

# ***Recommendation 28***

*10-400 kV oil-immersed shunt reactors*

*2<sup>nd</sup> edition*

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## 1. Subject and scope

This recommendation provides recommendations on a number of technical conditions to be considered in connection with invitations to tender for 10-400 kV oil-immersed shunt reactors. A shunt reactor is a reactor which is connected in parallel to an electric power system in order to compensate for the capacitive current in the system.

The recommendation does not cover the considerations to be made when the shunt reactor's rated power, adjustment range and physical location in the grid are determined.

The various potential forms of purchase applicable for EU invitations to tender have not been treated. Instead, see the EU's Procurement Directive (2004/17/EC).

When specifying a shunt reactor in connection with an invitation to tender, the design as well as the tests to be performed must be described in detail. A shunt reactor must comply with the requirements of the Danish Executive Order, Stærkstrømsbekendtgørelsen (in Danish), and thus the standards prepared by CENELEC and in some cases IEC (where no CENELEC standards are available) which are relevant to shunt reactors and accessories.

In areas where no international standards are available, tender offerers may apply their own requirements. Furthermore, technical requirements may be made of the supplier in connection with any prequalification. These requirements must not take the form of technical trade barriers.

The user of this recommendation must ensure that the current version and any applicable amendments to standards are used when preparing invitations to tender. Information about the applicable version and any amendments is available from Danish Standards (*Dansk Standard*) or IEC and CENELEC.

This recommendation includes a Danish and an English version. In case of any discrepancies between the two versions, the Danish version is valid.

## 2. DEFINITIONS

The following definitions for shunt reactors are used in this recommendation.

- 2.1 Shunt reactor** Reactor connected between phase and earth, phase and neutral or between phases in an electric power system to compensate for the capacitive current.
- 2.2 Linear shunt reactor** Shunt reactor with an inductance which is constant within the tolerances stated in this recommendation.
- 2.3 Adjustable shunt reactor** Shunt reactor in which the inductance can be adjusted by changing the number of turns on the winding or by varying the air gap in the iron core.
- 2.4 Oil-immersed shunt reactor** Shunt reactor in which the main winding and the magnetic circuit are immersed in oil.
- 2.5 Iron core with air gap** Shunt reactor core of ferromagnetic materials with one or more built-in air gaps.
- 2.6 Tap changer** Device used to change the number of turns on a winding.
- The tap changer may be dimensioned to change the number of turns while the winding is energised or while it is dead.

### 3. STANDARDS

The standard for shunt reactors is DS/EN 60076 – 6 ‘Power transformers – Part 6: Reactors’. The standard forms part of the 60076 series, cf. Table 1, which includes power transformers. Conditions which apply to transformers and reactors are described in the relevant parts of the 60076 series. Generally, a shunt reactor must be designed and tested in accordance with applicable CENELEC and IEC standards.

*Note 1: A shunt reactor can be considered as a transformer with an open-circuit secondary winding.*

*Table 1: Standards for shunt reactors*

<b>Standard</b>	<b>Title</b>
DS/EN 60076 – 1	Power transformers – Part 1: General
DS/EN 60076 – 2	Power transformers – Part 2: Temperature rise
DS/EN 60076 – 3	Power transformers – Part 3: Insulation levels, dielectric tests and external clearances in air
DS/EN 60076 – 4	Power transformers – Part 4: Guide to lightning impulse and switching impulse testing – Power transformers and reactors
DS/EN 60076 – 6	Power transformers – Part 6: Reactors
DS/EN 60076 – 10	Power transformers – Part 10: Determination of sound level

Other international standards which are relevant to shunt reactors are:

*Table 2: Standards relevant to shunt reactors*

<b>Standard</b>	<b>Title</b>
DS/EN 60137	Insulated bushings for alternating voltages above 1000 V
DS/EN 50180	Bushings above 1 kV up to 36 kV and from 250 A to 3,15 kA for liquid-filled transformers
DS/EN 50299	Oil-immersed cable connection assemblies for transformers and reactors having highest voltage for equipment $U_m$ from 72,5 kV to 550 kV
IEC/TR 61639	Direct connection between power transformers and gas-insulated metal-enclosed switchgear for rated voltages of 72,5 kV and above
DS/EN 60214 – 1	Tap-changers – Part 1: Performance requirements and test methods
DS/EN 60296	Fluids for electrotechnical applications. Unused mineral insulating oils for transformers and switchgear
DS/EN 50464-2-1	Three-phase oil-immersed distribution transformers 50 Hz, from 50 kVA to 2,500 kVA with highest voltage for equipment not exceeding 36 kV – Part 2-1: Distribution transformers with cable boxes on the high-voltage and/or low-voltage side – General requirements
DS/EN 50464-2-2	Three-phase oil-immersed distribution transformers 50 Hz, from 50 kVA to 2,500 kVA with highest voltage for equipment not exceeding 36 kV – Part 2-2: Distribution transformers with cable boxes on the high-voltage and/or low-voltage side – Cable boxes type 1 for use on distribution transformers meeting the requirements of EN 50464-2-1

DS/EN 50336	Bushings for transformers and reactor cable boxes not exceeding 36 kV
<b>Standard</b>	<b>Title</b>
DS/EN 62535	Insulating liquids. Test method for detection of potentially corrosive sulphur in used and unused insulating oil

Accessories for power transformers and reactors – including shunt reactors – are covered by different standards for the specific types of accessories. An important series of CENELEC standards is the EN 50216 series ‘Power transformers and reactor fittings’, which covers the majority of the most common accessories. Table 3 provides an overview of the series as well as the type of accessories which the individual parts cover (evident from the title).

*Table 3: Standards in the EN 50216 series*

<b>Standard</b>	<b>Title</b>
DS/EN 50216 – 1	Power transformers and reactor fittings – Part 1: General
DS/EN 50216 – 2	Power transformers and reactor fittings – Part 2: Gas and oil-actuated relay for liquid-immersed transformers and reactors with conservator
DS/EN 50216 – 3	Power transformers and reactor fittings – Part 3: Protective relays for hermetically sealed liquid-immersed transformers and reactors without gaseous cushion
DS/EN 50216 – 4	Power transformers and reactor fittings – Part 4: Basic accessories (earthing terminal, drain and filling devices, thermometer pocket, wheel assembly)
DS/EN 50216 – 5	Power transformers and reactor fittings – Part 5: Liquid level, pressure and flow indicators, pressure relief devices and dehydrating breathers
DS/EN 50216 – 6	Power transformers and reactor fittings – Part 6: Cooling equipment – Removable radiators for oil-immersed transformers
DS/EN 50216 – 7	Power transformers and reactor fittings – Part 7: Electric pumps for transformer oil
DS/EN 50216 – 8	Power transformers and reactor fittings – Part 8: Butterfly valves for insulating liquid circuits
DS/EN 50216 – 9	Power transformers and reactor fittings – Part 9: Oil-to-water heat exchangers
DS/EN 50216 – 10	Power transformers and reactor fittings – Part 10: Oil-to-air heat exchangers
DS/EN 50216 – 11	Power transformers and reactor fittings – Part 11: Oil and winding temperature indicators

Furthermore, new parts of the series are under way. The suggestions currently available (2009) are listed in Table 4. Please note that in the meantime, these may have been adopted as a European standard, ie EN, and subsequently as a Danish standard, ie DS.

*Table 4: Suggestions for the EN 50216 series (2009)*

<b>Standard</b>	<b>Title</b>
prEN 50216 – 12	Power transformers and reactor fittings – Part 12: Fans

The above are considered to be the most important standards in connection with shunt reactors, in which references to other relevant standards are available. Other standards may be relevant.

The majority of the above standards have a Danish title and are thus Danish standards, designated DS/EN. In these cases, however, often only the title has been translated into Danish. The document is therefore identical to the EN document.

*Note 1: In cases where only the designation IEC is used, an EN version of the standard currently does not exist. The majority of the standards are European Norms based on an IEC standard – these are normally numbered 6xxxx. If the standard is a European Norm which is not based on an IEC standard, the document is normally numbered 5xxxx. Users of the standard should be aware that the EN version may contain changes or additions to the IEC version. Consequently, in cases where both exist, the EN version (ie DS/EN) should always be applied.*

For standards applying to corrosion protection reference is made to Danish Standard, CEN and ISO.

*Note 1: Currently DEFU has a report RA 552 in the pipeline (2010), which will contain information about corrosion protection.*

## 4. Service conditions

When a new shunt reactor is procured, the conditions under which the shunt reactor is going to operate must be specified in the invitation to tender. The service conditions may be vital to the design and structure of the shunt reactor.

For oil-immersed shunt reactors, the general service conditions have been specified in DS/EN 60076 – 1.

### 4.1 Ambient temperature

The shunt reactor must be intended for installation at ambient temperatures in the following range:

$$-25^{\circ}\text{C} \dots +40^{\circ}\text{C}$$

Furthermore, the monthly average temperature must not exceed 30°C, and the annual average temperature must not exceed 20°C.

*Note 1: If the ambient temperature exceeds 40°C, this may impact the reliability and life of the shunt reactor unless measures are taken, for instance to limit the impact of the higher ambient temperature.*

*Note 2: The temperature requirements must normally also be met during transport and storage.*

### 4.2 Waveform of the operating voltage

The shunt reactor is intended for an operating voltage which approximately follows a sine curve.

A waveform can be assumed to be sinusoidal if the total harmonic factor does not exceed 5%, and the even harmonic factor does not exceed 1%. The harmonic factor is determined on the basis of the following expression:

$$H[\%] = 100 \cdot \left[ \sum_{h=2}^{h=H} \left( \frac{U_h}{U_1} \right)^2 \right]^{\frac{1}{2}}$$

where

$U_1$                       The 50 Hz voltage  
 $U_h$                       The  $h^{\text{th}}$  harmonic current

*Note 1: A high harmonic content in the load current causes increased loss due to additional eddy current losses in the winding, oil tank, iron core and other metallic parts, as well as increased  $I^2R$  loss. This could require measures to be taken to either reduce the harmonics in the current or to ensure that the design of the shunt reactor takes the increased losses due to harmonic currents into consideration.*

### 4.3 Three-phased shunt reactor

The load on the three phases must be approximately symmetrical.

### 4.4 Installation environment

For invitations to tender, the environment in which the shunt reactor is to be installed must be described. For instance, it must be stated whether the shunt reactor is to be installed indoors or outdoors, the level of contamination, the corrosion category, etc.

It may reasonably be assumed that the internal dielectric properties of an oil-immersed shunt reactor – ie the oil/paper insulation – are not affected by contamination, humidity etc. in the ambient air, because the oil tank shields the internal electrical insulation against such factors. Therefore, only the external insulation of the shunt reactor, in connection with eg bushings and connections, is affected by the surrounding environment.

If special considerations are required concerning the surrounding environment of bushings, due to eg heavy contamination, such considerations must be made in accordance with DS/EN 60137 and IEC/TR 60815 – see section 6.10.

### 4.5 EMC

The shunt reactor and its accessories must comply with the EMC Directive (2004/108/EC).

Please note that for fixed installations, documentation must also be submitted that the installation complies with the EMC Directive – ie when the shunt reactor and its accessories have been installed, it must be documented that the installation also complies with the EMC Directive.

**4.6 Abnormal conditions** **service** In case of abnormal service conditions, eg extremely low or high temperatures, high harmonic content in the voltage, heavy contamination, high salt content in air etc., such conditions must be specified in the invitation to tender.

## 5. Ratings

Rated parameters for a shunt reactor must refer to continuous operation with the service conditions described in section 4 being met.

- 5.1 Rated frequency** The rated frequency is 50 Hz.
- 5.2 Rated voltage** The rated voltage,  $U_r$ , forms the basis for the shunt reactor properties and is the voltage on the basis of which the manufacturer warrants the shunt reactor.
- The rated voltage is the voltage to which the rated power of the shunt reactor refers. The buyer must specify the rated voltage in the invitation to tender.
- 5.3 Rated reactance** The reactance of the shunt reactor,  $X_r$ , in Ohms per phase at rated voltage and frequency.
- For an adjustable shunt reactor, this is the reactance at minimum inductance, rated voltage and frequency. For a stepwise adjustable shunt reactor, this corresponds to the position with the fewest turns connected. For a shunt reactor with an adjustable air gap in the iron core, this corresponds to the position with the largest air gap.
- 5.4 Rated power** Reactive power,  $Q_r$ , at rated voltage and frequency.
- For a controllable shunt reactor, this is the reactive power at rated reactance, voltage and frequency.
- 5.5 Rated current** Current at rated voltage, reactance and frequency.
- 5.6 Linearity** Unless otherwise specified in the invitation to tender, a shunt reactor must be linear (constant reactance) up to and including 1.3 times the highest voltage for equipment,  $1.3 U_m$ , cf. section 5.9.1.
- For an adjustable shunt reactor, the linearity must be complied with for each inductance setting up to and including  $1.3 U_m$ .
- 5.7 Mutual reactance** The ratio between induced voltage over an open phase and the current in an energised phase.
- For an adjustable shunt reactor, this is the mutual reactance at rated reactance, voltage and frequency.
- 5.8 Zero reactance** The reactance,  $X_0$ , per phase for a three-phase star-connected shunt reactor at rated frequency and voltage, equalling three times the reactance measured between the interconnected line terminals and the neutral terminal.
- For an adjustable shunt reactor, this is the zero reactance at rated reactance, voltage and frequency.
- 5.9 Insulation level** The insulation level for a shunt reactor characterises the dielectric properties of the shunt reactor. The level must be specified in accordance with DS/EN 60076 – 3, based on the voltages below.
- 5.9.1 Highest voltage for equipment,  $U_m$**   
The highest phase-phase voltage (RMS) for which a shunt reactor is designed.
- The highest voltage for equipment,  $U_m$ , can be equal to or exceed the rated voltage of the shunt reactor and is normally selected on the basis of the standardised values in DS/EN 60076 – 3, cf. section 5.9.5.
- 5.9.2 Rated short-term AC withstand voltage**  
Test voltage used in connection with the induced withstand AC voltage test and separate source AC withstand voltage test.
- 5.9.3 Rated lightning impulse withstand voltage**  
Test voltage used in connection with the lightning impulse withstand tests.
- 5.9.4 Rated switching impulse withstand voltage**  
Test voltage used for switching impulse withstand tests. Normally only specified for shunt reactors to be used at a nominal line voltage of 400 kV (in Denmark).

### 5.9.5 Insulation level

Table 5 shows standardised insulation levels based on European practice in DS/EN 60076 – 3.

Table 5: Standardised insulation level for shunt reactors, cf. IEC and CENELEC

Nominal line voltage [kV] (RMS)	Highest voltage for equipment [kV] (RMS)	Rated short-term AC withstand voltage [kV] (RMS)	Rated lightning impulse voltage, 1.2/50 $\mu$ s [kV]	Rated switching impulse voltage (phase – earth) [kV]
10	12	28	75	-
15	17,5	38	95	-
20	24	50	125	-
30	36	70	170	-
50-60 kV	72,5	140	325	-
132	145	275	650	-
150	170	325	750	-
400	420	570	1425	1050

### 5.9.6 Insulation level for neutral terminal (if available)

#### 5.9.6.1 Voltages up to and including 72.5 kV

The insulation level of the neutral terminal must be selected in the same way as the insulation level for the shunt reactor, cf. Table 5.

#### 5.9.6.2 Voltages exceeding 72.5 kV

If the shunt reactor's neutral terminal is always directly earthed, the neutral terminal must have a minimum insulation level corresponding to a short-term AC withstand voltage of 50 kV, cf. Table 5.

If the neutral point can float in relation to earth, the insulation level of the neutral terminal must be selected in the same way as the insulation level for the shunt reactor, cf. Table 5.

### 5.10 Inrush current

In the invitation to tender, the buyer must specify that the manufacturer must document the inrush current level.

Unless otherwise agreed, the calculation of inrush current in accordance with DS/EN 60076 – 6 must be based on the rated voltage, reactance, frequency, maximum short-circuit power in the network and 'worst case' phase angle at connection.

### 5.11 Connection between phase windings

The connection – star or delta – between phase windings must be specified in the invitation to tender. If the neutral terminal is to be available, the windings must be star-connected.

### 5.12 Temperature rise

5.12.1 Under normal service conditions, including continuous operation at highest voltage for equipment,  $U_m$ , cf. section 5.9.1, the following thresholds apply to the temperature rise in the shunt reactor in accordance with DS/EN 60076 – 2:

Top oil temperature rise	60 K
Average temperature rise for winding	65 K

If the temperature of the external cooling medium (normally air) exceeds 40 °C, cf. section 4.1, the temperature rise thresholds must be reduced correspondingly.

Forced cooling in the form of an oil pump or fans (OFAF or ONAF, cf. section 6.5.) may be necessary under the given installation conditions in order to reduce the temperature rise in the shunt reactor. If a shunt reactor is to be installed under conditions restricting its cooling, this must be stated in the invitation to tender.

**5.12.2** Threshold values for temperature rise for core, oil tank etc. have not been specified. However, these parts must not be able to reach a temperature at continuous operation at which they damage the shunt reactor, affect its reliability or reduce its intended life.

**5.13 Adjustment (in case of an adjustable shunt reactor)** The desired adjustment method, range and interval for positions (in case of stepwise control) must be specified in the invitation to tender.

The adjustment methods can be stepwise control, in which a tap changer is used to change the number of turns on the shunt reactor winding, or continuous adjustment, where the size of the iron core air gap is changed. In sections 6.13 and 6.14, the requirements for the two adjustment methods are specified.

The choice of adjustment positions in stepwise control is partly determined by the tap changer and its rating and should therefore be finally determined in cooperation with the manufacturer. If on-load adjustment is requested, this should also be indicated in the invitation to tender.

**5.14 Loading of neutral terminal** For a three-phased shunt reactor or three single-phased shunt reactors in a three-phased shunt reactor battery with the three phase windings being star-connected, the neutral terminal must be able to bear a continuous load equal to the shunt reactor's rated current.

**5.15 Sound power level** The invitation to tender must specify a maximum allowable sound power level for the shunt reactor.

If the shunt reactor's cooling is designed with forced circulation of internal and/or external cooling medium, cf. section 6.6, the tender documents must specify that the additional sound power level from eg a fan or pump must be stated in dB.

The overall contribution of the shunt reactor's sound power level and the sound power level from the forced circulation of cooling medium must not exceed the maximum sound power level specified in the tender documents. If so, the buyer reserves the right to reject the shunt reactor.

**5.16 Capitalisation of losses** The invitation to tender must state a capitalisation factor,  $K_b$ , which is used to capitalise losses in the shunt reactor.

For a stepwise adjustable shunt reactor, the losses in the two extreme positions and the middle position must form the basis of calculation of the capitalisation factor. For a continuously adjustable shunt reactor, the losses in the two extreme positions (max. and min. reactive power) and the middle position must form the basis of calculation of the capitalisation factor. In the invitation to tender, the buyer must state how the losses in the three control positions are weighted in the calculation.

The capitalisation factor for losses ( $K_b$ ) stated in the invitation to tender must form the basis of the tender. If the losses deviate by more than +10%, cf. DS/EN 60076 – 6, from the losses guaranteed in the tender, the buyer reserves the right to reject the shunt reactor.

If the losses exceed the guaranteed value, a deduction in the purchase price corresponding to the excess must be made. The capitalisation factor of the invitation to tender must be used when calculating the deduction. If agreed between manufacturer and buyer, set-offs may take place for losses which are lower than the values stated in the invitation to tender.

When capitalising the power requirements of the cooling equipment, the capitalisation factor  $K_b$  must also be used, and the power consumption of the cooling equipment must be considered as a loss.

## 6. CONSTRUCTION

This section describes conditions regarding the construction of the shunt reactor.

### 6.1 Type

The shunt reactor may be a three-phased shunt reactor or three single-phased shunt reactors in a three-phased system. Three-phased shunt reactors may furthermore be subdivided into shunt reactors with three or five legs. In the five-legged shunt reactor, the magnetic circuits for the three reactor windings are mutually independent.

The tender documents may specify whether the shunt reactor should be three single-phased or one three-phased shunt reactor. Single-phased shunt reactors reduce the costs of having a shunt reactor as a reserve in case of a fault. Any transport restrictions may also influence whether one or the other type is chosen. The choice may therefore be made in cooperation with the manufacturer on the basis of information in the tender documents, taking the availability of the installation and the available space for the installation into consideration.

### 6.2 Core

The core must be an iron core with one or more air gaps.

The air-gapped iron core must be designed to resist the mechanical impacts during normal operation and fault situations in the network.

### 6.3 Insulation oil

Unless otherwise specified in the invitation to tender, the insulation oil must be a mineral oil which complies with the requirements of DS/EN 60296 for transformer oil (cf. Table 2 in IEC 60296), with the following additions:

– Surface tension	> 40 mN/m at 20°C
– Antioxidant additives	Min. 0.08% Max. 0.4%

To minimise the risk of copper sulphides forming in the oil, the oil must be tested as 'non-corrosive'. The test must be performed and the result documented in accordance with DS/EN 62535.

### 6.4 Copper parts immersed in insulation oil

Copper parts immersed in insulation oil must be lacquered.

### 6.5 Cooling medium

In oil-immersed shunt reactors, the insulation oil (designated O) is also the cooling medium which can both absorb heat from the reactor winding and conduct the heat away by circulating the oil. When the oil interacts with the oil tank, some of the heat contained in the oil is transferred to the tank, which again emits heat to the ambient air (designated A), which also circulates across the surface of the tank. The circulation of the oil in the tank may be due to natural causes (designated N) related to the temperature difference between the top and bottom oil, or it may be forced (designated F). Likewise, the air circulation around the oil tank may be due to natural causes (N), or it may be forced (F). In addition to air as an external cooling medium, water (designated W) may also be used, which is led by the tank in a heat exchanger.

If forced air cooling is chosen (eg ONAF), it must be temperature-controlled.

The choice of one or the other type of cooling of the shunt reactor depends on the installation conditions of the shunt reactor as well as on the desired rated power of the shunt reactor. In the invitation to tender, it may be chosen to let the manufacturer propose a solution which complies with the specifications of the invitation to tender. A financial comparison of solution proposals may be performed subsequently by capitalising the losses in the shunt reactor and the energy used for cooling, cf. section 5.17. This shall not exclude possible solutions in connection with the invitation to tender.

If the rated power of the shunt reactor requires forced cooling (eg ONAF or OFAF) to avoid exceeding the threshold limits for the temperature rise in the shunt reactor, this must be stated on the shunt reactor's rating plate. For an adjustable shunt reactor, it must also be stated at which adjustment positions cooling by natural air and oil circulation (ONAN) is sufficient without exceeding the temperature rise thresholds in the shunt reactor, cf. section 5.13.

## 6.6 Oil tank etc.

The oil tank, diverter switch tank, radiators, gaskets, valves, oil conservator etc. must be dimensioned to withstand, without permanent deformation, an internal overpressure corresponding to 100 kPa and to withstand full vacuum (100 Pa) without permanent deformation. Under these conditions, the shunt reactor must remain oil-tight at top oil temperatures which may exist during operation.

The oil tank may be designed with one or more pressure-relief devices designed and tested in accordance with DS/EN 50216 – 5 with measures having been taken to protect the surroundings against oil splashes. Remote monitoring of the pressure-relief devices must be possible, and they must be able to raise an alarm if activated. It must also be possible on-site – from the operating height at a safe distance from live parts without any danger to the operating personnel via a mechanical indicator – to visually determine whether a pressure-relief device has been activated.

The oil tank must be equipped with a valve for draining the top oil. The valve must be routed to operating height to enable oil sampling at a safe distance from live parts without any danger to the operating personnel while the shunt reactor is in operation.

The oil tank must be prepared for mounting of steps and rails on top. Furthermore, the oil tank and any accessories must be designed to allow compliance with applicable Danish regulations when working on the reactor.

## 6.7 Earthing terminals and connections

The oil tank must be equipped with two earthing terminals for connecting earth wires. Unless otherwise agreed with the manufacturer, these must be located at the bottom at two diagonally opposing corners. All dead parts – including accessories, cf. section 7 – must have a protective earth connection and be connected to the earthing terminals.

The earthing terminals must be designed for the maximum earth current in the network. In the invitation to tender, the buyer must state the maximum earth current.

## 6.8 Connections

The invitation to tender must specify how the connections to the shunt reactor should be designed. The following possible connections are treated in this recommendation:

- Bushings (section 6.10)
- Cable connection boxes (section 6.11)
- GIS connections (section 6.12)

## 6.9 Bushings

### 6.9.1 General

The bushings must be designed in accordance with DS/EN 60137.

The rated current of the bushings must be chosen on the basis of the current at the shunt reactor's highest voltage for equipment, rated reactance and frequency and must not be smaller than this.

*Note: If the rated current of the bushings is specified on the basis of the standardised rated currents in accordance with DS/EN 60137, the rated current closest to and larger than the reactor current at the shunt reactor's highest voltage for equipment, rated reactance and frequency must be specified, as a minimum.*

The invitation to tender must specify whether the bushings must be made of ceramic materials (porcelain), a polymer or a composite material. Special requests concerning electrical insulation – ie oil-filled bushings, gas-filled bushings or other in accordance with DS/EN 60137 – must be stated in the invitation to tender.

The highest voltage for equipment,  $U_m$ , for the bushings must be chosen similarly to the highest voltage for equipment of the shunt reactor, cf. section 5.10. The insulation level must be chosen in accordance with DS/EN 60137 on the basis of the highest voltage for equipment.

The minimum distance between live parts of the bushings in air and between the bushings and earthed parts must be specified in the invitation to tender. The minimum distances between live parts and between live parts and earthed parts mentioned in the Danish Executive Order on High Voltage (*Stærkstrømsbekendtgørelsen*), section 2, must be complied with, as a minimum.

*Note: Please note in this connection that at some voltage levels, the minimum distances listed in DS/EN 60076 – 3 deviate from the values listed in the Danish Executive Order on High Voltage (*Stærkstrømsbekendtgørelsen*), section 2.*

The minimum creepage distance for the insulators must be specified in the invitation to tender. When determining the minimum creepage length, parameters such as mean diameter of the bushing and the environment in which the shunt reactor is to be installed must be taken into consideration. As a point of departure, the minimum creepage length must be determined on the basis of the recommendations of IEC/TS 60815. IEC/TS 60815 currently consists of three parts. Part 1 contains definitions, information and general principles. Part 2 specifically concerns ceramic and glass insulators. Part 3 concerns polymer insulators.

The desired connection terminals must be specified in the invitation to tender. If special dimensions for connection bolts and nuts are requested, this must be specified in the invitation to tender. Dimensions should follow the recommendations of international standards to the extent that such standards exist. Connection terminals or flanges, bolts and nuts etc. on bushings must be made of kuprodur or another material with similar electrical and mechanical properties and must be surface-treated to be protected against corrosion.

The bushings must be designed with a test tap for carrying out PD tests (partial discharges) in accordance with DS/EN 60137. Generally, the test tap is only a standard design requirement for bushings with highest voltage for equipment higher than or equal to 72.5 kV. If such a terminal at highest voltage for equipment is requested for equipment below 72.5 kV, it is therefore important to specify this in the invitation to tender.

Inspection and replacement of the bushings must be possible without having to lift the cover of the oil tank. The connection of the windings to the insulators inside the shunt reactor must be secured against loosened nuts.

The bushings must be marked to indicate which phases they are associated with. The markings must be weather-proof and oil-proof.

#### **6.9.2 Highest voltage for equipment below or equal to 36 kV**

For highest voltage for equipment below or equal to 36 kV, there is a Europa Norm – EN 50180 – with the purpose of ensuring uniform dimensions for bushings and thus greater flexibility. DS/EN 50180 does not replace DS/EN 60137, and bushings in accordance with EN 50180 must also be in accordance with DS/EN 60137.

DS/EN 50180 also covers plug-in bushings.

### **6.10 Cable connection boxes**

#### **6.10.1 Highest voltage for equipment below or equal to 36 kV**

Cable connection boxes must be designed and tested in accordance with EN 50464-2-1 and EN 50464-2-2 or EN 50464-2-3. The three standards mentioned apply to oil-immersed distribution transformers with a highest voltage for equipment up to and including 36 kV and a rated power which does not exceed 2500 kVA. Thus, the three standards mentioned do not apply specifically to shunt reactors. Attention should be given to situations in which the rated current exceeds the interval of the three standards mentioned for rated currents. The bushings used in connection with the cable connection box must be designed and tested in accordance with DS/EN 50336.

The rated current of the cable connection must be selected on the basis of the current in the shunt reactor at its highest voltage for equipment, rated reactance and frequency.

The cable connection box shall have the same or higher insulation level as the shunt reactor, cf. section 5.9.

The cable connection box must be designed for connection of single-phased cables or one three-phased cable. Type and dimensions of cable to be connected to the shunt reactor must be stated in the invitation to tender.

Every measure must be taken to prevent earth faults in the cable connection box from developing into a short circuit (two-phased or three-phased).

All dead parts of the cable connection box must be earthed via appropriate protective earth connections to the shunt reactor's earthing terminals.

The cable connection box must be protected against corrosion from the environment in which the shunt reactor is to be installed, cf. section 6.14.

If the conditions in which the cable connection boxes are to be located are known, these must be stated in the invitation to tender.

#### **6.10.2 Highest voltage for equipment equal to 72.5 kV or above**

Cable connection boxes must be designed for connection of single-phased cables to the

shunt reactor, and they must be designed and tested in accordance with EN 50299. Type and dimensions of cable to be connected to the shunt reactor must be stated in the invitation to tender.

The rated current must be selected on the basis of the current in the shunt reactor at its highest voltage for equipment, rated reactance and frequency.

The cable connection box shall have the same or higher insulation level as the shunt reactor, cf. section 5.9.

Every measure must be taken to prevent earth faults in the cable connection box from developing into a short circuit (two-phased or three-phased).

The cable connection box must be oil-tight and vacuum-proof to the same level as the shunt reactor's oil tank, cf. section 6.7. Generally, the cable connection box and the cable connections must comply with the mechanical requirements of DS/EN 50299.

Insulation oil in the cable connection box must comply with the same requirements as the insulation oil in the shunt reactor, cf. section 6.4. It must be specified in the invitation to tender whether the oil in the cable connection box and the oil in the shunt reactor's oil tank are allowed to be in a common oil system, or whether two separate oil systems are required.

All dead parts of the cable connection box must be earthed via appropriate protective earth connections to the shunt reactor's earthing terminals.

The cable connection box must be protected against corrosion from the environment in which the shunt reactor is to be installed, cf. section 6.14.

The desired location of cable connection boxes must be specified in the invitation to tender.

## **6.11 GIS connections**

For shunt reactors with highest voltage for equipment above or equal to 72.5 kV, the shunt reactor may be connected directly to a GIS system (*gas-insulated switchgear*).

Direct GIS connection to the shunt reactor must be designed and tested in accordance with IEC/TR 61639. The bushing through the shunt reactor's oil tank must additionally be designed and tested in accordance with DS/EN 60137.

The connection must be single-phased. Every measure must be taken to prevent earth faults in the cable connection box from developing into a short circuit (two-phased or three-phased).

The insulation level for the GIS connection must be selected on the basis of IEC/TR 61639 and the shunt reactor's highest voltage for equipment. Insulation level for bushings through the shunt reactor's oil tank must be selected in accordance with section 6.10.

The rated current of the GIS connection must be selected on the basis of the current in the shunt reactor at its highest voltage for equipment, rated reactance and frequency.

Generally, the mechanical design of the GIS connection must be in accordance with the guidelines stated in IEC/TR 61639. However, it should be emphasised that the GIS connection must be able to withstand vibrations caused by the shunt reactor during normal operation. It must also be ensured that the GIS system to which the shunt reactor is connected is able to withstand the vibrations transferred through the direct GIS connection.

It may be specified that the earthed parts of the shunt reactor must be insulated from the earthed parts of the GIS system if this is required for correct function of any relay protection etc. In this case, the insulation between such parts must, in accordance with IEC/TR 61639, be able to withstand a test voltage of 5 kV between the earthed parts of the shunt reactor and the earthed parts of the GIS system. It may be stated in the invitation to tender where the insulation between the shunt reactor tank and the metal enclosure of the GIS system must be placed, if there are special requests in this regard.

The metal enclosure of the GIS connection must be protected against corrosion from the environment in which the shunt reactor is to be installed, cf. section 6.14.

## **6.12 Tap changer**

The following section applies to shunt reactors which are adjustable stepwise by varying the number of turns on the reactor winding.

**6.12.1** The tap changer must be designed for on-load adjustment in accordance with DS/EN 60214 – 1. The requirements for adjustment range, adjustment positions and rated current

are evident from section 5.13. Generally, the load capacity of the tap changer must be adapted to that of the shunt reactor.

Switches must be easily accessible for inspection and replacement, and exchange of the diverter switch must be possible on-site.

**6.12.2** If oil is selected as the breaking medium for the diverter switch, this must be separated from the oil in the shunt reactor's oil tank and oil conservator.

Vacuum can also be the breaking medium for the diverter switch.

**6.12.3** Auxiliary voltage for the tap changer motor, alarm measurements etc. must be specified in the invitation to tender. A safety switch must be installed in the main circuit for the tap changer motor. Generally, the requirements for auxiliary systems and control systems in accordance with the Danish Executive Order on High Voltage, section 2, (Stærkstrømsbekendtgørelsen afsnit 2) must be met. To the extent that components are covered by the Low Voltage Directive (2006/95/EC), they must comply with this directive.

The tap changer must be designed for compulsory completion of an initiated adjustment step. It must not be possible for the tap changer to rest between two steps due to fall-out of the auxiliary voltage, and the tap changer must be fully functional when the auxiliary voltage returns.

In relation to live parts, insulators etc., the tap changer machinery must be placed to allow easy access for inspection and maintenance from operating height without any danger to operating personnel.

**6.12.4** The tap changer must be designed for mechanical and electrical local control as well as for electrical remote control. The electrical control must be blocked during mechanical control. Control of the tap changer must be possible from operating height at a safe distance from live parts without any danger to the operating personnel.

The electrical control must be designed in such a way that it only moves one step for each control impulse, irrespective of the duration of the impulse.

The tap changer must be prevented from moving beyond the extreme positions by means of a mechanical and electrical blockage. Two free contacts must be available, and they must be closed during tap change operation.

**6.12.5** The step position must be mechanically transferred to an indicator showing the step position. The numbers 1, 2, 3 etc. must be used for indication, the number 1 indicating the step corresponding to the shunt reactor's smallest reactive power.

It must be possible to read the number of step changes on a mechanical six-digit counter. Reading of the position indicator and the counter must be possible from operating height at a safe distance from live parts without any danger to the operating personnel. Electrical remote reading of the tap changer's step position must be possible.

**6.12.6** The tap changer must be equipped with a visibly located readable rating plate. The rating plate must be in a weather-proof material. It may be specified in the invitation to tender that a copy of the tap changer's rating plate can be located next to the shunt reactor's rating plate.

**6.12.7** The tap changer must be of the IEC class II type and must have the same or higher insulation level as the shunt reactor.

For rated voltages above 72.5 kV, where the shunt reactor may be designed with reduced insulation level in the neutral point, a tap changer of the IEC class I type may be used, provided that the tap changer is installed in connection with the shunt reactor's neutral point.

**6.12.8** The tap changer must be tested in accordance with the test specified in DS/EN 60214 – 1. The tests must simulate the most unfavourable switching conditions.

## **6.13 Shunt reactor with continuous adjustment**

The following section applies to shunt reactors in which the adjustment of the shunt reactor's reactive power takes place by varying the air gap in the shunt reactor's iron core.

The adjustment must be designed for mechanical and electrical local control as well as for electrical remote control. The electrical control must be blocked during mechanical control.

The shunt reactor's reactive power must be evident from an indicator connected to the iron

core. Contrary to stepwise adjustable shunt reactors, a continuously adjustable shunt reactor in principle has an infinite number of adjustment positions. Therefore, the buyer should specify in the invitation to tender that the manufacturer must provide a calibration curve which shows the correspondence between the iron core position and the reactive power input. The number of requested calibration points on the curve must be specified in the invitation to tender and/or in cooperation with the manufacturer. Please note that the correspondence between the iron core position and the reactive power input is not 100% linear. Too few calibration points might therefore reduce the position accuracy of the shunt reactor's reactive power. The calibration points must be on the indicator connected to the iron core. Electrical remote reading of the iron core's position must be possible. If the shunt reactor must be designed for local control during operation, it must be possible to read the indicator from the operating height at a safe distance from live parts without any danger to the operating personnel.

Auxiliary voltage for the control motor, alarm measurements etc. must be specified in the invitation to tender. A safety switch must be installed in the main circuit for the control motor. The motor must be protected by a motor protection device. The auxiliary equipment must be designed for the same control voltage as the motor. A safety switch must be installed in the main circuit for the control motor. Generally, the requirements for auxiliary systems and control systems in accordance with the Danish Executive Order on High Voltage, section 2, (Stærkstrømsbekendtgørelsen afsnit 2) must be met. To the extent that components are covered by the Low Voltage Directive (2006/95/EC), they must comply with this directive.

The shunt reactor must be equipped with a mechanical limit switch and must not be damaged, should an electrical limit switch fail.

#### **6.14 Protection against corrosion**

All details, including bolts, nuts, valves, terminals, terminal blocks etc. must be protected against corrosion. The corrosion protection must be selected on the basis of the shunt reactor's intended life and the environment in which the shunt reactor is to be installed. For specification of corrosion category and corrosion protection.

For standards applying to corrosion protection reference is made to Danish Standard, CEN and ISO.

*Note 1: Currently DEFU has a report RA 552 in the pipeline (2010), which will contain information about corrosion protection.*

#### **6.15 Rating plate**

The shunt reactor must be equipped with a rating plate made of weather-proof material and mounted in a position which is visually readable from the operating height at a safe distance from live parts without any danger to the operating personnel, when the shunt reactor is energised. As a minimum, the rating plate must contain the following information:

- Reactor type
- Indoor/outdoor application
- Reference to standard (DS/EN 60076 – 6)
- Name of manufacturer
- Serial number
- Production year
- Insulation level
- Number of phases
- Rated power,  $Q_r$
- Rated frequency,  $f_r$
- Rated voltage,  $U_r$
- Rated current,  $I_r$
- Highest voltage for equipment,  $U_m$
- Connection between phase windings (star or delta connection)
- Rated reactance,  $X_r$
- Cooling method (ie ONAN, ONAF etc.)
- Temperature rise for top oil and average rise for winding
- Outer dimensions with accessories installed (length, width and height)
- Total weight
- Transport weight
- Weight without oil
- Weight of insulation oil
- Type of insulation oil
- Diagram of shunt reactor with adjustment positions indicating the reactive power at the individual positions
- Type of tap changer (for stepwise adjustable shunt reactor)
- Zero reactance (if requested)
- Mutual reactance (if requested)

- Losses at rating levels
- Type of instrument transformer, transformation ratio, accuracy class, performance etc.
- Diagram indicating the location of instrument transformers and cores etc.

It may be specified in the invitation to tender that a copy of the tap changer's rating plate and the rating plate of any associated control motor must be located next to the shunt reactor's rating plate.

## 7. ACCESSORIES

The following sections describe the most common accessories for oil-immersed shunt reactors. All sections may not be relevant for a given shunt reactor.

Generally, the requirements for auxiliary systems and control systems in accordance with the Danish Executive Order on High Voltage, section 2, (Stærkstrømsbekendtgørelsen afsnit 2) must be met. To the extent that components are covered by the Low Voltage Directive (2006/95/EC), they must comply with this directive.

Generally, oil and gas sampling, maintenance and reading of various measuring instruments etc. must be possible from operating height at a safe distance from live parts without any danger to the operating personnel if such activities can be performed while the shunt reactor is in operation.

### 7.1 Cooling equipment

It may be specified in the invitation to tender that the shunt reactor may be prepared for fitting of additional cooling equipment. Normally, the following possibilities are available for increasing the cooling of the shunt reactor (in order of priority):

- Additional radiators (ONAN)
- Fans to increase the circulation of external air (ONAF)
- Oil pumps to increase the oil circulation (OFAF)
- Water cooling (OFWF)

### 7.2 Oil conservator

The following applies to the oil conservator of the oil tank, cable bushings and the diverter switch tank (cf. the tap changer).

Oil conservators must be equipped with a rubber bag and be vacuum-proof, and the vacuum tube leading thereto must be at operating height at a safe distance from live parts.

The volume of the oil conservator must be at least 10% of the oil volume which is connected with the oil conservator.

The oil conservator must be equipped with a pipe stub with valve for draining the oil sump.

The oil conservator must be equipped with oil level indicators in accordance with EN 50216 – 5, including alarm contacts closing at min. and max. oil level, respectively. There must be an indication of min. and max. oil level as well as normal oil level at oil temperatures of -20, 0 and +20°C. Reading of the oil level indicator must be possible on-site at a safe distance from live parts and from operating height. Electrical remote reading and monitoring of the oil level indicators must be possible.

### 7.3 Dehydrating breather

Separate oil systems (oil tank, diverter switch container in the tap changer, cable bushings etc.) must have separate ventilations with each their dehydrating breather in accordance with EN 50216 – 5. The cable bushings (three phases) may share the same dehydrating breather and oil conservator.

The dehydrating breather may be designed for manual replacement of the dehydration agent or automatic regeneration of the dehydration agent.

The dehydrating breather must have an oil lock for reduction of the air exchange.

If silica gel is used as the dehydration agent, the dehydrating breather must also be equipped with a window to allow checking the colour of the dehydrating agent at the top and bottom of the dehydrating breather.

Dehydrating breathers must be installed in such a way as to be easily accessible for inspection and maintenance from the ground at a safe distance from live parts without any danger to the operating personnel. If the dehydrating breather is designed for manual replacement of the dehydration agent, this must also be possible from the ground.

#### **7.4 Gas relay**

A gas relay (Buchholz relay) in accordance with EN 50216 – 2 must be incorporated in the connection pipe between an oil volume and any associated oil conservators. The cable bushings (three phases) may share the same gas relay. The gas relay must have two free contacts, one of which must emit an alarm at a preset level of gas formation. The other must trip disconnection of the shunt reactor at a preset oil-flow level from the oil tank to the oil conservator.

It must be possible to visually check the presence and volume of collected gas in the relay. Gas sampling and air injection for testing must be possible. An indicator on the relay must indicate the direction of the oil flow between the transformer tank and the oil conservator.

A valve must be located between the oil conservator and the gas relay to allow replacement of the gas relay without having to empty the oil conservator.

Testing of the gas relay must be possible without dismounting it.

The gas relay must be equipped with a rating plate containing information in accordance with EN 50216 – 2. It may be specified in the invitation to tender that a rating plate for the gas relay must be located next to the shunt reactor's rating plate. In this case, a rating plate must still be located on the gas relay.

#### **7.5 Thermometers and thermometer pockets**

The oil tank cover must be equipped with thermometer pockets in accordance with EN 50216 – 4. The openings must be protected against penetration of moisture and foreign substances.

One of the pockets must be reserved for a thermometer for measuring the top oil temperature. Furthermore, there must be two free thermometer pockets. In case of forced oil and/or air circulation, one or both of the free pockets must be reserved for the oil pump and/or fan thermostat. It may be specified in the invitation to tender that the shunt reactor must also be equipped with a thermometer for measuring the winding temperature.

The thermometer for measuring the top oil temperature must be an indicator thermometer with a maximum pointer and must have class 2 measurement accuracy. The measuring range must be at least 30 to 150°C. The thermometer must have two independently adjustable contacts closing when the preset temperature values are exceeded. The thermometer must be mounted on an anti-vibration device and must be possible to read from the ground. Online remote reading and monitoring of the thermometers must be possible.

The thermometers must be located in the control cabinet.

If oil is used as the breaking medium for the diverter switch, the diverter switch container must also be designed with a thermometer pocket for measuring the oil temperature. Online remote reading of the thermometer and continuous monitoring of the temperature must be possible.

#### **7.6 Monitoring equipment**

The desired monitoring equipment may be specified in the invitation to tender.

Reference is made to CIGRE brochure 343 '*Recommendations for condition monitoring and condition assessment facilities for transformers*' for examples of monitoring equipment which may be relevant for a shunt reactor.

#### **7.7 Valves**

It must be specified in the invitation to tender whether valves should have welded or bolted flanges towards the shunt reactor.

#### **7.8 Console for overvoltage protection**

Shunt reactors for open-air installations may be equipped with a console intended for overvoltage protection (eg surge arresters). The console should be fitted to the shunt reactor's main tank. If the shunt reactor has a floating neutral point, it should also be specified that the shunt reactor's neutral point must be equipped with a console intended for an overvoltage protection device.

A copper bar must be installed on the console, intended for earthing of the bottom parts of the overvoltage protection device.

#### **7.9 Cabinet for auxiliary equipment**

The shunt reactor must be designed with a cabinet for various auxiliary equipment and external connections thereto and for measuring circuits etc. located in the same cabinet.

The cabinet must be of a protection class (IP) which is suited for outdoor installation, taking the local climate in which the shunt reactor is to be installed into consideration. The cabinet

must be protected against corrosion in accordance with section 6.14.

Condensation of water in the cabinet must be prevented by a thermometer-controlled and humidistat-controlled heating element for 230 V AC. The cabinet must be designed with a drain hole in the bottom.

The cabinet must be designed with a 16 A CEE plug and 230 V between phase and neutral. The plug must be protected by a HPFI relay mounted in front of it. A weather-proof current diagram must be located on the inside of the cabinet door. Cables must be reinforced or in other ways protected against mechanical damage.

### 7.10 Current transformers

In all phases, the shunt reactor's bushings should be designed with built-in current transformers. Specific requirements for current transformers must be specified in the invitation to tender.

The shunt reactor should also be designed with a current transformer for measuring the current at its neutral point (for a star-connected winding). It is recommended that the current contribution in the neutral point from the three phase windings be measured individually with current transformers installed in connection with the three phase windings, cf. Figure 1.

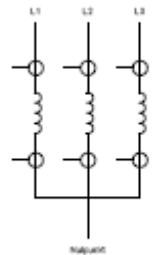


Figure 1: Location of current transformers.

### 7.11 Transport arrangements etc.

The shunt reactor must be equipped with the pulling lugs necessary for transport on the lower frame.

The main tank must be equipped with clearly marked reinforcements or lifting flanges for placing of jacks and crane connection.

The shunt reactor must be equipped with loops or hooks for lifting a completely oil-immersed shunt reactor.

### 7.12 Transport

In connection with transport of the shunt reactor from factory to installation site, it must be ensured that the shunt reactor is not damaged. It must be agreed between the supplier and the buyer which measures should be taken to protect the shunt reactor.

If measuring equipment is used to record loads (mechanical, thermal etc.) during transport, the thresholds for impacts must be agreed beforehand, and the supplier must be able to subsequently document to the buyer that these threshold values were not exceeded.

## 8. TESTING OF SHUNT REACTORS

Generally, tests must be carried out on a shunt reactor installed under operating conditions, to the extent that installation conditions will have an impact on the results of the tests.

The buyer must be informed of the test to allow a representative of the buyer to be present during testing.

The results of the test must be documented in a test report. Photos of each of the four sides of the reactor core with windings mounted, and two photos of the two outer longitudinal sides must be enclosed with the test report.

### 8.1 Routine tests

Unless otherwise agreed between buyer and manufacturer, routine tests must be carried out for each shunt reactor with all control equipment and accessories mounted.

#### 8.1.1 Measurement of winding resistance

To be carried out in accordance with DS/EN 60076 – 1.

#### 8.1.2 Measurement of current

The test must be carried out at rated voltage and frequency.

The measurement must be carried out across the shunt reactor's adjustment range. For shunt reactors with stepwise adjustment, the measurement must be carried out for each step. For shunt reactors with continuous adjustment, the current must, as a minimum, be measured at five positions which are evenly distributed across the entire adjustment range of the shunt reactor, including the minimum and maximum position.

The tolerance is  $\pm 5\%$  of the guaranteed values.

#### 8.1.3 Measurement of reactance

To be carried out in accordance with DS/EN 60076 – 6.

For an adjustable shunt reactor, the test must be carried out across the entire adjustment range of the shunt reactor. For shunt reactors with stepwise adjustment, the measurement must be carried out for each step. For shunt reactors with continuous adjustment, the reactance must, as a minimum, be measured at five positions which are distributed across the entire adjustment range of the shunt reactor, including the minimum and maximum position.

The tolerance is  $\pm 5\%$  of the guaranteed values.

#### 8.1.4 Measurement of losses at reference temperature

The test must be carried out at the shunt reactor's rated current and frequency and must be in accordance with DS/EN 60076 – 6. The test must be carried out as a three-phase test for a three-phased shunt reactor.

For an adjustable shunt reactor, the test must be carried out across the entire adjustment range of the shunt reactor. For shunt reactors with stepwise adjustment, the measurement must be carried out for each step. For shunt reactors with continuous adjustment, the losses must, as a minimum, be measured at five positions which are distributed across the entire adjustment range of the shunt reactor, including the minimum and maximum position.

The total losses for the individual unit must not exceed the guaranteed losses by more than 10%.

#### 8.1.5 Dielectric tests

Dielectric tests must be carried out in accordance with DS/EN 60076 – 6.

- Separate AC withstand voltage test
- Induced AC withstand voltage test
- Lightning impulse withstand test
- Switching impulse withstand test

Generally, for rated voltages below 72.5 kV, measurement of partial discharges is not an integrated part of the induced AC withstand voltage test, as is the case for rated voltages above 72.5 kV. If PD testing is requested as part of the induced AC voltage test for shunt reactors with rated voltages below 72.5 kV, this must therefore be stated in the invitation to tender.

Unless otherwise specified in the invitation to tender, switching impulse tests shall only be carried out as routine tests on shunt reactors with highest voltage for equipment of 420 kV (in Denmark).

For an adjustable shunt reactor, the tests must be carried out in the shunt reactor's two extreme positions – ie at the maximum and minimum inductance position – and in the middle position. If the shunt reactor's rating does not refer to one of the extreme positions, the tests must also be carried out at the inductance position corresponding to the shunt reactor's rating.

#### **8.1.6 Measurement of sound power level**

The test must be carried out in accordance with DS/EN 60076 – 6.

For an adjustable shunt reactor, the test must be carried out at rated voltage, rated frequency and the adjustment position corresponding to the rated reactance.

The shunt reactor must be equipped with all accessories which may contribute to its sound power level.

If the shunt reactor is designed with forced cooling in the form of a fan and/or oil pump, the contribution to the sound power level from such devices must also be documented.

#### **8.1.7 Test to indicate correct functioning of control equipment**

Indication of correct functioning of the adjustment equipment must be carried out in accordance with the test described in DS/EN 60076-1 or similar.

#### **8.1.8 Measurement of insulation resistance and/or capacitance and dissipation factor ( $\tan \delta$ ) of the winding insulation to earth**

DS/EN 60076 – 6 does not specify any test procedure. The buyer and manufacture shall agree upon the test procedure.

*Note: These are reference values for comparison with later measurements in the field.*

## **8.2 Special tests**

Special tests may be specified in the invitation to tender and must be carried out as either routine tests on each individual unit or as type tests on a unit which is representative to the shunt reactor type. Please note that all tests may not necessarily be relevant for a shunt reactor for a given installation. The buyer may, possibly in cooperation with the manufacturer, assess whether or not a test is relevant.

#### **8.2.1 Measurement of zero reactance**

The test must be carried out in accordance with DS/EN 60076 – 6.

For an adjustable shunt reactor, the test must be carried out across the entire adjustment range of the shunt reactor. For shunt reactors with stepwise adjustment, the measurement must be carried out for each step. For shunt reactors with continuous adjustment, the test must, as a minimum, be carried out at five positions which are distributed across the entire adjustment range of the shunt reactor, including the minimum and maximum position.

#### **8.2.2 Measurement of mutual reactance**

The test must be carried out in accordance with DS/EN 60076 – 6.

For an adjustable shunt reactor, the test must be carried out across the entire adjustment range of the shunt reactor. For shunt reactors with stepwise control, the measurement must be carried out for each step. For shunt reactors with continuous adjustment, the test must, as a minimum, be carried out at five positions which are distributed across the entire adjustment range of the shunt reactor, including the minimum and maximum position.

#### **8.2.3 Determination of the reactance linearity**

The test must be carried out in accordance with DS/EN 60076 – 6.

For an adjustable shunt reactor, the test must be carried out at the position where the reactive power input is the highest.

#### **8.2.4 Measurement of magnetic characteristics**

The test must be carried out in accordance with DS/EN 60076 – 6. The test is primarily interesting in the case of a non-linear shunt reactor or a shunt reactor with a saturated iron core, as well as in cases where it is desirable to know the characteristics in connection with eg simulations.

### **8.2.5 Measurement of harmonic currents**

The test must be carried out in accordance with DS/EN 60076 – 6.

### **8.2.6 Dielectric special tests**

Dielectric special tests must be carried out in accordance with DS/EN 60076 – 6.

- Lightning impulse test at high humidity

For an adjustable shunt reactor, the tests must be carried out in the shunt reactor's two extreme positions – ie at the maximum and minimum inductance position – and in the middle position. If the shunt reactor's rating does not refer to one of the extreme positions, the tests must also be carried out at the inductance position corresponding to the shunt reactor's rating.

## **8.3 Type tests**

Type tests must be carried out on a representative unit for a shunt reactor type.

### **8.3.1 Temperature rise test**

The test must be carried out in accordance with DS/EN 60076 – 6.

The test must be carried out at the highest voltage for equipment,  $U_m$ , cf. 5.10.1, and the rated frequency. If this is not practically possible, the test may be carried out at a lower voltage, however not less than 0.9 times the shunt reactor's rated voltage. The test voltage must be stated in the invitation to tender and must be approved by the buyer. The temperature rise at a lower test voltage must be corrected subsequently in accordance with DS/EN 60076 – 6. The corrected temperature rise is then an expression of the temperature rise in the shunt reactor at the highest voltage for equipment,  $U_m$ .

For an adjustable shunt reactor, the test must be carried out at the adjustment position for the shunt reactor's rated current (smallest inductance).

For an adjustable shunt reactors in which forced circulation of cooling medium is necessary at maximum reactive power input, it may be specified in the invitation to tender that a temperature rise test at the adjustment position where forced cooling is no longer necessary must be carried out to document that the threshold values for the temperature rise in connection with ONAN cooling are not exceeded in the shunt reactor.

### **8.3.2 Dielectric tests**

Dielectric type tests must be carried out in accordance with DS/EN 60076 – 6.

- Switching impulse test

For an adjustable shunt reactor, the tests must be carried out in the shunt reactor's two extreme positions – ie at the maximum and minimum inductance position – and in the middle position. If the shunt reactor's rating does not refer to one of the extreme positions, the tests must also be carried out at the inductance position corresponding to the shunt reactor's rating.

### **8.3.3 Measurement of vibration level**

The test must be carried out in accordance with DS/EN 60076 – 6. Special attention should be paid to the following;

- Vibration of core and winding assemblies
- Vibration of oil tank
- Vibration of instruments, accessories (including tap changers and associated short-circuit motors) and cooling equipment

The test must be carried out with the accessories mounted which are specified in the invitation to tender, cf. section 8, unless otherwise agreed between the buyer and the manufacturer.

### **8.3.4 Measurement of power consumption by fans and oil pumps**

In case of a shunt reactor with forced cooling in the form of oil pumps and/or fans, the power consumption must be documented through measurements.

## 9. INFORMATION AT INVITATION TO TENDER

The information below must be specified in the invitation to tender:

Technical:

- Single-phased or three-phased shunt reactor
- Connection between phase windings
- Should the neutral point be accessible?
- Insulation (oil)
- Special requirements for oil type
- Cooling
- Special conditions regarding ambient temperature and any restrictions in connection with cooling
- Level of contamination of the surrounding environment
- Atmospheric corrosion category
- Any other conditions in connection with the surrounding environment
- Rated power
- Rated frequency
- Rated voltage
- Rated current
- Capitalisation factor for losses
- Maximum sound power level
- Insulation level
- System earthing
- Dimensioning earth current
- Insulation level for neutral point
- Dimensioning short-circuit power
- Requested connections (bushings, cable connection boxes, GIS connection)
- In the case of bushings, it may be stated whether porcelain, polymer or composite insulators are requested
- Requested connection terminals
- Location of earthing terminals
- Adjustment method – stepwise or continuous control
- Requested auxiliary voltage (regulation)
- Special requirements for testing
- Should a lightning impulse test be carried out, regardless of voltage level?
- Is a PD test requested as part of the induced AC withstands voltage test for rated voltage up to 72.5 kV?
- Special requirements for surface treatment and corrosion protection
- Should the shunt reactor cover be bolted or welded on?
- Special requirements for transport arrangements
- Any requirements for dimensions etc.
- Any special restrictions for dimensions and weight
- Information about foundation and erection site
- Special conditions in connection with installation, mounting, transport and handling
- Information about oil handling, eg oil filling
- Indication of the requested location of various accessories
- Are separate oil conservator, air breather and gas relay requested in connection with each individual phase bushing? Or can the three bushings share oil conservator, gas relay and air breather?
- Should the bushings be made with current transformers?
- Special requirements for instrument transformers
- Any requests in connection with monitoring equipment
- Documentation requirements (hard copy and electronic)

Commercial:

- Delivery time and unloading conditions
- Delivery address
- Any delivery terms; unless otherwise stated, CPT (Carriage Paid To (named place of destination), cf. Incoterms 2000)
- Deadline for submission of tender, binding dimensioned sketches etc.
- Any requirements concerning terms of payment, insurance, warranty period, deposits, tender term of validity etc.

Furthermore, the commercial terms should be specified in detail.

## 10. INFORMATION AT TENDER

The information below must be specified in the tender:

Technical:

- Guaranteed reactance for the individual adjustment positions
- Guaranteed current values for the individual adjustment positions
- Guaranteed values for losses at ratings and reference winding temperature
- Guaranteed sound power level with and without forced cooling during operation at rated power
- Cooling equipment design and power consumption, Operating mode for any oil pumps
- Adjustment range and control positions
- Data for tap changer: rated current, manufacturer, type and testing (including mechanical lifetime), maximum number of tap changes between inspections
- Position indication for tap changer (remote display)
- Data for bushings: creepage distances, insulation level, rated current, manufacturer, type and type testing
- Information about any built-in current transformers in bushings
- For all connection terminals, material and dimensions must be stated
- Oil manufacturer, type and inhibitor, if any
- Information about how to connect vacuum to oil treatment installations and any precautions to be taken before evacuation
- Data for gas relay
- Whether the shunt reactor is equipped with pressure relief devices
- Information about surface treatment and corrosion protection
- Total weight of shunt reactor
- Weight of active part and cover and required crane height for extraction thereof
- Weight of oil
- Maximum transport weight and transport dimensions
- Dimensioned sketches, current diagrams, descriptions etc. necessary for assessing the design of the shunt reactor
- Maintenance instructions

Commercial:

- Price of complete shunt reactor (including erection and commissioning, carriage paid to named place of destination, with oil)
- Quotation for any supplementary or alternative monitoring equipment
- Price for spare parts in accordance with invitation to tender
- Any price regulations
- Information about custom duties, exchange rates and VAT
- Terms of payment
- Delivery time
- Warranty period

In addition, the manufacturer must confirm that the shunt reactor complies with the requirements set out in the terms of the invitation to tender. Any deviations from the requirements must be specified in detail.