-voltage (HV) winding and small letters y, d or z for the intermediate and low-voltage (LV) windings. If the neutral point of a star-connected or zigzag-connected winding is brought out, the indication shall be YN (yn) or ZN (zn) respectively.

Open windings in a three-phase transformer (that are not connected together in the transformer but have both ends of each phase winding brought out to terminals) are indicated as III (HV), or iii (intermediate or low-voltage windings).

For an auto-connected pair of windings, the symbol of the lower voltage winding is replaced by 'auto', or 'a', for example, 'YNauto' or 'YNa' or 'YNa0', 'ZNa11'.

Letter symbols for the different windings of a transformer are noted in descending order of rated voltage. The winding connection letter for any intermediate and low-voltage winding is immediately followed by its phase displacement 'clock number' (*see* **3.10.6**). Three examples are shown below and illustrated in Fig. 2.

The existence of a stabilizing winding (a delta-connected winding which is not terminated for external three-phase loading) is indicated, after the symbols of loadable windings, with the symbol '+d'.

If a transformer is specified with its winding connection changeable (series-parallel or Y-D), both connections will be noted, coupled with the corresponding rated voltages as indicated by the following examples:

220(110)/10,5 kV	YN(YN)d11
110/11(6,35)kV	YNy0(d11)

Full information shall be given on the rating plate [*see* **7.2** (e)].

Examples of connections in general use, with connection diagrams, are shown in Annex E.

Diagrams, with terminal markings, and with indication of built-in current transformers when used, may be presented on the rating plate together with the text information that is specified in **7**.

The following conventions of notation apply:

The connection diagrams show the high-voltage winding above, and the low-voltage winding below. (The directions of induced voltages are indicated.)

The high-voltage winding phasor diagram is oriented with phase I pointing at 12 O'clock. The phase I phasor of the low-voltage winding is oriented according to the induced voltage relation which results for the connection shown.

The sense of rotation of the phasor diagrams is counter-clockwise, giving the sequence I — II — III.

NOTE — This numbering is arbitrary. Terminal marking on the transformer follows national practice.

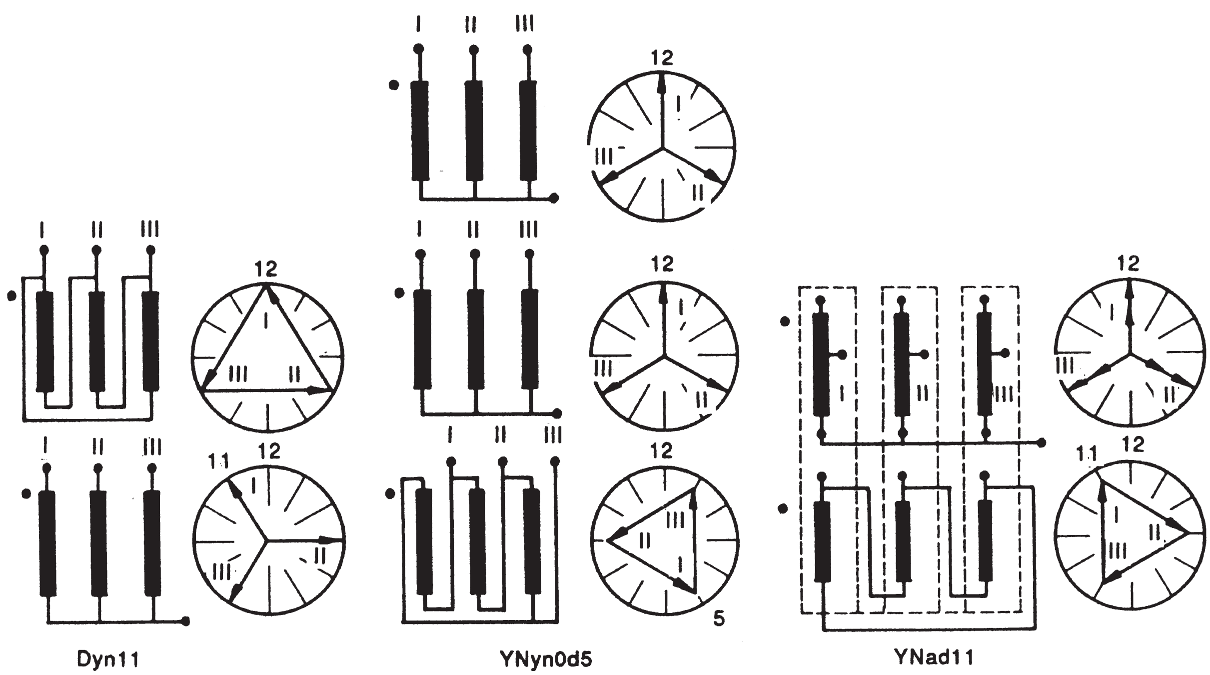


FIG. 2 ILLUSTRATION OF 'CLOCK NUMBER' NOTATION — THREE EXAMPLES

Example 1

A distribution transformer with high-voltage winding for 20 kV, delta-connected. The low-voltage winding is 400 V star-connected with neutral brought out. The LV winding lags the HV by 330°.

Symbol: Dyn11

Example 2

A three-winding transformer: 123 kV star with neutral brought out. 36 kV star with neutral brought out, in phase with the HV winding but not auto-connected. 7.2 kV delta, lagging by 150°.

Symbol: YNyn0d5

Example 3

A group of three single-phase auto-transformers

$$\frac{400}{\sqrt{3}} \bigg/ \frac{130}{\sqrt{3}} \text{ kV with 22 kV tertiary windings.}$$

The auto-connected windings are connected in star, while the tertiary windings are connected in delta. The delta winding phasors lag the high-voltage winding phasors by 330°.

Symbol: YNautod11 or YNad11

The symbol would be the same for a three-phase auto-transformer with the same connection, internally.

If the delta winding is not taken out to three line terminals but only provided as a stabilizing winding, the symbol would indicate this by a plus sign. No phase displacement notation would then apply for the stabilizing winding.

Symbol: YNauto+d.

7 RATING PLATES

The transformer shall be provided with a rating plate of weatherproof material, fitted in a visible position, showing the appropriate items indicated below. The entries on the plate shall be indelibly marked.

7.1 Information to be Given in All Cases

a) Kind of transformer (for example transformer, auto-transformer, booster transformer, etc);
b) Number of this standard;
c) Manufacturer's name;
d) Manufacturer's serial number;
e) Year of manufacture;
f) Number of phases;
g) Rated power (in kVA or MVA). (For multi-winding transformers, the rated power of each winding should be given. The loading combinations should also be indicated unless the rated power of one of the windings is the sum of the rated powers of the other windings);
h) Rated frequency (in Hz);
j) Rated voltages (in V or kV) and tapping range;
k) Rated currents (in A or kA);
m) Connection symbol;
n) Short-circuit impedance, measured value in percentage. For multi-winding transformers, several impedances for different two-winding combinations are to be given with the respective reference power values. For transformers having a tapped winding [*see also* **5.5** and **7.2**(b)];
p) Type of cooling. (If the transformer has several assigned cooling methods, the respective power values may be expressed as percentages of rated power, for example ONAN/ONAF 70/100 percent);
q) Total mass; and
r) Mass of insulating oil.

If the transformer has more than one set of ratings, depending upon different connections of windings which have been specifically allowed for in the design, the additional ratings shall all be given on the rating plate, or separate rating plates shall be fitted for each set.

7.2 Additional Information to be Given when Applicable

a) For transformers having one or more windings with 'highest voltage for equipment' U_m equal to or above 3.6 kV:

   short notation of insulation levels (withstand voltages) as described in IS 2026 (Part 3).

b) For transformers having a tapped winding, particulars about the tappings are as follows:
   1) for transformers having a tapping range not exceeding ±5 percent: tapping voltages on the tapped winding for all tappings. This applies in particular to distribution transformers;
   2) for transformers having a tapping range exceeding ±5 percent: a table stating tapping voltage, tapping current and tapping power for all tappings. In addition the short-circuit impedance values for the principal tapping and at least the extreme tappings shall be given, preferably in ohms per phase referred to a specific winding.

c) Temperature-rises of top oil and windings (if not normal values). When a transformer is specified for installation at high altitude, this shall be indicated, together with information on either the reduced temperature-rise figures valid under normal ambient conditions, or the reduced loading which will result in normal temperature rise at the high altitude (standard transformer with normal cooling capacity).

d) Insulating liquid, if not mineral oil.
e) Connection diagram (in cases where the connection symbol will not give complete information regarding the internal connections). If the connections can be changed inside the transformer, this shall be indicated on a separate plate or with duplicate rating plates. The connection fitted at the works shall be indicated.
f) Transportation mass (for transformers exceeding 5 t total mass).
g) Untanking mass (for transformers exceeding 5 t total mass).
h) Vacuum withstand capability of the tank and of the conservator.

In addition to the main rating plate with the information listed above, the transformer shall also carry plates with identification and characteristics of auxiliary equipment according to standards for such components (bushings, tap-changers, current transformers, special cooling equipment).

8 MISCELLANEOUS REQUIREMENTS

8.1 Dimensioning of Neutral Connection

The neutral conductor and terminal of transformers intended to carry a load between phase and neutral (for example, distribution transformers) shall be dimensioned for the appropriate load current and earth-fault current.

The neutral conductor and terminal of transformers not intended to carry load between phase and neutral shall be dimensioned for earth-fault current.

8.2 Oil Preservation System

For oil-immersed transformers the type of oil preservation system shall be specified in the enquiry and order. The following types are distinguished:

a) Freely breathing system or conservator system where there is free communication between the ambient air and an air-filled expansion space above the surface of the oil, in the tank or in a separate expansion vessel (conservator). A moisture-removing breather is usually fitted in the connection to the atmosphere.
b) Diaphragm-type oil preservation system where an expansion volume of air at atmospheric pressure is provided above the oil but prevented from direct contact with the oil by a flexible diaphragm or bladder.
c) Inert gas pressure system where an expansion space above the oil is filled with dry inert gas at slight over-pressure, being connected to either a pressure controlled source or an elastic bladder.
d) Sealed-tank system with gas cushion, in which a volume of gas above the oil surface in a stiff tank accommodates the oil expansion under variable pressure.
e) Sealed, completely filled system in which the expansion of the oil is taken up by elastic movement of the permanently sealed, usually corrugated tank.

8.3 Load Rejection on Generator Transformers

Transformers intended to be connected directly to generators in such a way that they may be subjected to load rejection conditions shall be able to withstand 1.4 times rated voltage for 5 s at the transformer terminals to which the generator is to be connected.

9 TOLERANCES

It is not always possible, particularly in large, multi-winding transformers with relatively low rated voltages, to accommodate turns ratios which correspond to specified rated voltage ratios with high accuracy. There are also other quantities which may not be accurately explored at the time of tender, or are subject to manufacturing and measuring uncertainty.

Therefore tolerances are necessary on certain guaranteed values.

Table 1 gives tolerances to be applied to certain rated quantities and to other quantities when they are the subject of manufacturer's guarantees referred to in this standard. Where a tolerance in one direction is omitted, there is no restriction on the value in that direction.

A transformer is considered as complying with this part when the quantities subject to tolerances are not outside the tolerances given in Table 1.

10 TESTS

10.1 General Requirements for Routine, Type and Special Tests

Transformers shall be subjected to tests as specified below.

Table 1 Tolerances
(*Clause* 9)

Sl No.	Item	Tolerance
(1)	(2)	(3)
i)	a) Total losses	+10 percent of the total losses
	b) Component losses (*see* Note 1)	+15 percent of each component loss, provided that the tolerance for total losses is not exceeded
ii)	a) Voltage ratio at no load on principal tapping for a specified first pair of windings	The lower of the following values: a) ±0.5 percent of declared ratio b) ±1/10 of the actual percentage impedance on the principal tapping
	b) Voltage ratio on other tappings, same pair	To be agreed, but not less than the lesser of the values given in (a) and (b) above
	c) Voltage ratio for further pairs	To be agreed, but not less than the lesser of the values given in (a) and (b)
iii)	Short-circuit impedance for: a) separate-winding transformer with two windings, or b) a specified first pair of separate windings in a multi-winding transformer	
	1) principal tapping	When the impedance value is ≥10 percent ±7.5 percent of the declared value When the impedance value is <10 percent ±10 percent of the declared value
	2) any other tapping of the pair	When the impedance value is ≥10 percent ±10 percent of the declared value When the impedance value is <10 percent ±15 percent of the declared value
iv)	Short-circuit impedance for: a) an auto-connected pair of winding, or b) a specified second pair of separate windings in a multi-winding transformer	
	1) principal tapping	±10 percent of the declared value
	2) any other tapping of the pair	±15 percent of the declared value for that tapping
	3) further pairs of windings	To be agreed, but ≥15 percent
v)	No-load current	+30 percent of the declared value

NOTES

1 The loss tolerances of multi-winding transformers apply to every pair of windings unless the guarantee states that they apply to a given load condition.

2 For certain auto-transformers and booster transformers the smallness of their impedance justifies more liberal tolerance. Transformers having large tapping ranges, particularly if the range is asymmetrical, may also require special consideration. On the other hand, for example, when a transformer is to be combined with previously existing units, it may be justified to specify and agree on narrower impedance tolerances. Matters of special tolerances shall be brought to attention at the tender stage, and revised tolerances agreed upon between manufacturer and purchaser.

3 'Declared value' should be understood as meaning the value declared by the manufacturer.

Tests shall be made at any ambient temperature between 10 °C and 50 °C and with cooling water (if required) at any temperature not exceeding 30 °C.

Tests shall be made at the manufacturer's works, unless otherwise agreed between the manufacturer and the purchaser.

All external components and fittings that are likely to affect the performance of the transformer during the test shall be in place.

Tapped windings shall be connected on their principal tapping, unless the relevant test clause requires otherwise or unless the manufacturer and the purchaser agree otherwise.

The test basis for all characteristics other than insulation is the rated condition, unless the test clause states otherwise.

All measuring systems used for the tests shall have certified, traceable accuracy and be subjected to periodic calibration, according to IS/ISO 9001.

Where it is required that test results are to be corrected to a reference temperature, this shall be:

a) for oil-immersed transformers: 75 °C; and
b) for dry-type transformers: according to the general requirements for tests in IS 11171.

NOTE — Specific requirements on the accuracy and verification of the measuring systems are under consideration.

10.1.1 *Routine Tests*

a) Measurement of winding resistance (*see* **10.2**);
b) Measurement of voltage ratio and check of phase displacement (*see* **10.3**);
c) Measurement of short-circuit impedance and load loss (*see* **10.4**);
d) Measurement of no-load loss and current (*see* **10.5**);
e) Dielectric routine tests IS 2026 (Part 3); and
f) Tests on on-load tap-changers, where appropriate (*see* **10.8**).

10.1.2 *Type Tests*

a) Temperature-rise test [*see* IS 2026 (Part 2)]; and
b) Dielectric type tests [*see* IS 2026 (Part 3)].

10.1.3 *Special Tests*

a) Dielectric special tests [*see* IS 2026 (Part 3)];
b) Determination of capacitances windings-to-earth, and between windings;
c) Determination of transient voltage transfer characteristics;
d) Measurement of zero-sequence impedance(s) on three-phase transformers (*see* **10.7**);
e) Short-circuit withstand test [*see* IS 2026 (Part 5)];
f) Determination of sound levels (*see* IS 13964);
g) Measurement of the harmonics of the no-load current (*see* **10.6**);
h) Measurement of the power taken by the fan and oil pump motors; and
j) Measurement of insulation resistance to earth of the windings, and/or measurement of dissipation factor (tan δ) of the insulation system capacitances. (These are reference values for comparison with later measurement in the field. No limitations for the values are given here.)

If test methods are not prescribed in this standard, or if tests other than those listed above are specified in the contract, such test methods are subject to agreement.

10.2 Measurement of Winding Resistance

10.2.1 *General*

The resistance of each winding, the terminals between which it is measured and the temperature of the windings shall be recorded. Direct current shall be used for the measurement.

In all resistance measurements, care shall be taken that the effects of self-induction are minimized.

10.2.2 *Dry-Type Transformers*

Before measurement the transformer shall be at rest in a constant ambient temperature for at least 3 h.

Winding resistance and winding temperature shall be measured at the same time. The winding temperature shall be measured by sensors placed at representative positions, preferably inside the set of windings, for example, in a duct between the high-voltage and low-voltage windings.

10.2 *Oil-Immersed Type Transformers*

After the transformer has been under oil without excitation for at least 3 h, the average oil temperature shall be determined and the temperature of the winding shall be deemed to be the same as the average oil temperature. The average oil temperature is taken as the mean of the top and bottom oil temperatures.

In measuring the cold resistance for the purpose of temperature-rise determination, special efforts shall be made to determine the average winding temperature accurately. Thus, the difference in temperature between the top and bottom oil should be small. To obtain this result more rapidly, the oil may be circulated by a pump.

10.3 Measurement of Voltage Ratio and Check of Phase Displacement

The voltage ratio shall be measured on each tapping. The polarity of single-phase transformers and the connection symbol of three-phase transformers shall be checked.

10.4 Measurement of Short-Circuit Impedance and Load Loss

The short-circuit impedance and load loss for a pair of windings shall be measured at rated frequency with approximately sinusoidal voltage applied to the terminals of one winding, with the terminals of the other winding short-circuited, and with possible other windings open-circuited (For selection of tapping for the test, *see* **5.5** and **5.6**). The supplied current should be equal to the relevant rated current (tapping current) but shall not be less than 50 percent thereof. The measurements shall be performed quickly so that temperature rises do not cause significant errors. The difference in temperature between the top oil and the bottom oil shall be small enough to enable the mean temperature to be determined accurately. If the cooling system is OF or OD, the pump may be used to mix the oil.

The measured value of load loss shall be multiplied with the square of the ratio of rated current (tapping current) to test current. The resulting figure shall then be corrected to reference temperature (*see* **10.1**). The I^2R loss (R being dc resistance) is taken as varying directly with the winding resistance and all other losses inversely with the winding resistance. The measurement of winding resistance shall be made according to **10.2**. The temperature correction procedure is detailed in Annex F.

The short-circuit impedance is represented as reactance and ac resistance in series. The impedance is corrected to reference temperature assuming that the reactance is constant and that the ac resistance derived from the load loss varies as described above.

On transformers having a tapped winding with tapping range exceeding ±5 percent, the short-circuit impedance shall be measured on the principal tapping and the two extreme tappings.

On a three-winding transformer, measurements are performed on the three different two-winding combinations. The results are re-calculated, allocating impedances and losses to individual windings. Total losses for specified loading cases involving all these windings are determined accordingly.

NOTES

1 For transformers with two secondary windings having the same rated power and rated voltage and equal impedance to the primary (sometimes referred to as 'dual-secondary transformers'), it may be agreed to investigate the symmetrical loading case by an extra test with both secondary windings short-circuited simultaneously.

2 The measurement of load loss on a large transformer requires considerable care and good measuring equipment because of the low power factor and the often large test currents. Correction for measuring transformer errors and for resistance of the test connections should be applied unless they are obviously negligible.

10.5 Measurement of No-load Loss and Current

The no-load loss and the no-load current shall be measured on one of the windings at rated frequency and at a voltage corresponding to rated voltage if the test is performed on the principal tapping, or to the appropriate tapping voltage if the test is performed on another tapping. The remaining winding or windings shall be left open-circuited and any windings which can be connected in open delta shall have the delta closed.

The transformer shall be approximately at factory ambient temperature.

For a three-phase transformer the selection of the winding and the connection to the test power source shall be made to provide, as far as possible, symmetrical and sinusoidal voltages across the three wound limbs.

The test voltage shall be adjusted according to a voltmeter responsive to mean value of voltage but scaled to read the r.m.s. voltage of a sinusoidal wave having the same mean value. The reading of this voltmeter is U'.

At the same time, a voltmeter responsive to the r.m.s. value of voltage shall be connected in parallel with the mean-value voltmeter and its indicated voltage U shall be recorded.

When a three-phase transformer is tested, the voltages shall be measured between line terminals, if a delta-connected winding is energized, and between phase and neutral terminals if a YN or ZN connected winding is energized.

The test voltage wave shape is satisfactory if the readings U' and U are equal within 3 percent.

The measured no-load loss is P_m, and the corrected no load loss is taken as:

$$P_o = P_m(1 + d)$$

$$d = \frac{U' - U}{U'} \text{ (usually negative)}$$

If the difference between voltmeter readings is larger than 3 percent, the validity of the test is subject to agreement.

The r.m.s. value of no-load current is measured at the same time as the loss. For a three-phase transformer, the mean value of readings in the three phases is taken.

NOTES

1 It is recognized that the most severe loading conditions for test voltage source accuracy are usually imposed by large single-phase transformers.

2 In deciding the place of the no-load test in the complete test sequence, it should be borne in mind that no-load loss measurements performed before impulse tests and/or temperature rise tests are, in general, representative of the average loss level over long time in service. Measurements after other tests sometimes show higher values caused by spitting between laminate edges during the impulse tests, etc. Such measurements may be less representative of losses in service.

10.6 Measurement of the Harmonics of the No-load Current

The harmonics of the no-load current in the three phases are measured and the magnitude of the harmonics is expressed as a percentage of the fundamental component.

10.7 Measurement of Zero-Sequence Impedance(s) on Three-Phase Transformers

The zero-sequence impedance is measured at rated frequency between the line terminals of a star-connected or zigzag-connected winding connected together, and its neutral terminal. It is expressed in ohms per phase and is given by 3 U/I, where U is the test voltage and I is the test current.

The test current per phase $\frac{I}{3}$ shall be stated

It shall be ensured that the current in the neutral connection is compatible with its current-carrying capability.

In the case of a transformer with an additional delta-connected winding, the value of the test current shall be such that the current in the delta-connected winding is not excessive, taking into account the duration of application.

If winding balancing ampere-turns are missing in the zero-sequence system, for example, in a star-star-connected transformer without delta winding, the applied voltage shall not exceed the phase-to-neutral voltage at normal operation. The current in the neutral and the duration of application should be limited to avoid excessive temperatures of metallic constructional parts.

In the case of transformers having more than one star-connected winding with neutral terminal, the zero-sequence impedance is dependent upon the connection (*see* **3.7.3**) and the tests to be made shall be subject to agreement between the manufacturer and the purchaser.

Auto-transformers with a neutral terminal intended to be permanently connected to earth shall be treated as normal transformers with two star-connected windings. Thereby, the series winding and the common winding together form one measuring circuit, and the common winding alone forms the other. The measurements are carried out with a current not exceeding the difference between the rated currents on the low-voltage side and the high-voltage side.

NOTES

1 In conditions where winding balancing ampere-turns are missing, the relation between voltage and current is generally not linear. In that case several measurements at different values of current may give useful information.

2 The zero-sequence impedance is dependent upon the physical disposition of the windings and the magnetic parts and measurements on different windings may not, therefore, agree.

10.8 Tests on On-load Tap-Changers

10.8.1 *Operation Test*

With the tap-changer fully assembled on the transformer the following sequence of operations shall be performed without failure:

a) with the transformer un-energized, eight complete cycles of operation (a cycle of operation goes from one end of the tapping range to the other, and back again);
b) with the transformer un-energized, and with the auxiliary voltage reduced to 85 percent of its rated value, one complete cycle of operation;
c) with the transformer energized at rated voltage and frequency at no load, one complete cycle of operation; and
d) with one winding short-circuited and, as far as practicable, rated current in the tapped winding, 10 tap-change operations across the range of two steps on each side from where a coarse or reversing changeover selector operates, or otherwise from the middle tapping.

10.8.2 *Auxiliary Circuits Insulation Test*

After the tap-changer is assembled on the transformer, a power frequency test shall be applied to the auxiliary circuits as specified in IS 2026 (Part 3).

11 ELECTROMAGNETIC COMPATIBILITY (EMC)

Power transformer shall be considered as passive elements in respect to emission of, and immunity to, electromagnetic disturbances.

NOTES

1 Certain accessories may be susceptible to electromagnetic interference.

2 Passive elements are not liable to cause electromagnetic disturbances and their performance is not liable to be affected by such disturbances.

ANNEX A

(*Clause* 2)

LIST OF REFERRED INDIAN STANDARDS

IS No	*Title*
1076 (Part 1): 1985	Preferred numbers: Part 1 Series of preferred number
2026	Power transformers:
(Part 2) : 2010	Temperature rise (*first revision*)
(Part 3) : 2009	Insulation levels and dielectric tests
(Part 4) : 1977	Terminal marking, tappings and connections
(Part 5) : 2011	Ability to withstand short circuit (*first revision*)
5553 : 1989 (All parts)	Reactors
6600 : 1972	Guide for loading of oil immersed transformers
11171 : 1985	Specification for dry-type power transformers
13964 : 1994	Methods of measurement of transformer and reactor sound levels
IS/ISO 9001 : 2000	Quality management systems — Requirements

ANNEX B

(*Clause* 1.1.2)

INFORMATION REQUIRED WITH ENQUIRY AND ORDER

B-1 RATING AND GENERAL DATA

B-1.1 Normal Information

The following information shall be given in all cases:

a) Particulars of the specifications to which the transformer shall comply;

b) Kind of transformer, for example, separate winding transformer, auto-transformer or booster transformer;

c) Single or three-phase unit;

d) Number of phases in system;

e) Frequency;

f) Dry-type or oil-immersed type. If oil-immersed type, whether mineral oil or synthetic insulating liquid. If dry-type, degree of protection (*see* IS 11171);

g) Indoor or outdoor type;

h) Type of cooling;

j) Rated power for each winding and, for tapping range exceeding ±5 percent, the specified maximum current tapping, if applicable. If the transformer is specified with alternative methods of cooling, the respective lower power values are to be stated together with the rated power (which refers to the most efficient cooling);

k) Rated voltage for each winding;

m) For a transformer with tappings:

   1) which winding is tapped, the number of tappings, and the tapping range or tapping step;

   2) whether ‘off-circuit’ or ‘on-load’ tap-changing is required;

   3) if the tapping range is more than ±5 percent, the type of voltage variation, and the location of the maximum current tapping, if applicable, (*see* **5.4**).

n) Highest voltage for equipment (U_m) for each winding [with respect to insulation [*see* IS 2026 (Part 3)];

p) Method of system earthing (for each winding);

q) Insulation level [*see* IS 2026 (Part 3)], for each winding;

r) Connection symbol and neutral terminals, if required for any winding;

s) Any peculiarities of installation, assembly, transport and handling. Restrictions on dimensions and mass;

t) Details of auxiliary supply voltage (for fans and pumps, tap-changer, alarms, etc);

u) Fittings required and an indication of the side from which meters, rating plates, oil-level indicators, etc, shall be legible;

v) Type of oil preservation system; and

w) For multi-winding transformers, required power-loading combinations, stating, when necessary, the active and reactive outputs separately, especially in the case of multi-winding auto-transformers.

B-1.2 Special Information

The following additional information may need to be given:

a) If a lightning impulse voltage test is required, whether or not the test is to include chopped waves [*see* IS 2026 (Part 3)];

b) Whether a stabilizing winding is required and, if so, the method of earthing;

c) Short-circuit impedance, or impedance range (*see* Annex D). For multi-winding transformers, any impedances that are specified for particular pairs of windings (together with relevant reference ratings, if percentage values are given);

d) Tolerances on voltage ratios and short-circuit impedances as left to agreement in Table 1, or deviating from values given in the table;

e) Whether a generator transformer is to be connected to the generator directly or through switchgear, and whether it will be subjected to load rejection conditions;

f) Whether a transformer is to be connected directly or by a short length of overhead line to gas-insulated switchgear (GIS);

g) Altitude above sea-level, if in excess of 1 000 m (3 300 ft);

h) Special ambient temperature conditions or restrictions to circulation of cooling air;

j) Expected seismic activity at the installation site which requires special consideration;

k) Special installation space restrictions which may influence the insulation clearances and terminal locations on the transformer;

m) Whether load current wave shape will be heavily distorted. Whether unbalanced three-phase loading is anticipated. In both cases, details to be given;

n) Whether transformers will be subjected to frequent overcurrents, for example, furnace transformers and traction feeding transformers;

p) Details of intended regular cyclic overloading other than covered by **4.2** (to enable the rating of the transformer auxiliary equipment to be established);

q) Any other exceptional service conditions;

r) If a transformer has alternative winding connections, how they should be changed, and which connection is required ex works;

s) Short-circuit characteristics of the connected systems (expressed as short-circuit power or current, or system impedance data) and possible limitations affecting the transformer design [*see* IS 2026 (Part 5)];

t) Whether sound-level measurement is to be carried out (*see* IS 13964);

u) Vacuum withstand of the transformer tank and, possibly, the conservator, if a specific value is required; and

v) Any special tests not referred to above which may be required.

B-2 PARALLEL OPERATION

If parallel operation with existing transformers is required, this shall be stated and the following information on the existing transformers given:

a) Rated power;

b) Rated voltage ratio;

c) Voltage ratios corresponding to tappings other than the principal tapping;

d) Load loss at rated current on the principal tapping, corrected to the appropriate reference temperature;

e) Short-circuit impedance on the principal tapping and at least on the extreme tappings, if the tapping range of the tapped winding exceeds ±5 percent; and

f) Diagram of connections, or connection symbol, or both.

NOTE — On multi-winding transformers, supplementary information will generally be required.

ANNEX C

(*Clause* 5.4)

EXAMPLES OF SPECIFICATIONS FOR TRANSFORMERS WITH TAPPINGS

C-1 EXAMPLE 1 — CONSTANT FLUX VOLTAGE VARIATION

Transformer having a 66 kV/20 kV three-phase 40 MVA rating and a ±10 percent tapping range on the 66 kV winding, with 11 tapping positions. Short notation: (66 ± 5 × 2 percent) / 20 kV.

Category of voltage variation	:	CFVV
Rated power	:	40 MVA
Rated voltages	:	66 kV/20 kV
Tapped winding	:	66 kV (tapping range ±10 percent)
Number of tapping positions	:	11

If this transformer shall have reduced power tappings, say, from tapping –6 percent, add:

maximum current tapping	:	tapping –6 percent

The tapping current of the HV winding is then limited to 372 A from the tapping –6 percent to the extreme tapping –10 percent where tapping power is reduced to 38.3 MVA.

C-2 EXAMPLE 2 — VARIABLE FLUX VOLTAGE VARIATION

Transformer having a 66 kV/6 kV, three-phase 20 MVA rating and a +15 percent, –5 percent tapping range on the HV winding, but having a constant tapping voltage for the HV winding and a variable tapping voltage for the LV winding, between:

$$\frac{6}{0.95} = 6.32\,\text{kV} \;\text{ to }\; \frac{6}{1.15} = 5.22\text{ kV}$$

Category of voltage variation	:	VFVV
Rated power	:	20 MVA
Rated voltages	:	66 kV/6 kV
Tapped winding	:	66 kV (tapping range +15 percent,–5 percent)
Number of tapping positions	:	13
Tapping voltages of 6 kV winding	:	6.32 kV, 6 kV, 5.22 kV

If this transformer shall have reduced power tappings, add for example:

maximum current tapping	:	tapping +5 percent

The 'tapping current' of the untapped winding (LV) is then limited to 2 020 A from the tapping +5 percent to the extreme tapping +15 percent where the tapping power is reduced to 18.3 MVA.

C-3 EXAMPLE 3 — COMBINED VOLTAGE VARIATION

Transformer having a 160 kV/20 kV three-phase 40 MVA rating and a ±15 percent tapping range on the 160 kV winding. The changeover point (maximum voltage tapping), is at +6 percent, and there is also a maximum current tapping in the CFVV range at –9 percent:

Tapped winding: 160 kV, range ± 10 × 1.5 percent.

Tappings	*Voltage Ratio* U_{HT}/U_{MT}	*Tapping Voltage* U_{HT} kV	*Tapping Current* I_{BT} A	*Tapping Power* S_{MVA} I_{HT} A	I_{BT} A	I_{HT}/I_{BT}
(1)	(2)	(3)	(4)	(5)	(6)	(7)
1 (+15 percent)	9/20	169.6	18.43	125.6	1 155	36.86
7 (+6 percent)	8/48	169.6	20	136.2	1 155	40
11 (0 percent)	8	160	20	144.4	1 155	40
17 (–9 percent)	7/28	145.6	20	158.7	1 155	40
21 (–15 percent)	6/80	136	20	158.7	1 080	37.4

NOTES

1 On completing with data for intermediate tappings, the preceding table can be used on a rating plate.

2 Compare this specification and a CFVV specification which would be:

(160 ± 15 percent) / 20 kV — 40 MVA

The difference is that the HV tapping voltage, according to the example, does not exceed the 'system highest voltage' of the HV system, which is 170 kV (IEC standardized value). The quantity 'highest voltage for equipment' which characterizes the insulation of the winding, is also 170 kV [*see* IS 2026 (Part 3)].

ANNEX D

(*Clauses* 5.5 *and* B-1.2)

SHORT-CIRCUIT IMPEDANCE BY BOUNDARIES

The upper boundary (Fig. 3) is a constant value of short-circuit impedance as a percentage, which is determined by the permissible voltage drop at a specified loading and at a specified power factor.

The lower boundary is determined by permissible overcurrent on the secondary side during a through-fault.

The dashed line is an example of a transformer short-circuit impedance curve which would satisfy this specification.

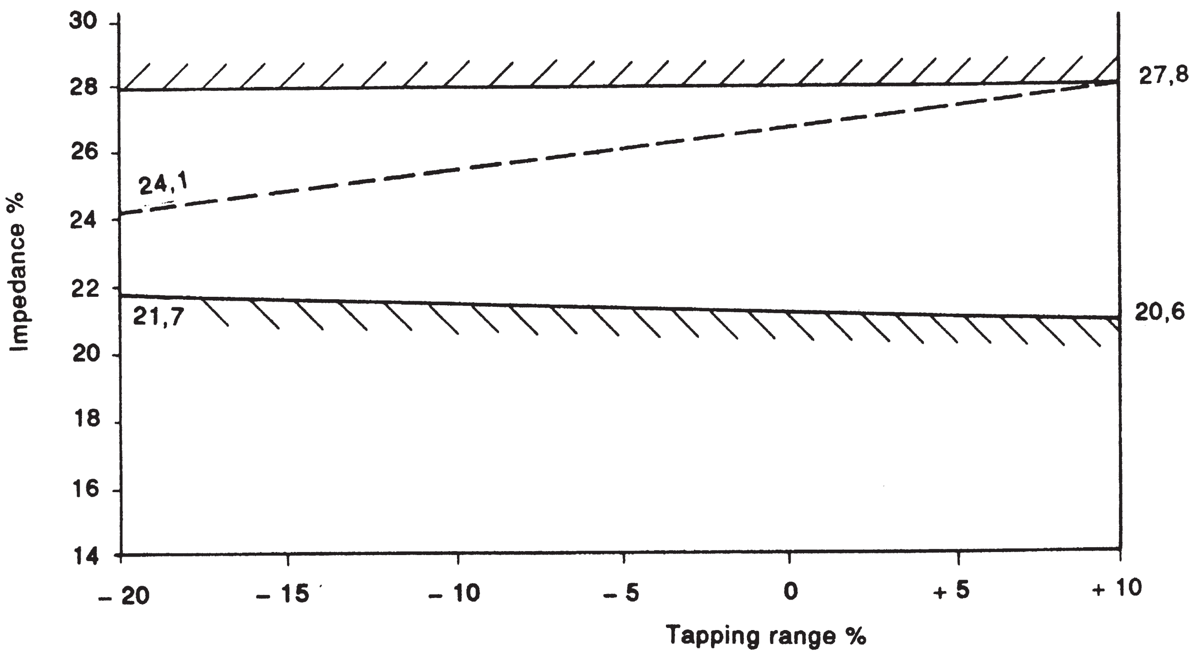


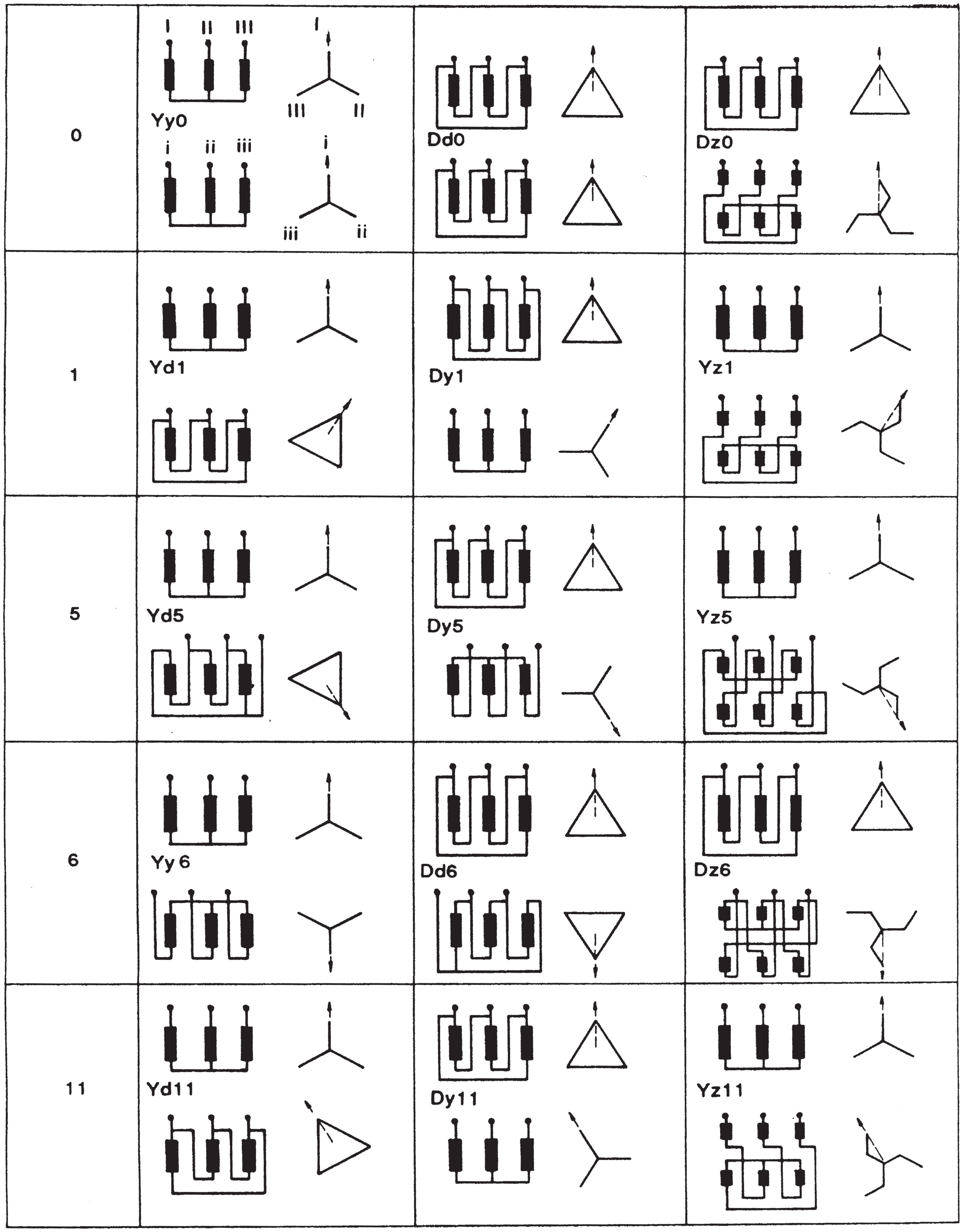
FIG. 3 EXAMPLE OF SPECIFICATION OF SHORT-CIRCUIT IMPEDANCE BY BOUNDARIES

ANNEX E

(*Clause* 6)

THREE-PHASE TRANSFORMER CONNECTIONS

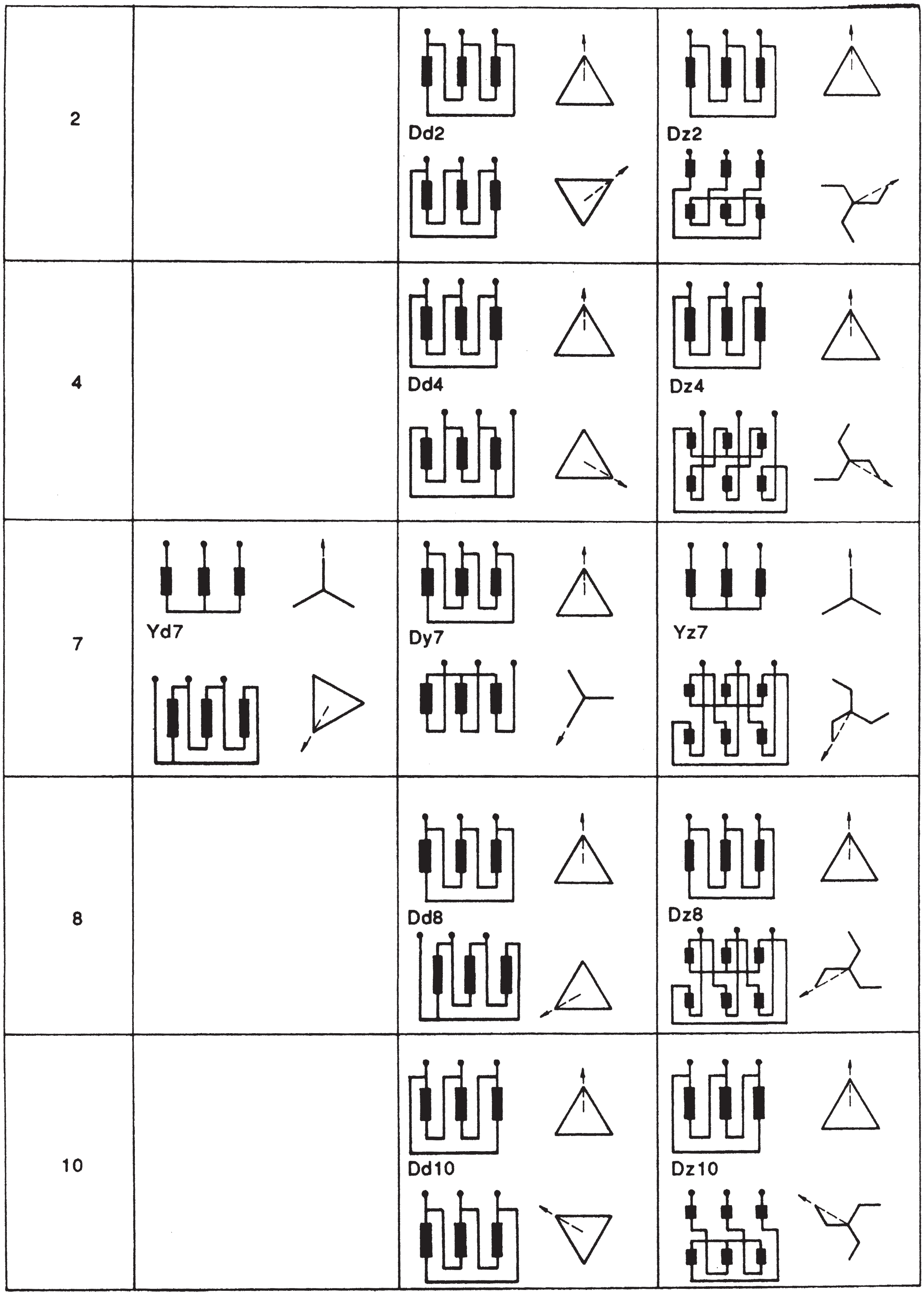
Common Connections are given in Fig. 4 and other connections are given in Fig. 5, 6 and 7.



NOTE — It should be noted that these conventions differ from those previously used in Fig. 5 of IS 2026 (Part 5).

FIG. 4 COMMON CONNECTIONS

Additional Connections



NOTE — It should be noted that these conventions differ from those previously used in Fig. 5 of IS 2026 (Part 4)

FIG. 5 ADDITIONAL CONNECTIONS

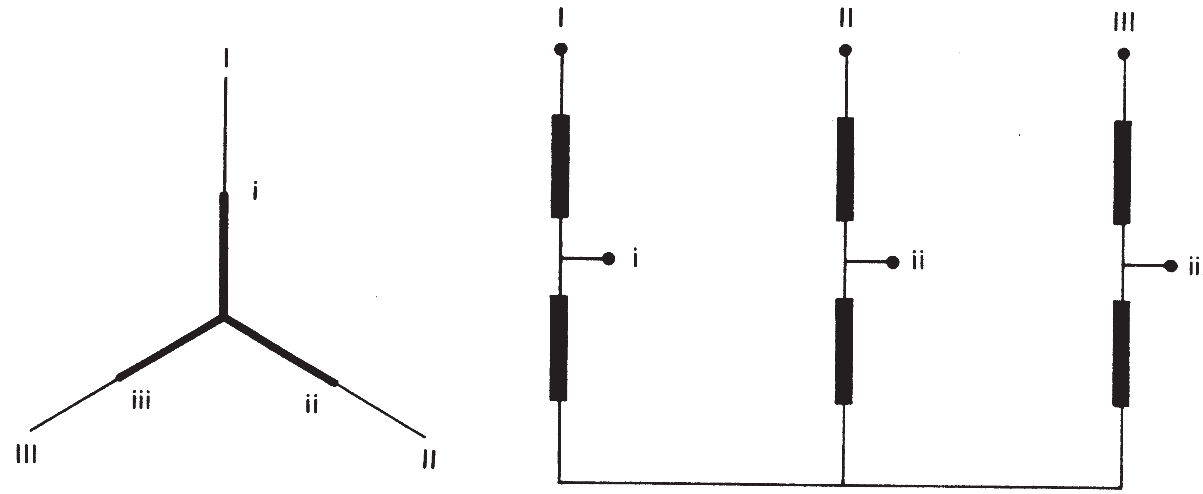


FIG. 6 DESIGNATION OF CONNECTIONS OF THREE-PHASE AUTO-TRANSFORMERS BY CONNECTION SYMBOLS AUTO-TRANSFORMER YA0

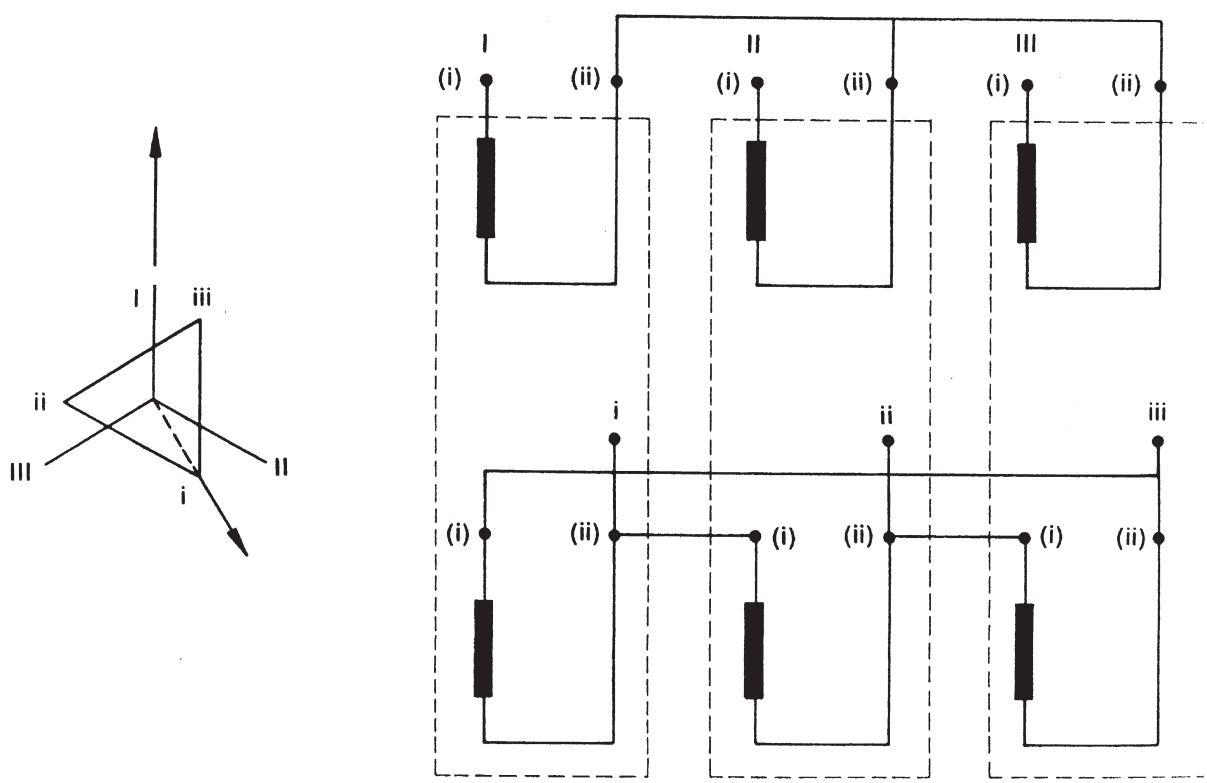


FIG. 7 EXAMPLE OF THREE SINGLE-PHASE TRANSFORMERS CONNECTED TO FORM A THREE-PHASE BANK (CONNECTION SYMBOL YD5)

ANNEX F

(*Clause* 10.4)

TEMPERATURE CORRECTION OF LOAD LOSS

F-1 LIST OF SYMBOLS

Index 1 : Refers to measurement of 'cold winding resistance' (*see* **10.2**).

Index 2 : Indicates conditions during measurement of load loss (*see* **10.4**).

r : Indicates conditions at 'reference temperature' (*see* **10.1**).

R : Resistance.

θ : Winding temperature, in °C.

P : Load loss.

I : Specified load current for loss determination (rated current, tapping current, other specified value related to a particular loading case).

P_a : Additional loss.

The winding resistance measurement is made at a temperature θ_1. The measured value is R_1.

The load loss is measured with the winding at an average temperature θ_2. The measured loss referred to specified current I, is P_2. This loss is composed of ohmic loss: I^2R_2 and 'additional loss': P_{a2}

$$R_2 = R_1 \frac{235+\theta_2}{235+\theta_1} \text{ (copper)}$$

$$R_2 = R_1 \frac{225+\theta_2}{225+\theta_1} \text{ (aluminium)}$$

$$P_{a2} = P_2 - I^2R_2$$

At reference temperature θ_r, the winding resistance is R_r, the additional loss P_{ar}, the whole load loss P_r.

$$R_r = R_1 \frac{235+\theta_r}{235+\theta_1} \text{ (copper)}$$

$$P_{ar} = P_{a2} \frac{235+\theta_2}{235+\theta_r}$$

$$R_r = R_1 \frac{225+\theta_r}{225+\theta_1} \text{ (aluminium)}$$

$$P_{ar} = P_{a2} \frac{225+\theta_2}{225+\theta_r}$$

For oil-immersed transformers with reference temperature 75 °C the formulae become as follows:

$$R_r = R_1 \frac{310}{235+\theta_1} \text{ (copper)}$$

$$P_{ar} = P_{a2} \frac{235+\theta_2}{310}$$

$$R_r = R_1 \frac{300}{225+\theta_1} \text{ (aluminium)}$$

$$P_{ar} = P_{a2} \frac{225+\theta_2}{300}$$

Finally: $P_r = I^2R_r + P_{ar}$

Bureau of Indian Standards

BIS is a statutory institution established under the *Bureau of Indian Standards Act*, 1986 to promote harmonious development of the activities of standardization, marking and quality certification of goods and attending to connected matters in the country.

Review of Indian Standards

Amendments are issued to standards as the need arises on the basis of comments. Standards are also reviewed periodically; a standard along with amendments is reaffirmed when such review indicates that no changes are needed; if the review indicates that changes are needed, it is taken up for revision. Users of Indian Standards should ascertain that they are in possession of the latest amendments or edition by referring to the latest issue of 'BIS Catalogue' and 'Standards : Monthly Additions'.

This Indian Standard has been developed from Doc No.: ETD 16 (6058).

Amendments Issued Since Publication

Amend No.	Date of Issue	Text Affected

BUREAU OF INDIAN STANDARDS

Headquarters:

Manak Bhavan, 9 Bahadur Shah Zafar Marg, New Delhi 110 002
Telephones : 2323 0131, 2323 3375, 2323 9402 *Website*: www.bis.org.in

Regional Offices: *Telephones*

Central	:	Manak Bhavan, 9 Bahadur Shah Zafar Marg NEW DELHI 110002	2323 7617 2323 3841
Eastern	:	1/14 C.I.T. Scheme VII M, V. I. P. Road, Kankurgachi KOLKATA 700054	2337 8499, 2337 8561 2337 8626, 2337 9120
Northern	:	SCO 335-336, Sector 34-A, CHANDIGARH 160022	60 3843 60 9285
Southern	:	C.I.T. Campus, IV Cross Road, CHENNAI 600113	2254 1216, 2254 1442 2254 2519, 2254 2315
Western	:	Manakalaya, E9 MIDC, Marol, Andheri (East) MUMBAI 400093	2832 9295, 2832 7858 2832 7891, 2832 7892

Branches: AHMEDABAD. BANGALORE. BHOPAL. BHUBANESHWAR. COIMBATORE. FARIDABAD. GHAZIABAD. GUWAHATI. HYDERABAD. JAIPUR. KANPUR. LUCKNOW. NAGPUR. PARWANOO. PATNA. PUNE. RAJKOT. THIRUVANANTHAPURAM. VISAKHAPATNAM.

Published by BIS, New Delhi