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Tap-changers –

Part 2: Application guide

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INTERNATIONAL ELECTROTECHNICAL COMMISSION

TAP-CHANGERS –

Part 2: Application guide

FOREWORD

1) The International Electrotechnical Commission (IEC) is a worldwide organization for standardization comprising all national electrotechnical committees (IEC National Committees). The object of IEC is to promote international co-operation on all questions concerning standardization in the electrical and electronic fields. To this end and in addition to other activities, IEC publishes International Standards, Technical Specifications, Technical Reports, Publicly Available Specifications (PAS) and Guides (hereafter referred to as "IEC Publication(s)"). Their preparation is entrusted to technical committees; any IEC National Committee interested in the subject dealt with may participate in this preparatory work. International, governmental and non-governmental organizations liaising with the IEC also participate in this preparation. IEC collaborates closely with the International Organization for Standardization (ISO) in accordance with conditions determined by agreement between the two organizations.
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International Standard IEC 60214-2 has been prepared by IEC technical committee 14: Power transformers.

This standard cancels and replaces IEC 60542 (1976) and its amendment 1 (1988). This first edition constitutes a technical revision of that standard.

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

FDIS	Report on voting
14/490/FDIS	14/492/RVD

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

This publication has been drafted in accordance with the ISO/IEC Directives, Part 2.

IEC 60214 consists of the following parts, under the general title *Tap-changers*:

Part 1: Performance requirements and test methods

Part 2: Application guide

The committee has decided that the contents of this publication will remain unchanged until the maintenance result date indicated on the IEC web site under "http://webstore.iec.ch" in the data related to the specific publication. At this date, the publication will be

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- withdrawn;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

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

INTRODUCTION

The recommendations in this application guide represent advice to the tap-changer manufacturer and purchaser.

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 guide

1 Scope

This part of IEC 60214 is intended to assist in the selection of tap-changers designed in accordance with IEC 60214-1 for use in conjunction with the tapped windings of transformers or reactors. It is also intended to assist in understanding the various types of tap-changers and their associated equipment available. The application guide covers on-load tap-changers (resistor and reactor types) and off-circuit tap-changers.

2 Normative references

The following referenced documents are indispensable for the application of this document. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

IEC 60076-1:1993, *Power transformers – Part 1: General*
Amendment 1(1999)[1]

IEC 60076-3:2000, *Power transformers – Part 3: Insulation levels, dielectric tests and external clearances in air*

IEC 60076-5:2000, *Power transformers – Part 5: Ability to withstand short circuit*

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

IEC 60214-1:2003, *Tap-changers – Part 1: Performance requirements and test methods*

IEC 60296:2003, *Fluids for electrotechnical applications – Unused mineral insulating oils for transformers and switchgear*

IEC 60354:1991, *Loading guide for oil-immersed power transformers*

IEC 60599:1999, *Mineral oil-impregnated electrical equipment in service – Guide to the interpretation of dissolved and free gases analysis*

3 Terms and definitions

For the purposes of this document, the terms and definitions given in IEC 60214-1 apply.

4 Symbols and abbreviations

DGA	Dissolved gas analysis
HVDC	High-voltage direct current
PST	Phase-shifting transformer

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[1] There exists a consolidated edition 2.1 (2000) that includes edition 2.0 and its amendment.

5 Types of tap-changer

5.1 General

Tap-changers are devices that will vary the turns ratio of a transformer and hence regulate the voltages of that transformer. Tap-changers that can perform this operation can broadly be divided into two fundamental types as follows:

– on-load tap-changers;

– off-circuit tap-changers.

5.2 On-load tap-changers

5.2.1 General

The on-load tap-changer is designed to change tap position and hence vary the turns ratio of the transformer whilst it is both energized and on load. It performs this function without any interruption of the supply. This is achieved with mechanically operated devices that will select the various tap positions and switch the load currents and step voltages.

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

The two most common switching principles are:

– high-speed transition resistor type switching; and

– transition reactor (preventive autotransformer) type switching.

5.2.2 Resistor-type on-load tap-changers

5.2.2.1 General

Resistor-type on-load tap-changers can be divided into two distinctive types:

– external out-of-tank tap-changers (air environment), as described in 5.2.2.2;

– in-tank tap-changers (liquid environment), as described in 5.2.2.3.

The operating sequences of the different resistor type tap-changers are shown in IEC 60214-1, Table A.1.

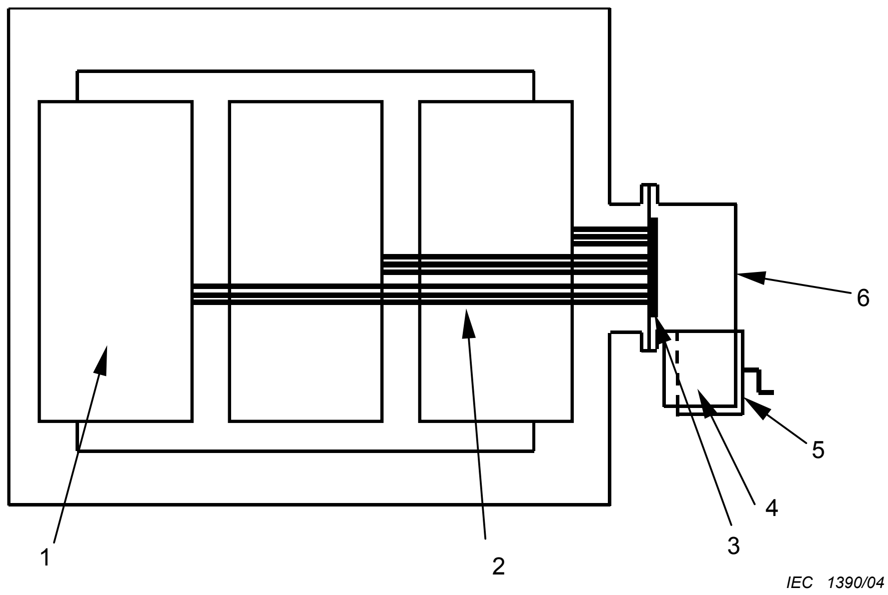
5.2.2.2 External resistor-type on-load tap-changers

5.2.2.2.1 General

These tap-changers are self-contained in their own tanks (except dry-type tap-changers) and mounted on the side or end of the transformer. Four types of tap-changer arrangements are considered, all employing the high-speed transition resistor switching principle.

5.2.2.2.2 External separate selector and diverter compartments

This type of tap-changer has two separate compartments, one for the pre-selection of the transformer taps called the tap selector compartment and the other for the on-load switching called the diverter switch compartment. The two compartments have separate liquid chambers and both are isolated from the liquid in the main transformer tank, although the tap selector compartment and the main tank may share the same conservator. The taps from the transformer are taken to the selector contacts through a liquid-tight barrier board. The tap selector compartment contains clean liquid enabling it to withstand the required higher voltages across the contacts. The diverter switch compartment isolates the carbonized liquid and gases. As can be seen from Figure 1, the tap-changer bolts on the side or end of the transformer. This arrangement is generally used for the larger MVA transformers.



Key

1 Transformer windings
2 Tap leads
3 Liquid and gas tight barrier
4 Diverter switch compartment
5 Drive mechanism
6 Tap selector compartment

Figure 1 – External separate selector and diverter compartments (for mounting on the end or side of the transformer)

The switching can be by arc extinction in the liquid or by vacuum interrupters/power electronics.

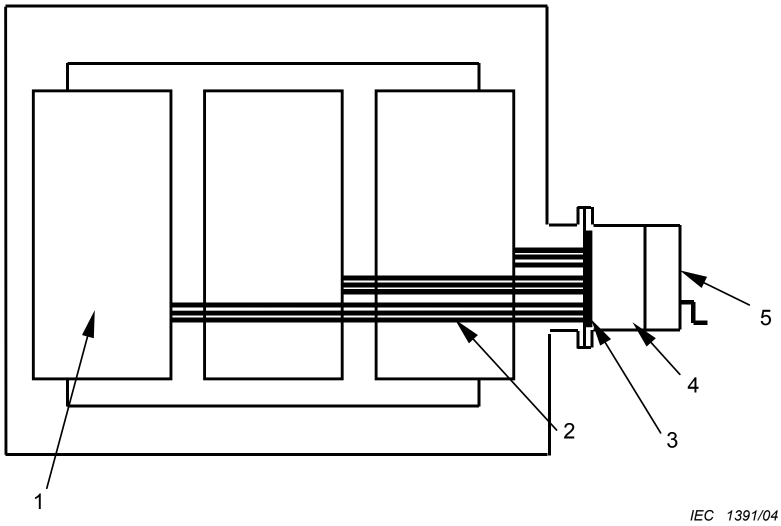
5.2.2.2.3 External mounted separate selector and diverter in single compartment

This type of tap-changer uses separate selector and diverter contact systems in a similar way to the double compartment arrangement in 5.2.2.2.2 but combines them in a single compartment.

The switching can be by arc extinction in the liquid or by vacuum interrupters/power electronics.

5.2.2.2.4 External mounted selector switch tap-changers

Selector switch tap-changers are contained in a single compartment, normally bolted on the side or the end of the transformer (see Figure 2). Again, the transformer taps are taken to the tap-changer contacts through a liquid-tight barrier board. The selection and switching are carried out using common contacts in the same liquid and chamber. These tap-changers tend to be used on the smaller MVA and voltage class transformers.



Key

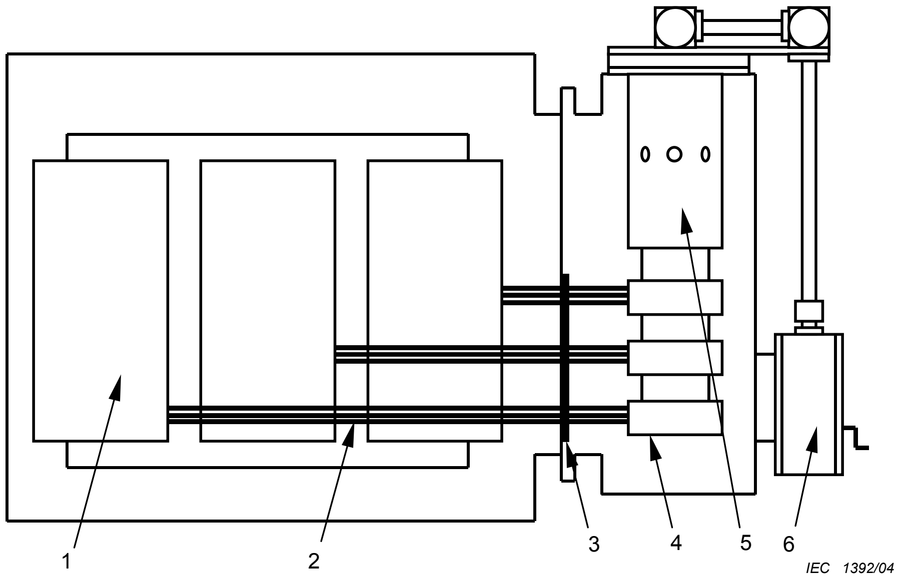
1 Transformer windings
2 Tap leads
3 Liquid and gas tight barrier
4 Selector switch compartment
5 Drive mechanism

Figure 2 – External mounted selector switch tap-changer (for mounting on the end or side of the transformer)

5.2.2.2.5 External mounted in-tank with separate barrier board

By using an in-tank tap-changer in a separate pocket with a liquid-tight barrier board between the tap-changer and the transformer, it effectively becomes a separate bolt-on type of tap-changer. The liquid from the selector is totally isolated from the transformer although the selector compartment and the main tank may share the same conservator.

Figure 3 shows how this arrangement works and gives all the advantages of the separate tank tap-changer for the higher voltage classes.



Key

1 Transformer windings
2 Tap leads
3 Liquid and gas tight barrier
4 Tap selectors
5 Diverter switch
6 Drive mechanism

Figure 3 – External mounted in-tank with separate barrier board

5.2.2.2.6 Advantages and disadvantages of external mounted on-load tap-changers

External mounted on-load tap-changers generally have the advantage of being easier for the user to maintain. Access to the complete tap-changer and all contacts is obtained by removal of inspection covers. Because the selectors are always in a separate chamber, the DGA of the transformer is not affected by capacitive sparking of the selector and change-over of selector contacts. Monitoring of the separate selector compartments can be carried out in isolation allowing early diagnosis of selector problems and the ability to differentiate between selector and main transformer defects. Due to voltage clearance considerations, external mounted out-of-tank on-load tap-changers have the disadvantage of not being practical for line-end applications above 145 kV.

5.2.2.3 In-tank resistor type on-load tap-changers

5.2.2.3.1 General

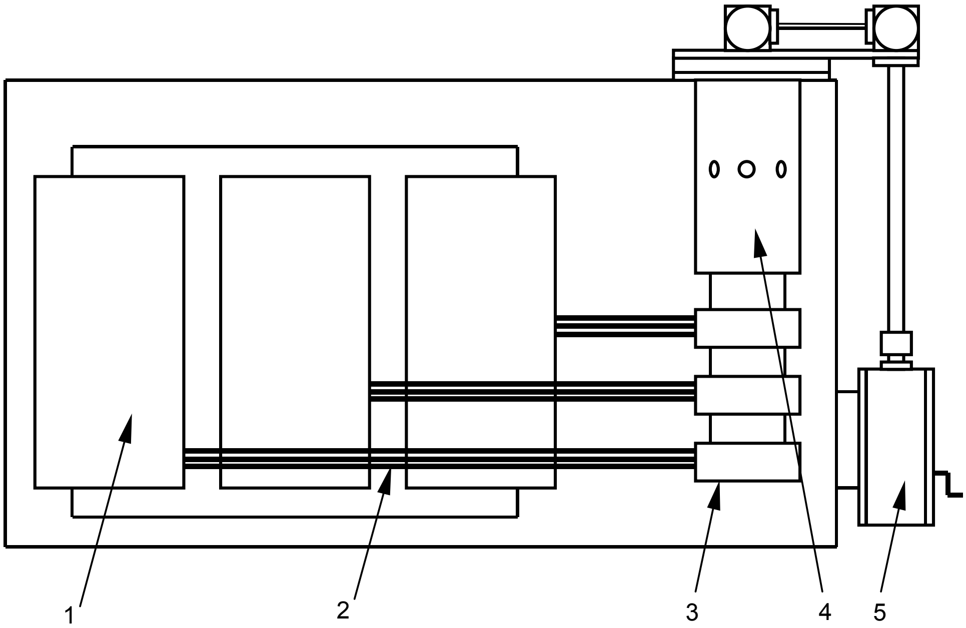
As their name implies, these tap-changers are fitted inside the transformer. They are normally suspended from the lid of the transformer either at one end in the case of a single three-phase pole or along the side when three single-phase poles are used. A pole can consist of one, two or three phases. Two poles can also be used for some Delta applications. Three types are considered, all of them having high speed resistor switching.

5.2.2.3.2 In-tank separate selector and diverter switch

With this type of tap-changer, separate selectors are mounted underneath the diverter switch and operate in the same liquid as the transformer. There are two selector rings per phase, one containing the odd-numbered taps and the other the even-numbered taps, and moving contact arms radially pre-select a tap position without current flowing prior to the diverter switching to that position.

The diverter switch is mounted in a gas- and liquid-tight insulated compartment which separates the arcing gases and carbonized liquid from the transformer liquid. Usually the diverter compartment is equipped with a separate conservator breathing to atmosphere.

This type of tap-changer is used for the higher MVA ratings and voltage classes. Figure 4 shows how this arrangement works.



Key

1 Transformer windings
2 Tap leads
3 Tap selectors
4 Diverter switch
5 Drive mechanism

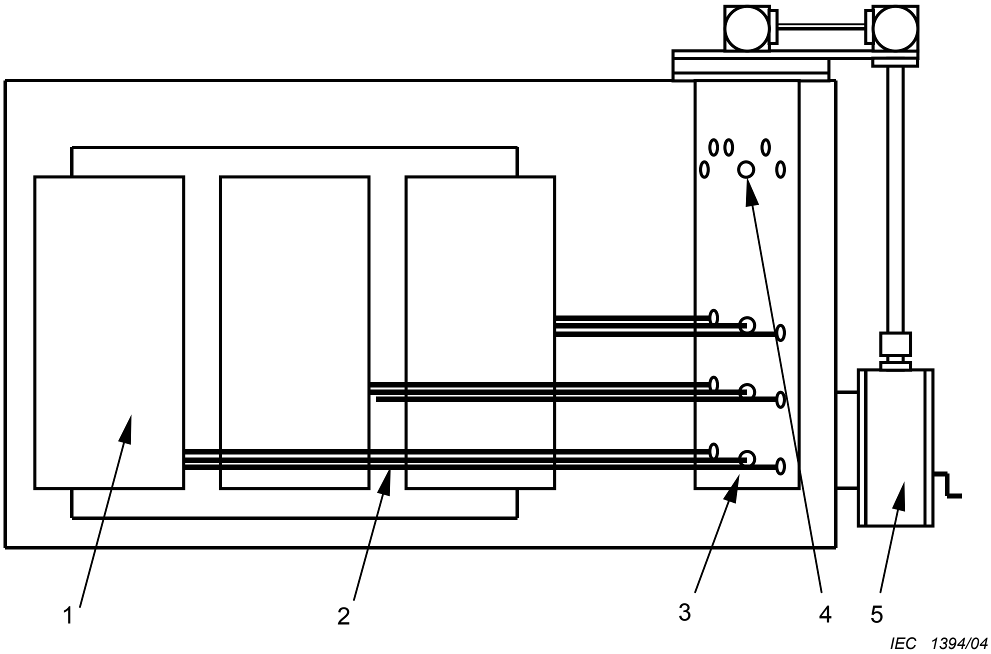
Figure 4 – In-tank separate selector and diverter switch

The switching can be by arc extinction in the liquid or by vacuum interrupters/power electronics.

5.2.2.3.3 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. The fixed contacts are radially mounted around a vertical insulated compartment with the three phases mounted one above the other. The carbonized liquid and gases are separated from the main transformer liquid by the liquid-tight compartment. The moving contacts are fixed to a central insulated drive shaft.

This type of tap-changer tends to be used for the lower MVA and voltage class transformers (see Figure 5).



Key

1 Transformer windings
2 Tap leads
3 Selector switch terminals
4 Change-over selector terminals
5 Drive mechanism

Figure 5 – In-tank selector switch tap-changer

5.2.2.3.4 In-tank separate selector and diverter switch in single compartment

This type of tap-changer uses separate contacts for the selection of the taps and different contacts for the switching. Normally, all moving selector contacts would pre-select a tap before the diverter contacts switch to that tap. The sequence of operation would be similar to a tap-changer described in 5.2.2.3.2 but both sets of contacts are contained in the one compartment. The switching can be by arc extinction in the liquid or by vacuum interrupters/power electronics.

5.2.2.3.5 Advantages and disadvantages of in-tank on-load tap-changers

In-tank on-load tap-changers have the advantage of being 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, an in-tank tap-changer will generally have a smaller oil volume. This has the advantage of smaller oil volumes to handle during maintenance but a disadvantage that more frequent maintenance may be required. Where in-tank tap-changer types have their selectors and change-over selectors in particular, operating in the same liquid as the transformer, the DGA of the transformer can be influenced by capacitive arcing from the contacts.

5.2.3 Reactor-type on-load tap-changers

5.2.3.1 General

Reactor-type on-load tap-changers are normally designed to be applied to the low voltage winding of the transformer. They can be divided into two distinctive types:

– external out-of-tank tap-changers (air environment), as described in 5.2.3.2;
– in-tank tap-changers (liquid environment), as described in 5.2.3.3.

5.2.3.2 Reactor-type external on-load tap-changers

5.2.3.2.1 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 liquid tight barrier board (component of the on-load tap-changer). The liquid from the tap-changer is totally isolated from the transformer main tank and, therefore, can be checked separately by liquid sampling. Three types of tap-changer arrangements are considered.

5.2.3.2.2 Diverter switch and tap selector

This type of tap-changer consist of change-over selectors and tap selectors, designed to select tap connections, and transfer switches (diverter switches or vacuum interrupters), designed to break and make current and, therefore, perform the arcing duty of the tap-changing operations. The separate devices are normally located in a common liquid compartment similar to that shown in Figure 1. This design of a tap-changer tends to be used on the larger MVA transformers.

The operating sequence of a reactor type tap-changer with diverter switch and tap selector is shown in IEC 60214-1, Figure B.5.

5.2.3.2.3 Selector switch (arcing tap switch) tap-changers

This type of tap-changer will incorporate a selector switch (arcing tap switch) which performs the functions of making/breaking current and selection of tap connections, combining the duties of a tap selector and a diverter switch. The selector switch and the change-over selector, if they exist, are contained in one single compartment. This design of a tap-changer tends to be used on the smaller MVA transformers.

The operating sequence of reactor type tap-changers with selector switch is shown in IEC 60214-1, Figure B.1.

5.2.3.2.4 Vacuum interrupter (with by-pass switches) and tap selector

This tap-changer design also consists of a single liquid compartment containing change-over and tap selectors to select taps and one vacuum interrupter per phase to break and make current. In addition, they may be equipped with by-pass switches, mainly designed to by-pass the vacuum interrupter when the tap-changer is not performing a tap-change operation. By using vacuum interrupters to perform the breaking duty of the tap-changing operations, the carbonization of the insulating liquid is minimized which enables the device to withstand higher voltages. This arrangement is generally used for the larger MVA transformers.

The operating sequence of a reactor-type tap-changer with vacuum interrupter and tap selector is shown in IEC 60214-1, Figure B.7.

5.2.3.3 Reactor-type internal on-load tap-changers

These designs are exclusively used in voltage regulators. The tap-changer is fitted inside the transformer tank and is normally located on top of the transformer adjacent to the preventive autotransformer (reactor).

This type of tap-changer will incorporate a load transferring selector switch (arcing tap switch) which performs the functions of switching current and tap selection. Since tap changing is performed in the same tank as the main transformer windings the insulating liquid should be checked frequently to insure the dielectric integrity of the transformer. The transformer taps are taken to the tap-changer contacts that are located on an insulated board. The selection and switching are carried out using common contacts.

The transformer manufacturer needs to take into account the potentially heavy carbonization of the liquid in the main transformer tank.

5.3 Off-circuit tap-changers

The off-circuit tap-changer is designed to change tap position and hence vary the turns ratio of the transformer whilst it is de-energized.

This is achieved with mechanically operated devices that will select the various taps. The fixed contacts may 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.

5.4 Liquid-immersed tap-changers

5.4.1 General

Liquid-immersed tap-changers cover all the types described in 5.2 and 5.3 that require a liquid for use as either insulation or arc quenching during the switching operation. A typical, and the most common, liquid is mineral oil (transformer oil) according to IEC 60296. Other types of liquids may be employed for insulation and switching purposes but care has to be exercised to ensure its compatibility with the tap-changer under consideration.

5.4.2 Liquid immersed on-load tap-changers

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 to IEC 60296. 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 fluids have very poor lubricating properties and no arc-quenching ability and cannot be used for on-load tap-changers. Synthetic esters and High Molecular Weight (HMW) paraffins have good lubrication and arc extinction properties and may be suitable for some on-load tap-changers. The temperature operating range may be restricted due to higher viscosities than transformer oil at lower temperatures.

Where a liquid other than mineral oil according to IEC 60296 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 transformer oil according to IEC 60296. For temperatures below –25 °C, the tap-changer manufacturer may recommend a lower viscosity oil, the installation of heaters in the switching and mechanism compartments or other precautions to prohibit tap-changing whilst below a given temperature limit.

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

5.4.3 Liquid-immersed off-circuit tap-changers

Liquid-immersed off-circuit tap-changers are tested to operate in mineral oil to IEC 60296; however, in service they may be required to operate on one position for long periods of time, and, if operating in high liquid temperatures, pyrolytic carbon may eventually form on the contacts. For this reason, a lower temperature rise value is stipulated in 7.2.2 of IEC 60214-1. The type of material used for the contacts should be suitable for the intended application. Prolonged operation on one position may influence the pyrolitic carbon formation; hence, silver plating/silver plating, silver plating/copper, copper/copper and copper/brass contact materials may be preferable.

During transformer maintenance, it is recommended that the off-circuit tap-changer is operated to clean the contacts (see 9.1.3).

Unlike liquid-immersed on-load tap-changers, off-circuit tap-changers do not require arc quenching or good lubricating properties. Also, cold temperature viscosity is not so important to their operation. For these reasons, the use of many different types of fire-retardant fluids are possible.

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

5.5 Dry-type tap-changers

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 hazards and prevention of water pollution.

In contrast to conventional tap-changers, which are located in separate housings filled with insulating liquid or inside the main transformer tank, dry-type tap-changers can be subject to different service conditions due to environmental influences. They can be used with or without a housing in indoor or outdoor installations.

In liquid-filled on-load tap-changers the insulating liquid is used as insulating, switching and cooling medium and as lubricant. Dry-type on-load tap-changers usually use vacuum interrupters as switching elements and gas (SF_6 or air) as the insulating medium as well as the cooling medium. Lubrication 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 of frequent lubrication measures, especially for dry-type tap-changers in an SF_6-gas environment, contacts, bearings and gears are specially designed to significantly reduce mechanical fatigue and the necessary mechanical torque.

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 gas-filled dry-type transformers

   The tap-changer and the transformer are incorporated in a pressurized and gas-filled (mainly SF_6) enclosure.

b) 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.

c) 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.

d) 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 may have its own enclosure (usually a ventilated enclosure).

For dry-type tap-changers the normal service conditions such as altitude, temperature of cooling air and humidity will be in accordance with IEC 60076-11 if applicable.

Furthermore, the purchaser should check, when selecting an appropriate dry-type tap-changer for a certain application, whether the dry-type transformer will still meet the stated climatic, environmental and fire behaviour classes according to IEC 60076-11 once the selected tap-changer has been incorporated in the transformer. 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.

When using dry-type on-load tap-changers in SF_6 gas atmosphere, the effects of the above-mentioned sparks or hot spots should be considered, as SF_6 gas may decompose.

It can be assumed that no decomposition of the SF_6 gas takes place below 150 °C. At temperatures higher than 200 °C some metals may have a decomposing effect on the SF_6 gas. 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.

The SF_6 gas decomposes into gaseous and solid by-products, some of which may have toxic effects. Therefore, careful handling of the SF_6 gas in use is required, for example, during maintenance work. Adequate precautions should be taken to ensure the safety of personnel.

5.6 Other types

5.6.1 General

There are also other less common 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 may also be made on the tap-changer.

The following are some other types of tap-changers described.

5.6.2 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 and thereby no arcing will take place. Electronic tap-changers are usually designed to replace only the diverter switch function but can also take care of the tap selector function. The electronic tap-changer can be of totally dry type or have the electronic immersed in liquid. It can also be of dry type but cooled with some other type of media.

5.7 Protective devices

5.7.1 General

According to 5.1.4 of IEC 60214-1, 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, 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 may 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.

5.7.2 Increase of pressure within diverter or selector switch liquid compartments

5.7.2.1 General

Faults 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.

5.7.2.2 Liquid-flow controlled relay

Liquid-flow controlled relays inserted into the pipes 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 and 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. Dual element relays, incorporating a contact that is operated by accumulation of gas, are not applicable to diverter or selector switches as they inherently generate gas during their normal operation.

The liquid-flow controlled relay should be installed in the pipe leading from the on-load tap-changer switching compartment to the conservator, located as near as possible to the on-load tap-changer switching compartment. 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 for tripping the transformer to reduce danger to personnel, and to limit consequential damage. Alarm-only systems are not recommended.

5.7.2.3 Overpressure relay

Pressure-sensing devices are often used, either alone or in addition to liquid-flow controlled relays. Usually, they are mounted to 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. While such relays are of proven technology, their application on transformers is less common, and so evidence to prove reliability and absence of spurious operation is not so comprehensive as for the liquid-flow controlled relay.

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

5.7.2.4 Pressure-relief device

Pressure-relief devices are frequently used, either alone or in parallel to the liquid-flow controlled relay. Such 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 liquid compartment can generate very strong pressure waves with extraordinarily 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 protective ducting.

To this end, 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, preventing 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.

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.

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 also commercial fire prevention systems may not contain any resultant fire. Protective devices detecting increase of pressure are, therefore, intended to minimize the liquid spillage and fire risk.

5.7.3 Switching under excessive overload or short circuit conditions

In order to minimize switching under excessive overload or short-circuit conditions, 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 has to 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.

When a manual control is used, protective devices are not considered necessary, as it is not normal practice to tap-change manually during periods of excessive overload.

The probability of a tap-changer operation under short-circuit conditions is negligible.

5.7.4 Excessive liquid temperatures

During extreme ambient temperatures and possible low liquid temperatures (below –25 °C for mineral oil according to IEC 60296), it may be necessary to provide special devices to obtain reliable service behaviour. Other liquids (see 5.4.2) may have differing temperature restrictions. Such a device may use a thermo-sensor to measure the liquid temperature in the on-load tap-changer and a relay amplifier installed in the motor-drive mechanism to block the electrical operation.

In some cases, for air environment on-load tap-changers, the inclusion of a device to detect excessively high liquid temperatures (perhaps in excess of 90 °C) may be necessary. Such devices would normally be used to generate an alarm or to trip the transformer.

5.7.5 Increase of pressure within separate tap selector liquid compartments

5.7.5.1 General

In tap-changer designs in which the tap selector is assembled in a separate liquid compartment, protection devices similar to those described in 5.7.2 may be used.

5.7.5.2 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 would be 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 would normally supply this relay.

Consideration should also be given to fitting 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 identifying whether the source of the fault is in the tap selector or in the main transformer tank. These relays would also be a double element type.

They would 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 would cause a spurious trip condition. Gassing at the changeover selector does not cause any problem for this application. The transformer manufacturer would normally supply such relays.

5.7.5.3 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 5.7.2.3 regarding speed of operation, reliability and spurious operation apply.

5.7.5.4 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 5.7.2.4 regarding self-sealing, ductwork, alarm and trip requirements apply.

5.7.6 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) may 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 may also be detected by phase-voltage unbalance protection which normally trips the transformer. Out-of-step conditions are common for certain applications (see 6.2.8).

6 Selection of tap-changers

6.1 General

Since the tap-changer represents only a small part of the total cost of the equipment in which it is used, it should be freely chosen to suit the equipment. However, account should be taken of the available standard types of tap-changers.

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

6.2 On-load tap-changers

6.2.1 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 5.2.6.4 of IEC 60214-1.

a) Normal power-frequency operating voltages appearing on the tap-changer in service.
b) Separate source a.c. 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 1 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.

These voltages can be affected considerably by the choice of linear, coarse/fine or reversing tap arrangements. Methods of catering for voltage variation 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).

NOTE 2 Switching operations may cause very fast transient over-voltages in networks which may 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 Clause 15 of IEC 60076-3.

6.2.2 Current and step voltage

6.2.2.1 General

The tap-changer should satisfy the conditions prescribed in 6.2.2.2 to 6.2.2.5.

6.2.2.2 Rated through-current

The rated through-current of the tap-changer as defined in 3.26 of IEC 60214-1 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 4.1 of IEC 60076-1. 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.

6.2.2.3 Overload current

Tap-changers in accordance with 5.2.1 of IEC 60214-1 meet the overload requirements of IEC 60354.

The number of tap-changes for each overload period should be limited to the same number of operations as is required to move from one end of the tap range to the other.

When, for a particular application, a transformer is to be subjected to loading conditions in excess of the limitations in IEC 60354, the tap-changer manufacturer should be asked to recommend a suitably rated tap-changer.

6.2.2.4 Rated step voltage

The rated step voltage of the tap-changer (see 3.28 of IEC 60214-1) 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 4.4 of IEC 60076-1.

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

6.2.3 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 rated through-current and relevant rated step voltage declared by the tap-changer manufacturer for the particular tap-changer.

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

For application to transformers with several different currents and step voltages, the transition impedance should be designed so that the switched current and 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 may 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 their influence on the breaking capacity.

6.2.4 Short-circuit current

The short-circuit current of the tap-changer as given in 5.2.3 of IEC 60214-1 should be not less than that resulting from the overcurrent of the associated transformer as given in 3.2 of IEC 60076-5.

NOTE Particular care should 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.

6.2.5 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 taps range increases, the voltages to be catered for also increase, and it is essential that precautions be taken to avoid excessive voltages over the taps 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 taps 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.

6.2.6 Change-over selector recovery voltages

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 due to capacitive coupling between the tap winding and adjacent winding(s). 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 may be necessary.

There are many different methods of limiting the problem, such as the use of tie-in resistors or providing capacitive control of the tap winding or the use of two-way change-over selectors.

The transformer manufacturer should ensure that the winding design does not exceed the switching parameters, either with or without any limiting devices (such as tie-in resistors) fitted, declared by the tap-changer manufacturer.

During transformer testing, the tap-changer change-over selector should be tested in accordance with 10.8 of IEC 60076-1 to confirm satisfactory switching.

NOTE 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 may exceed the breaking capacity of the change-over selector or may result in higher formation of gases.

6.2.7 Coarse fine regulation leakage induction switching (resistor type tap-changers only)

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 may 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.

6.2.8 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 shall be considered.

An out-of-step condition 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 applying the correct current rating of the tap-changer.

6.2.9 Enforced current splitting (paralleled selectors/diverters on same phase)

If an enforced current splitting is required for special on-load tap-changer types or applications, the transformer design with two or more parallel winding paths has to be considered well. The impedances between the parallel windings must be at minimum 2 to 3 times higher than the effective transition resistor of the diverter switch to ensure an enforced current splitting even during the diverter switch operation to limit the circulating current. Any additional circulating current between parallel winding paths should not cause the last diverter that operates, to switch beyond its declared parameters.

The tap-changer manufacturer should be consulted when such conditions are envisaged.

6.2.10 On-load tap-changers for application in special transformers with non-sinusoidal currents (for example, HVDC converter transformers)

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 has to 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 flag cycle 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 transformer manufacturer should supply the tap-changer manufacturer with details regarding waveshape and overload conditions. 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.

6.2.11 On-load tap-changers for phase-shifting transformers (PST)

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 may affect the step voltage of the on-load tap-changer. Therefore, the standard requirement of overload conditions shall be considered.

The breaking capacity of an on-load tap-changer shall be verified according to 5.2.2.2 of IEC 60214-1, 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 has to supply the maximum step voltage that can occur in any position and the maximum through-current.

NOTE The required values for this calculation (maximum step voltage, maximum through-current) may 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 may 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 conditions should be within the declared parameters of the on-load tap-changer.

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.

6.2.12 Contact life

The test for 5.2.5.1 of IEC 60214-1 stipulates that the tap-changer has to 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 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 equal basis, such as current level, voltage level, power factor and tap-change range. When determining contact life, overload conditions or durations, if known, shall also be considered since they can decrease the expected contact life.

The manufacturer’s contact life charts 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 plant 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.

6.2.13 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.

6.2.14 Motor-drive mechanism

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.

6.2.15 Pressure and vacuum tests

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

6.2.16 Low-temperature conditions

Should the tap selectors, diverter switches or selector switches be located in separate containers outside the transformer tank, in air, and the ambient temperature can be lower than –25 °C, it is advisable to specify the quality of the insulating and/or lubricating liquid.

Should the tap selectors, diverter switches or selector switches be located inside the transformer tank and the liquid temperature can be lower than –25 °C during operation, the tap-changer manufacturer shall be consulted, taking the quality of the transformer oil into consideration.

NOTE The lower limit of –25 °C applies to mineral oil in accordance with IEC 60296. When other liquids 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 may be considered.

6.2.17 Continuous operation

If the tap-changer is required to operate continuously, the temperature conditions may need to be checked and the tap-changer manufacturer should be consulted.

6.2.18 Preventive autotransformer circuit (reactor type tap-changers 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. Preventive autotransformer can also be energized in the non-bridging position (service position, where both movable contacts on the same fixed contact) and a circulating current will result if an equalizer winding is incorporated in the voltage regulator design. Preventive autotransformers are not components of the on-load tap-changer and must be designed and provided by the transformer manufacturer and are located within the transformer tank.

Two opposing requirements must 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 has to be kept high to reduce the circulating current (to avoid overload of tap section and to minimize reactive kVA taken from the line). On the other hand, the reactance has to be kept low to minimize reactance drop (elimination of flicker during 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 must 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 direction for bridging and non-bridging positions.

6.3 Off-circuit tap-changers

6.3.1 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 7.2.5.3 of IEC 60214-1:

a) normal power-frequency operating voltages appearing on the tap-changer in service;
b) separate source a.c. 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 1 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.

Methods of catering for voltage variation 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).

6.3.2 Rated through-current

The rated through-current of the tap-changer as defined in 3.26 of IEC 60214-1 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 4.1 of IEC 60076-1. 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.

6.3.3 Overload current

Tap-changers in accordance with 7.2.2 of IEC 60214-1 meet the overload requirements of IEC 60354.

When, for a particular application, a transformer is to be subjected to loading conditions in excess of the limitations in IEC 60354, the tap-changer manufacturer should be asked to recommend a suitably rated tap-changer.

6.3.4 Rated step voltage

The rated step voltage of the tap-changer (see 3.28 of IEC 60214-1) should be at least equal to the highest step voltage of the tapped winding.

6.3.5 Short-circuit current

The short-circuit current of the tap-changer as given in 7.2.3 of IEC 60214-1 should be not less than that resulting from the overcurrent of the associated transformer as given in 3.2 of IEC 60076-5.

NOTE Particular care should 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.

6.3.6 Paralleling off-circuit tap-changers

Equal current sharing is best achieved by using parallel winding paths. A high impedance between the windings, as required for on-load tap-changers, is unnecessary as there is no on-load circulating current switching requirement.

If off-circuit tap-changers are paralleled on a common conductor, it must be understood that the current may not be divided equally between the two due to contact resistance variations. For this reason, off-circuit tap-changers of a higher current rating may need to be considered assuming a current sharing ratio of approximately 60/40.

6.3.7 Number of tap positions

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

6.3.8 Mechanical life

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

6.3.9 Motor-drive mechanism

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 Location of liquid immersed tap-changers

7.1 Tap selectors

Unless otherwise agreed between the transformer manufacturer and the purchaser, the tap selectors may be located within the main transformer liquid.

NOTE Where change-over selectors are incorporated in the selector design, gassing from their contacts can occur (see 6.2.6). This may affect any dissolved gas in oil analysis of the transformer.

7.2 Diverter and selector switches

To avoid contamination of the liquid in the transformer tank, the diverter switch and selector switch should be housed in a separate leak proof compartment inside or outside the transformer tank.

8 Fittings

8.1 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.

Air environment 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.

8.2 Liquid level gauges

Subclause 5.1.3 of IEC 60214-1 requires that liquid level gauges should 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.

8.3 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 condition, giving early warning to prevent a possible catastrophic failure due to low liquid. The device may be separate to, or integral with, any liquid-flow operated relay. In some instances, this device may be supplied by the transformer manufacturer rather than the tap-changer manufacturer.

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

8.4 Nameplate and other plates

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

8.5 Devices to aid maintenance

The design of the tap-changer and transformer should take into account the need to be able to carry out maintenance safely. Items that require regular maintenance should be made reasonably accessible. Any devices required for lifting heavy items, such as diverter switches or covers of tap selector compartments, should be provided.

8.6 Dehydrating breathers

If the tap-changer breathes to atmosphere, 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, either with separate conservators or connected to the conservator 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.

9 Field service (operation, maintenance and monitoring)

9.1 Operation

9.1.1 Parallel operation

In the case of parallel operation of transformers with tapped windings, care should be taken by the manufacturer and the user of the transformer to ensure that the currents circulating between the transformers are limited to acceptable values.

NOTE See 6.2.8.

9.1.2 Contact erosion and liquid contamination

Tap-changers have expendable items in their construction and the manufacturer's figures should be noted for maintenance periods in terms of time and numbers of operations. Generally, expected life of contacts for diverter or selector switches of a particular on-load tap-changer is given assuming maximum rated through current. If the load current of the transformer is lower than this, then contact life will be longer. For reactor type tap-changers, contact life may be affected by recovery voltages since arc extinction may not occur at the first current zero.

The number of operations before a liquid change is necessary for diverter or selector switches is conditional on the liquid being in good condition originally and maintained in a dry state.

The fitting of a fixed liquid filter (or combined filter and drier) to provide in service filtering (or filtering and drying) of the liquid in diverter or selector switches could be considered, to extend the period before a liquid change is required. This can also reduce mechanical wear by removing particles earlier. Filtering is normally only considered necessary for tap-changers performing very high numbers of operations. Where on-load tap-changers operate at high voltage stresses or at extremes of temperature and/or humidity a combined filter and drier may be considered necessary.

9.1.3 Overheating of selector contacts when operating on fixed tap position

Overheating of selector contacts can occur for the following reasons:

– low selector contact spring pressure;
– operation on one position for long periods (months);
– high ambient oil temperature.

If the contact spring pressures become low and the contact resistance higher than normal, it is possible that overheating can begin to occur at the contact surfaces, creating carbon growth which progressively worsens the situation. This can eventually lead to the generation of free gas, and potentially to a flashover situation which may catastrophically damage the transformer. In extreme cases, the carbon growth (sometimes referred to as pyrolytic carbon growth) between and around the contacts can bind the contacts together preventing movement, which can also cause mechanical damage if an attempt is subsequently made to operate the tap-changer

When tap-changers remain for long periods (months) on fixed tap position, the normal wiping action which cleans the contact surfaces during operation of the tap selector contacts, does not occur. Depending on the design, this may be a potential problem for off-circuit tap-changers and for the change-over selector of on-load tap-changers. It should be noted that even when the on-load tap-changer is operated frequently, the change-over selector may remain on the same position for long periods and this may cause similar problems to the change-over contacts.

High ambient oil temperatures combined with normal contact temperature rise can lead to pyrolitic carbon formations under extreme conditions.

Regular DGA of the oil should lead to early detection of the above problems. Hydrogen may be an early indicator although a positive interpretation is difficult at that stage, with generation of methane, ethane and ethylene occurring as the problem worsens. If DGA results indicate overheating, it should be assumed that pyrolytic carbon growth and contact binding has possibly already occurred. Such instances produce high levels (tens or hundreds of parts per million) of methane and, particularly, of ethylene with characteristic T3 according to IEC 60599. Where evidence suggests pyrolytic carbon growth and contact binding may have occurred, the tap selector should be opened for inspection before it is operated otherwise mechanical damage may occur.

When it is known that selectors (especially change-over selectors and off-circuit selectors) have remained in one position for an extended period of time, the operation of the selector across its complete tapping range during routine maintenance is recommended to clean the contact surfaces.

9.1.4 Discharges during the operation of changeover selectors

The discharges that occur between the opening and closing contacts of a change-over selector generate gases, in particular acetylene and hydrogen, which, while not being particularly significant, can mask other defects when DGA is used to monitor the tap-changer oil for on-going problems. In extreme cases, the gases can contribute to dielectric breakdown, but this is rare. Tap-changers performing high numbers of operations through the change-over position can generate considerable quantities of acetylene and hydrogen in the oil. Control measures, such as the inclusion of tie in resistors, may reduce the gas generation but do not eliminate it entirely.

9.2 Maintenance

9.2.1 Liquid replacement

Mineral oil should not be replaced by oil of a different class, or by a different liquid, without consulting the tap-changer manufacturer. This is because different oils or liquids may have different viscosities or dielectric characteristics, which may affect the operating speed and dielectric integrity of the tap-changer.

9.2.2 Contact resistance measurement

Contact resistance measurements can be used as a diagnostic check, or as part of the maintenance regime, to identify or prevent problems caused by weakened contact springs and overheated contacts.

Acceptable values for contact resistance depend on the design and current rating of the tap-changer. If the contact resistance deteriorates significantly then overheating may occur. For guidance only, if the contact power loss (the product of contact resistance and the square of the current) is greater than 100 W (or less for very high current ratings) then overheating may occur. In cases of doubt, resistance can be compared with figures measured as new if available, with manufacturers recommended figures or with figures for similar contacts.

9.3 Monitoring in service

9.3.1 DGA of mineral oil

Routine DGA on the oil from tap selector compartments or tanks including off-circuit tap-changers provides a powerful monitoring tool to identify ongoing or slowly developing problems. Experience suggests an annual frequency is a reasonable compromise between the cost and the ability to find slowly developing faults before they cause failure.

Routine DGA can be of assistance in the following situations:

– developing overheating of contacts or connections, including carbon growth situations, characterized by increasing levels of, in particular, methane and ethylene;
– capacitive discharging, such as from loose stress shields, items at different or floating potentials or operation of change-over selectors, characterized by increasing levels of acetylene and hydrogen, but with little or none of the gases generated by overheating;
– power arcing, from open circuits or selectors breaking current, characterized by high levels of acetylene and ethylene with significant increases in most of the other diagnostic gases.

Continuous DGA monitors are available and are usually employed to monitor the continued service of a tap-changer with a known defect, until such time as the defect can be rectified.

Advice on interpretation of the DGA results can be found in IEC 60599.

DGA on diverter or selector switch oil could be of some benefit to determine possible overheating of the contacts.

If a vacuum interrupter is employed, no arcing gas is generated during the switching operation.

NOTE DGA could also be used for the diagnosis of major faults.

9.3.2 Other liquid testing

Routine (at least annual) testing of the liquid in the diverter switch, selector switch and tap selector compartments should be carried out to ensure that levels of moisture and breakdown voltage of the liquid are within recommended criteria.

9.3.3 Non-invasive monitoring techniques

Such monitoring may be continuous or may be installed in response to a suspected defect condition and may include

– monitoring of motor current or shaft torque to check that no undue stiffness exists during the operation of the tap-changer;
– monitoring of discharge levels around the tap-changer, usually in response to abnormal DGA results or other defect indicator;
– monitoring of acoustic noise levels around the tap-changer, usually in response to reports of abnormal noise characteristics, abnormal DGA results or other defect indicator;
– contact thermometer or infrared monitoring of compartments to identify any abnormal temperature conditions;
– monitoring the temperatures of the tap-changer and transformer tanks and checking trends of the temperatures and the temperature differentials to establish whether there may be an increasing trend for the temperature in the tap-changer;
– monitoring of contact wear.

9.3.4 Invasive monitoring techniques

Such monitoring may be continuous or may be installed in response to a suspected defect condition and may include

– the monitoring of diverter switch operation. This may be achieved by fitting current transformers on the connections in the diverter switch. The current transformers can be arranged to monitor the switching sequence of the diverter switch and to check that the transition resistors are not left in circuit for too long a period. They can also be used for monitoring or as a protection system;
– the monitoring of tap selector angular position to ensure that the selector drive shafts are in the correct position thus ensuring that contacts are fully made.

NOTE Such monitoring devices should only be fitted after consultation with the tap-changer manufacturer and the transformer manufacturer.

9.3.5 Commercial monitoring systems

Tap-changers can suffer from various types of defect or failure modes, and no single monitoring technique can cover every situation. Commercial monitoring systems are available that incorporate a number of the foregoing monitoring techniques, and users will need to consider the benefits against the cost of such systems.

10 Information to be provided by the transformer manufacturer

10.1 Information required at the enquiry or order stage for an on-load tap-changer

a) Relevant specification (IEC 60214-1)

b) Number of tap-changers required

c) Single or polyphase units

d) Number of phases in the system

e) Frequency

f) Rated power of apparatus to which the tap-changer is to be connected

g) Rated voltage of the winding to which the tap-changer is to be connected

h) Winding connections

i) Tap range required, given in per cent above and below the rated voltage of the winding

j) Number of service tap positions required, the numbering of these positions and their identification with reference to the transformer tapings

k) Tap arrangement (for example, linear, reversing or coarse/fine)

l) Position of taps in winding (for example, line end, middle, neutral point)

m) Highest tap current of the winding to which the tap-changer is to be connected (see 3.5.10 of IEC 60076-1)

n) Maximum value and duration of short-circuit current passing through the tap-changer

o) Phase voltage per step (if the step voltage varies over the range, give full details, together with associated currents)

p) On neutral point tap-changers, whether one neutral terminal or three separate neutral terminals are required (not available on all tap-changer designs)

q) The power-frequency voltage appearing between the opening and closing contacts of the change-over selector (see 6.2.6)

r) Insulation levels in accordance with 6.2.1:

    i) highest voltage between the extreme taps and, where applicable, the highest voltage between the ends of the coarse tap winding section and the fine tap section

    ii) highest voltage between the most onerously stressed tap and earth

    iii) highest voltage between taps of adjacent phases

    iv) highest voltage between the diverter switch and earth

    v) highest voltage between phases of the diverter switch

    vi) highest voltage between open diverter switch contacts

s) Special design options (for example, fork mounting, tropical environment)

t) Specifications for painting

u) Driving assembly specifications including information for intermediate bearings and guard plates

v) Pressure, vacuum and temperature requirements:
   i) maximum working pressure when liquid filled
   ii) maximum pressure during liquid tests on the apparatus
   iii) maximum vacuum to be applied
   iv) type of processing, maximum temperature, vacuum and duration if the tap-changer is fitted before this operation
   v) temperatures in special environments, for example, noise enclosures, etc.
   vi) minimum operating temperatures and details of any special low temperature requirements if below –25 °C

w) Special
   i) details of periods of abnormal overload, value and duration (exceeding IEC 60354)
   ii) details of excessive number of operations
   iii) details of use if of a heavy duty application, such as arc furnaces, rolling mills, HVDC (see 6.2.10), generator transformers, phase-shifting transformers (see 6.2.2.4) and quadrature booster transformers
   iv) details of the transformer transport arrangements
   v) any other special requirements

x) Number, type and position of fittings

y) Position and specification of voltage-limiting elements (for example, protection spark gaps, ZnO surge arrestors)

z) Leakage inductance between coarse winding and fine tapped winding (for coarse/fine winding connection only) (see 6.2.7)

aa) Number, type and position of protective devices including number, type and position of local and remote indication.

bb) Drive mechanism

cc) To enable the correct control devices to be included in the drive mechanism, the fullest possible details of the control scheme should be given by the purchaser, including which, if any, of the following basic control functions are required, together with the type of device necessary for the function:
   i) local electrical control and indication
   ii) remote electrical control and indication
   iii) local automatic control and indication, with or without line drop compensation
   iv) remote automatic control and indication, with or without line drop compensation
   v) parallel control of two or more transformers
   vi) supervisory control and indication
   vii) in the case of remote and supervisory control and indication, the load and the approximate distance between the tap-changer and the control point should be stated
   viii) auxiliary supply details for electrical motor and control equipment, that is, normal voltage, maximum and minimum voltage limits if not within the standard limits given in 11.2 of IEC 60214-1, a.c. or d.c. If a.c. frequency, number of phases and availability of neutral point

dd) Specifications of the housing of the drive mechanism including special requirements (for example, padlock facility, position of hinges)

ee) Kind and number of documentation and labels required

ff) Specification of accessories (for example, lifting device, liquid filter unit, spare parts)

10.2 Information required with enquiry or order for off-circuit tap-changers

10.2.1 General

a) Number of tap-changers required
b) Rated voltage of the winding to which the tap-changer is to be connected
c) Winding connections and potential of that point of the winding where the tap-changer is connected
d) Rated current of the windings to which the tap-changer is to be connected
e) Number of positions (taps)
f) Adjustment: tap range required, given in per cent above and below the rated voltage of the winding. If nothing is said, it is intended a value of 2,5 % as a standard
g) Type of tap connections: single or double bridging (pawl adjustment), single or double linear (fixed point), star-delta, series-parallel or combinations of these
h) For fixed point tap-changers, whether one neutral terminal or three separate neutral terminals are required
i) Structure: single-phase or three-phase
j) If the drive mechanism is not directly fitted on the lid of the transformer tank
   i) length of horizontal shaft
   ii) length of vertical shaft
k) Type of drive mechanism: handle (hand crank or hand wheel) or motor drive
l) Auxiliary supply details for electrical motor and control equipment, that is, normal voltage, maximum and minimum voltage limits if not within the standard limits given in 11.2 of IEC 60214-1, a.c. or d.c. If a.c. frequency, number of phases and availability of neutral point

10.2.2 Only for rack or slide-type design off-circuit tap-changer

a) Position: horizontal or vertical
b) Control shaft exit: on the cover, high on the wall or low on the wall

10.2.3 Small off-circuit tap-changers

For small off-circuit tap-changers intended for use on low-voltage distribution and similar systems, only 10.2.1 items a) to i) are required as a minimum.

10.3 Documentation

Technical and dimensional information of the tap-changer should be made available from the tap-changer manufacturer prior to an order.

Instruction concerning installation requirements, transport, erection, maintenance and operations should be made available from the tap-changer manufacturer to the purchaser in advance of delivery. This will make it possible for the purchaser to check the correctness in installation and the steps taken for transport, storage and erection.

The transformer designers should take due account of the relevant information about the tap-changer before any mechanical or electrical design work starts.

Users of the tap-changer should familiarize themselves with the instructions for the job to be done.

11 Protection and safety

11.1 Protection

On-load tap-changers will be equipped with at least one type of over-pressure protection device described in 5.1.4 of IEC 60214-1. This protection will be connected to the compartment where the arcing will take place, and elsewhere if recommended by the manufacturer. The manufacturer of the on-load tap-changer will give the recommended setting of the protection device. The protection device should have one output that is suitable for connection to the transformer tripping system.

11.2 Safety aspects

11.2.1 Gases

The gases generated by the arcing in the on-load tap-changer could be a hazard from the point of view of both fire and health. In outdoor installations, the dispersion of the gases is not a problem. With regard to indoor installations, however, adequate ventilation should be provided.

11.2.2 Operation of an on-load tap-changer

If any problems with the tap-changer are suspected, it should not be operated when the transformer is energized. However, if operation is unavoidable,

– avoid changing the tap manually; or
– avoid automatic operation if personnel are close by.

Note that sluggish movement under motor operation or undue torque to operate under manual operation may indicate a problem.

11.2.3 Manual operation of an off-circuit tap-changer

It is most important to understand that an off-circuit tap-changer should never be operated with the transformer energized. It is definitely not sufficient to operate the unit off load, as, in this condition, the off-circuit tap-changer will, in most cases, try to break the full transformer phase voltage with possible catastrophic consequences. The contacts are not designed to break current or voltage. It is for this reason that the term “off-circuit tap-changer” is used both in this publication and in IEC 60214-1. The use of the term “off-load tap-changer” is deprecated.

Attention is drawn to the warning label shown in Figure 4 of IEC 60214-1 and the requirement for the manufacturer to fit or supply it. When supplied, the responsibility of fitting the label rests with the purchaser. The label should be fitted adjacent to the operating handle. Attention is also drawn to the use of safety interlocks described in 7.1.5 of IEC 60214-1.

11.2.4 Pressure-relief devices

For pressure-relief devices, consideration should be given to fitting an outlet such as ducting or trunking from the pressure-relief device to protect personnel from the displaced liquid.

11.3 Immersing medium

The tap-changer manufacturer shall recommend an appropriate immersing medium for use with the tap-changer. If an alternative non-recommended medium is used it is at the risk of the user since the different properties could affect the function of the on-load tap-changer. To go outside the tap-changer manufacturer’s recommendations could result in tap-changer failure.

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