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INTERNATIONAL STANDARD

TAP-changers –
Part 2: Application guidelines

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TAP-CHANGERS –

Part 2: Application guidelines

FOREWORD

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International Standard IEC/IEEE 60214-2 has been prepared by IEC technical committee 14: Power transformers, in cooperation with the Transformers Committee of the IEEE Power and Energy Society, under the IEC/IEEE Dual Logo Agreement between IEC and IEEE.

This publication is published as an IEC/IEEE Dual Logo standard.

This second edition cancels and replaces the first edition published in 2004. This edition constitutes a technical revision.

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

a) title has been updated from "Application guide" to "Application guidelines";
b) tap-changers for gas-filled transformers have been added;
c) description of typical circuits for regulation has been added;
d) description of basic arrangements of tapped windings with on-load tap-changers and de-energized tap-changers has been added;
e) types of tap-changers are explained in more detail (e.g. vacuum type on-load tap-changer) and new types have been added (e.g. step-voltage regulator, advance retard switch (ARS), on-load tap-changers for distribution transformers);
f) selection of tap-changers (on-load and de-energized) are described in more detail with respect to applications and parameters, which have to be considered (e.g. current wave shapes, operating pressure, temperature conditions, overloading conditions, continuous consecutive operations);
g) storage and installation has been considered;
h) field service, including commissioning, operation, maintenance and monitoring, has been considered;
i) safety aspects have been updated.

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

FDIS	Report on voting
14/1000/FDIS	14/1006/RVD

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

International Standards are drafted in accordance with the rules given in the ISO/IEC Directives, Part 2.

A list of all parts in the IEC 60214 series, published under the general title *Tap-changers*, can be found on the IEC website.

The IEC Technical Committee and IEEE Technical Committee have decided that the contents of this publication will remain unchanged until the stability date indicated on the IEC website under "http://webstore.iec.ch" in the data related to the specific publication. At this date, the publication will be

- reconfirmed,
- withdrawn,
- replaced by a revised edition, or
- amended.

A bilingual version of this publication may be issued at a later date.

INTRODUCTION

The recommendations in these application guidelines represent advice to the tap-changer manufacturer, the transformer manufacturer, and the end user. When using these guidelines, the recommendations and instructions of the tap-changer manufacturer should prevail.

These guidelines apply to typical tap-changers currently in production at the time of publication. However, much of the information is applicable to older designs.

It is stressed that the responsibility for the correct application of the fully assembled tap-changers in connection with the transformer lies with the manufacturer of the transformer.

TAP-CHANGERS –

Part 2: Application guidelines

1 Scope

This part of IEC 60214 is intended to assist in the selection of tap-changers designed in accordance with IEC 60214-1 or IEEE Std C57.131 for use in conjunction with the tapped windings of transformers or reactors. Requirements, references and definitions relevant to either IEC 60214-1 or IEEE Std C57.131 are given and their use is described in Clause 4. It is also intended to assist in understanding the various types of tap-changers and their associated equipment available. These application guidelines cover on-load tap-changers (resistor and reactor types) and de-energized tap-changers.

2 Normative references

The following documents are referred to in the text in such a way that some or all of their content constitutes requirements of this document. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

2.1 IEC references

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

IEC 60076-1:2011, *Power transformers – Part 1: General*

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

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

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

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

IEC 60076-21, *Power transformers – Part 21: Standard requirements, terminology, and test code for step-voltage regulators*

IEC 60156, *Insulating liquids – Determination of the breakdown voltage at power frequency – Test method*

IEC 60214-1:2014, *Tap-changers – Part 1: Performance requirements and test methods*

IEC 60296, *Fluids for electrotechnical applications – Unused mineral insulating oils for transformers and switchgear*

IEC 60567, *Oil-filled electrical equipment – Sampling of gases and analysis of free and dissolved gases – Guidance*

IEC 60814, *Insulating liquids – Oil-impregnated paper and pressboard – Determination of water by automatic coulometric Karl Fischer titration*

2.2 IEEE references

ASTM D877 / D877M-2013, *Standard Test Method for Dielectric Breakdown Voltage of Insulating Liquids Using Disk Electrodes*

ASTM D1533, *Standard Test Method for Water in Insulating Liquids by Coulometric Karl Fischer Titration*

ASTM D3487, *Standard Specification for Mineral Insulating Oil Used in Electrical Apparatus*

IEEE Std C57.12.00™-2015, *IEEE Standard for General Requirements for Liquid-Immersed Distribution, Power, and Regulating Transformers*

IEEE Std C57.12.01™, *IEEE Standard for General Requirements for Dry-Type Distribution and Power Transformers*

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

IEEE Std C57.15™, *Power transformers – Part 21: Standard requirements, terminology, and test code for step-voltage regulators*

IEEE Std C57.91™, *IEEE Guide for Loading Mineral-Oil-Immersed Transformers and Step-Voltage Regulators*

IEEE Std C57.131™-2012, *IEEE Standard Requirements for Tap Changers*

3 Terms, definitions and abbreviated terms

3.1 Terms and definitions

For the purposes of this document, the terms and definitions given in IEC 60050-421, IEC 60214-1 and IEC 60076-21 apply for IEC-specified tap-changers. For IEEE-specified tap-changers, the terms and definitions given in IEEE Std C57.131 and IEEE Std C57.15 apply. For all tap-changers, the following apply and take precedence.

ISO, IEC and IEEE 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
- IEEE Dictionary Online: available at http://dictionary.ieee.org

3.1.1
mechanically linear
de-energized tap-changer, where the stationary contacts are arranged in a line (or series of lines) and the moving contacts operate in an inline manner to connect with the stationary contacts

Note 1 to entry: The definition only applies to the general operational characteristics of the switch, not to the type of contacts or actual operating mechanism.

3.1.2
mechanically rotary
de-energized tap-changer, where the stationary contacts are arranged along a circumference surrounding a central axis and the moving contacts operate in a rotational manner around that same central axis

Note 1 to entry: The definition only applies to the general operational characteristics of the switch, not to the type of contacts or actual operating mechanism.

3.1.3
fritting
electrically intimate metal-to-metal contact created by the dielectric breakdown of a very thin film of oil, oxides, sulfites, etc.

3.1.4
continuous consecutive operation
uninterrupted operation with the driving mechanism operating at its normal speed

3.2 Abbreviated terms

ARS	Advance retard switch
DETC	De-energized tap-changer
DGA	Dissolved and free gases analysis
EAF	Electrical arc furnace
GIC	Geomagnetic induced current
HV	High-voltage
HVDC	High-voltage direct current
IGBT	Insulated-gate bipolar transistor
LCSET	Lowest cold start energizing temperature (see IEC 60296)
LV	Low-voltage
OLTC	On-load tap-changer
PD	Partial discharge
PST	Phase-shifting transformer
VI	Vacuum interrupter
VSR	Variable shunt reactor

4 Use of normative references

This document can be used with either 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 tap-changers intended for installation in North America where IEEE standards shall be used.

If only one alternative is given in a certain part of the document, i.e. only IEC reference(s) or only IEEE reference(s), then that/these reference(s) is/are valid independently of the choice of normative references.

5 Application of tap-changers for transformers and reactors

5.1 General

Tap-changers are devices that vary the active turns in a winding of a transformer or reactor. Tap-changers can perform this operation either on-load or with the transformer de-energized. Therefore, they can broadly be divided into two fundamental types as follows:

– on-load tap-changers;

– de-energized tap-changers.

When the operation of the tap-changer changes the excitation level of the device to which it is applied, then the volts per turn of all windings wound on the same core will change.

Tap-changers are used with all types of distribution and power transformers as well as with reactors. Also transformers for special applications (e.g. HVDC-transformers, phase-shifting transformers (PSTs), transformers for electrical arc furnace (EAF) applications) are equipped with tap-changers.

5.2 Typical circuits for regulation

Figure 1 shows a common winding arrangement for a typical star-connected winding with the regulating winding located at the neutral point. In those applications a compact three-phase tap-changer without a full insulation between phases can be used, when applicable.

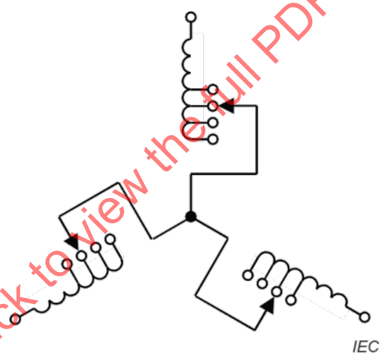


Figure 1 – Tap-changers in a star-connected winding

Series transformers (Figure 2) when applied to tap-changers are completely separate transformers or autotransformers used to trade off high current for increased voltage or high voltage for increased current. These devices, when applied, are supplied by and added to a larger main transformer where voltage regulation via an OLTC is needed. They are called series transformers because their output voltage is connected in series with the windings of the main transformer.

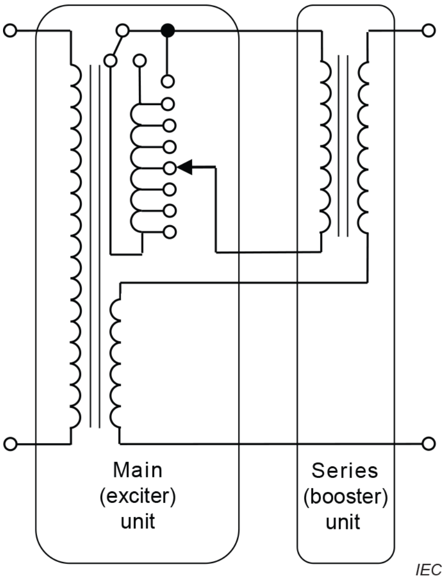
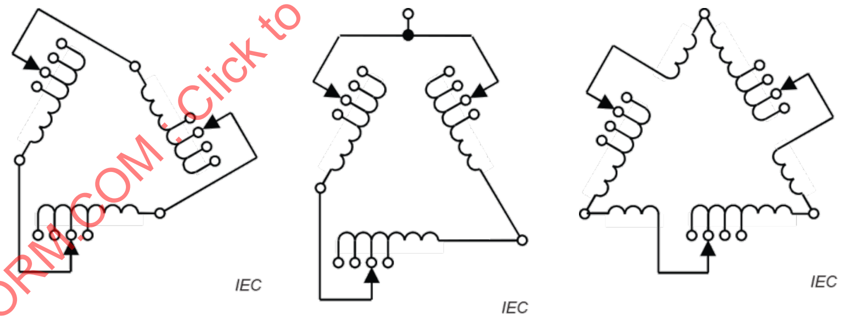


Figure 2 – Tap-changers in series transformers

Figure 3 a) to Figure 3 c) show the regulation in delta-connected windings. Figure 3 a) shows a winding arrangement where a three-phase tap-changer is needed with full insulation between phases dictated by the highest voltage for equipment U_m. The winding arrangement shown in Figure 3 c) allows the use of a tap-changer with reduced phase-to-phase insulation (around half of U_m). However, the insulation distance-to-ground shall be dimensioned for U_m because of the applied voltage test (AV) of the transformer (see IEC 60076-3:2013, Clause 10). If three-phase tap-changers of the required insulation level are not available, both above-mentioned arrangements can be used, of course, with three single-phase line-end tap-changers. When using a winding arrangement as shown in Figure 3 b), the number of tap-changer units can be reduced to two, a two-phase and a single-phase unit.



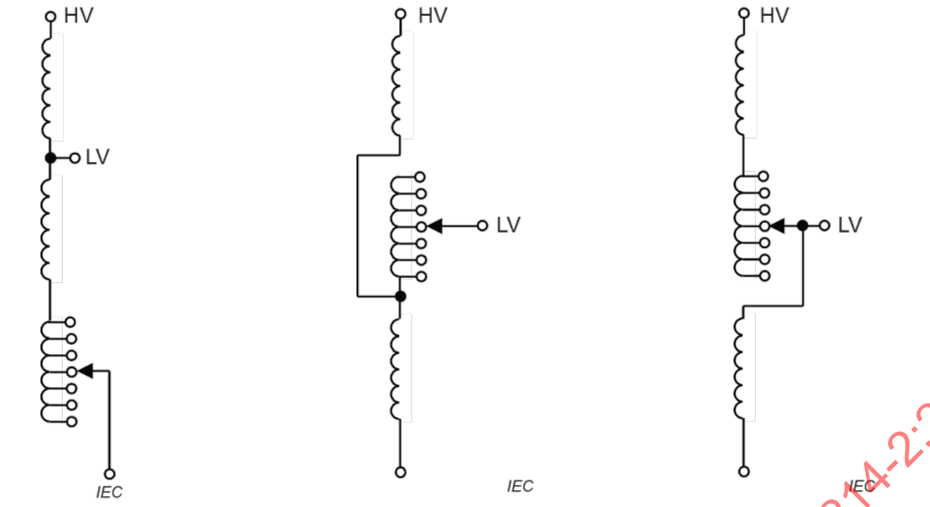
a)
Line-end arrangement

b)
Line-end arrangement with two units

c)
Mid-winding arrangement

Figure 3 – Tap-changers in delta-connected windings

Figure 4 shows winding arrangements for regulated autotransformers. The most appropriate arrangement is chosen depending on the regulating range, system conditions and/or weight and transportation restrictions.



a) Neutral end arrangement **b) Common winding (LV) arrangement** **c) Series winding (HV) arrangement**

Figure 4 – Tap-changers in autotransformers

The arrangement in Figure 4 a) shows the tap-changer at the neutral end, which allows, with respect to its insulation, the use of a compact design with a three-phase neutral end tap-changer. Such an autotransformer is used to compensate voltage fluctuations either on the HV or on the LV; however, this arrangement always has variable flux taps.

Figure 4 b) shows an arrangement mainly to vary the LV of the transformer. Using this arrangement to compensate for voltage fluctuations on the LV leads to constant flux taps. The compensation of voltage fluctuations on the HV leads to variable flux taps. The situation changes when using an arrangement according to Figure 4 c). In this case, the constant flux taps exist with the compensation of HV and the variable flux taps of LV voltage fluctuations. Single-column, three-phase tap-changers with full insulation between phases according to the U_m of the LV or three single-column line-end tap-changers have to be used in applications shown in Figure 4 b) and Figure 4 c).

5.3 Basic arrangements of tapped windings with on-load tap-changers

Each of the Figures 1 to 4 only shows one exemplary arrangement (linear regulation) of the tapped windings. For all these examples, one of the following three basic arrangements of the regulating winding (Figure 5) can be used. Depending on the system and design parameters of the transformer application, any of these arrangements can be used.

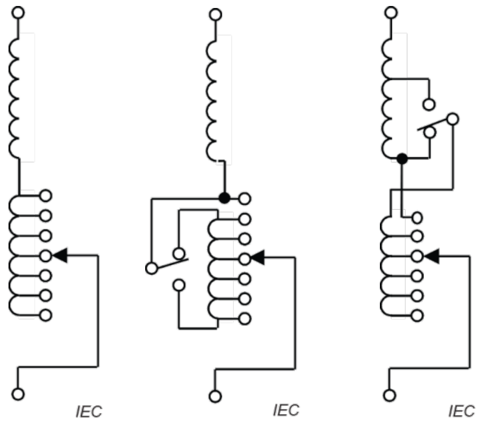


Figure 5 – Basic arrangements of the regulating winding

On power transformers, the linear connecting scheme (Figure 5 a)) is generally applied for a moderate regulating range up to typically 20 %. Industrial process transformers often work with a variable flux density and this scheme allows a variable number of turns between taps for optimum process control.

The regulating range can be approximately doubled by using a tap winding in conjunction with a change-over selector. A reversing change-over selector (Figure 5 b)) allows the tap winding to be connected in vectorial addition (boost) or subtraction (buck) to the main winding. Figure 5 c) shows a scheme with coarse and fine tap winding arrangements. The electrical length of the coarse winding is approximately the same as the fine tap winding. From the dielectric point of view this arrangement, however, requires a more sophisticated winding layout.

In the extreme "boost" position both regulating schemes with change-over selector show all windings in the circuit. In the extreme "buck" position, the reversing arrangement utilizes the main winding and the entire tap winding in the circuit, whereas the coarse/fine arrangement only utilizes the main winding, which furthermore has fewer turns. This leads to additional load losses with the reversing scheme when in buck tap-change position.

5.4 Basic arrangements of tapped windings with step-voltage regulator on-load tap-changers

See the latest edition of IEC 60076-21 or IEEE Std C57.15 for the different step-voltage regulator constructions such as:

– Type A,

– Type B,

– series transformer,

– equalizer winding.

5.5 Basic arrangements of tapped windings with de-energized tap-changers

5.5.1 Bridging contact scheme for DETC

The arrangement of the interaction of stationary and moving contacts on a DETC is such that the moving contact connects two of the stationary contacts per phase on the DETC (see Figure 6 a)). Multiple connections can be made providing a wide variety of connection options (see Figure 6 b)).

5.5.2 Linear contact scheme for DETC

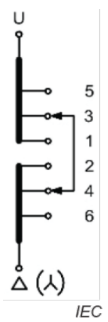
The arrangement of the interaction of stationary and moving contacts on a DETC is such that the moving contact connects a desired stationary contact to an output terminal (see Figure 6 c) and Figure 6 d)).

5.5.3 WYE (star) contact scheme for DETC

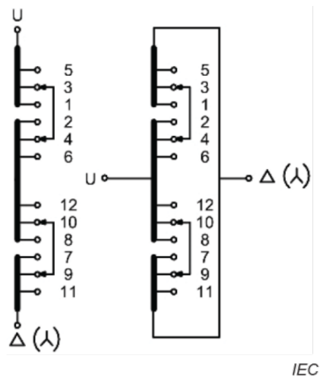
The arrangement of the interaction of stationary and moving contacts on a DETC is such that the three simultaneously operated moving contacts (one for each phase) connect three desired stationary contacts (one for each phase) to the star point, with or without a common neutral output (see Figure 6 e)).

5.5.4 Most common basic arrangements for different combinations

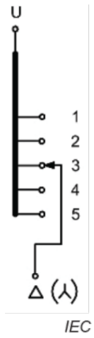
The choice of an electrically bridging contact scheme, electrically linear contact scheme, or combinations of the schemes is defined by the specific winding connections required. Various mechanical arrangements of the DETC are available. The tap-changer manufacturers should be consulted for specific options.



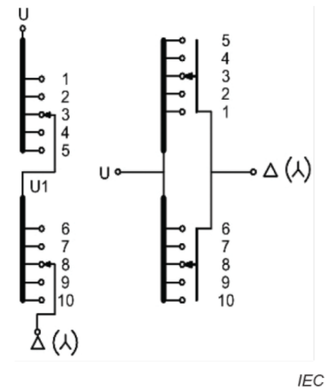
a)
Bridging contact scheme (1-Ph)



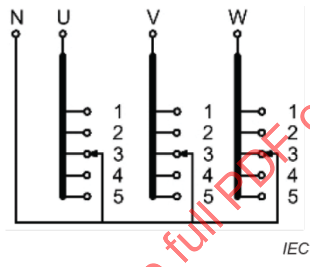
b)
Double bridging contact scheme (1-Ph)



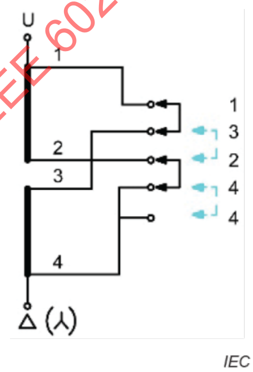
c)
Linear contact scheme (1-Ph)



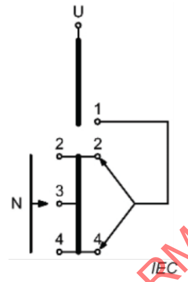
d)
Double linear contact schemes (1-Ph)



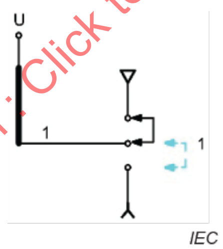
e)
WYE (Star) contact scheme (3-Ph)



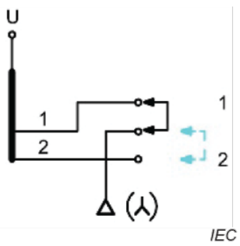
f)
Series/parallel contact scheme (1-Ph)



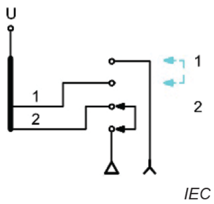
g)
Linear contact scheme with polarity inversion (1-Ph)



h)
Delta/star contact scheme (1-Ph)



i)
Exclusion of turns contact scheme (1-Ph)



k)
Delta/star contact scheme with exclusion of turns (1-Ph)

Figure 6 – Common connection arrangements

6 Types of tap-changers

6.1 On-load tap-changers (OLTCs)

6.1.1 General

The on-load tap-changer is designed to change tap connections while the transformer/reactor is both energized and on load. It performs this function without any interruption of the load. This is achieved with the mechanically operated components of the OLTC.

On-load tap-changing can be employed by using various switching principles.

The two most common switching principles can be distinguished by means of the transition impedance:

– resistor type switching, using a resistor as transition impedance (see 6.1.2.1);
– reactor type switching, using a reactor (preventive autotransformer) as transition impedance (see 6.1.2.2).

Furthermore, in reactor type tap-changers, both tap selector arms and both sides of the diverter switch are carrying the through-current in parallel in the service positions, whereas in resistor type tap-changers only one tap selector arm and one side of the diverter switch carries the through-current. This allows for reactor type tap-changers to use the position with the two tap selector arms connected to two adjacent taps (bridging position, IEC 60214-1:2014, 3.21) as well as the position with the tap selector arms connected to the same tap (non-bridging position, IEC 60214-1:2014, 3.22) as a service position. In resistor type tap-changers, the position between two taps is only a passage position. Therefore, the regulating winding for reactor type tap-changers needs only half as many taps to gain the same number of positions.

Traditionally, in the USA where tap-changers have been applied at the neutral end of the low-voltage windings, reactor tap-changers have been dominant. Conversely, elsewhere where tap-changers have frequently been applied to the high-voltage windings, resistance tap-changers have been dominant.

Both on-load tap-changer switching principles are available as non-vacuum type and vacuum type tap-changers.

Non-vacuum type tap-changers are equipped with contacts which break and make the load and circulating currents in liquid or gas. The arcing takes place within the same medium which is used as the insulation medium (and in case of liquids also as the lubrication medium) and causes a degradation of the medium.

Vacuum type tap-changers are not completely under vacuum, but they are equipped with vacuum interrupters (VIs) which break and make the load and circulating currents. However, the VI housing is sealed and therefore the degradation of the surrounding medium is minimized.

6.1.2 Principles of operation

6.1.2.1 Resistor types

6.1.2.1.1 General

Resistor type OLTCs are realized either as devices with a diverter switch (see IEC 60214-1:2014, 3.5, or IEEE Std C57.131-2012, Clause 3) and tap selector (see IEC 60214-1:2014, 3.4, or IEEE Std C57.131) or as selector switches (IEC 60214-1:2014, 3.6, or IEEE Std C57.131-2012, Clause 3). Such devices can be designed as:

– non-vacuum type on-load tap-changer (see 6.1.2.1.2);
– vacuum type on-load tap-changer (see 6.1.2.1.3).

In the diverter switch and tap selector concept, the switching operation is carried out by the positioning of the tap selector followed by the movement of the diverter switch. The basic mode of operation is exemplified in Figure 7 for a non-vacuum type diverter switch and tap selector utilizing operating cycle number 1 (according to IEC 60214-1). The tap selector is equipped with two independently movable contact decks. At first, that contact deck, which is not carrying the through-current, is actuated directly by the motor-drive mechanism. The tap adjacent to the tap in service will be pre-selected without any breaking or making of current (see Figures 7 a) to c)) in a time span of some seconds. Then, the diverter switch transfers the load current from the tap in service to the pre-selected one in a time span of around 50 ms to 150 ms (see Figure 7 d) to Figure 7 i)). This action is actuated in most designs by a spring-loaded energy accumulator, which will be wound up during the tap selector operation and will be mechanically released when the tap selector operation is finished. For this load transfer, the diverter switch of a non-vacuum type is equipped with main switching and transition contacts made from copper or copper-tungsten alloys.

This concept of two consecutive steps of the tap selector and the diverter switch is used for non-vacuum as well as for vacuum type diverter switch and tap selector designs. In vacuum type tap-changers the main switching and transition contacts are replaced by vacuum interrupters.

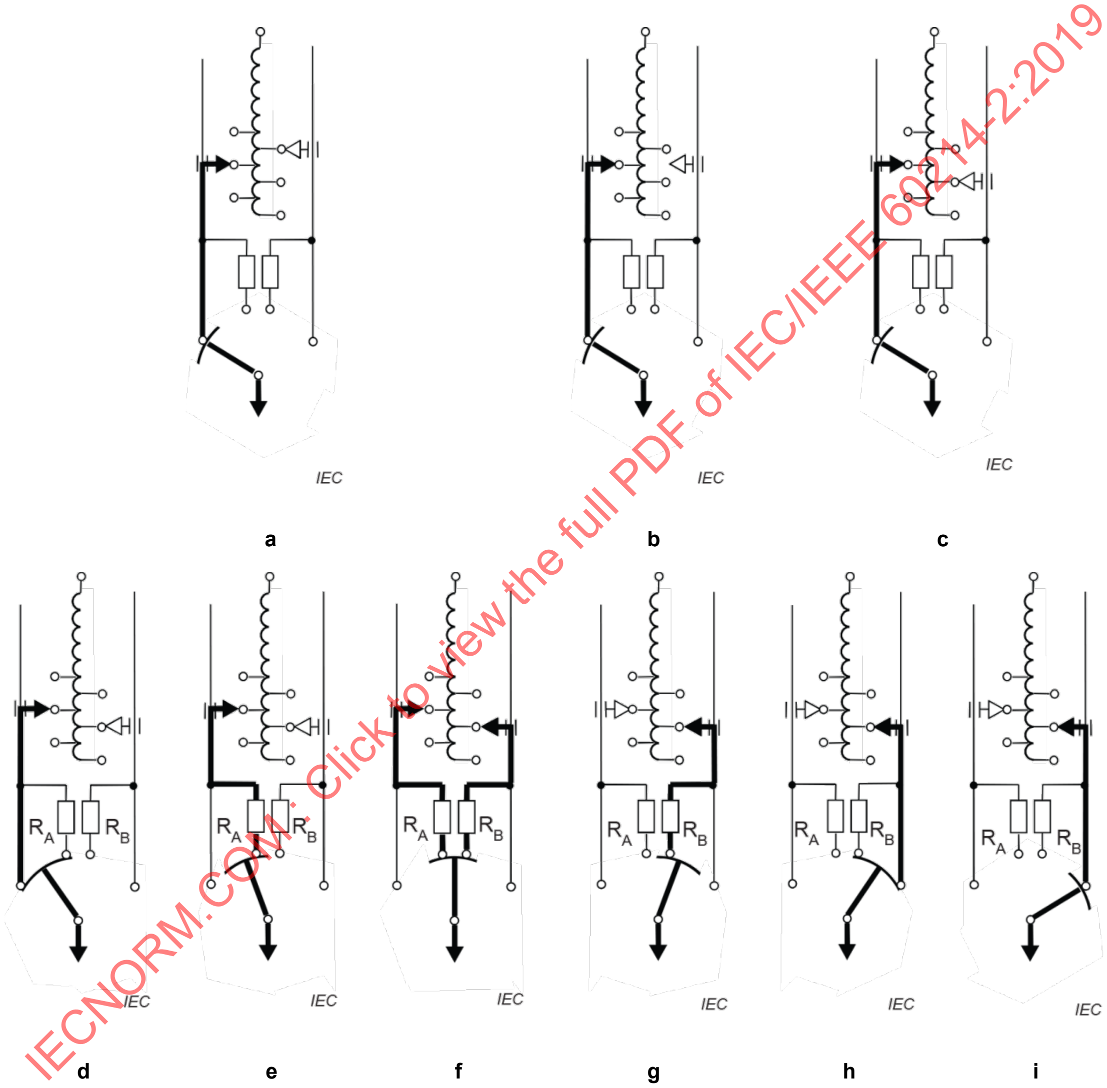


Figure 7 – Operating sequence of a diverter switch (d to i) and tap selector (a to c) (non-vacuum type diverter switch with operating cycle number 1)

The selector switch concept combines the aforementioned two moves of operation in one movement, in one device. Figure 8 exemplifies the operation order of contacts for a non-vacuum type selector switch utilizing operating cycle number 1 (see IEC 60214-1).

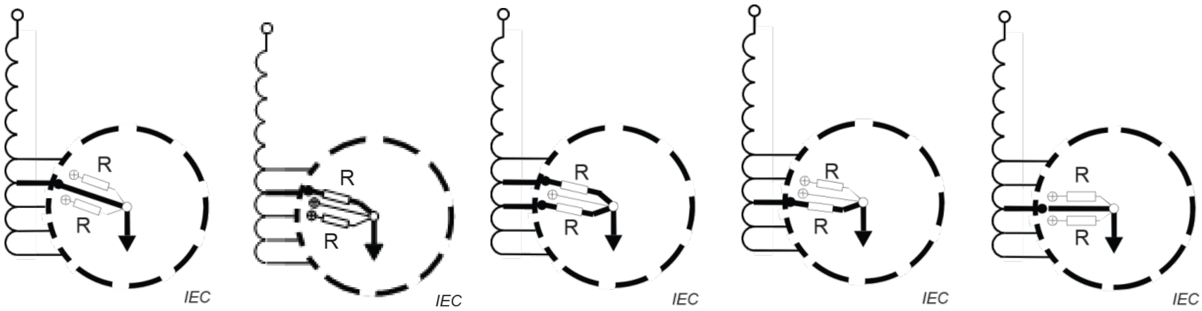


Figure 8 – Operating sequence of a selector switch (a to e)
(non-vacuum type selector switch with operating cycle number 1)

6.1.2.1.2 Non-vacuum types

6.1.2.1.2.1 General

Non-vacuum type OLTCs with the resistor switching principle according to IEC 60214-1:2014, 3.2, mostly operate utilizing one of the following three basic switching modes:

1) diverter switch (Figure 9 a)) or selector switch (Figure 9 b)) utilizing operating cycle number 1, formerly known as "flag cycle" operation (6.1.2.1.2.2);
2) diverter switch (Figure 9 a)) utilizing operating cycle number 2, formerly known as "symmetrical pennant cycle" operation (6.1.2.1.2.3);
3) selector switch (Figure 9 c)) utilizing operating cycle number 2, formerly known as "asymmetrical pennant cycle" operation (6.1.2.1.2.4).

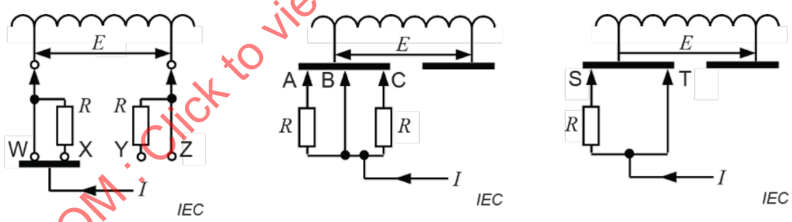


Figure 9 – Diagram of connections of non-vacuum, resistor type on-load tap-changers (IEC 60214-1:2014, Table A.1, or IEEE Std C57.131-2012, Table A.1)

The formerly used designations "flag cycle", "symmetrical pennant cycle" and "asymmetrical pennant cycle" arise from the appearance of the vector diagrams showing the change in output voltage of the transformer in moving from one tap position to the adjacent one (see IEC 60214-1:2014, Figure A.1, or IEEE Std C57.131-2012, Figure A.1).

6.1.2.1.2.2 Diverter or selector switch with operating cycle number 1 (formerly known as flag cycle)

Figure 9 a) and Figure 9 b) show the diagrams of connections of these designs, which minimally incorporate diverter switch or selector switch main switching contacts (W and Z, B), diverter switch and selector switch transition contacts (X and Y, A and C) and two transition resistors (R). The step voltage is indicated with E.

A tap-change operation is performed by diverting the through-current from the main switching contacts before the circulating current starts to flow; this mode of operation can be referred to as "break-before-make operation" according to the contact operating order.

NOTE This cycle calls for a through-current connection being at the midpoint of the transition impedance when it is carrying the circulating current.

The order of contacts as well as the duty of the main switching and transition contacts is described in detail in IEC 60214-1:2014, Figure A.1a and Tables A.1 and A.2, or IEEE Std C57.131-2012, Figure A.1 and Tables A.1 and A.2.

6.1.2.1.2.3 Diverter switch with operating cycle number 2 (formerly known as symmetrical pennant cycle)

This design consists of the same elements as described in 6.1.2.1.2.2 and uses the same diagram of connections (Figure 9 a)).

In tap-change operations following this operating cycle, the circulating current starts to flow before diverting the through-current from the main switching contacts; this mode of operation can be referred to as "make-before-break operation" according to the contact operating order.

NOTE This cycle calls for a through-current connection being at the midpoint of the transition impedance when it is carrying the circulating current.

The order of contacts as well as the duty of the main switching and transition contacts is described in detail in IEC 60214-1:2014, Figure A.1b and Tables A.1 and A.2, or IEEE Std C57.131-2012, Figure A.2 and Tables A.1 and A.2.

6.1.2.1.2.4 Selector switch with operating cycle number 2 (formerly known as asymmetrical pennant cycle)

The diagram of connections of this design is shown in Figure 9 c), which usually incorporates a selector switch main switching contact (T), a selector switch transition contact (S) and one transition resistor (R).

Tap-change operations following this operating cycle use the two above-mentioned methods (6.1.2.1.2.2, 6.1.2.1.2.3) depending on the direction of movement. In one direction, the circulating current starts to flow before the through current is diverted from the main switching contacts ("make-before-break operation"), while in the opposite direction of movement, the through-current is diverted before the circulating current starts to flow ("break-before-make operation").

NOTE 1 This cycle calls for a through-current connection being at one end of the transition impedance when this is carrying the circulating current.

NOTE 2 Non-vacuum type tap-changers employing the selector switch operating cycle number 2 are often used with load flow in one direction only.

The order of contacts as well as the duty of the main switching and transition contacts is described in detail in IEC 60214-1:2014, Figure A.1c and Tables A.1 and A.2, or IEEE Std C57.131-2012, Figure A.3 and Tables A.1 and A.2.

6.1.2.1.3 Vacuum types

6.1.2.1.3.1 General

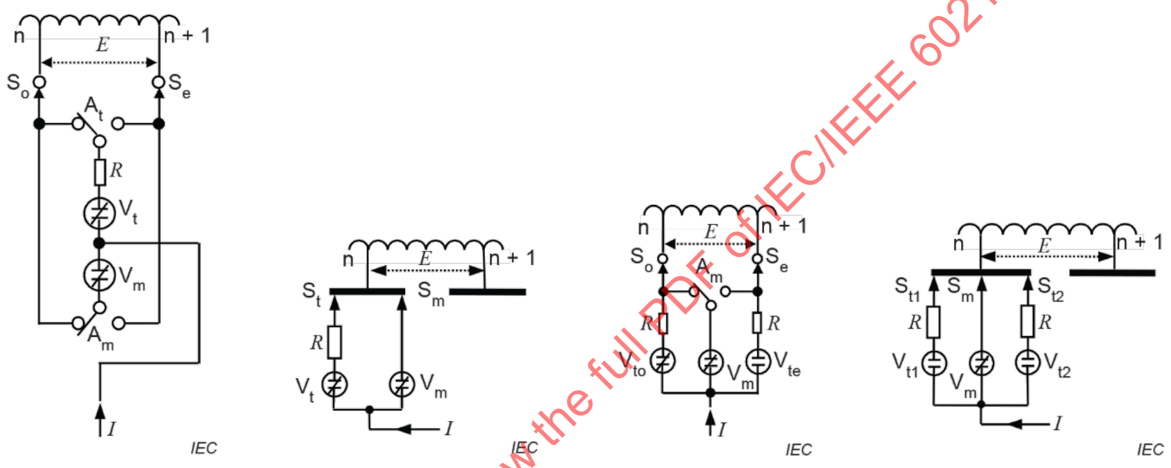
Vacuum type OLTCs with the resistor switching principle according to IEC 60214-1:2014, 3.3, mostly operate utilizing the following basic switching modes:

– diverter switch with one transition resistor and two vacuum interrupters (Figure 10 a)) utilizing operating cycle number 1 or number 2 (see 6.1.2.1.3.2);

– selector switch with one transition resistor and two vacuum interrupters (Figure 10 b)) utilizing operating cycle number 1 (see 6.1.2.1.3.3);
– diverter switch with two transition resistors and three vacuum interrupters (Figure 10 c)) utilizing operating cycle number 1 or number 2 (see 6.1.2.1.3.4);
– selector switch with two transition resistors and three vacuum interrupters (Figure 10 d)) utilizing operating cycle number 1 (see 6.1.2.1.3.5);
– diverter switch with two transition resistors and four vacuum interrupters utilizing operating cycle number 1 or 2 of the non-vacuum type diverter switches (see 6.1.2.1.3.6).

NOTE 1 The operating cycles number 1 and 2 according to IEC 60214-1 are defined differently for diverter and selector switches of the several designs.

NOTE 2 While the configurations/designs mentioned 6.1.2.1.3.1 are specifically noted in IEC 60214-1, other options are certainly possible.



a b c d

Figure 10 – Diagram of connections of vacuum, resistor type on-load tap-changers (IEC 60214-1:2014, Table A.3)

6.1.2.1.3.2 Diverter switch with one transition resistor and two vacuum interrupters utilizing operating cycle number 1 or number 2

This diverter switch design (Figure 10 a)) usually incorporates one transition resistor (R), one vacuum interrupter acting as main switching contact (V_m), one vacuum interrupter acting as transition contact (V_t) and at least two auxiliary contacts (auxiliary transfer switches A_m, A_t).

The diverter switch operation of operating cycle number 1 is performed by diverting the through-current from the main switching vacuum interrupter before the circulating current starts to flow; this mode of operation is also called "break-before-make operation" according to the switching element operating order and is similar to the flag cycle.

The same design can be used to perform diverter switch operations according to operation cycle number 2. Here, the circulating current starts to flow before diverting the through-current from the main switching vacuum interrupter; this mode of operation is also called "make-before-break operation" according to the switching element operating order and is similar to the pennant cycle.

NOTE These cycles call for the path with the main switching vacuum interrupter as well as the path with the transition vacuum interrupter each to be equipped with at least one auxiliary transfer contact.

The order of switching elements as well as the duty of the main switching and transition contact vacuum interrupter is described in detail in IEC 60214-1:2014, Table A.3.

6.1.2.1.3.3 Selector switch with one transition resistor and two vacuum interrupters utilizing operating cycle number 1

This selector switch design (Figure 10 b)) usually incorporates one transition resistor (R), one vacuum interrupter acting as main switching contact (V_m) and one vacuum interrupter acting as transition contact (V_t). This selector switch design needs no auxiliary transfer contact, but two selector contacts (S_m, S_t).

The selector switch operation is performed in one switching direction by diverting the through-current from the main switching vacuum interrupter before the circulating current starts to flow ("break-before-make operation"). In the opposite direction the through-current will be diverted from the main switching vacuum interrupter after the circulating current started to flow ("make before break operation"). This operation is similar to the asymmetrical pennant cycle.

The operation order of switching elements as well as the duty of main switching vacuum interrupter and transition contact vacuum interrupter is described in detail in IEC 60214-1:2014, Table A.3.

6.1.2.1.3.4 Diverter switch with two transition resistors and three vacuum interrupters utilizing operating cycle number 1 or number 2

This diverter switch design (Figure 10 c)) usually incorporates two transition resistors (R), one vacuum interrupter acting as main switching contact (V_m), two vacuum interrupters acting as transition contact (V_{to}, V_{te}) and at least one auxiliary contact (auxiliary transfer switch A_m).

The description of the diverter switch operations can be taken from 6.1.2.1.3.2.

6.1.2.1.3.5 Selector switch with two transition resistors and three vacuum interrupters utilizing operating cycle number 1

This selector switch design (Figure 10 d)) usually incorporates two transition resistors (R), one vacuum interrupter acting as main switching contact (V_m) and two vacuum interrupters acting as transition contact (V_{t1}, V_{t2}). This selector switch design needs no auxiliary transfer contact, but three contacts acting as tap selector (S_m, S_{t1}, S_{t2}).

The selector switch operation is performed by diverting the through-current from the main switching vacuum interrupter before the circulating current starts to flow; this mode of operation is also called "break before make operation" according to the switching element operating order.

The order of switching elements as well as the duty of the main switching vacuum interrupter and transition contact vacuum interrupter is described in detail in IEC 60214-1:2014, Table A.3.

6.1.2.1.3.6 Diverter switch with two transition resistors and four vacuum interrupters utilizing operating cycle number 1 or 2 of the non-vacuum type diverter switches

This diverter switch design (similar to Figure 9 a); contacts W, X, Y and Z are replaced by vacuum interrupters) usually incorporates two transition resistors, two vacuum interrupters acting as main switching contact, two vacuum interrupters acting as transition contact and does not necessarily need an auxiliary transfer contact. The method to perform the tap-change operation is very close to that of the non-vacuum diverter switch utilizing operating cycle number 1 or 2.

The description of the diverter switch operations can be taken from 6.1.2.1.2.2 in case of operating cycle number 1 and from 6.1.2.1.2.3 for operating cycle number 2.

6.1.2.2 Reactor types

6.1.2.2.1 General

Reactor type OLTCs can employ either a diverter switch (also known as arcing switch) and a tap selector or selector switches (also known as arcing tap switch). Furthermore, reactor type OLTCs can be designed as:

– non-vacuum type on-load tap-changer (see 6.1.2.2.2);

– vacuum type on-load tap-changer (see 6.1.2.2.3).

Figure 11 a) to Figure 11 g) show the switching sequence from a non-bridging position through a bridging position to the next non-bridging position as examples for a diverter switch and tap selector design. In contrast to resistor type tap-changers, which make two moves and only load one selector arm when on position, the reactor type tap-changer uses three moves for a tap-change operation from a non-bridging to a bridging position, or vice versa, and always loads both selector arms when on position.

In the first move, the diverter switch transfers the through-current from two parallel branches into one branch by opening one transfer switch (Figure 11 b)). Then, the tap selector, equipped with two independently movable contact arms, moves the now unloaded arm to the next adjacent tap. This pre-selection is therefore accomplished without making or breaking any current (Figure 11 c)). Subsequently, in the third move, the open diverter switch closes, dividing the through-current again into two parallel branches (Figure 11 d)). This leaves both parts of the diverter and the selector carrying current in this bridging position, which can be used as a service position. This sequence is essentially repeated, as can be seen in Figure 11 d) to Figure 11 g), to reach the next non-bridging service position.

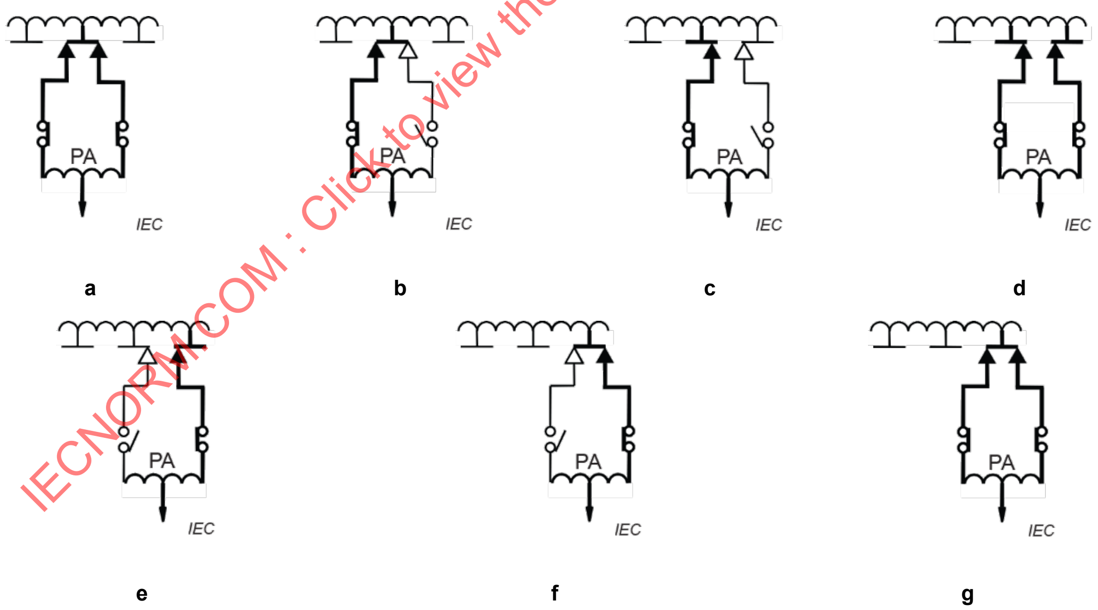


Figure 11 – Operating sequence (a) to g)) of a diverter switch and tap selector (non-vacuum type)

6.1.2.2.2 Non-vacuum types

6.1.2.2.2.1 General

Non-vacuum type OLTCs with the reactor switching principle according to IEC 60214-1:2014, 3.2, mostly operate according to the following basic switching modes:

– arcing tap switch (Figure 12 a));

– arcing tap switch with equalizer windings (Figure 12 b));
– arcing switch and tap selector (Figure 12 c)).

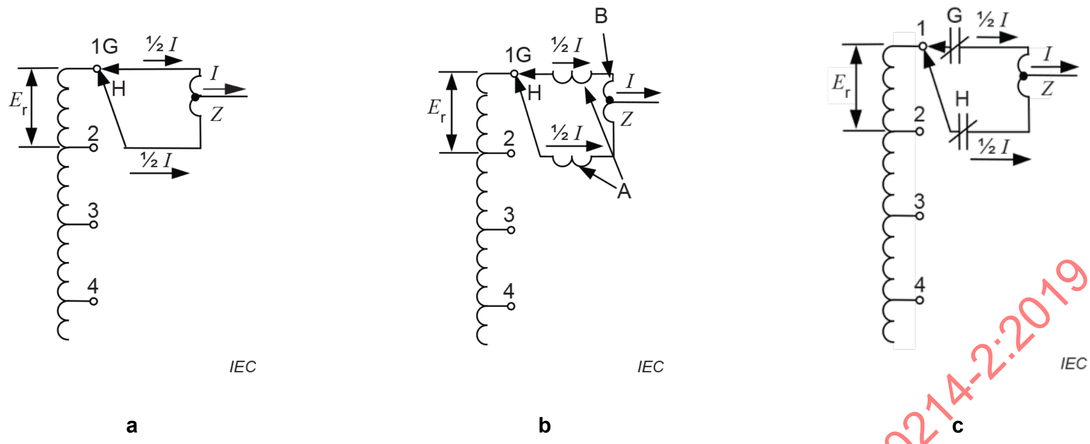


Figure 12 – Diagram of connections of non-vacuum, reactor type on-load tap-changers (IEC 60214-1:2014, Annex B, or IEEE Std C57.131-2012, Annex B)

IEC 60214-1:2014, Annex B or IEEE Std C57.131-2012, Annex B, shows in full detail the diagrams of connections, operating sequence and duty on switching contacts for these designs of reactor type tap-changers.

6.1.2.2.3 Vacuum types

Figure 13 shows the diagram of connections of a vacuum interrupter and tap selector design. IEC 60214-1:2014, Annex B or IEEE Std C57.131-2012, Annex B, shows in full detail the operating sequence and duty on the vacuum interrupter for this design.

NOTE The contacts G and H in Figure 12 c) can be vacuum interrupters.

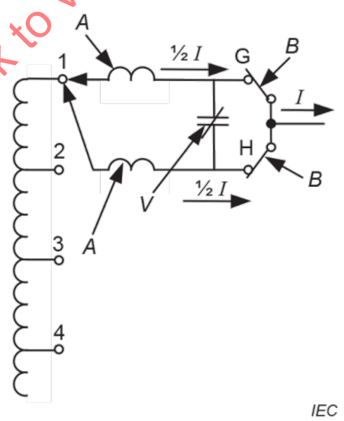


Figure 13 – Diagram of connections of reactor type on-load tap-changer with vacuum interrupter and tap selector (IEC 60214-1:2014, Annex B, or IEEE Std C57.131-2012, Annex B)

6.1.3 Physical layouts

6.1.3.1 General

Tap-changers are mounted within the transformer tank (in-tank tap-changer) or in their own housing outside the transformer tank (compartment type tap-changer). The in-tank tap-changer is immersed in the liquid of the transformer whereas the compartment type tap-changer is immersed in its own liquid. Thus the tap-changer environment is different with respect to IEC 60214-1 or IEEE Std C57.131. For in-tank tap-changers, the environment is defined as the liquid of the transformer and for compartment type tap-changers it is defined as the ambient air outside the housing.

Tap selectors typically include the change-over selector, if provided.

For both types, to avoid exchange of gases (dissolved or free) between the OLTC and the transformer, it is recommended to use separate conservators and breathing pipes for the diverter or selector switch compartment(s). It could be considered, as a precaution against possible leaks, that the diverter or selector switch conservator should be lower than that of the main tank to ensure positive pressure and prevent migration of contaminated liquid into the main tank.

6.1.3.2 Compartment type tap-changers

6.1.3.2.1 General

These tap-changers are self-contained in their own tanks and mounted on the side or end of the transformer. The taps from the transformer regulating winding are taken to the tap selector contacts through a barrier board (component of the on-load tap-changer). It is recommended to use a liquid-tight barrier board to isolate the liquid from the tap-changer from the transformer main tank. Compartment type tap-changers are equipped with a separate conservator or a gas space at the top of the OLTC compartment.

Compartment type on-load tap-changers generally have the following features:

- They are easier for the user to maintain. Access to the complete tap-changer and all contacts is obtained by removal of inspection covers or doors. Care should be taken to avoid damage to the barrier board from static pressure in the main tank of the transformer.
- Because the tap selectors are always in a separate chamber from the main tank, the DGA of the transformer is not affected by capacitive sparking of the change-over of selector contacts.
- Transformer main tank size and liquid volume can be minimized.
- They offer a plane and well defined location (barrier board) for the winding conductors to be connected.
- Due to voltage clearance considerations, compartment type on-load tap-changers may not be practical for line-end applications above 145 kV.

Two types of compartment tap-changer arrangements are considered as shown in Figure 14. The descriptions in 6.1.3.2.2 and 6.1.3.2.3 are generally valid for both switching principles (resistor and reactor) and interrupting media (liquid and vacuum). The reactor is not shown in Figure 14 but would be located in the main transformer tank, typically in the immediate vicinity of the barrier board to the OLTC. For the sake of simplicity, the term "diverter switch" will also designate the so-called arcing switch used in some reactor type OLTCs.

6.1.3.2.2 Single compartment

In this type of tap-changer layout, tap selectors and diverter switches, or selector switches are contained in a single compartment and therefore share the same insulating liquid such as illustrated in Figure 14 a) where the motor-drive is schematized on the side of the compartment. Another common arrangement is to have the motor-drive underneath the compartment.

The main features of this design are:

- Simplicity and compactness, therefore it is often more cost-effective.

– The tap selector is in contaminated liquid, so the resulting reduction in voltage breakdown capacity of the liquid will usually limit the use of single compartment OLTCs to the smaller voltage class transformers. The restriction does not apply, of course, for vacuum switching principles for which carbon contamination is not an issue.

6.1.3.2.3 Separate tap selector and diverter switch compartments

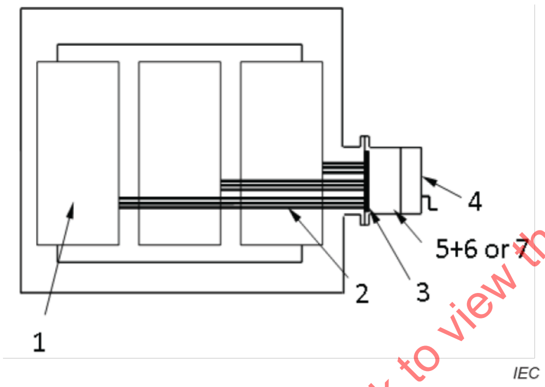
To overcome the issue of liquid contamination with non-vacuum switching OLTCs in single compartments as described in 6.1.3.2.2, a common arrangement is to separate the diverter switches and the tap selectors into two different compartments, normally standing on top of each other such as illustrated in Figure 14 b). A possible variant of this layout is to have the diverter compartment underneath the tap selector compartment.

The main features of this design are:

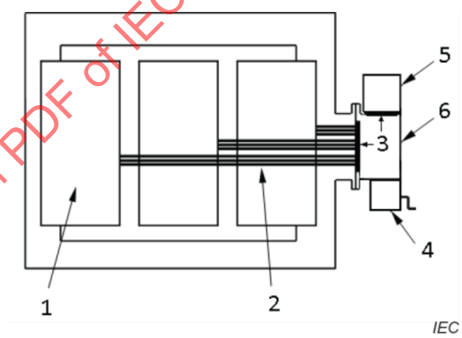
– Increased insulation capabilities for use on higher voltage class transformers at the cost of a higher complexity.

– DGA monitoring can be carried out in isolation, allowing early diagnosis of tap selector problems and the ability to differentiate between tap selector and diverter switch defects.

– It can minimize liquid handling during the maintenance activity by giving users the ability to choose to carry out maintenance on one or both chambers.



a) Single compartment



b) Separate tap selector and diverter switch compartments

Key

1 – Transformer windings
2 – Tap leads
3 – Liquid- and gas-tight barrier
4 – Motor-drive mechanism
5 – Diverter switch
6 – Tap selector
7 – Selector switch

Figure 14 – Common layouts for compartment type tap-changers

6.1.3.3 In-tank type tap-changers

6.1.3.3.1 General

As their name implies, these tap-changers are fitted inside the transformer. To avoid contamination (carbon, gases, etc.) of the liquid in the transformer tank, the diverter switch (or selector switch) is usually housed in a separate, leak-proof compartment inside the transformer main tank (see Figure 15 a), Figure 15 b), or Figure 15 d)) or in a separate tank (see Figure 15 c)).

NOTE Although the carbonization is the critical issue, gas-tight compartments can still be deemed necessary for vacuum type tap-changers because of minimum gassing that would interfere with the transformer main tank DGA monitoring.

In-tank tap-changers have the following features:

– They are usually more suitable for the higher voltage class line-end applications.
– They can also benefit the transformer manufacturer by allowing the tap-changer to be connected to the transformer prior to processing.
– For a given power rating, the diverter or selector switch liquid volume of an in-tank tap-changer is generally smaller than in compartment type tap-changers. This will reduce the liquid handling effort during maintenance.
– The diverter switch can easily be replaced or swapped out with a reserve unit for minimal outage time. However, accessing the top of the transformer can require work at significant height.
– Where in-tank tap-changer types have their tap selectors and, in particular, their change-over selectors operating in the same liquid as the transformer, the DGA of the transformer can be influenced by capacitive arcing from the contacts. Small amounts of gasses (including acetylene) can indeed develop under normal conditions in the main tank due to the change-over selector operations.

These designs are almost exclusively used for resistor type tap-changers. Three types of in-tank arrangement are described below and illustrated in Figure 15.

NOTE The only in-tank design application that has a reactor switching principle is a step-voltage regulator (for more information, see IEC 60076-21 or IEEE Std C57.15).

6.1.3.3.2 In-tank diverter switch-type tap-changers

Unless otherwise agreed between the transformer manufacturer and the purchaser, the tap selectors may be located within the main transformer liquid. With this type of tap-changer, separate tap selectors are mounted underneath the diverter switch and operate in the same liquid as the transformer.

It is recommended to use diverter switches mounted in liquid-tight insulating compartments. These compartments isolate the dissolved gases and particles, which have developed during switching operations, from the transformer liquid. Usually the diverter switch compartment is equipped with a separate conservator.

Generally, this type of tap-changer is used for the higher MVA ratings and voltage classes.

6.1.3.3.3 In-tank diverter switch-type tap-changer with barrier board

By using an in-tank tap-changer in a separate housing with a liquid-tight barrier board between the tap-changer and the transformer, the liquid volumes of the transformer main tank and the tap selector can be isolated from each other so that:

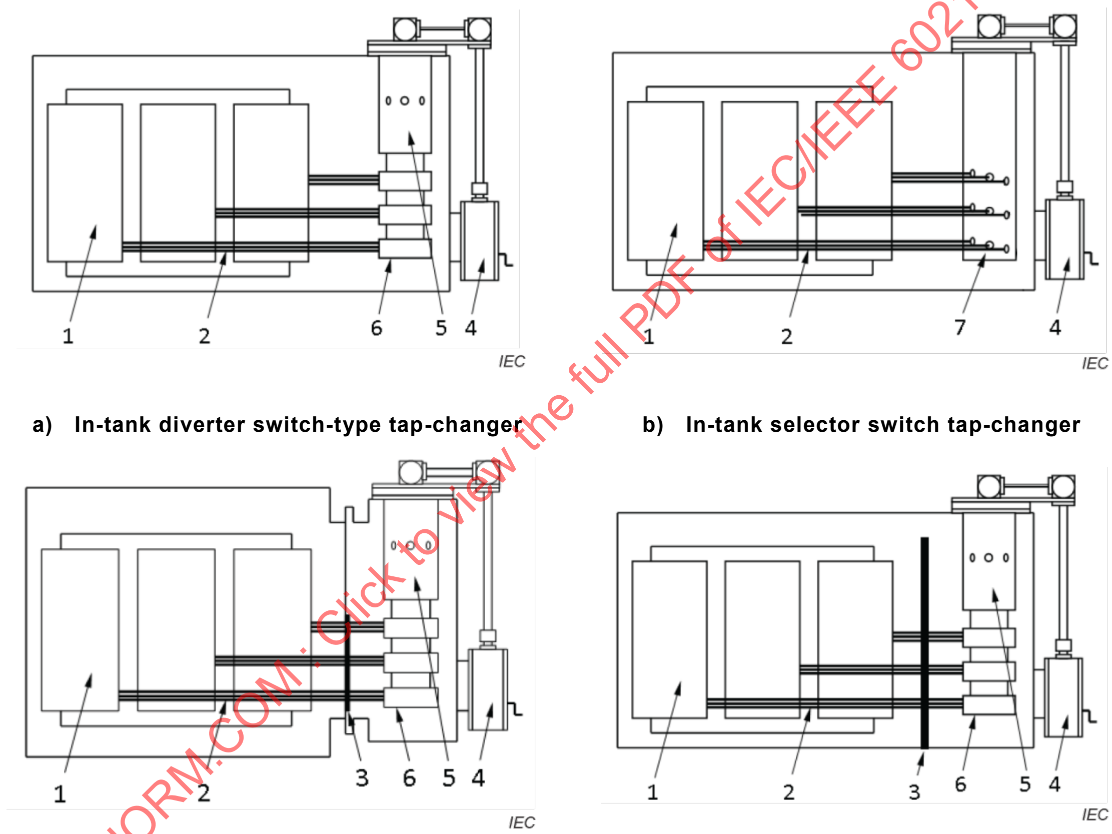
a) the same conservator can be used for both liquid volumes;
b) increased accuracy in DGA monitoring can be achieved if the two liquid volumes are piped to separate conservators;
c) the housing and barrier board can be designed in such a way that:
   - the housing can be removed, for example for transportation restrictions;
   - servicing can be performed on the tap selectors without draining the main tank and exposing the active part to the environment.

A variant of this arrangement includes a partial barrier board such as illustrated in Figure 15 d). Compared to the complete board, this arrangement will simplify the piping to the main conservator, and possibly reduce overall transformer size and liquid volume. On the other hand, possible gassing from the tap selector and/or change-over selector will mix with the main tank liquid and therefore DGA interpretation will be as it is in the case without barrier board.

6.1.3.3.4 In-tank selector switch tap-changers

In-tank selector switch tap-changers carry out their selection and switching in the one compartment using the same contacts and liquid. It is recommended to use selector switches mounted in liquid-tight insulating compartments. These compartments isolate the dissolved gases and particles, which have developed during switching operations, from the transformer liquid. The change-over selector can be either within or outside the selector switch compartment. In the latter case, the transformer main tank DGA monitoring can be affected. Usually the selector switch compartment is equipped with a separate conservator.

This type of tap-changer tends to be used for the lower MVA and voltage class transformers. It offers a very compact design for tap-changers for line end applications.



a) In-tank diverter switch-type tap-changer

b) In-tank selector switch tap-changer

c) In-tank diverter switch-type tap-changer with complete barrier board

d) In-tank diverter switch-type tap-changer with partial barrier board

Key

1 – Transformer windings
2 – Tap leads
3 – Barrier board
4 – Motor-drive mechanism
5 – Diverter switch
6 – Tap selector
7 – Selector switch

Figure 15 – Common layouts for in-tank-type tap-changers

6.1.3.3.5 Integrated tap-changer

The integrated tap-changer consists of a diverter switch and tap selector and represents an advancement of the conventional in-tank diverter switch-type tap-changer. The integrated OLTC is located directly in the main tank of the transformer without separate diverter switch compartment. To avoid contamination of the liquid in the transformer tank, the diverter switch should be designed so that no arcing during tap-change operation occurs in the insulating liquid (e.g. by vacuum interrupter).

Integrated tap-changers have their tap selectors and, in particular, their change-over selectors (as most of the in-tank tap-changers) operating in the same liquid as the transformer, which can influence the DGA of the transformer due to capacitive arcing from the contacts. As there is no diverter switch compartment present, the transition resistors of the diverter switch can influence the DGA as well due to heating.

Today the integrated tap-changer is mainly used for smaller MVA ratings and voltage classes.

6.2 De-energized tap-changers (DETCs)

6.2.1 General

The de-energized tap-changer is designed to change tap connections only while the transformer/reactor is de-energized.

This is achieved with mechanically operated devices that will select the various taps. The fixed contacts can be arranged in a circular configuration (for rotary types) or in a straight line (for rack and slide types). Normally, the drive mechanism is manual, but motor-drive units are also available.

This type of tap-changer is usually mounted inside the transformer tank with the drive mechanism mounted on the transformer lid or on the wall of the transformer tank.

6.2.2 Types of DETC

Various physical arrangements of DETCs are available to integrate into the wide variety of transformer designs. Some DETC designs are arranged in a mechanically linear (see 3.1.1) fashion while others are arranged in a mechanically rotary (see 3.1.2) fashion. These configurations can be made up of multiple groups of the mechanically linear or mechanically rotary configuration for multiple phases or groups of taps.

6.2.3 Location of DETC in the transformer tank or enclosure

6.2.3.1 General

Within a transformer enclosure, the location of the DETC is determined by a number of factors. Potential options are shown in Figure 16. The tap-changer can be located above the core and coil assembly with a handle coming out in a variety of locations. A location directly above the core and coil assembly locates the DETC in one of the hotter areas inside the enclosure or transformer tank as this is directly above the heat source of the core and coil assembly. While the temperature at this location does not approach the hot spot of the windings, a determination of the expected temperature can be required to evaluate the suitability of a specific DETC for the application based on the dielectric components' suitability to the temperature. The temperature class of the DETC dielectric materials can be below those required within the transformer winding.

The DETC can also be located beside the core and coil on one end or another similar to an in-tank OLTC (Figure 15 a) – 6.1.3.3).

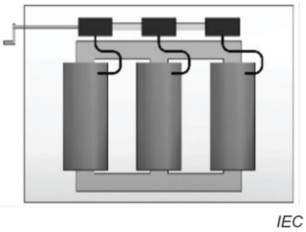
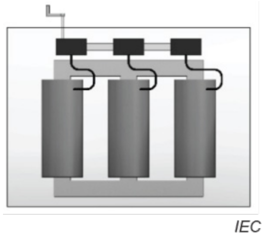
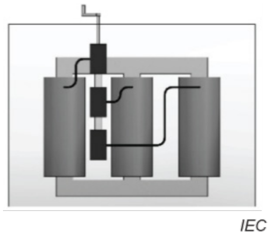
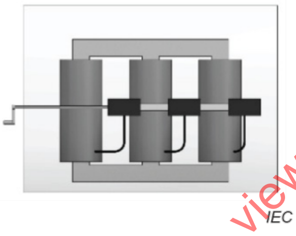
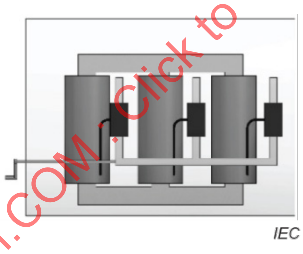
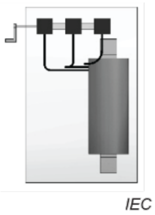
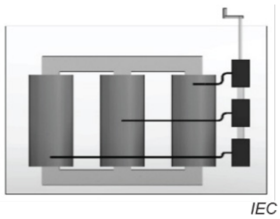
Example	Location of the DETC	Notes
1		DETC located above the core and coil assembly with drive on short tank sidewall
2		DETC mounted from the cover of the transformer above the core and coil with the drive on the tank cover.
3		DETC mounted on the support structure near the core and coil with the drive on the tank cover
4		DETC mounted in the middle of the core and coil with the drive on the short tank sidewall
5		DETC units driven from the bottom of the short tank sidewall
6		DETC driven from the top of the long tank sidewall
7		DETC mounted on a tank sidewall

Figure 16 – Common arrangements of DETCs in the transformer main tank

6.2.3.2 Dry-type transformers

Besides the locations described in Figure 16, the DETC can also be located and mounted on a support structure beside the coil (between the coil and enclosure panels) or it can be located and mounted directly on a side enclosure panel. Arrangements can be made for the location of the DETC and the operating handle on any enclosure panel. Location in these areas reduces the temperature requirements of the DETC dielectric components as this area will typically be at a cooler temperature than that above the core and coil. A lower temperature requirement for the DETC may allow the required temperature class of the DETC dielectric materials to be below that required within the transformer winding or even below that required for a DETC located directly above the core and coil assembly.

6.2.3.3 Liquid-filled-type transformers

Besides the locations described in Figure 16, the DETC can also be located and mounted on a support structure beside the coil (between the coil and transformer tank sidewall) or it can be located and mounted directly on a tank sidewall or even fixed to the cover. Cover mounted tap-changers (often found in submersible-type transformers) should be designed to account for the minimum oil levels of the specific unit. It is also possible to locate the DETC above the core and coil assembly and provide an operating mechanism on the cover. In this case, the DETC will be located in an area below the minimum oil level, but evaluation of the possible effect of the minimum oil level should still be considered. Since this locates the DETC in an area with possibly the highest (or at least one of the highest) oil temperatures in the unit, the suitability of the DETC dielectric materials should be considered and this evaluation should include the expected temperature rise of contacts under load conditions.

Locating the DETC on a support structure in a manner that lowers the position of the switch to cooler oil, can allow better overload characteristics for a specific switch. It can also allow location of the operating handle at a height more directly accessible to ground level operation without additional drive features. Arrangements can be made for the location of the DETC and the operating handle on any desired sidewall or even the cover of the transformer. Location in these areas reduces the temperature requirements of the DETC dielectric components as this area will typically be at a cooler temperature than the one directly above the core and coil. A lower temperature requirement for the DETC may allow the required temperature class of the DETC dielectric materials to be below that required within the transformer winding or even below that required for a DETC located directly above the core and coil assembly.

6.3 Tap-changer environment

6.3.1 Liquid immersed tap-changers

6.3.1.1 General

Liquid-immersed tap-changers cover all the types described in 6.1 and 6.1.3.3.5 that require a liquid for establishing their functions. A typical, and the most common, liquid is mineral oil (transformer oil) according to IEC 60296 or ASTM D3487. Other types of liquids may be employed but care shall be exercised to ensure their compatibility with the tap-changer under consideration. If nothing else is stated, data given from the OLTC manufacturer are valid in mineral insulating oil.

6.3.1.2 Liquid immersed OLTCs

The liquid used for on-load tap-changers, as well as having electrical insulation and switching functions, also acts as a lubricant and coolant. The most commonly used liquid for tap-changers is mineral oil according to IEC 60296 or ASTM D3487. Although this oil has relatively poor lubricating properties, it is nevertheless essential for the mechanical operation of the tap-changer. It is therefore recommended that the tap-changer manufacturer be consulted before operating mechanically off circuit in a non-immersed (unfilled) condition.

Other liquids that are sometimes used in transformers for fire-retardant and environmental purposes may not be suitable for on-load tap-changers. Silicone liquids have very poor lubricating properties and no arc-quenching ability and are usually not suitable for on-load tap-changers. Esters and other liquids can be suitable for some tap-changer models. The temperature operating range can be restricted due to higher viscosities than mineral oil at lower temperatures. For the above liquids, possible modifications of ratings and admissible withstand voltages should also be considered.

Where a liquid other than mineral oil according to IEC 60296 or ASTM D3487 is being considered, the tap-changer manufacturer should be consulted to establish its suitability.

Liquid immersed on-load tap-changers tested to IEC 60214-1 are suitable for operation down to −25 °C in insulating liquid according to IEC 60296 with LCSET of at the most −30 °C. For temperatures below −25 °C, the tap-changer manufacturer can recommend a lower viscosity liquid, the installation of heaters in the switching and mechanism compartments or other precautions to prohibit tap-changing while below a given temperature limit.

Where temperatures below −25 °C are envisaged, the tap-changer manufacturer should be consulted.

6.3.1.3 Liquid immersed DETCs

Liquid-immersed de-energized tap-changers are tested to operate in mineral oil according to IEC 60296 or ASTM D3487; however, in service they can be required to operate on one position for long periods of time, and, if operating in high liquid temperatures, pyrolytic carbon (coking) can eventually form on the contacts. For this reason, a lower temperature rise value is stipulated in IEC 60214-1:2014, 7.2.2, or IEEE Std C57.131-2012, 7.2.2. The type of material used for the contacts should be suitable for the intended application. Prolonged operation on one position can influence the pyrolytic carbon formation; hence, silver plating/silver plating, silver plating/copper, copper/copper and copper/brass contact materials can be preferable.

During transformer maintenance, it is recommended that the de-energized tap-changer be operated to clean the contacts (see 12.2.3).

Unlike liquid-immersed on-load tap-changers, de-energized tap-changers do not require arc quenching or good lubricating properties. For these reasons, the use of many different types of fire-retardant liquids is possible. For liquid temperatures below −25 °C, the DETC should not be operated in consideration of possible mechanical issues.

Silicone liquids, esters and other liquids can be suitable for some DETC. The temperature operating range can be restricted due to higher viscosities than mineral oil at lower temperatures. For the above liquids, possible modifications of ratings and admissible withstand voltages should also be considered.

Where a liquid other than mineral oil according to IEC 60296 or ASTM D3487 is being considered, the tap-changer manufacturer should be consulted to establish its suitability.

6.3.2 Dry-type tap-changers (OLTC and DETC)

Dry-type tap-changers are usually used in conjunction with dry-type transformers. This type of tap-changer has several advantages compared to the conventional tap-changer in mineral oil such as reduced fire and environmental hazards.

Dry-type tap-changers, when exposed to external air, require special considerations. If lubrication is needed, it is achieved by the application of grease on the movable mechanical parts. Usually, the lubrication measures have to be repeated during maintenance work. In order to reduce the need for frequent lubrication measures, contacts, bearings and gears are specially designed to significantly reduce mechanical fatigue and the necessary mechanical torque. Consult the tap-changer manufacturer's instructions.

The following list of applications of dry-type tap-changers can be deduced from the different types of dry-type transformers.

a) Dry-type tap-changers for totally enclosed dry-type transformers

   The tap-changer and the transformer are incorporated in an unpressurized enclosure, cooled by the circulation of internal air.

b) Dry-type tap-changers for enclosed dry-type transformers

   The tap-changer and the transformer are incorporated in a ventilated enclosure, cooled by the circulation of external air.

c) Dry-type tap-changers for non-enclosed dry-type transformers

   The tap-changer is used in conjunction with a transformer which is installed without a protective enclosure (mainly indoor applications). The dry-type tap-changer can have its own enclosure (usually a ventilated enclosure).

The purchaser of the tap-changer should verify suitability when choosing an appropriate dry-type tap-changer for a certain application to fully meet the service condition requirements according to IEC 60076-11 or IEEE Std C57.12.01 once the chosen tap-changer has been incorporated in the transformer design. In the case of dry-type on-load tap-changers, it has to be considered that despite the use of vacuum interrupters as switching elements in common designs, arcing and hot spots can occur at, for example:

– change-over selectors (if applicable);
– commutation sparks at non-enclosed mechanical switching elements (if applicable);
– temperature rise of the transition resistors.

Dry-type on-load tap-changers that are not totally enclosed are not suitable for use in explosion hazardous areas.

6.3.3 Gas-immersed tap-changers (SF_6-insulated tap-changers)

6.3.3.1 General

SF_6-insulated tap-changers include as liquid-immersed tap-changers:

– on-load tap-changer (OLTC); and
– de-energized tap-changer (DETC).

Current SF_6-insulated OLTC designs make use of the resistor switching principle with vacuum interrupters.

Moisture content is very important and should be controlled. Monitoring, for instance, can be done through dew point measurements. Desiccants (such as zeolite) are often used in the diverter switch compartment to ensure adequate SF_6-insulation performance.

Possible effects of sparks or hot spots should be considered, as SF_6 gas can decompose. It can be assumed that no decomposition of the SF_6 will take place below 150 °C. At temperatures higher than 180 °C, some metals can have a decomposing effect on the SF_6. At temperatures of 500 °C and higher, SF_6 gas starts to decompose into its constituent elements, with the decomposition process being directly proportional to the quantity of energy converted.

Decomposed SF_6 contains toxic components. Therefore, adequate precautions should be taken to ensure the safety of personnel when handling SF_6, for example during maintenance work.

SF_6 insulated tap-changers need to be incorporated in a pressurized SF_6-filled enclosure. There are two main types of construction in use as described in 6.3.3.2 to 6.3.3.4.

6.3.3.2 In-tank SF_6 tap-changers

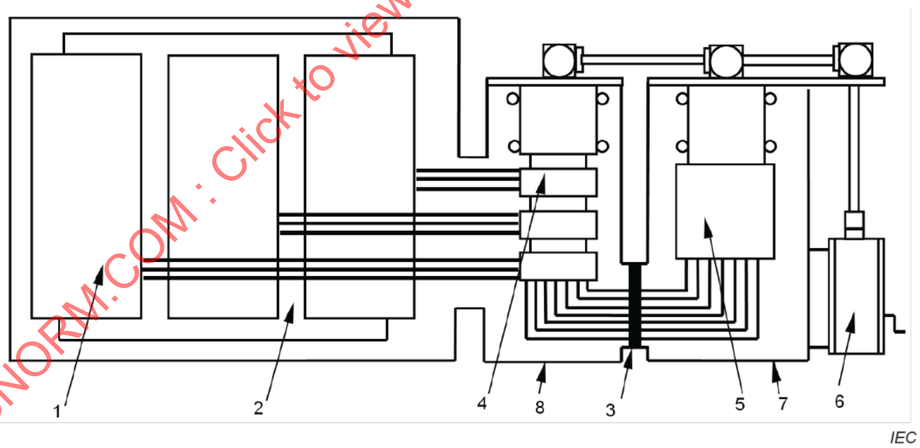
The diverter switch and selector switch arrangements are identical for SF_6 as for liquid applications as shown in Figure 15 a) and Figure 15 b).

The SF_6 pressure in the diverter or selector switch compartment is limited to a level typically lower than in the main tank to accommodate the operating requirements of the vacuum interrupters (e.g. opening of the VI). There is a resulting pressure difference that should not exceed the compartment's withstand capability. Accordingly, pressure in the main tank is limited and therefore these arrangements are not typical where higher transformer pressure is required. Maintenance of the diverter or selector switch can normally be carried out without reducing the gas pressure in the main tank.

6.3.3.3 Externally mounted diverter compartment with an in-tank tap selector and a barrier board

Generally, this arrangement is used when higher transformer pressure is required. The tap selector, which does not have a high pressure limit, is still mounted in the main tank, but the diverter switch compartment is mounted in an external container of lower pressure with a pressure-tight barrier board to the main tank. In performing maintenance of the diverter switch, this arrangement also allows for the work to be carried out without reducing the gas pressure of the main tank.

Figure 17 shows a typical arrangement. A possible variant that offers more flexibility for the installation is to have the tap selector mounted in a separate container which is directly connected with the main tank (communicating gas and pressure).



Key

1 Transformer windings
2 Tap leads
3 Gas-tight barrier
4 Tap selector
5 Diverter switch
7 External container
6 Motor-drive mechanism
8 Reduced part of the main tank

Figure 17 – Externally mounted diverter compartment with an in-tank tap selector and a barrier board

6.3.3.4 Use of SF_6 gas with transformers and DETCs

SF_6-insulated DETCs are installed in gas-filled power transformers similar to liquid immersed DETCs as described in 6.2.3.

SF_6-insulated DETCs are in the same SF_6 gas atmosphere as the transformer and considerations for SF_6 gas should be the same as for the whole transformer.

6.4 Other types

6.4.1 General

There are also other types of tap-changers not fully covered by the above types. The standards, type and routine tests to be applied are those relevant for the design. Other tests to fulfil the intention of the standards and to support the tap-changer manufacturer's technical data of the products can also be made on the tap-changer.

In 6.4.2 to 6.4.5, some other types of tap-changers are described.

6.4.2 Electronic tap-changers

In an electronic on-load tap-changer, the transferring of load from one tap to another is performed by power electronics such as thyristors or IGBTs and therefore no arcing will take place. In general, the electronic tap-changer is excellent in the durability of switching because there is neither consumption of contacts nor high speed operation by an energy accumulation mechanism. The electronic tap-changer can be of a totally dry type or have the electronics immersed in liquid. It can be cooled by air or by some cooling system. At the time this document was written, the following two types of electronic tap-changers were available:

1) All semiconductors types

   Diverter switches and tap selectors consist only of power semiconductors integrated in one unit. The power semiconductors are installed on each tap, and by switching operation of these elements, it is possible to change directly to any tap. Today, these units are only used in small capacity tap-changers, because the costs for the power semiconductors and cooling systems are presently extremely high.

   Large-sized devices are needed in order to produce tap-changers with higher capacities.

2) Hybrid types

   The diverter switches consist mainly of semiconductors, while the tap selectors are mechanically of the same type as the tap selectors of conventional tap-changers. The two units are separated. The power semiconductors are installed in place of the arc-switching contacts or vacuum interrupters. Additional bypass contacts are often used in parallel to the power semiconductors.

6.4.3 Step-voltage regulators

See IEC 60076-21 or IEEE Std C57.15 for design and construction of step-voltage regulators and their field of application.

6.4.4 Advance retard switch (ARS)

The ARS allows the reversion of the polarity of the regulating voltage under load condition without disconnecting the winding to be reversed and is primarily used in applications with large regulating ranges, for example in PST-applications. Figure 18 a) shows an often used winding scheme for dual core PSTs when using OLTCs with coarse/fine winding arrangements to allow a reversion of the polarity. However, the ARS is also applicable in single-core PSTs or it can be used in power transformers as a reversing change-over selector to overcome high change-over selector recovery voltages (see 7.2.1.8).

A principle operation sequence of the ARS is shown in Figure 18 b) to Figure 18 d). In those applications the winding to be reversed may not be excited (no voltage across the winding).

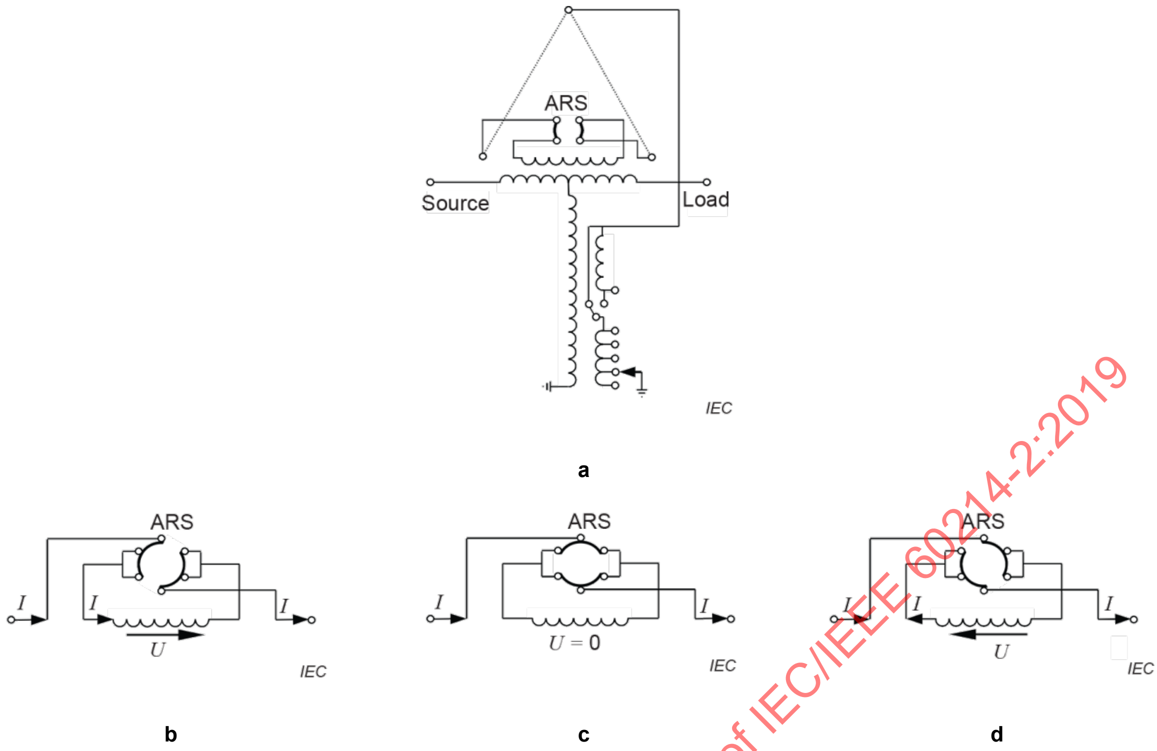


Figure 18 – ARS application and mode of operation in a PST

6.4.5 OLTCs for distribution transformers

The volatility of power flow in distribution networks, for example due to distributed power generation by renewables, can stipulate the use of voltage regulated distribution transformers. Those regulation demands have arisen over the last several years, and the number of available designs is yet limited. Today's available OLTCs for distribution transformer applications are designed as integrated tap-changers (see 6.1.3.3.5). In most of the applications, the OLTC is directly mounted above the active part of the transformer, but other locations within the transformer tank are also possible. Figure 16 shows a variety of locations for DETCs, which can, in general, be used also for OLTCs for distribution transformers designed as integrated tap-changers.

The switching principle is implemented as the known resistor or reactor switching types (see 6.1.2).

7 On-load tap-changers

7.1 General

The OLTC should be chosen to suit the requirements of the application.

The responsibility for the correct selection and application of the fully assembled tap-changer for a given transformer lies with the manufacturer of the transformer.

7.2 Selection of OLTCs

7.2.1 Basic parameters

7.2.1.1 General

The tap-changer should satisfy the conditions specified in 7.2.1.2 to 7.2.1.9, if applicable.

7.2.1.2 Frequencies

OLTCs designed and tested according to IEC 60214-1 or IEEE Std C57.131 are suitable for use in both 50 Hz and 60 Hz systems. For use with other frequencies (16 2/3, in railways, for instance), the tap-changer manufacturer shall be consulted.

7.2.1.3 Currents

7.2.1.3.1 Rated through-current for the OLTC

The rated through-current of the tap-changer as defined in IEC 60214-1:2014, 3.29, or IEEE Std C57.131-2012, Clause 3, should be not less than that resulting from the highest value of tap current of the tapped winding at the assigned rated power of the transformer in accordance with IEC 60076-1:2011, 5.1. The rated through-current refers to continuous loading. If different values of apparent power for the transformer are assigned under different circumstances, for example, with different methods of cooling, the highest of these values is the rated power and, therefore, the basis for the rated through-current of the tap-changer.

7.2.1.3.2 Overload current

On-load tap-changers in accordance with IEC 60214-1:2014, 5.2.2 or IEEE Std C57.131-2012, 5.2.1 meet the overload requirements of IEC 60076-7 or IEEE Std C57.91.

In IEC 60076-7, different types of loading (normal cyclic loading, long-time emergency loading, short-time emergency loading) are defined with respect to the time duration and the maximum allowed currents within those periods.

Overcurrent conditions begin whenever the rated through-current of the tap-changer is exceeded (see also 7.4.8). The number of consecutive tap-changes during overload should be limited to the same number of operations as is required to move from one end of the tap range to the other.

NOTE According to IEC 60214-1 or IEEE Std C57.131 the rated through-current of the tap-changer is stated on its name plate.

OLTCs designed and tested according to IEC 60214-1 or IEEE Std C57.131 are able to perform operations at a current corresponding to at most twice the rated through-current at its relevant rated step voltage. Operations between 1,5 times and 2 times the rated through-current should be kept to a minimum while considering the temperature requirements in 7.4.7.2.

When, for a particular application, a transformer is to be subjected to loading conditions in excess of the limitations in IEC 60076-7 or IEEE Std C57.91, the tap-changer manufacturer should be asked to recommend a suitably rated tap-changer.

7.2.1.3.3 Short-circuit current

The short-circuit current of the OLTC as given in IEC 60214-1:2014, 5.2.4, or IEEE Std C57.131-2012, 5.2.3, should not be less than that resulting from the overcurrent condition due to an external short-circuit of the associated transformer as given in IEC 60076-5:2006, 3.2 or IEEE Std C57.12.00.

The probability of a tap-changer operation under short-circuit conditions is very low (for EAF transformers, see 7.3.4). Therefore, the on-load tap-changer is not required to be capable of switching the short-circuit current. The tap-changer manufacturer is not responsible for an operation of a tap-changer during short-circuit. Protective devices might be incorporated in the system as described in 9.4.

NOTE Take particular care to check this current on low-impedance, booster, phase-shifting transformers and step-voltage regulators. In some instances, the fault-current value could dictate the choice of tap-changer.

7.2.1.4 Rated step voltage

7.2.1.4.1 General

The rated step voltage of the tap-changer (see IEC 60214-1:2014, 3.31, or IEEE Std C57.131, Clause 3) should be at least equal to the highest step voltage of the tapped winding. The tap-changer is then suitable for operation as long as the applied voltage on the transformer does not exceed the limitations of IEC 60076-1:2011, 5.4.3, or IEEE Std C57.12.00 (see also the limits given in 7.2.1.5).

If the tap-changer is required to operate frequently at a higher applied transformer voltage, its rated step voltage should be increased accordingly.

7.2.1.4.2 Varying flux and varying number of turns per tap

In applications with variable flux conditions, the tap changer will get different stresses in different tap positions. OLTCs in such applications require more specification parameters compared to those for power transformers without variable flux conditions.

Transformers with variable flux can have step voltages and through currents with different values in each tap position. These values influence both the selection of the tap-changer as well as the design of transition impedances.

For transformers having regulating windings with a different number of turns between taps all different positions need to be evaluated. The most severe condition should be found and be the base for selecting the OLTC with respect to the breaking and dielectric stresses.

The transformer manufacturer should supply the tap-changer manufacturer with details regarding the step voltage in each tap position, with a table showing the corresponding current and the number of turns between every tap and in the main winding, since it makes the OLTC choice accurate.

7.2.1.5 Breaking capacity

The breaking capacity requirements are met if the highest tap current and the voltage per step of the transformer are within the values of the rated through-current and the relevant rated step voltage declared by the tap-changer manufacturer for the particular tap-changer.

A tap-changer should be capable of normal operation at rated power under conditions of "overfluxing" (see IEC 60076-1:2011, 5.4.3.). At full load, the value of voltage divided by frequency (V/Hz) should not exceed 105 % of the corresponding value at rated voltage and rated frequency. Under no-load conditions, tap-changers should be capable of operation at a V/Hz up to 110 % of the rated V/Hz.

For values outside those declared, the tap-changer manufacturer should be consulted.

For applications with varying currents and/or step voltages, the transition impedance should be designed so that the switched current and the recovery voltage in the tap-changer do not exceed those covered by the type tests.

NOTE In certain applications, such as furnace and rectifier transformers, the tap-changer can be called upon to operate during periods of momentary overcurrent of two to three times the transformer's continuous maximum rated through-current or distorted step voltage or current. This requires a higher breaking capacity than according to rated values.

In case of distorted voltages and currents, the manufacturer should declare upon request the influence of such voltages and currents on the breaking capacity.

In case of oversaturation of the transformer core, high magnetizing currents can be present and the tap-changer manufacturer should be consulted at design stage of the transformer.

Tap-changers intended to be used in transformers connected directly to generators in such a way that they can be subjected to load rejection conditions should be able to withstand 1,4 times the rated voltage for 5 s in accordance with IEC 60076-1:2011, 5.3. During such periods of overvoltage, the breaking capacity should be considered carefully.

7.2.1.6 Insulation level

The following values occurring on all tap positions of the transformer should be checked against the tap-changer manufacturer's declared values in accordance with IEC 60214-1:2014, 5.2.8.2, or IEEE Std C57.131-2012, 5.2.6.3:

a) normal power-frequency operating voltages appearing on the tap-changer in service.

b) AC voltages appearing on the tap-changer during tests on the transformer.

c) impulse voltages appearing on the tap-changer during tests on the transformer.

NOTE With some winding arrangements, the voltages appearing on the transformer can be abnormally high, for example:

– neutral point taps in autotransformers;

– line-end taps;

– series or booster transformer arrangements.

These voltages can be affected considerably by the choice of linear, coarse/fine or reversing tap arrangements. Methods of catering for voltage variations which involve variations in the magnetic flux in the transformer core can also affect the voltages appearing on various parts of the tap-changer (see IEC 60076-3 or IEEE Std C57.12.90).

Switching operations can cause very fast transient over-voltages in networks which can lead to very fast oscillating over-voltage stresses on the tap-changer. These stresses have to be considered when selecting the lightning impulse level of the tap-changer; they are not covered by the switching impulse tests of the transformer which are performed in accordance with IEC 60076-3:2013, Clause 14 or IEEE Std C57.12.90.

When using alternative insulating liquids, the tap-changer manufacturer should be consulted.

The partial discharge (PD) levels of tap-changers as given in IEC 60214-1 or IEEE Std C57.131 shall be in line with the requirements for power transformers given in IEC 60076-3 or IEEE Std C57.12.90. However, distribution transformers, especially cast resin transformers, often have lower PD limits as power transformers. Therefore, the PD level of tap-changers shall be considered during selection.

Tap-changers intended to be used in transformers connected directly to generators in such a way that they can be subjected to load rejection conditions should be able to withstand 1,4 times rated voltage for 5 s in accordance with IEC 60076-1:2011, 5.3.

7.2.1.7 Number of tap positions

The number of inherent tap positions of the tap-changers is generally standardized with various manufacturers' equipment. The selection of the number of service tap positions should preferably be made within that range.

As the extent of the tap range increases, the voltages to be considered also increase, and it is essential that precautions are taken to avoid excessive voltages over the tap range when operating or testing at minimum winding positions. The effect can be very marked on furnace and rectifier transformers feeding electrolytic plants where wide tap ranges are often necessary and the tap-changer is in the constant voltage winding, that is, wide variations in the magnetic flux in the transformer core occur.

7.2.1.8 Change-over selector recovery voltages

7.2.1.8.1 General

When coarse fine or reversing change-over selectors operate, they momentarily disconnect the tap winding. This can cause high recovery voltages across the change-over selector contacts during contact separation. In such cases, discharges between the opening and closing contacts can occur during the operation of the change-over selector. In order to avoid difficulties with regard to the dielectric stress and the formation of gases, special precautions can be necessary. The transformer manufacturer should ensure that the winding design prevents the maximum permissible switching parameters from being exceeded, either with or without any limiting devices (such as tie-in resistors) installed, which are declared by the tap-changer manufacturer.

During transformer testing, the tap-changer change-over selector should be tested in accordance with IEC 60076-1:2011, 11.7, to confirm satisfactory switching.

Particular care should be taken regarding the frequency of the test voltage during the above-mentioned operations. Higher than rated frequencies will result in higher capacitive currents to be switched. This can exceed the breaking capacity of the change-over selector or can result in a higher amount of gases forming.

7.2.1.8.2 Winding locations

The operation of the change-over selector only takes place in OLTC positions where the load current does not flow through the tap winding. Therefore, the change-over selector can disconnect the tap winding momentarily from the main winding. During this operation the potential of the tap winding is floating and is determined by the voltages of the adjacent windings as well as by the coupling capacitances to these windings and/or grounded parts.

When checking the dielectric stress on the change-over selector, the location of the tap winding within the winding arrangement and the capacitances to other windings and/or grounded parts of the transformer has to be known. The capacitances between the windings are often given as values taken from a measurement or can be calculated from the dimensions of the winding arrangement. The transformer manufacturer shall provide these values.

The stresses of the change-over selector have to be verified as acceptable by the tap-changer manufacturer.

7.2.1.8.3 Methods for controlling the recovery voltage

The admissible limits of the recovery voltage at the change-over contacts and the capacitive current are defined by the OLTC manufacturer and depend on the design (e.g. contact geometry, contact material, contact velocity).

There are different methods to decrease the stresses on the opening change-over selector contacts, such as:

– capacitance control,
– resistive control.

The capacitance control uses additional capacitors to adjust the change-over selector stresses to the admissible limits, whereas the resistive control uses resistors for the same purpose.

NOTE The use of capacitance control can lead to voltage oscillations due to resonant conditions.

The use of a two-way change-over selector, also called a double reversing change-over selector, prevents the disconnection of the tap winding from the main winding. This two-way change-over selector is a specially designed selector. It is not suitable for coarse/fine regulations.

7.2.1.8.4 Gases and noise

Even if methods for controlling the voltages (see 7.2.1.8.3) are applied, the amounts of switching gases and noise can only be reduced, not completely avoided.

The amount of gases generated due to the change-over selector operation is in the range of a few millilitres per operation and can affect the DGA of the transformer if the change-over selector is operating within the main transformer tank liquid.

The change-over selector operation generates a discharge noise due to the breaking action, which can be noticeable. This noise is normal and is not problematic.

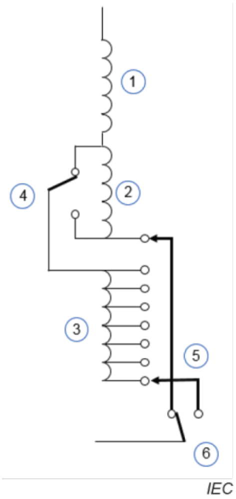
7.2.1.9 Coarse/fine regulation

When changing from the end of the fine winding to the end of the coarse winding with resistor type tap-changers, a high leakage inductance can be set up with the two windings in series opposition. This can cause a phase shift between the switched current and recovery voltage of the diverter or selector switch, which can result in extended arcing of the switch.

The transformer manufacturer should ensure that the winding design does not exceed any maximum leakage reactance levels or switching parameters declared by the tap-changer manufacturer.

It should be noted that axially disposed tap winding designs, as opposed to radially disposed designs, may lead to higher leakage induction values.

At the diverter switch, high lightning impulse voltages might appear if the tap selector is in a position where one connection is made to the end of the fine tap winding and the other is connected to the coarse winding (see Figure 19).



Key

1 Main winding

2 Coarse winding

3 Fine tap winding

4 Change-over selector

5 Tap selector arms

6 Diverter switch

Figure 19 – Selector at both fine tap and coarse winding

7.2.2 Additional data

7.2.2.1 Current splitting

7.2.2.1.1 General

Current splitting in one phase is sometimes desirable if the current is too high for available tap-changers or to get a more economical selection of tap-changer.

Since tap-changers are mechanical devices, neither poles in a diverter/selector switch nor different tap-changers will operate at exactly the same time. To make the paralleling of poles or tap-changers work properly, different methods of current splitting are needed, which can generally be divided into two kinds:

– current splitting in position,
– enforced current splitting.

It is most important to consult the tap-changer manufacturer in all cases with current splitting between tap-changers or between poles in one tap-changer.

7.2.2.1.2 Current splitting in position (lower rating of tap selector compared to diverter switch)

The current splitting shall be effective only on position, i.e. distributing the load current between paths to such a degree that none of the paths carry current higher than that which they are rated for (e.g. paralleling of only the tap selector levels and without paralleling of diverter switches). This condition should work in all positions and requires in practice separate winding paths through the main winding. The risk of circulating currents due to leakage flux has to be considered.

7.2.2.1.3 Enforced current splitting during switching (paralleled selectors/diverters on same phase)

The current splitting shall be effective even during operation of the selector switch or the diverter switch. The impedance between the parallel winding paths should be such that during no part of the switching sequences, the currents to be switched and the arising recovery voltages exceed the declared capacity of the tap-changer (in particular, the last operating diverter switch of those paralleled should not be loaded with any additional circulating current between the parallel winding paths, which would lead to switching conditions beyond the declared parameters). This requires normally higher impedances than in the former case but depends on the degree of current splitting needed.

NOTE As a rule of thumb, it can be expected that a two to three times higher (at minimum) impedance between parallel windings than the effective transition resistor of the diverter switch, leads to an acceptable enforced current splitting.

7.3 Application of OLTCs

7.3.1 General

There are some transformers or reactors for certain applications, where the selection of the tap-changer needs special consideration. In all applications given in 7.3.2 to 7.3.8, the OLTCs are subject to special requirements and the tap-changer manufacturer should be consulted and involved in the selection of the tap-changer.

7.3.2 OLTCs for application in special transformers with non-sinusoidal currents (HVDC, rectifier transformers, converter transformers, etc.)

When using on-load tap-changers in special transformers where through-currents with a high degree of harmonics occur, then the non-sinusoidal wave shape of the through-current shall be defined by the transformer manufacturer. These non-sinusoidal through-currents have a large impact on the switching stresses, which have to be controlled by the diverter switch. In resistor type tap-changers working according to the operation cycle number 1 of the diverter and selector switches or multiple resistor cycle method, the recovery voltage arising at the main switching contacts corresponds to the voltage drop across the transition resistor caused by the through-current. Consequently, the recovery voltage also has a non-sinusoidal wave shape.

The breaking capacity of an on-load tap-changer depends on the maximum slope after the current zero. For converter transformers, this value differs from the one found in applications for power transformers (as described in IEC 60076-1 or IEEE Std C57.12.00) and is essential for the proper selection of the on-load tap-changer. This value, expressed in A/s, should be provided to the tap-changer manufacturer by the transformer manufacturer or the purchaser. Similarly, the tap-changer manufacturer should check the switching capability of the on-load tap-changer with respect to such through-currents, because, besides the amplitude, the wave shape of the recovery voltage decisively influences the switching capability.

7.3.3 OLTCs for PSTs

Unlike standard transformers, the overloading of a PST influences the rated values of the transformer.

The rated phase shift of a PST is defined under no-load conditions. However, the operation at this phase angle in the advanced position is impossible due to the effect of the internal voltage drop of the PST caused by internal impedances. This internal voltage drop depends on the load current (through-put power) and can affect the step voltage of the on-load tap-changer. Therefore, the standard requirement of overload conditions should be considered.

The breaking capacity of an on-load tap-changer should be verified according to IEC 60214-1:2014, 5.2.3.3, or IEEE Std C57.131-2012, 5.2.2.2, at a current corresponding to twice the maximum rated through-current and at its relevant rated step voltage. This requirement is based on the assumption that the rated step voltage does not change with the through-current, which is not true in every case of PST applications. Therefore, an individual study of the breaking capacity should be carried out by the tap-changer manufacturer in case of PSTs. For this calculation the transformer manufacturer shall supply the maximum step voltage that can occur in any position and the maximum through-current.

NOTE It is possible that the required values for this calculation (maximum step voltage, maximum through-current) will not occur simultaneously at the same tap-changer position.

Overloading of a PST in the sense of operating it with a current beyond the nameplate rating increases the internal phase angle and consequently the load phase shift angle in the retard position. This can result in a load phase angle exceeding the maximum rated no-load phase angle. The voltage across the regulating winding and consequently the voltage per step of a single-core type and the voltage across the series winding of a two-core type will exceed the rated voltage. Voltage ratings are defined at no-load and based on turn ratios.

Furthermore, in a two-core design, the main transformer will also experience a certain degree of over-excitation with the same consequences for the regulating winding. The degree depends on the ratio of the impedances of the series and main transformer windings.

The values of voltage, current and switching capability under the above-mentioned overload and over-excitation conditions should be within the declared parameters of the on-load tap-changer.

In the case of PSTs having regulation at the line end (extended DELTA design), high recovery voltages can occur during the operation of the reversing change-over selector. Those recovery voltages can become higher than the system line-to-ground voltages.

It should be noted that service positions will exist where the load current does not flow through the regulating winding. In these positions, there is no (one-core design) or only a reduced (two-core design) short-circuit impedance effective between the load and the source side of the PST.

7.3.4 OLTCs for arc furnace transformers

Arc furnace transformers are one of the most demanding applications of an OLTC because of the high number of operations, the frequent overload, the presence of harmonics and the peak currents from the short-circuits of the furnace electrodes during melting. Therefore, different specification parameters are needed when selecting OLTCs.

NOTE See IEEE Std C57.17 for additional information.

The rated current of the tap-changer should be chosen with respect to overloads and electrode short-circuit currents.

In case of transformer designs with variable flux, see 7.2.1.4.2.

The presence of harmonics affects the through-current by making the wave shape non-sinusoidal. These non-sinusoidal through-currents have an impact on the switching stresses, which have to be handled by the diverter switch. Often the maximum allowed step voltage for the OLTC will be reduced with regard to harmonics for arc furnace applications.

The number of operations is typically several hundred thousand a year, so overloads are more common and current peaks occur. Maintenance intervals are therefore stated according to the number of operations, and maintenance actions might be expected as often as once or twice a year. Sometimes it is recommended to use on-line oil filtration and/or oil temperature supervision.

The often required high number of operations in arc furnace transformers might generate unacceptably high oil temperatures within the diverter switch or selector switch compartment. The transformer manufacturer should supply the tap-changer manufacturer with details regarding overload conditions, electrode short-circuit currents and, in case of transformer designs with variable flux, a table with currents and step voltages.

Due to the high switching frequency, several parts of the tap-changer or the tap-changer itself might need to be replaced during the transformer life time. It is recommended to prepare for this when designing, manufacturing and installing the transformer and especially making it possible to bring in and out the tap selector from the transformer tank.

7.3.5 OLTCs for shunt reactors

Shunt reactors with regulation by OLTCs are often called variable shunt reactors (VSRs). They can be seen as a transformer at no-load with a high magnetising current.

At rated voltage, the load will also be 100 %. Higher voltage will result in higher load as well. Therefore, for the configuration of the tap-changer, the maximum operating voltage should be provided. Voltage causing oversaturation of the core will result in considerably higher currents.

The load will always be reactive. It is always a variable flux regulation, see 7.2.1.4.2.

No short-circuit current appears, but in-rush currents will occur if the reactor is of the gapped iron core type.

The regulating ranges are often large, resulting in high service and test voltages across the regulating range.

When coarse/fine regulation is used, high leakage induction between coarse and fine winding might occur and should be considered, see 7.2.1.9.

7.3.6 OLTCs for series reactors

According to IEC 60076-6, there are different series reactors for different purposes. These types are current-limiting reactors to limit the current under system fault conditions, neutral-earthing reactors to limit the line-to-earth current under system fault conditions, power flow control reactors to control the power flow, motor starting reactors to limit the inrush current during the motor starting operation and arc-furnace series reactors to increase the efficiency of the metal melting operation and limit the system disturbance.

All these reactor types can be designed with or without taps. Tapped reactors can be equipped with de-energized or on-load tap-changers.

When using on-load tap-changers, the value of the reactance and the number of turns in all tap positions as well as the maximum operating current are necessary to evaluate the duties on the diverter switch contacts for a given application. In all those cases, the reactor manufacturer should contact the tap-changer manufacturer for consultation and the choice of the correct tap-changer model.

7.3.7 OLTCs for unit auxiliary transformers

OLTCs applied in unit auxiliary connected transformers are subjected to a variety of system conditions that should be considered in the application of the OLTC. In such applications the impact of frequent large size motor starting, long duration fault currents, fast bus transfers, larger than normal required tap ranges, out-of-phase bus transfers, and load rejection overvoltages should be considered.

NOTE See IEEE Std C57.116 for additional information.

7.3.8 OLTCs for railway supply transformers

Railway supply transformers are used between normal AC networks and the single-phase overhead traction wire. Due to the frequent occurrence of short-circuits in these systems, the transformer windings as well as the OLTC are subject to higher stresses. Therefore, the number of short-circuits per year should be provided and considered for the OLTC selection.

7.3.9 Transformers and phases out-of-step condition

When connecting two (or more) regulating transformers in parallel, an out-of-step condition for a very short time period can occur due to non-synchronous operation of the different on-load tap-changers. This will lead to different loadings of the transformers and the on-load tap-changers. Besides the effects of the unequal loading caused by the different impedance voltages, a circulating current will flow, driven by the voltage difference between the transformers, and this is limited by the impedances within the circuit. These circulating currents are superimposed on the transformer load currents and influence the breaking stresses at the last operating on-load tap-changer. When evaluating the breaking conditions, not only the absolute values of the switching currents but also the occurring phase shift at the opening diverter switch contacts should be considered.

An out-of-step condition also occurs when using individual single-pole on-load tap-changers in a delta or star configuration. Even if the individual on-load tap-changer poles are driven by only one motor-drive mechanism or three drive mechanisms operated by a single control, synchronous operation of the diverter or selector switches cannot be guaranteed. If the tapped windings are delta-connected, unbalanced voltages will cause a circulating current. Consideration of the additional current should be made in the design of the transformer winding and in the application of the correct current rating of the tap-changer.

7.4 Other important parameters for OLTCs

7.4.1 Current wave shapes other than sinusoidal

7.4.1.1 Inrush current

Inrush currents can easily exceed the switching capability of the OLTC. Therefore, tap-changers should not be operated during periods of inrush currents.

7.4.1.2 DC current

A phenomenon can occur whereby the normal AC current to be switched by the OLTC contains a DC component thus minimizing or eliminating zero current crossings. Consideration of the magnitude of the DC component should be included in the selection of the OLTC.

These situations can occur for example:

– when paralleling transformers (out-of-step condition);

– during event of geomagnetic induced currents (GICs);

– (HV)DC supplies using earth return.

7.4.1.3 Impulse voltage distortion on tap-changers

When impulse testing the transformer, the voltages and wave shapes experienced by the tap-changer can be significantly different from the applied voltage magnitude and wave shape at the transformer terminals. This shall be taken into consideration when designing the transformer and applying the tap-changer. Since these voltage magnitudes and wave shapes can unexpectedly exceed the insulation limits of the tap-changer, careful transient analysis should be carried out to ensure proper application.

7.4.2 Operating pressure

Some minimal considerations should be given to the arrangement of the oil conservation system in order to ensure:

– integrity of the seals and compartments;

– correct operation of the pressure dependent protection;

– correct operation of the switching system.

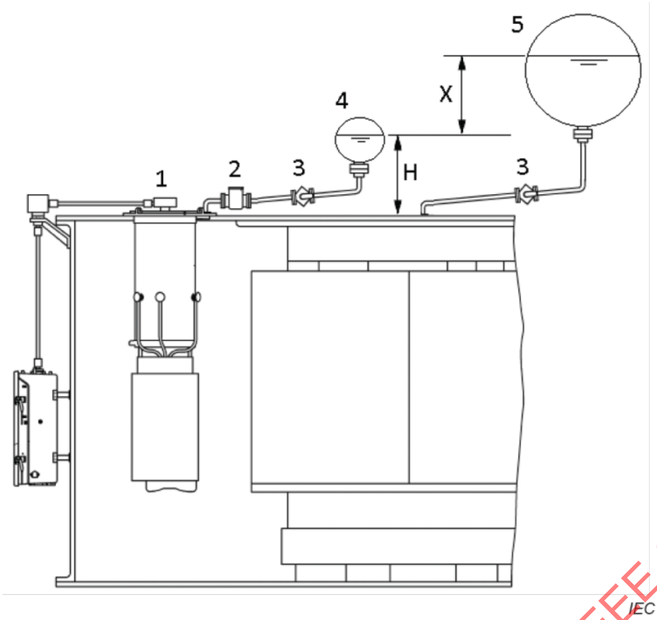
Referring to Figure 20, these considerations include:

- maximum conservator height H for the correct coordination of the pressure sensing devices and for the seals' integrity;
- maximum height difference X for the tap-changer compartment pressure withstand;
- for vacuum switching principle, maximum conservator height to ensure vacuum bottle opening mechanism capability (breaking) and the lifetime of the bellows.

For high-altitude applications (above 1 000 m), the tap-changer manufacturer should always be consulted for conservator height compensation (minimal H):

a) conservator height compensation (minimal H) for vacuum type tap-changers to ensure the closing capabilities (making) of the vacuum interrupters;

b) for non-vacuum type tap-changers to maintain the breaking capacity. There are possible restrictions in the case of non-vacuum type tap-changers.



Key

1 – Tap-changer head cover

2 – Liquid-flow controlled relay

3 – Shut-off valve

4 – OLTC liquid conservator

5 – Transformer liquid conservator

Figure 20 – Tap-changer oil conservator arrangement

7.4.3 Operational life of breaking and making contacts

The test for IEC 60214-1:2014, 5.2.6.2, or IEEE Std C57.131-2012, 5.2.5.1, stipulates that the tap-changer shall perform a minimum of 500 000 mechanical operations. This does not necessarily mean, however, that the tap-changer is suitable for that number of operations at its maximum rated load current without carrying out maintenance and changing contacts.

The service duty test for on-load tap-changers in IEC 60214-1:2014, 5.2.3.2, or IEEE Std C57.131-2012, 5.2.2.1, establishes a base line for the number of operations guaranteed by the manufacturer at the maximum rated through-current and relevant step voltage. Contact life data provided by manufacturers should be determined on an equal basis, such as current level, voltage level, power factor and tap-change range. When determining contact life, overload conditions or durations, if known, should also be considered since they can decrease the expected contact life.

The manufacturer's contact life charts (normally available only for non-vacuum OLTCs) give the contact life for varying contact load currents. However, when a tap-changer is required to perform an abnormally high number of tap-change operations per annum, such as for rolling mills, electrolytic plants and furnace transformers, without contact change, these values should be treated with caution. If a higher rating tap-changer is chosen to achieve the required contact life, it should be noted that a tap-changer might have a disproportionate wear on the transition contacts due to circulating currents.

The same considerations are valid for the lifetime of vacuum interrupters in tap-changers, where the contact life normally is dependent on the breaking current and number of operations. The data provided by the manufacturer should be considered. The contact erosion of main vacuum interrupters in resistor type tap-changers will also be affected by their making operations. In normal service, the contact life of vacuum interrupters (VIs) is not an issue due to the very low contact erosion.

Applications with VIs, which are stressed almost only by making operations, should be considered very carefully, even if these operations occur at very low load currents. Making operations without subsequent breaking operations can lead to worn VI contacts, which tend to stronger contact welding. If the opening mechanism for the VI is too weak this can result in a malfunction.

Since the preventive autotransformer is not designed or supplied by the tap-changer manufacturer and can affect the ultimate contact life of the tap-changer, it is the responsibility of the transformer manufacturer to provide an adequate coordination.

7.4.4 Tap-changer mechanical life

When selecting a tap-changer for an abnormal number of service operations, the tap-changer manufacturer should be consulted. Due consideration should also be given to ease of service maintenance under such requirements.

7.4.5 Motor-drive mechanism

Mechanisms should be specified by the end user in conjunction with the transformer manufacturer.

It is most important that the specification for the voltage for the motor, the voltage for the indications and alarms and the type of tap position indication are compliant with the end customer's requirements. Additionally, the following should be considered:

– single-phase motors require capacitors, which can have a limited life;
– when auxiliary circuit insulation testing is performed by the customer, care should be taken to understand the tap-changer manufacturer's wiring diagram to avoid damage to the equipment.

The raise/lower indicator for both the electrical and manual controls should be provided in the correct configuration for the customer. The customer should specify what a "raise" operation means:

- increasing the tap position number (e.g. 1 to 2, −10 to −9), or
- increasing the voltage on a specific winding

which can or can not be the same result.

If the motor-drive is equipped with a heating device for anti-condensation, this device should be in service even if the transformer is out of service.

If the motor-drive mechanism is purchased from a manufacturer other than the manufacturer of the tap-changer, then it is the purchaser's responsibility to ensure that the motor-drive mechanism is suitable for all its necessary duties.

7.4.6 Pressure and vacuum test

Where applicable, the tap-changer when fully assembled shall withstand all the pressure and vacuum tests of its associated transformer. In such cases, all the relevant information should be given in the purchase order to the manufacturer of the tap-changer.

7.4.7 Temperature conditions

7.4.7.1 Low temperature conditions

If the tap selectors, diverter switches or selector switches are located in separate containers outside the transformer tank, in air, where the ambient temperature can be lower than −25 °C, or if the tap selectors, diverter switches or selector switches are subjected to oil or SF_6 temperatures lower than −25 °C during operation, the tap-changer manufacturer should be consulted, taking the characteristics of the transformer and tap-changer insulation medium into consideration.

The lower limit of −25 °C applies to mineral oil in accordance with IEC 60296 or ASTM D3487. This limit also applies to SF_6, but the pressure should be considered. If other media are used, a different lower limit will apply and the tap-changer manufacturer should be consulted.

If necessary, automatically controlled heating devices could be provided or, alternatively, means of preventing tap-change operation at abnormally low temperatures can be considered.

7.4.7.2 High temperature conditions

Oil temperatures exceeding the temperatures according to IEC 60214-1 and IEC 60076-7, or IEEE Std C57.131 and IEEE Std C57.91, could be considered by the application of a high temperature capable OLTC or will require limiting the number of operations per time unit and/or the number of continuous consecutive operations. To obtain a detailed specification regarding temperature range for the actual tap-changer, the manufacturer should be consulted. If the actual transformer oil and ambient temperatures are different from those in the loading guides, these temperatures should be given to the tap-changer manufacturer to enable a more precise calculation of the permissible number of operations.

The important parameter for the limit in the number of operations is the liquid temperature inside the diverter or selector switch compartment of resistor type tap-changers. The temperature limit will differ between manufacturers, OLTC type and type of insulating medium.

NOTE 1 There is an upper limit for transformer top oil temperatures of 115 °C under overload conditions which applies to mineral oil in accordance with IEC 60076-7 or IEEE Std C57.91.

NOTE 2 For gas-filled power transformers, an upper limit for transformer top gas temperature depends on operation conditions specifically agreed between the user and the tap-changer manufacturer.

If other insulating liquids or gases are used, a different limit will apply and the tap-changer manufacturer should be consulted.

If necessary, temperature measuring devices or, alternatively, means of preventing tap-change operation at abnormally high temperatures can be considered.

7.4.8 Overloading conditions

For the permissible overload current, refer to 7.2.1.3.2.

Overload conditions begin whenever any rated parameter of the tap-changer is exceeded. Both overloading in terms of higher currents and higher voltage due to overexcitation should be considered. High loading conditions affect the tap-changer in several ways. In the short run, the breaking capacity, heating of transition resistors and heating of insulating liquid limit the load. In the long run, the life time reduction of both the breaking contacts and current carrying contacts, as well as the insulating material, set the limit.

NOTE 1 According to IEC 60214-1 or IEEE Std C57.131, the rated parameters of the tap-changer are stated on its name plate.

For normal cyclic loading and planned overload beyond the rated through-current of the tap-changer, the overload is normally compensated for by periods of loads less than unity.

Overloads will normally accelerate the ageing of the OLTC as well as of the transformer. The contact erosion will increase, and current carrying contacts (especially those seldom or never operated) will experience loss of life time. Ageing of all insulation parts including the liquid or gas will accelerate. Increased maintenance might be needed, especially for the non-vacuum types.

Operations with an overexcited transformer core are allowed without restrictions to levels specified in IEC 60076-1 or IEEE Std C57.12.00. Operation at overexcitation exceeding these levels or operations with any overvoltage when exceeding rated load is not allowed. If such conditions are expected to occur, the tap-changer manufacturer shall be consulted.

For loading conditions in demanding applications such as HVDC or industrial applications, for example, arc furnaces, it is recommended to consult the tap-changer manufacturer for assistance in the selection of a proper tap-changer for the actual service conditions.

NOTE 2 For reactor type tap-changers where no transition resistors are applied, additional overload capacity can be available. To investigate, the transformer and tap-changer manufacturers are consulted for specific data.

For gas-filled power transformers, overloading condition is a factor of the transformer design and not defined generally. For specific loading conditions and limitations, consult the SF_6 insulated tap-changer manufacturer.

7.4.9 Continuous consecutive operations

In some applications, continuous consecutive operations through part of or through the whole regulating range, or even more (e.g. HVDC applications), are required. In resistance-type tap-changers, substantial heat is generated in the transition resistors during switching and will be dissipated into and accumulated by the insulating fluid.

The heating of the insulating fluid will depend on a number of parameters such as number of positions, rating, load, fluid volume and type of tap-changer. Operation through half the typical regulating range consecutively is normally not a problem at normal load with normal transformer fluid temperatures.

For continuous consecutive operations over more than half the typical regulating range, at overloads and/or at high transformer fluid temperatures, it is possible that the maximum permissible fluid temperature will be exceeded. The tap-changer manufacturer should be consulted with data required for a proper evaluation.

NOTE A typical operating range is assumed to be up to 34 positions.

7.4.10 Preventive autotransformer circuit (reactor type tap-changer only)

A preventive autotransformer is used with reactor type tap-changers as transition impedance to limit the circulating current when operating on a bridging position (service position where two adjacent taps are bridged), or during the change of taps between adjacent positions. A preventive autotransformer can also be energized in the non-bridging position (service position, with both movable contacts on the same fixed contact), where a circulating current will result if an equalizer winding is incorporated in the design. Preventive autotransformers are not components of the on-load tap-changer; they are designed and provided by the transformer manufacturer and are located in the transformer tank. The design limits of the OLTC have to be respected.

Two opposing requirements should be kept in mind in the design of the amount of reactance to which the value of the circulating current is set. First, the reactance of the preventive autotransformer shall be kept high to reduce the circulating current (to avoid overload of the tap section and to minimize the reactive kVA taken from the line). On the other hand, the reactance shall be kept low to minimize reactance drop (elimination of flicker during the tap-change operation). In addition, the circulating current affects the switching duty to the tap-changer.

Sometimes voltage regulators are equipped with equalizer windings. Without an equalizer winding, the highest temperature rises will be experienced in the bridging position. When an equalizer winding is used, the highest temperature rises can be experienced in the bridging or non-bridging position depending on which position has the highest net tap voltage impressed on the reactor. The current in these positions is determined by the through current, as well as by the circulating current and power factor of the through current.

Equalizer windings are also used in circuits where the voltage should be stepped down to a lower level so a lower voltage tap-changer can be used in the circuit. The use of equalizer windings in the reactor circuit reduces the recovery voltage during switching from a bridging position and increases the recovery voltage during switching from a non-bridging position. The duty on the moving contacts is equalized since the net circulating current reverses the direction for the bridging and non-bridging positions.

8 De-energized tap-changers

8.1 General

The DETC should be chosen to suit the requirements of the application.

The responsibility for the correct selection and application for the DETC for a given transformer lies with the manufacturer of the transformer.

8.2 Selection of DETCs

8.2.1 Currents

8.2.1.1 Maximum rated through-current for the DETC

The maximum rated through-current of the DETC as defined in IEC 60214-1:2014, 3.30, or IEEE Std C57.131-2012, Clause 3, should be not less than that resulting from the highest value of the tap current of the tapped winding at the assigned rated power of the transformer in accordance with IEC 60076-1:2011, 5.1. The maximum rated through-current refers to continuous loading. If different values of apparent power for the transformer are assigned under different circumstances, for example, with different methods of cooling, the highest of these values is the rated power and, therefore, the basis for the maximum rated through-current of the DETC.

Refer to 8.4.3 for paralleling.

8.2.1.2 Overload current

De-energized tap-changers in accordance with IEC 60214-1:2014, 7.2.2, or IEEE Std C57.131-2012, 7.2.2, meet the overload requirements of IEC 60076-7 or IEEE Std C57.91.

When, for a particular application, a transformer is to be subjected to loading conditions in excess of the limitations in IEC 60076-7 or IEEE Std C57.91, the tap-changer manufacturer should be asked to recommend a suitably rated tap-changer.

For gas-filled power transformers, overloading condition is a factor of the transformer design and not defined generally. Thus, the SF_6 insulated tap-changer manufacturer should be consulted for specific loading conditions and limitations.

8.2.1.3 Short-circuit current

The short-circuit current of the DETC as given in IEC 60214-1:2014, 7.2.3, or IEEE Std C57.131-2012, 7.2.3, shall be not less than that resulting from the overcurrent condition of the associated transformer as given in IEC 60076-5:2006, 3.2 or IEEE Std C57.12.00-2015, Clause 7.

Particular care shall be taken to check this current on low-impedance, booster and phase-shifting transformers. In some instances, the fault-current value could dictate the choice of tap-changer.

8.2.2 Rated step voltage

The rated step voltage of the tap-changer (see IEC 60214-1:2014, 3.31, or IEEE Std C57.131-2012, Clause 3) should be at least equal to the highest step voltage of the tapped winding.

8.2.3 Insulation level

The following values occurring on all tap positions of the transformer should be checked against the tap-changer manufacturer's declared values in accordance with IEC 60214-1:2014, 7.2.5.2, or IEEE Std C57.131-2012, 7.2.5.3:

a) normal power-frequency operating voltages appearing on the tap-changer in service;

b) AC voltages appearing on the tap-changer during tests on the transformer;

c) impulse voltages appearing on the tap-changer during tests on the transformer.

NOTE With some winding arrangements, the voltages appearing on the transformer can be abnormally high, for example:

– neutral point taps in autotransformers;

– line-end taps; and

– booster transformer arrangements.

The methods of considering voltage variation which involves variations in the magnetic flux in the transformer core can also affect the voltages appearing on various parts of the tap-changer (see IEC 60076-3 or IEEE Std C57.12.90).

Tap-changers intended to be used in transformers connected directly to generators in such a way that they can be subjected to load rejection conditions should be able to withstand 1,4 times the rated voltage for 5 s in accordance with IEC 60076-1:2011, 5.3.

8.2.4 Number of tap positions

The number of tap positions of the tap-changers is generally standardized with various manufacturers' tap-changer models. The selection of the number of tap positions should preferably be made within that range.

8.3 Application of DETCs

8.3.1 General

As in the case of OLTCs, there are some transformers and applications where the selection of the DETC needs special consideration. In all the applications given in 8.3.2 to 8.3.5, the DETC manufacturer should be consulted and involved in the selection of the tap-changer.

8.3.2 Frequencies

When using a DETC in an application involving frequencies other than the rated frequency of the DETC, the DETC manufacturer should be consulted and involved in the selection of the tap-changer.

8.3.3 Application involving non-sinusoidal currents (HVDCs, rectifier transformers, converter transformers, etc.)

When using a DETC in special applications where through currents with a high degree of harmonics occur, the harmonic content of the non-sinusoidal wave shape can impact the selection of the DETC in question. The DETC manufacturer should be informed of the harmonic contents (both frequency and magnitude) of the through current and be involved in the selection of the DETC.

8.3.4 DETCs for arc furnace transformers and other high load cycle applications

Arc furnace transformers are one of the most demanding applications of a DETC because of the frequent overloads, the presence of harmonics, and the peak currents from the short-circuits of the furnace electrodes during melting. Similar loads include transformers feeding large motors, glass furnaces, rectifiers, and other loads that frequently stop and restart along with applications that are subjected to overloading albeit for short durations (not continuous ratings). Transformers connected to wind energy generators are also subject to heavily changing load (not overload) conditions. When the application involves these types of load cycles, the DETC manufacturer should be consulted and involved with the selection of the DETC.

8.3.5 DETCs for peaking pulsing loads

When the load cycle is less strenuous than that described in 8.2.1.3 but still exhibits loads that peak regularly for short time periods, then return to a much reduced ampere draw for extended periods of time, the DETC manufacturer should be consulted and involved in the proper selection of the DETC. These types of peak loads can be measured in terms of minutes and relatively small overload percentages compared to the nameplate of the transformers. In practical terms, these loads may not have any long term effect on the transformer windings. It can be, however, that the effect can impact the contacts of the DETC.

8.4 Other important parameters for DETCs

8.4.1 Tap-changer mechanical life

If a motor-drive unit is used after 10 000 operations, a check of mechanical parts and, in particular, of electrical contacts is recommended.

8.4.2 Motor-drive

If the motor-drive mechanism is purchased from a manufacturer other than the manufacturer of the tap-changer, then it is the purchaser's responsibility to ensure that the motor-drive mechanism is suitable for all its necessary duties.

8.4.3 Paralleling de-energized tap-changers/current splitting

For high currents, paralleling of DETC decks or DETCs might be needed. This can be done with or without enforcing the current splitting.

- Without enforced current splitting (Figure 21 a)):

  If de-energized tap-changers or decks are paralleled on a common conductor, it should be understood that the current may not be divided equally between the DETCs or decks due to resistance variations of the current paths. For this reason, in case of decks in parallel or DETCs in parallel, the following formula applies to give the maximum current on any of the decks or DETCs:

  I_t = taps' total current

  I_m = maximum current of each deck

  n = number of DETC decks

k = 1,2

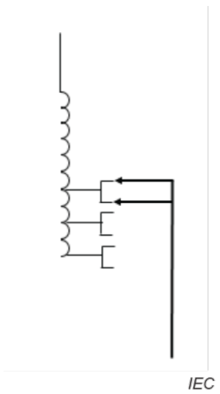
$I_m = I_t \times k/n$

- With enforced current splitting (Figure 21 b)):

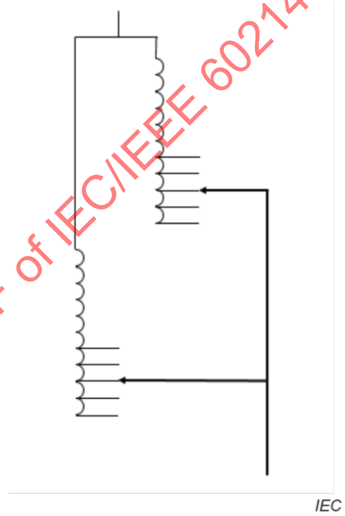
  By connecting separate windings or paths in a winding to separate DETCs or decks in a DETC, the impedance between these windings or winding paths improves the splitting of the load current.

  The degree of splitting depends on the ratio between the resistance difference of the current paths to and through the DETCs or DETC decks and the impedance between the winding paths or windings. Thus, to establish the degree of splitting, the relation between winding impedances and resistance of the current paths shall be evaluated.

The risk for circulating currents due to leakage flux shall be considered for all paralleling measures.



a) **Arrangement without current splitting**



b) **Arrangement with enforced current splitting**

Figure 21 – Current splitting in DETCs

9 Protective devices for OLTCs

9.1 General

According to IEC 60214-1:2014, 5.1.4, or IEEE Std C57.131-2012, 5.1.4, the use of protective devices is required for on-load tap-changers to minimize the risk of fire or explosion resulting from an internal failure within the diverter or selector switch compartment.

Protective devices for diverter or selector switches are designed to counter the action of the following stresses:

– inadmissible increase of pressure within the diverter or selector switch liquid compartment;

– on-load tap-changer operation with excessive transformer overcurrents;

– on-load tap-changer operation at liquid temperatures below the limit of −25 °C given in IEC 60214-1 or IEEE Std C57.131, or, in some cases, above an agreed maximum limit.

If the tap selector is assembled in its own and separate liquid compartment, then protective devices designed to counter the action of an inadmissible increase of pressure within the tap selector liquid compartment may be employed.

In some applications, it can be necessary to supervise the simultaneous operation of different poles of an on-load tap-changer or of different phases to avoid excessive circulating currents caused by a possible out-of-step position of the on-load tap-changers.

9.2 Increase of pressure within diverter or selector switch liquid compartments

9.2.1 General

Breakdowns occurring in on-load tap-changers usually have the effect of converting electrical energy into heat due to arcing. The heat vaporizes the insulating liquid, which will result in an increase of pressure within the liquid compartment. The amount of energy released during a fault depends upon various factors such as the rated capacity of the transformer, the operating voltage, the on-load tap-changer through-current, the short-circuit power of the grid, the connection of the star point, the length of the fault arc, etc.

Protective devices for supervision of the increase of pressure within diverter or selector switch liquid compartments have to respond to every form of abnormal energy release, from long-term low-energy phenomena to an explosive energy release. However, the energy release during normal operation should not operate the protective devices. Such supervision can be achieved by direct pressure sensing or by monitoring the surge speed of the liquid flow, resulting from the pressure increase to the separate conservator. Each on-load tap-changer should have such a protective device. In the case of on-load tap-changers consisting of more than one pole, each pole should be equipped with a separate protective device.

9.2.2 Liquid flow controlled relay

Liquid-flow controlled relays inserted into the pipe between the on-load tap-changer switching compartment and the conservator are most frequently used. Such relays are actuated by an increased liquid flow from the diverter or selector switch liquid compartment to the conservator. They respond to relatively low- up to high-power short-duration disturbances within the diverter switch compartment by tripping the circuit breaker of the transformer, thus avoiding or limiting damage to the on-load tap-changers and the transformer.

Liquid-flow controlled relays have been used for many years in transformer engineering applications and have the advantage of proven reliability and little or no evidence of spurious operations. The disadvantage is that the response time of the relay, being essentially hydraulic, is relatively long compared to some other relay types.

The liquid-flow controlled relay should be installed in the pipe from every switching compartment leading to the conservator, located as near as possible to the on-load tap-changer switching compartments. The pipe to the liquid conservator should be installed with a rising inclination sufficient to ensure the free escape of switching gas. For further information, see the installation instructions of the manufacturer.

Liquid-flow controlled relays would normally be set to trip the transformer to reduce danger to personnel, and to limit consequential damage. Alarm-only systems are not recommended.

9.2.3 Overpressure relay

Usually, overpressure relays are mounted on the outside of the on-load tap-changer switching compartment and respond to internal static and dynamic pressures. However, such overpressure relays will not be actuated by weak disturbances, as they will not reach the necessary pressure for response.

Overpressure relays have the advantage that the response time of the relay is much shorter in the case of steep pressure waves than that of a corresponding liquid-flow controlled relay.

If the pressure-sensing relay is used as the sole protection, it would normally be set to trip the transformer to reduce danger to personnel and to limit consequential damage.

9.2.4 Sudden pressure relay

When a fault, such as a flashover, occurs inside the diverter switch or selector switch compartment, the sudden pressure relay responds to the rate of the pressure increase. Those devices are normally used together with seal-in relays.

9.2.5 Pressure relief device

Faults in the tap-changer switching compartment will result in either a liquid spillage or a release of liquid into the transformer tank. The former could result in a fire risk and/or pollution risk to the environment. The latter could cause severe transformer liquid contamination and/or major transformer failure.

Pressure relief devices may be installed on the diverter or selector switch compartment and be designed to open when a predetermined pressure is exceeded. Faults with large energy releases in the diverter switch or selector switch liquid compartment can generate very strong pressure waves with extremely high pressure peaks. These could lead to damage of the diverter or selector switch liquid compartment. In order to prevent such damage, a pressure relief device is usually mounted to the switching compartment of the on-load tap-changer. If the pressure relief device is used as the sole protection, it would normally be arranged with contacts to enable the circuit-breaker of the transformer to be tripped. It is preferable to be able to test or reset the electrical contacts without removing the protective ducting.

To protect against such events, very often a pressure-relief diaphragm (rupture disk) is used. When responding, this pressure-relief diaphragm will operate and leave a sufficiently large aperture in the switching compartment cover to allow an immediate drop of the pressure.

Another type of a pressure-relief device is the pressure-relief valve, which is of a self-sealing type. When responding, a spring-operated valve cover will open and instantly provide for the pressure relief required in the event of a pressure rise. After the release of the pressure, the valve will close, thus minimizing liquid loss in the event of an operation.

Both devices are designed to ensure an immediate pressure drop in the diverter switch liquid compartment, thus preventing or at least mitigating any further damage. In either case, determination of the setting at which the device operates should take due regard of the static head of liquid on the device in normal service.

However, it is not feasible to protect the on-load tap-changer against all possible faults, particularly worst-case high-energy faults such as an earth fault in a line-end on-load tap-changer. In such cases, commercial depressurization systems may also fail to prevent any resultant fire. Protective devices detecting an increase of pressure are, therefore, intended to minimize the liquid spillage and fire risk. Fire detection and suppression systems should be considered by the end user. For further information, see CIGRE Technical Brochure 537.

9.3 Increase of pressure within a diverter or selector switch in SF_6

9.3.1 General

To detect the increase of pressure within diverter or selector switch compartments, there are mainly two devices used as described in 9.3.2 and 9.3.3.

9.3.2 Pressure gauge (compound gauge)

A pressure gauge (compound gauge) indicates the actual pressure value within the diverter or selector switch compartment continuously.

Typically, signal contacts are provided for alarm when the actual pressure exceeds the set maximum value or falls below the set minimum value. The pressure has to be related to the temperature.

Since the SF_6 gas absolute pressure depends on the temperature, the pressure gauge alarm relays should be set to be activated at pressures corresponding to the allowed temperature range.

9.3.3 Sudden pressure relay

When a fault, such as a flashover, occurs inside the diverter switch or selector switch compartment, the sudden pressure relay responds to the rate of the pressure increase. The relay is provided with contacts to enable the transformer to be tripped and can have alarm contacts in addition.

9.4 Switching under excessive overload

In order to minimize switching under excessive overload, it is recommended that in the case of motor control, a protective device should be fitted to prevent or, if initiated, to interrupt an operation of the motor-drive mechanism when the transformer load exceeds the agreed value. Attention shall be paid to the fact that in the case of spring-loaded mechanisms, the movement of the energy accumulator, when initiated, cannot be interrupted.

Many utilities customarily use an overcurrent blocking device to stop the motor-drive mechanism of the on-load tap-changer from operating when the transformer load current exceeds a pre-set overload limit.

To monitor diverter switch or selector switch compartment temperatures and tap-changer compartment temperatures under excessive load, a temperature limit device can be used to monitor the different temperatures between the selector or diverter switch compartment, when applicable. It is up to the tap-changer manufacturer to decide on the temperature set point, or, if for example the final customer has lower temperature demands for the transformer, those should be valid. Different compartment temperatures can give different signals, for example alarm or blocking of tap-change operation.

9.5 Extreme medium temperatures

During periods with extremely low ambient temperatures and possible low temperatures of the insulation medium (below −25 °C for SF_6 or mineral oil according to IEC 60296 or ASTM D3487), it can be necessary to provide special devices to obtain reliable service behaviour. Such a device may use a thermo-sensor to measure the medium temperature in the on-load tap-changer and a relay amplifier installed in the motor-drive mechanism to block the electrical operation. Other liquids mentioned in 6.3 can have differing low temperature restrictions.

At possible high temperatures of the insulation medium, it can be necessary to provide a device detecting extremely high medium temperatures in the on-load tap-changer. Such a device normally generates an alarm and/or blocks further operation.

Generally, independent of liquid type, the viscosity and all other properties of the liquid within the temperature working range should be considered. If liquids other than mineral oil are used, or if the normal temperature range of mineral oil is abandoned, the tap-changer manufacturer should be consulted.

9.6 Increase of pressure within separate tap selector liquid compartments

9.6.1 General

In tap-changer designs in which the tap selector is assembled in a separate liquid compartment, protection devices similar to those described in 9.2 may be used.

9.6.2 Double element gas and liquid operated relay (Buchholz)

The separate tap selector liquid compartments are usually piped via the main transformer gas and liquid-operated (Buchholz) relay to the main transformer conservator. This relay is a double element relay, which normally provides protection by giving an alarm on accumulation of gas and tripping the transformer on liquid surge. Relays that provide protection by giving an alarm on accumulation of gas and tripping the transformer on further accumulation of gas as well as liquid surge are also available. The transformer manufacturer normally supplies this relay.

Consideration should also be given to the fitting of additional gas and liquid-operated relays (Buchholz), close to every tap selector compartment, in the pipe from the tap selector compartment to the main transformer conservator. This measure offers the advantage of improved fault diagnosis and better identification of whether the source of the fault is in the tap selector or in the main transformer tank. These relays are a double element type. They aid fault diagnosis by identifying whether the fault is caused by an accumulation of gas or a liquid surge. When fitted, consideration should be given to using both the gas accumulation and the liquid surge elements to trip the transformer. The reasoning for this policy is that any free gas in a tap selector compartment is a sign of a defect or fault condition and the transformer should be tripped before the fault causes an internal flashover. It is important to ensure that all air is vented from tap selectors when the compartment is filled, otherwise that air can cause a spurious trip condition. Gassing at the changeover selector does not cause any problem for this application. The transformer manufacturer normally supplies such relays.

9.6.3 Overpressure relay

Overpressure relays can be mounted on the outside of the tap selector compartment. They respond to static and dynamic pressures arising within the tap selector liquid compartment; however, such relays will not be actuated by weak disturbances, as they do not reach the necessary pressure for response. If such a device is used, it should enable the circuit-breaker of the transformer to be tripped.

The comments of 9.2.3 regarding speed of operation, reliability and spurious operation apply.

9.6.4 Pressure relief device

This device, when installed on any tap selector compartment, is designed to open when a predetermined pressure is exceeded. This opening will help to protect the tap selector compartment from damage due to overpressure from an internal fault in the tap selector or any inadvertent over-pressurization of the compartment during liquid filling.

The comments of 9.2.5 regarding self-sealing, ductwork, alarm and trip requirements apply.

9.7 Tap-change supervisory circuit and phase unbalance protection

If there is a failure in the simultaneous operation between different on-load tap-changer poles (for example, breaking of a drive shaft), the independent on-load tap-changers of different phases reach different tap positions. Any further operation will increase the discrepancy between the phases, and excessive circulating currents for the transformer as well as for the on-load tap-changer can be generated. In such cases, the supervisory control circuit (if fitted) can respond and ensure that further electrical operation of the motor-drive is prevented. No further tap-change operation should be carried out, either electrically or manually as long as the transformer is energized.

Discrepancies between the tap positions of different phases will create unbalanced voltages, and so can also be detected by phase-voltage unbalance protection which normally trips the transformer. Out-of-step conditions are common for certain applications (see 7.3.8).

9.8 Vacuum interrupter monitoring system

Monitoring systems for detecting the electrical current flow through the vacuum interrupter are available for reactor type tap-changers with vacuum interrupter and tap selector design (see Figure 13), which prevent the tap selector from operating in case of vacuum interrupter failure.

The system monitors the current through the vacuum interrupters utilizing saturating current detectors located in the stationary leads to or from the vacuum interrupter. The logic circuit of the device controls the current after the vacuum interrupters have opened but prior to the movement of the tap selector contacts. If there is current flowing when it should not be, the monitoring system commands the motor-drive to return the OLTC to the position of origin before the tap selector opens any contact and prevents further operations.

It should be borne in mind that while handcranking a tap-changer, the monitoring system is disabled and cannot prevent the equipment from operating with a malfunctioning vacuum interrupter.

10 Fittings and accessories for OLTCs

10.1 General

The use and application of the fittings and accessories described in 10.2 to 10.8 should be agreed to between the transformer and the tap-changer manufacturers.

10.2 Valves, air release vents and liquid-sampling devices

All valves should be capable of withstanding the pressure and vacuum requirements of the tap-changer and the transformer to which the tap-changer is to be fitted.

Diverter compartments should be fitted with drain and filter valves and air-release vents. For some tap-changers, an isolating valve, fitted between the diverter compartment and the conservator, normally provided by the transformer manufacturer, is required for each diverter compartment.

Separate tap selector compartments should be fitted with a drain valve and top and bottom filter valves, a liquid sampling device accessible from ground level, and air release vents. The bottom filter valve may be combined with the drain valve. An isolating valve fitted between the selector and the conservator, normally provided by the transformer manufacturer, is required for each selector compartment. Where required, equalizing valves between the tap selector compartment and the main tank should be provided by the transformer manufacturer.

A plate showing the function of all valves, air-release vents and liquid-sampling devices, normally provided by the transformer manufacturer, is recommended for each installation.

10.3 Liquid-level gauges

IEC 60214-1:2014, 5.1.3, or IEEE Std C57.131-2012, 5.1.3, requires that liquid-level gauges be fitted to the liquid compartments for diverter or selector switches with integral expansion volume or separate conservators for these compartments. Such gauges should be readily visible with the transformer in service. In some instances, this gauge may be supplied by the transformer manufacturer rather than the tap-changer manufacturer.

In most instances, tap selectors are connected to the conservator of the main tank, and the gauge on the main conservator provides liquid-level indication for the tap selector liquid system. When tap selectors are connected to integral expansion volume or separate conservators, a separate gauge should be provided. These gauges are often supplied by the transformer manufacturer rather than the tap-changer manufacturer.

10.4 Low liquid-level alarms

Consideration should be given to fitting a device to detect low liquid level in the liquid compartments for diverter or selector switches with integral expansion volume or separate conservators for these compartments. This device should normally initiate an alarm in the event of a low liquid-level condition. The device may be separate from, or integral with, any liquid-flow operated relay. In some instances, this device may be supplied by the transformer manufacturer rather than by the tap-changer manufacturer.

Similarly, a device should be fitted to detect low liquid level in the liquid compartments for tap selectors, with separate conservators of the main tank. In most instances, this device may be supplied by the transformer manufacturer rather than the tap-changer manufacturer.

10.5 Dehydrating breathers

If the tap-changer can interact with the atmosphere external to the transformer, a dehydrating breather or other suitable device should be fitted to the liquid compartments for diverter or selector switches with integral expansion volume or separate conservators for these compartments. In some instances, this breather may be supplied by the transformer manufacturer rather than the tap-changer manufacturer.

Similarly, a dehydrating breather should be fitted to the liquid compartments for tap selectors, with separate conservators of the main tank. In most instances, this breather may be supplied by the transformer manufacturer rather than the tap-changer manufacturer.

When determining the appropriate volume of the dehydrating breather, it has to be considered that the liquid volume of the tap-changer compartment is small compared to the transformer, although breathing is more frequent.

10.6 Oil filtering equipment

Oil filtering units can be used to maintain the oil quality within the tap-changer diverter switch or selector switch compartment at a high level. Such oil filtering equipment is available for use either to keep the water content of the oil at a low level or to reduce carbon contamination of the oil caused by the arcing of non-vacuum type tap-changers. Commercial oil filtering equipment combining both functions is also available.

Oil filtering is recommended mainly for non-vacuum type OLTCs in humid climates, when high operation frequencies are expected and/or at high dielectric stresses.

The use of such oil filtering equipment does not extend the contact life.

10.7 Devices to aid maintenance

The design of the tap-changer and transformer should take into account the need to carry out maintenance safely. Items that require regular maintenance should be made reasonably accessible.

10.8 Nameplate and other plates

In addition to the nameplates for the tap-changer and motor-drive mechanism required by IEC 60214-1:2014, Clause 9, or IEEE Std C57.131-2012, Clause 9, where appropriate, a vacuum capability plate should be attached, identifying the vacuum capability of the various compartments of the tap-changer.

11 Storage and installation of the tap-changer

11.1 Storage of OLTC and DETC when not in operation

11.1.1 General

Subclause 11.1 is broken down into two subclauses, 11.1.2 and 11.1.3. First is 11.1.2, on storage of the uninstalled tap-changing equipment prior to becoming part of an apparatus, such as a transformer, on which it will be applied. Then 11.1.3 concerns the storage when the equipment is installed on the apparatus, but while the apparatus is not in service for significant periods of time (more than a few weeks).

11.1.2 Storage prior to installation

During the shipment and pre-installation storage of the tap-changing equipment, it is important to consider the fact that it is not typically protected from the environment by an insulating medium (liquid, SF_6, etc.), and parts not intended for exposure to the environment can be affected adversely. Ferrous materials can rust, and current carrying material can oxidize, tarnish, or otherwise deteriorate. Hygroscopic materials (e.g. paper insulation) can absorb sufficient moisture to affect their insulating characteristics and, in extreme cases, their mechanical suitability. Therefore, it is important to protect this equipment during this storage period. Typically, tap-changer manufacturers package their equipment for short-term exposure, and it is suitable for storage for several months under roof as long as the packaging has not been compromised. Once removed from the packaging, it should be stored in a dry environment and installed as soon as practical. If the tap-changing equipment has been exposed to the environment for a significant period, all current carrying contacts should be cleaned according to the manufacturer's recommendations before the tap-changer is installed. Also, perform a careful inspection for corrosion in general, followed by appropriate cleaning/repair according to the manufacturer's recommendations. If the equipment packaging is opened or has been removed, it should be repackaged in such a way as to protect it from moisture. This could include, but is not limited to, sealed moisture-proof wrapping with a desiccant, or placement in a temporary liquid or gas filled container.

For tap-changers which come in their own tank, such as "compartment type tap-changers", the internal components should be protected by the presence of dry air or nitrogen. If those tap-changers have been opened, for any reason, they should be purged and refilled with dry gas before being placed in storage. Humidity in the compartment should be checked at least annually. A desiccant can be used as long as it is removed before the tap-changer is used.

External operating mechanisms should be protected as well. For hand operated tap-changers and gear boxes the same guidelines as for the tap-changer should be followed. For motor-drive mechanisms, it is recommended that an anti-condensation heater be energized at low wattage to prevent corrosion inside the cabinet. Many motor-driven mechanisms are supplied with these heaters which can be energized even if the motor-drive is not installed.

11.1.3 Storage after installation

Once a tap-changer is installed and is part of the complete apparatus, it is much more protected. If the apparatus and tap-changer are liquid filled with liquid preservation systems in place or SF_6 gas closed systems, the tap-changer is fully protected in most cases. The only limitation is that the liquid preservation system or SF_6 gas closed system should be maintained even when the apparatus is out of service. If the apparatus and/or the tap-changer is/are not liquid/SF_6 gas filled, the unfilled compartments should be filled with dry air or nitrogen and checked regularly for dryness according to the tap-changer manufacturer's recommendation.

Once installed, most hand operated external mechanisms are fully protected by their inherent design. However, installed motor-drive mechanisms should be protected from moisture and corrosion by energizing an anti-condensation heater. Most are provided with such a heater. If vent openings are provided, they should not be blocked.

11.2 Leads assembly to/at the tap-changer

In the case of in-tank-type tap-changers, it should be ensured that the layout of conductive parts in the vicinity of the tap-changer does not adversely affect the internal electrical field distribution within the tap-changer. The connection of the leads to the tap-changer should not affect the thermal and dielectric integrity of the tap-changer.

Where many leads are connected to the tap-changer, all these leads can form an electrical shield to the surroundings. However, single conductors or tap-changer contacts may need additional insulation or shielding when they are directly exposed to the surroundings.

Tap-changers are connected to the transformer with many conductors, and these can exert significant forces on the tap-changer during short-circuits and inrush currents. These conductors can also exert weight and forces on the tap-changer body and exert unacceptable forces during installation and transport and influence resistance against earthquake forces.

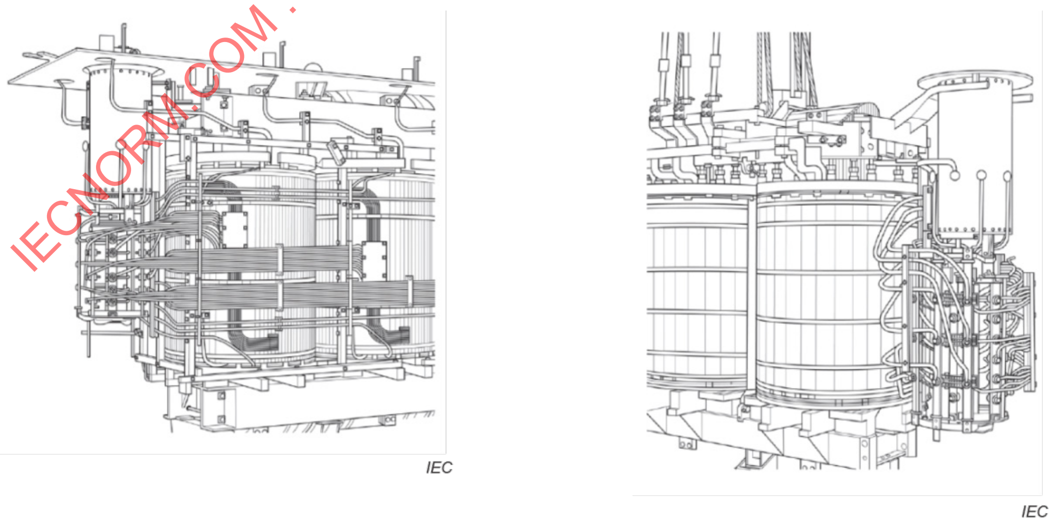
The transformer manufacturer should ensure that the conductors are adequately supported and attached, so that the forces and unsupported weight are kept to a minimum to prevent improper operation or mechanical damage to the tap-changer.

11.3 Tap-changer mounting to the transformer tank

Compartment type OLTC can be installed either by means of a bolted flange or welded directly on the transformer tank. In the latter case, the benefit is the elimination of potential leaks that could develop in gaskets over the transformer's lifetime.

Attention should be given to provide sufficient access (e.g. manholes) to the leads/terminals and the reactor (reactor type tap-changer only) in the event of a field repair.

In-tank OLTCs can have two types of installation as illustrated in Figure 22.



a) **Cover mounted** b) **On the active part**

Figure 22 – Types of in-tank OLTC installations within the transformer

There is no clear preferential design at the manufacturing stage; the choice of the transformer manufacturers is generally determined by their design philosophy, experience and occasionally the crane and drying oven capacities. However, for field repairs, the mounting on the active part would complicate removal and insertion of OLTC components.

For applications where replacement of the OLTC is anticipated during the life of the transformer, facilities should be incorporated for the removal of the tap-changer.

If the tap-changer is operated without the motor-drive unit, for example during the transformer assembly at the transformer manufacturer, the coupling of the tap-changer with its motor-drive should be done with careful coordination of the position as indicated in the manufacturer's handbook.

Oil leaks to the environment and moisture ingress are a serious concern to all transformer users. Consideration should therefore be given to the evaluation of sealing systems which are incorporated. While some general good practices are well known, such as the use of compression controlling assemblies (stops, grooves) for soft gaskets, the most appropriate solution to each application is always determined by the best compromise over multiple factors, including temperature, dimensions, material compatibility, usage, etc. For more details on this topic, refer to CIGRE Technical Brochure 445.

11.4 Processing and filling

Processing of transformer insulation requires the application of heat and vacuum. When this processing is performed with the tap-changer included, it is important to avoid damaging it by staying within the limits provided by the manufacturer. These include, but are not limited to, temperature, temperature rate of rise, pressure differential (pressure or vacuum applied), solvent compatibility, and the duration of exposure to any of these. During the drying process, it is necessary to ensure that if liquids are involved, they can drain from all parts of a tap-changer during the drying process.

Sometimes, internal tap-changer assemblies also require drying before use.

In case of drying of gas-filled power transformers (SF_6-insulated tap-changer) with ovens previously used for liquid-immersed transformers, proper treatment of the oven shall be performed to reduce the effects of residual vapour.

Typically, tap-changers are suitable, within limits, for the same processing as the active element of the transformer, but the accessory components may not be. Accessory components can include breathers, gauges, sensors, barrier boards, gear boxes, etc.

After drying, the lubricants used in tap-changer assemblies are removed. Therefore, it is often recommended that moving parts, such as sliding contacts, are re-lubricated. In some cases, the drying process results in the loosening of hardware, which requires re-torqueing and, in some cases, the locking of screw joints according to the manufacturer's recommendations. After drying, a general inspection of the tap-changer components should be performed to ensure there is no damage, corrosion, deterioration, or warping of components.

During liquid or gas filling, it is important to follow the manufacturer's guidelines for temperature and pressure/vacuum. Temperatures and differential pressures should always be taken into account. In most cases it is required that the compartments be connected together to eliminate a differential pressure.

11.5 Operation of OLTC for ratio measurement

To verify the sequencing of contacts is correct, it is recommended to operate the tap selector slowly enough to recognize a loss of continuity within the tap-changer circuit. The device used to ensure continuity should be such that it can detect very brief open circuit conditions. Note that if tie-in resistors are applied to control the open circuit voltage of the change-over selector, it can mask an open circuit condition, making detection of erroneously sequencing contacts more difficult.

NOTE 1 The operation of some OLTCs other than by using their motor-drive might cause severe damage to the tap-changer. The tap-changer manufacturer's handbook is followed.

NOTE 2 When operating the OLTC from the motor-drive cabinet using the hand crank, the direction of rotation is never reversed before the initiated operation has been finished.

One method for detecting an unacceptable loss of continuity is to excite the transformer's high-voltage side with a low voltage (e.g. 200 V AC) and monitor the output with an analog meter while very slowly moving the tap-changer between positions and carefully watching for a very brief loss or drop-off of the output voltage which corrects itself before reaching the next on-position condition.

When performing a diverter switch sequence testing, consider that since the current level is only in the mA range, a contact bounce of a few milliseconds (absence of an arc) can be observed on an oscilloscope. Therefore, it can be necessary to check the waveform only after the waveform has stabilized.

12 Field service (operation, maintenance and monitoring)

12.1 Commissioning

12.1.1 General

Depending on design, transport limitations, etc., the tap-changer, when delivered on-site, might be anything from totally disassembled from the transformer to fully assembled, oil filled and ready for service.

Any sign of transportation damage should be investigated to see whether it requires measures to be taken or whether it can be accepted.

It is important to follow the transformer and tap-changer manufacturer's instructions on how to re-assemble and test the tap-changer before energizing the transformer.

A number of tests are available to verify the basic functions of the OLTC; a complete detailed list with descriptions can be found in CIGRE Technical Brochure 445 and IEEE Std C57.152.

Certain measurements to verify the basic functions are given in 12.1.2 to 12.1.5.

Instruments used to detect problems with OLTCs have been constructed to enable monitoring of the action of some of the moving parts of the tap-changer. These will provide an analysis of the mechanical action within the tap-changer diverter, selector and motor-drive mechanism.

It is important to understand how each type of tap-changer operates and what the normal characteristics should be. For example, certain types of tap-changers will exhibit contact bounce, which is quite normal but, if not understood, can cause concern to the operator of the test equipment.

12.1.2 Transformer ratio measurement

For most utilities, a transformer ratio test and evaluation before commissioning is a routine requirement. If not, it is strongly recommended to perform and evaluate such a measurement if any form of dismantling of the tap-changer has been done due to transport or other reasons.

For more information, refer to 11.5.

12.1.3 Tap-changer concerns during winding resistance measurement

12.1.3.1 General

Metallic contacts immersed in insulating liquids can show high variability in resistance when measured at low currents, due to the formation of resistive films (especially if there is high oxygen concentration in the oil). Such films need a certain voltage drop to be completely fritted or to have been connected for a certain amount of time to plastically deform the oxide layer, and thereby establish metal-to-metal low resistance contact. The fritting requires a current of a few tens of amperes, which is not always possible during DC resistance measurements in a transformer. In most practical cases when the transformer is loaded, the contact surface films are fully fritted and the resistance will have normal values. The preferable current level should be at least 10 A. Also in cases with harmless resistive films on the tap-changer contacts and measuring with low currents, applicable limits of the resistance readings might be exceeded.

NOTE OLTCs are not intended to interrupt pure DC-loads. Therefore, when doing resistance measurements and operating the OLTC with the DC-current present, this can result in pitting of contacts and generation of acetylene. These phenomena are accelerated with increasing current level and number of operations.

12.1.3.2 Test guidance

As an important point of reference, it is recommended that before operating the tap-changer, the test sequence should be started by measuring the resistance in the position in which the tap-changer is found.

In case of measuring results outside the given limits in any position, the following steps are recommended to determine whether there is only a harmless resistance film phenomenon or if there is another more serious condition in the equipment.

a) Carry out the measurement through the different tap positions as usual.

   In the event that the test shows random variation in resistances through the different positions, when a normal resistance was measured previously, this is a preliminary indication of the presence of harmless resistive contact films.

Continue with the following steps to further investigate whether an issue of concern exists.

b) Operate the tap-changer without load at least five times across the contacts in question and repeat the measurement.

   A significant reduction in resistance indicates only a harmless resistance film phenomenon.

   If the change in resistance is insignificant, continue with step c) or d), as applicable.

c) If there is increased resistance in only one or a few positions, it might be useful to leave the contact in position for at least 2 h and measure again.

   A significant change in resistance indicates only a harmless resistance film phenomenon.

   If the change in resistance is insignificant, continue with step d).

d) If there are still unacceptable measured values, force a current as high as possible for a few seconds considering the acceptable limits for the connected winding and the power source, but at least 20 A, and repeat the measurement.

   A significant change in resistance indicates only a harmless resistance film phenomenon.

   If the change in resistance is insignificant, further investigation is needed. For assistance, consult the transformer and the tap-changer manufacturers.

12.1.4 Check of the synchronization of the drive system

Before commissioning or after repair work involving the dismantling of anything in the drive system, it is important to check the coordination between the drive system and tap-changer as well as between the tap-changing units driven by a common drive system following the manufacturer's instructions.