Company	Replaces previous document	Document ID	Issue
E.ON Energidistribution AB		D10-0015669	12.0
Organisation	Valid from	Valid until	
Regionnätsaffärer	2020-12-15		
Responsible for the document	Secrecy class	Approved by	
Robert Berg Nordmark	Open	Claes Ahlrot	

Title

Technical Requirements for Power Transformers

E.ON Energidistribution AB

Technical Requirements

Power Transformers

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1 General

1.1 Scope

This document constitutes E.ON Energidistribution AB technical demands at procurement of power transformers.
These requirements cover the general demands made by E.ON Energidistribution AB on three-phase, 50 Hz, oil-immersed, power transformers with rated power 6.3 MVA and above, and highest voltage for equipment 12-420 kV.

1.2 Standards

The transformer supplied with accessories shall be designed, manufactured and tested in accordance with the latest edition of the Swedish standards. If Swedish standard is missing corresponding European standard shall be applied. In the event of differences between this document and the relevant standard, the technical requirements in this document shall have precedence.

1.3 Marking

The rating plate shall contain all rated data for the transformer, the serial number, year of manufacture, weights, type of oil, vacuum proof tank, etc. The connections used shall be shown. On transformers with tap-changer, the tapping position shall also be shown.

Rating plates and signs shall be made of stainless steel. Rating plate shall be provided on the operating side of transformer. The plates and signs shall be secured by stainless steel screws.

Transformers with tap-changers shall be provided with signs that specify the voltage and current ratios in all tap-changer positions.

For current transformers, including those for winding temperature measurement, a sign shall be provided for each current transformer with a clear diagram of the current transformer connection, ratio and terminal marking.

Durable terminal marking of bushings shall be provided on the transformer tank cover adjacent to each bushing, by means of raised letters which are welded or secured by screws to the tank cover. The terminal marking shall follow international standard according to IEC (1U, 1V, 1W etc). Each bushing shall have a rating plate with type designation and article number. For 12 and 24 kV bushings the designation can be punched on the flange or be specified on special plate on the transformer.
Cables shall be marked with embossed metal plates. All junction boxes, thermometers, etc shall be marked with a clear description of their functions.

2 Changes compared to earlier version

Changes compared to earlier versions are marked with a line in the right side of the document.

3 Electrical, mechanical and other requirements

The transformer shall be designed and manufactured so that the stipulated requirements in accordance with valid standard will be met. Upon request, the manufacturer shall produce the necessary technical data for the construction and design of the transformer. Examples of such data may be information regarding the calculated electrical, mechanical and thermal stresses associated with short circuit, current density in the windings and the calculated flux density in the core.

The transformer shall be constructed so that required air distances are respected without use of any special arrangements such as shields or elevation at site.

The transformer shall be equipped with junction boxes with degree of protection at least IP 43, according to SS-EN 60529.

All windings shall be made of copper.

Transformers with secondary voltage of 34.5 kV shall be switchable to 23 kV and 11.5 kV for power up to 40 MVA. The power rating shall be the same for all voltage levels.
Transformers above 40 MVA, with secondary voltage of 34.5 kV, shall be switchable to 57.5 kV.

Two-winding transformers with secondary voltage 23 or 11.5 shall be performed with interchangeability between 23 and 11.5 kV. The rated power shall be equal for the two voltage levels.

Three-winding transformer shall be equipped with an off-circuit connection plate under a service lid on the cover with bolted connections and a switching range of ±2x2.5 % on MV side

Power values of the transformer windings are specified in the technical specification. The primary side power value specifies the rating.

- Primary side power value< 40 MVA shall reflect to ONAN-ratings.
- Primary side power value 40 - 100 MVA shall reflect to ONAF-ratings.
- Primary side power value > 100 MVA shall reflect to OFAF, ODAF-ratings.

3.1 Electrical requirements

Creepage distance

The creepage distance must not be less than 43,3 mm/kV phase-earth using phase voltage. Phase voltage= Highest voltage for equipment/$\sqrt{3}$.

Insulation levels

The transformer shall be designed and manufactured for the insulation levels tabulated below.

Rated voltage	Highest voltage for equipment primary side	Insulation level IEC 60076-3 and SS-EN61936-1				
(kV)	(kV)	Phase (kV)	Min air clearance phase-earth (N) (mm)	Min air clearance phase-phase (mm)	Neutral (kV)	Min air clearance phase-earth (N) (mm)
11.8	12	LI75 AC 28	150	150	LI75 AC 28	150
23	24	LI125 AC 50	220	220	LI125 AC 50	220
34.5	36	LI170 AC70	320	320	LI170 AC70	320
46	52	LI250 AC95	480	480	LI250 AC95	480
57.5	72,5	LI325 AC140	630	630	LI325 AC140	630
77	82,5	LI380 AC150	750	750	LI380 AC150	750
140	145	LI550 AC230	1100	1100	LI250 AC95	480
140	170	LI550 AC230	1100	1100	LI250 AC95	480
220	245	LI850 SI750	1900	2250	LI325 AC140	630
380	420	LI1300 SI1050	3100	3500	LI650 AC325	1300

Table 1. Insulation levels and air clearances

For transformers with connection group YNd5, the phase-earth test shall be carried out with connection a1) according to SS-EN 60076-1 figure 2.

The tap-changer position for the test shall be selected according to SS-EN 60076-3 to reach voltages on secondary side according to rated voltages in table 1.

The air clearance between the phase bushing terminals and earth shall not be less than the air clearance specified in the table 1.
Air clearances for 170 kV and below are based on SS-EN61936-1.
Air clearances for 245 kV and 420 kV are based on SS-EN60076-3.

All air clearances on the transformer shall consider necessary connection terminals.

Safety distances

The transformer shall be mounted in such way that the safety distances in SS-EN 61936-1 are fulfilled. If extra equipment is necessary it shall be part of the transformer delivery. The minimum air clearance phase-earth (N) is according to table 1.

- Live parts without protection must have the height H= N + 2500 mm (min 3000mm) as a minimum over accessible areas.
- The lowest part of an insulator, i.e the top part of the metallic insulator stand, shall not be lower than 2250 mm over accessible areas.

Figure 1 illustrates safety distances according to SS-EN 61936-1.

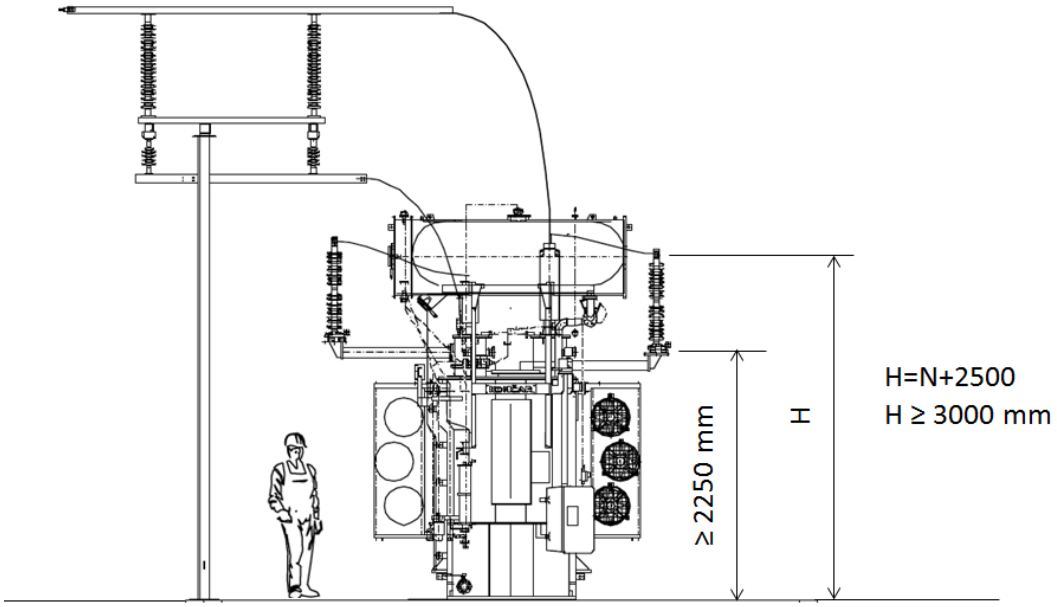

Figure 1. Min. distances according to SS-EN 61936-1

Short circuit capability

The transformer shall fulfil the short circuit requirements according to SS-EN 60076-5. The short circuit capability shall be verified. Unless otherwise specified the following times for thermal capability shall at least be valid.

5 seconds on transformers rated ≤ 40 MVA
2 seconds on transformers rated > 40 MVA

Unless otherwise specified short circuit power in the network shall at least be according to table 2.

Highest voltage for equipment (kV)	Short-circuit power (MVA)
≤ 24	800
36	1 000
52, 72.5 and 82.5	3 000
145	10 000
170	10 000
245	17 000
420	25 000

Table 2. Short circuit capability

Unless otherwise specified, the short-circuit impedance shall be selected according to the table3.

Rated power (MVA)			***6.3***	***10***	***16***	***25***	***40***	***63***	***80***	***100***
Rated voltage (kV)			**Short-circuit impedance (%)**							
Primary side	**Secondary side**									
23		11.5	7	8						
34.5		11.5	7	8	9					
46	23	11.5	7	8	9					
57.5	23	11.5	7	8	9	10				
77	23	11.5		8	9	10	10			
140	23	11.5			9	10	10	12	12	12
140	57.5	46					10	12	12	12
140	34.5				9	10	10	12	12	12

Table 3. Recommended standard ratings

For a three-winding transformer short circuit impedance between HV and MV, HV and LV shall be selected according to Table 3.
MV and LV short circuit impedance shall be selected according to manufacturer's suggestions.

Connection group & Ratios
The connection group and precise voltage ratio shall be specified in the project unique technical specification for the transformer.

Stabilizing winding (delta connected)
All transformers with connection symbol Y/y shall be provided with a delta connected stabilizing winding. The stabilizing winding shall be performed with open delta connection via two bushings. Closing the delta and earthing shall be done on the transformer tank cover.

Earthing
For earthing of 145 kV transformers neutral and surge arresters in both neutral and phases for all voltages the transformer shall be provided with separate conductors insulated from the transformer tank. These conductors shall be linked together close to the bottom of the transformer tank. The surface of the conductor shall be bare metal or black. For directly earthed neutrals these conductors shall be connected directly to the neutral terminal.

For earthing of the transformer tank, a plate shall be welded at two diametrically opposite points at the bottom of the transformer tank. The plate shall be provided with four holes, with a distance between centres of 40 mm vertically and 50 mm horizontally. The holes shall be 14 mm diameter. The surface shall be protected against corrosion and have good electrical conductivity.

All current transformer secondary terminals shall be brought down to a separate junction box, where every 3-phase group shall be connected by its own earth conductor to a common earthing point. A copper conductor with a cross-section area of at least 25 mm^2 shall also be connected to this earthing point.

Power supply for motors and control equipment
Equipment shall be designed for a maximum permitted voltage variation between -15% to +10% in the connection point of the apparatus.

Auxiliary contacts/switches
The rated current of the auxiliary contacts shall be at least 0.4 A at 110 V DC inductive circuit with a time constant of 40 ms.

Terminal blocks
Terminal blocks for external cables shall be provided with open-circuiting facilities and 4 mm test outlets. The terminal board screw for securing the wire shall not be of the lift cage type.
Jumpers between terminals shall be made with insertion bridge or similar on either the internal or external side.

Power and control cables
Shielded or wire-armoured cables shall be used.

The cable size shall be decided by the transformer supplier, although the cross-section area for the current transformers shall not be less than 2.5 mm^2 and for other applications not less than 1.5 mm^2.

3.1.1 On-load tap-changer and cooling equipment

Fan and pump motors shall be designed for a 400 V, 3-phase, 50 Hz power supply. The control voltage shall be 230 V, 50 Hz. Failure of a fan to start shall be detectable by sensing the contactors. The equipment shall have degree of protection IP 54 according to SS-EN 60529.

The control voltage for the on-load tap-changer shall be 110 V DC. Unless otherwise specified, the drive motor shall be designed for 400 V AC, 3-phase, 50 Hz power supply.

For protection against condensation the OLTC drive mechanism shall be equipped with a permanently connected heater element provided with a guard to prevent inadvertent touching and designed for a 230 V, 50 Hz power supply. Monitoring of the heating via potential-free contacts shall be installed.

3.1.2 Off-circuit tap-changer

A connection plate under cover with bolted connections ±2x2.5 % shall be used.

If off-circuit tap-changer are requiered (ex mobile transformers) the off-circuit tap-changer shall have a switching range of ±2x2.5 %. The external parts shall be made of corrosion-free- and UV-resistant material. The switchgear shall have a secure position lock and the maneuverability not impaired by oxidation or bimetallic corrosion. Type and fabrication shall be stated in the tender by the supplier.

3.2 Mechanical requirements

3.2.1 Transformer tank

General

The tank shall be designed and manufactured to withstand full internal vacuum (vacuum-proof), and all welds shall be continuous welds. Pressure relief valves must not be fitted to the transformer.

Bottom

The bottom of the transformer tank shall be flat and self-supporting. The transformer shall be designed for placement on two beams.

Jacks

The tank shall be provided with clearly marked places to which jacks can be applied. The distance between the bottom of the tank and the jacking surface shall be between 300 and 350 mm. The size of the jacking surface shall not be less than 300 x 300 mm.

Tank cover
The transformer tank cover shall be welded to the transformer tank. Welding shall be done in such a manner that it will allow for simple opening of the tank in the future. Clear instructions for opening shall be included in the transformer documentation. The transformer tank cover shall be designed to prevent accumulation of water.

3.2.2 Valves and manhole covers

Sampling
Two separate valves shall be provided for oil sampling at the bottom of the transformer tank for analysis of the bottom and top oil. The valves shall be clearly marked “Provtagning bottenolja” and “Provtagning toppolja”. The valve connections shall have R ¾” male threads.

Oil regeneration
All transformers shall be provided with two valves for connection to an oil treatment unit. The size shall at least be DN 80 with R 1 ½” male thread.

Manhole covers
Transformers ≥ 40 MVA with immersed on-load tap-changers in the transformer tank shall be provided with manhole cover for possible future inspection of the contacts on the selector section of the tap-changer. The manhole cover shall be continuous welded.

3.2.3 Gaskets and seals

All sealings shall be vacuum proofed. O-rings shall be used in general. Silicon seals are not permitted. At design review the supplier shall present specification and solution for the sealing system, to be agreed with client.

3.2.4 Surface treatment

External surface treatment
The transformer tank and the accessories fitted to it shall be surface treated according to corrosivity category C4 specified in SS-EN ISO 12944-2. The expected durability shall be (H) 15 to 25 years., SS-EN ISO 12944-1. Corrosion protection system shall be designation C4.11 (SS-EN ISO 12944-5). All outside surfaces grit blasted to at least surface cleanliness Sa 2 ½ according to SIS 8501-1, blown clean and then painted.

Internal treatment
The inside of the transformer tank and conservator shall be degreased, shot blasted to at least surface cleanliness Sa 2 ½ according to SIS 8501 -1, blown clean and then painted.

All painting, including surface on windings, shall be carried out with a surface treatment that does not cause elevated gas evolution in the oil or that has an otherwise detrimental effect on the performance of the transformer.

Control cabinets, cooling radiators, brackets and screws
All external components on the transformer shall be either hot-dip galvanized or made of stainless steel. Cooling radiators and brackets shall be hot-dip galvanized with a zinc coat thickness of at least 60 µm (SS-EN ISO 1461) and shall **not** be painted. Control cabinets shall be of stainless steel or aluminium.

All screws, washers and nuts shall be of acid proof steel (steel grade A4) in according to, SS 14 2324 and SS-EN 10088-3. Screws and nuts shall be waxed in order to prevent seizing. Type of washers shall be chosen to prevent paint from cracking.

3.2.5 Surge arresters

Mechanical design
The surge arrester shall be designed to withstand static and dynamic forces in the direction that is most disadvantageous.

3.2.6 Junction boxes/control cubicles and cables

Separate junction boxes for each purpose are preferable, although the supplier is free to connect the equipment to a common control cubicle, provided that distinct partitions clearly separate the various parts.

For transformers ≥40 MVA, a cabinet to store flanges and parts after assembly shall be mounted on the transformer.

NOTE! Current transformers and any capacitive terminals shall **always** be wired to separate junction boxes.

Junction box 1. Supervisory equipment;
- Gas-actuated protective device (Buchholz relay)
- Oil level indicators
- Thermometers
- Pressure switch for tap-changer

Junction box 2. Secondary windings of the current transformers on the transformer primary side
Junction box 3. Secondary windings of the current transformers on the transformer secondary side
Junction box 4. Cooling equipment controls. This control cubicle shall be mounted on anti-vibration pads

Power and control cables
Cables running on the transformer must not rest directly on the cover or the tank. Cables shall be protected against physical damage by sheet steel protection or effective armouring. However, the protection of the cables must not be located so that water run-off will be hampered.

Clamps and straps shall be made of stainless steel.

Cables shall enter the junction boxes from below or diagonally from below, so that water will be unable to run along the cable towards the seal.

3.3 Other requirements

3.3.1 Oil and oil system

Oil
The necessary quantity of transformer oil for commissioning the transformer shall be included in the delivery and safely stored with no chance for leakage to the surrounding. The oil shall be inhibited, fulfil SS-EN 60296 and specification in Annex 1. Only oil that has been approved in writing by the Purchaser is acceptable.

The supplier shall submit an oil specification for the Purchaser's approval. The specification shall clearly specify the principal base of the oil, the refining site and the country of origin.

Contents of PCB in the oil are strictly forbidden, down to lowest detectable ppm level of PCB.

Oil filling during assembly at site, shall be performed with vacuum filter.

Oil system
The oil system of the transformer shall be separated from the surrounding with for example a rubber bag or another expansion system. If rubber bag is used it shall be air filled and have same temperature capability as the transformer. The filler opening on the conservator shall have a diameter of at least 150 mm, so that the sensor for the magnetic oil level indicator can be tested by activating it by hand, where applicable.

The connection between the conservator and the transformer tank shall be fitted with a shut-off valve, to enable the oil level in the tank to be lowered without the need for draining the oil from the conservator. In addition, the conservator of both the transformer and the on-load tap-changer shall be equipped with a drain valve at the bottom. Similarly,

the on-load tap-changer shall be equipped with shut-off and drain valves for draining the tap-changer compartment.

The dehydrating breather shall be equipped with an oil trap through which the air drawn in must flow before it comes into contact with the dehydrating material. The quantity of dehydrating material shall consist of at least 0.5 litres Silicagel for each 1000 kg oil. The Silicagel shall be environmentally friendly. The granulate may not contain any dust or small particles that could interfere the air flow in the dehydrating breather. The dehydrating breather shall be located a maximum of 1.2 metres from the bottom of the tank.

For transformers ≥100 MVA the dehydrating breathers shall be of maintenance free type.

All pipes between conservator, transformer tank and dehydrating breathers shall be of steel. Rubber hose, flexible hose or other similar materials will not be accepted.

3.3.2 On-Load Tap-Changer (OLTC)

On-load tap changing shall be carried out by means of a quick-switching tap-changer utilizing both local and remote control. The OLTC shall withstand the routine and type tests according to SS-EN 60214.

The OLTC shall be rated for at least the same current as the transformer winding. When over current flows through the OLTC, the drive motor shall stop. This shall be arranged by means of external breaking contacts in series with the control circuit in the drive mechanism. When the external breaking contacts re-close, i.e. when the over current has ceased, the operation shall be completed.

Diverter switch shall be vacuum type. The oil in the diverter switch compartment shall be totally separated from the oil in the transformer. This applies also for vacuum type diverter switches. The OLTC conservator shall be equipped with magnetic oil level indicator similar to the transformer conservator magnetic oil level indicator.

The OLTC shall be equipped with a pressure activated switch that is wired to the junction box for supervisory equipment.

The drive mechanism shall utilize electrical operation directly from controls inside the drive mechanism and from the control room. It shall also be possible to operate the OLTC by hand using a crank.

The drive mechanism shall be provided with an electrical extra limit position for interlocking of higher voltages on the transformer secondary side.

The motor circuit must not contain fuses located in the drive mechanism and the motor itself shall be protected against overload by a motor protective switch. The circuits for the motor, control and position indication shall be galvanically separated.

OLTC position shall be shown in the drive mechanism. Number of operations shall be recorded by a six-digit mechanical counter, readable from the outside. It shall not be possible to reset the counter.
When the drive mechanism is not in the rest position, it shall be indicated, both mechanically and electrically.

The drive mechanism shall be provided with distinct and durable marking with arrows for both operating directions when using the crank.
Operation towards a higher tapping position shall correspond to a reduced ratio implying a higher voltage on the secondary side of the transformer.

An electrical operation that has been started shall be completed even if the duration of the control signal is shorter than the drive mechanism operating time.

End positions shall be equipped with contacts opening both motor and control circuits for relevant direction.

Following auxiliary contacts and functions shall be provided and clearly visible in documents and drawings:

- One change-over contact activated as soon an operation is initiated and remains activated until the operation is finalized.

- One auxiliary contact that is closed during switching of the primary current. The operation of this contact shall correspond as closely as possible to the critical switching time.

- OLTC position shall be indicated by two analogue potentiometers with as many positions as the OLTC and OLTC minus one. Potentiometer one shall have 50 ohm/step and potentiometer two shall have 10 ohm/step.

3.3.3 Bushings

Bushings shall fulfill SS-EN 60137. For windings rated 52 kV and higher condenser (capacitor) bushings with capacitive taps shall be used. The taps shall be grounded.

Bushing terminals shall be according table 4 if not otherwise specified.

Terminal	Type of terminal	Material
≥52 kV Phase and neutral	Cylindrical stud: Length 125 mm. For rated currents < 1250 A ∅ 30 mm. ≥ 1250 A, max 2500 A ∅ 60 mm.	Aluminum
36, 24 and 12 kV Phase and neutral	Vertical plate: Four holes for currents < 2500 A. Nine holes for currents ≥ 2500 A. Hole diameter ∅ 14 mm, c-c 40 mm.	Brass

Table 4. Bushing terminals

Bushings ≥52 kV shall be dry type, oil and SF_6 gas free insulation with RIP condenser core. Insulators shall be made of silicone rubber on all voltage levels.

3.3.4 Current transformers

Terminals

All phase bushings with highest voltage for equipment ≥52kV shall be provided with current transformers. The current transformers shall be designed, manufactured and tested in accordance with SS-EN 60044.

For transformers ≥145 kV also the neutral bushing shall be provided with a current transformer. The ratio for the neutral current transformer shall be the same as for current transformers at phase bushings. The current transformer in the neutral shall have two protection cores and no metering core.

Current transformers shall be selected as follows:

Highest voltage for equipment (kV)	Rated power (MVA)	Ratio of metering core, 1 unit (A)	Ratio of protection cores, 2 units (A)
52	6,3	150/2	150/1
52	10	200/2	200/1
52	16	300/2	300/1
52	25	500/2	500/1
52	40	800/2	800/1
52	63	1200/2	1200/1
52	80	1500/2	1500/1
52	100	2000/2	2000/1

Table 5. Current transformer ratings

Highest voltage for equipment (kV)	Rated power (MVA)	Ratio of metering core, 1 unit (A)	Ratio of protection cores, 2 units (A)
72,5	6,3	100/2	100/1
72.5	10	150/2	150/1
72.5	16	250/2	250/1
72.5	25	400/2	400/1
72.5	40	600/2	600/1
72.5	63	1000/2	1000/1
72,5	80	1200/2	1200/1
72.5	100	1500/2	1500/1

Table 6. Current transformer ratings

Highest voltage for equipment (kV)	Rated power (MVA)	Ratio of metering core, 1 unit (A)	Ratio of protection cores, 3 units (A)
145	10	60/2	60/1
145	16	100/2	100/1
145	25	150/2	150/1
145	40	250/2	250/1
145	63	400/2	400/1
145	80	500/2	500/1
145	100	600/2	600/1

Table 7. Current transformer ratings

In the standard case, the precision class requirements on current transformers are as follows:

Protection cores

Class	5P20
Rated burden	20 VA

Metering core

Class	0.2s FS 5
Rated burden	10 VA

For each current transformer following shall be stated:

- Rct-value (Secondary winding resistance at 75 ºC) and
- ALF (Accuracy Limit Factor)

The markings P1 of the current transformers shall face towards the external connection of the bushing. The instrument core shall be located nearest the external connection of the bushing. The secondary circuit shall be earthed towards S1 with jumpers on the external side of the terminals.

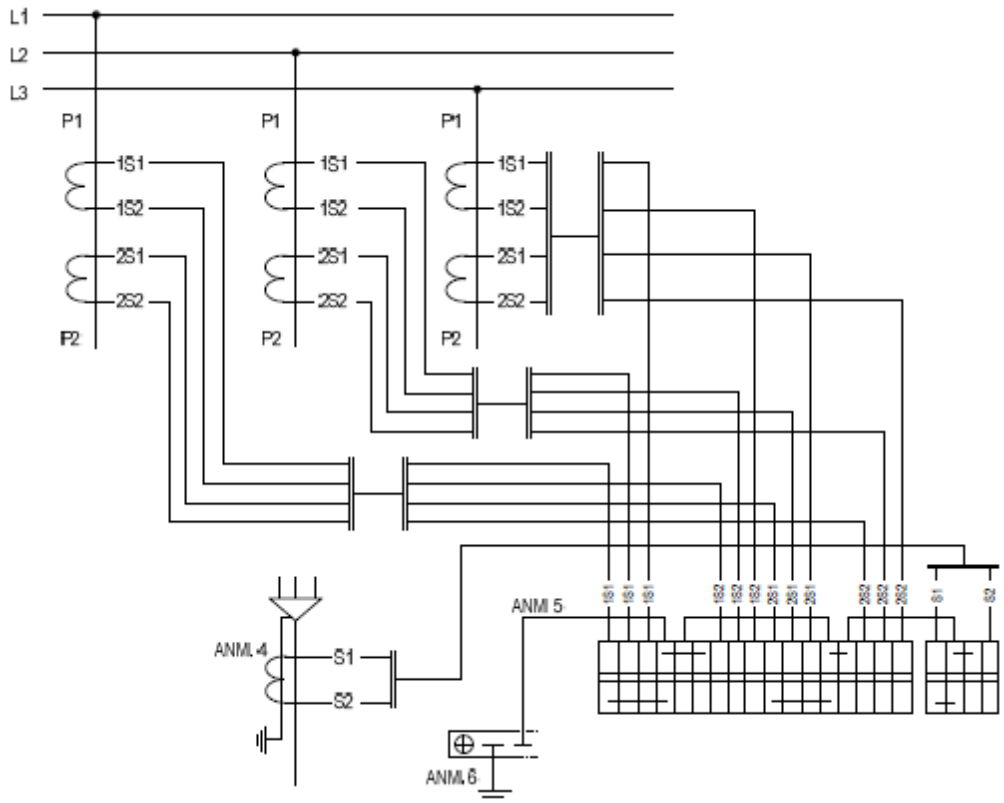

Figure 2. Example of jumpers for current transformer connection.

A test conductor with an area of 35 mm^2 shall be provided in each current transformer (also the CT for the compensated winding thermometer), drawn once through the core. The test conductor shall be earthed at the end corresponding to P2.

3.3.5 Cooling equipment

For transformers with forced cooling, the cooling equipment shall be controlled by means of adjustable temperature sensors which follow the temperature in the hottest winding and in the top oil. The contacts for the hottest winding and top oil shall be connected in parallel. Fans for the cooling equipment shall be mounted vertically.

Transformer < 40 MVA shall have cooling method ONAN.
Transformer 40 - 100 MVA shall have cooling method ONAF.
Transformer > 100 MVA shall have cooling method OFAF or ODAF.

When using OFAF, ODAF, following values shall be fulfilled:

- ONAN 60 % of rated power
- ONAF 80 % of rated power

Transformers with a rated power exceeding 25 MVA shall have cooling equipment divided into two groups. One top oil temperature sensor and two mutually independent winding temperature sensors shall be provided for control and supervision.

3.3.6 Surge arresters

Surge arresters shall be zinc oxide arresters and designed, manufactured and tested according to SS-EN 60099-4.

Transformer ≤145 kV shall be provided with surge arresters for phase terminals and neutral. The surge arresters shall be mounted on the transformer. The surge arresters shall have voltage levels according to table 8 and table 9.

The **phase** arresters shall have the following minimum voltages:

Nominal system voltage (kV)	Highest voltage for equipment (kV)	Min. arrester continuous operating voltage (U_c) (kV)	Min. Rated voltage (U_r) (kV)
130	170	91	114
130	145	87	108
70	82,5	86	107
60	72,5	65	81
50	72,5	60	75
45	52	51	63
40	52	47	59
30	36	36	45
20	24	24	30
10	12	12	15

Table 8. Minimum voltages for phase arresters.

The **neutral** arresters shall have the following minimum voltage:

Nominal system voltage (kV)	Highest voltage for equipment (kV)	Min. Rated voltage (U_r) (kV)
130	170	60
130	145	57
70	82,5	59
60	72,5	44
50	72,5	41
45	52	35
40	52	33
30	36	25
20	24	17
10	12	8

Table 9. Rated voltage for neutral arresters.

Consoles for surge arresters shall always be included; even if no surge arresters are included in the delivery due to a special agreement.

The surge arrester housings shall be made of silicone rubber or proven polymer material.

Surge arresters with highest voltage for equipment 52 -145 kV shall be provided with insulated base.

Surge arresters terminals shall be vertical plate, hole diameter ∅ 14 mm, c-c 40 mm.

Rated discharge current

The rated discharge current shall be at least 10 kA for highest voltage for equipment ≤ 145 kV.

Arrester classification

Arresters shall, at least, conform to the requirements for line discharge class according to the table below:

Highest voltage for equipment (kV)	Arrester classification according to SS-EN 60099-4:2014	Therma energy rating Wth [kJ / kV]	Repetitive charge transfer rating Qrs [C]	Thermal charge transfer rating Qth [C]
145-170	SM	7,0	1,6	--
36-82,5	SL	4,0	1,0	--
≤24	DH	--	0,4	1,1

Table 10. Arrester classification

Residual voltages

The maximum residual voltages of the arresters shall not exceed the values set out in the following table.

Highest voltage for equipment (kV)	Discharge current (kA)	Max residual voltage (kV/U_r)		
		Steep front/ FOW [1] (10 kA)	Fast front/ lightning [2] (10 kA)	Slow front/ switching [3] (0.5 kA)
≤ 170	10	3.1	2.8	2.2

Table 11 Maximum residual/discharge voltages at current waves

1) Steep-front/FOW 1/(2-20) µs
2) Fast-front/lightning 8/20 µs
3) Slow-front/switching 30/60 µs

Short-circuit capability

Arrester with silicone rubber housing does not need to be equipped with pressure release device but shall however fulfill following short-circuit capability:

Highest voltage for equipment (kV)	Short-circuit capability (kA, 0.2 s)
≥82,5	40
≤ 72,5	20

Table 12. Short-circuit capability

3.3.7 Auxiliary winding

If stated in the technical specification the transformer shall be equipped with an auxiliary winding.

The winding shall be capable of:

- supplying external loads at 3-phase 0,42 ±2x2,5 % kV rated voltage and up to 500 kVA, rated power

The supplier shall select rated voltage and rated power for this winding and propose a short circuit-proof solution that meets these requirements.

This auxiliary distribution transformer shall be selected according to its highest voltage for equipment and through calculations verified by the supplier. Fuses and winding terminals shall be provided with a single-phase insulating enclosure of incombustible material, which also must withstand arcing. The equipment shall be enclosed in a cubicle with a hinged and bolted front cover.

This cubicle shall be provided with a legible plate reading "**Får endast öppnas i spänningslöst tillstånd**" (Only to be opened when off circuit).

Maintenance works (fuse replacement for instance) must not interfere with main transformer operation.

3.3.8 Monitoring equipment

The transformer shall be equipped with following equipment:

- Gas relay/Buchholz relay
- Oil level indicator transformer
- Oil level indicator OLTC
- Thermometer, top oil temperature
- Thermometer, winding temperature

Gas relay/Buchholz relay

Gas relay shall be provided with shut-off valves and a by-pass to enable replacement of the gas relay as quickly as possible. The valves shall have distinct position indication “ÖPPET” (open) and “STÄNGT” (closed).

The gas relay shall be provided with two galvanically separated set of contacts with following functions:

- Contacts that close in the event of slow gas production, intended for alarm.
- Contacts that close in the event of a rapid oil flow or low oil level, intended for trip. Function for low oil level shall be possible to de-activate.

The gas relay shall have valves for sampling of the gas and for testing at the gas relay.

Oil level indicator
The magnetic oil level indicators shall visually present the oil level and be equipped with normally open contacts for high and low oil level. The float shall be accessible for testing of the oil level indicator.

Thermometers/temperature instruments
Transformers shall be provided with following thermometers and thermometer pockets:

Rated power (MVA)	Thermometer for	Number of thermometer pockets
< 10	Top oil temperature	2
≥ 10 and < 25	Top oil temperature and hottest winding temperature	3
≥ 25 and < 40	Top oil temperature and hottest winding temperature	4
≥ 40	Top oil temperature and all winding temperatures	5

Table 13. Thermometers and thermometer pockets

Each thermometer/temperature instrument shall have four galvanically separated contacts. Thermometers/temperature instruments shall be installed using resilient mountings and be positioned on the operating side of the transformer, maximum 1.2 m from the bottom of the tank. Oil temperature and winding temperature instruments shall be furnished with analogue temperature output 4-20 mA. Temperature action levels shall be set according to table 14.

	Top oil temperature			Winding temperature	
	ONAN	ONAF	OFAF	ONAF	OFAF
	°C	°C	°C	°C	°C
Start of fan group 1		55	50	65	65
Signal “no fan start” fan group 1, (only used when only one fan group are installed on the transformer)		57	52	67	67
Start of fan group 2		60	55	75	75
Signal “no fan start”, fan group 1 and 2		62	60	77	77
Signal ”top oil temperature”	85	85	75		
Trip top oil temperature	95	95	85		
Signal ”winding temperature”				100	100
Trip winding temperature				110	110

Table 14. Temperature action levels

3.3.9 Sound power

Unless otherwise specified in the enquiry documentation, the noise levels from the transformer may not, under any circumstances, exceed the following limit values of maximum sound power. This applies both with and without the cooling system in operation.

Rated power (MVA)	Overall sound power level, dB(A)
6.3	62
10	65
16	66
25	68
40	78
63	79
80	80
100	81
150	83
200	84
300	87
500	90
750	97

Table 15. Sound levels

3.3.10 Impact recorder

During transport the transformer shall be equipped with an impact recorder to register g-forces in x-, y- and z-directions.

4 Functional requirements

Operating conditions

The transformer shall be designed and verified for continuous operation at a rated power stated in the technical specification.

A transformer with ONAF cooling shall without fans be possible to load according to table 14 without exceeding permissible temperatures or temperature rises according to SS-EN 60076-2.

Primary side ONAN/ONAF
31.5/40 MVA
40/50 MVA
50/63 MVA
63/80 MVA
80/100 MVA

Table 16. ONAF/ONAN ratings

Secondary side (for 3 windings) ONAN/ONAF
10/12 MVA
12/16 MVA
16/20 MVA
20/25 MVA
31.5/40 MVA
40/50 MVA
50/63 MVA
63/80 MVA

Table 17. ONAF/ONAN secondary side ratings for 3 winding transformers

The transformer with accessories shall be possible to load up to at least 140% of rated load at an ambient temperature of -10 °C according to SS-EN 60076-7, Short-time emergency loading.

The transformer shall, without negative consequences, energized or not withstand a lowest average ambient temperature of -40 ºC during one hour.

Bushings, OLTC, DETC, CT´s and all other accessories shall be designed and chosen so that they can carry at least the highest current for respective ratio and/or the highest current for the winding during a time that is at least equal to the time for the corresponding winding.

5 Testing

Testing of the power transformer shall be performed as factory acceptance test on the manufacturer factory area. Following chapters describes the scope, steering standards and the purchaser requirements. The manufacturer shall at tender stage clearly describe what type of site acceptance test that will be performed before commissioning to secure that the transformer has arrived at site without any internal or external damages.

Scope

Unless otherwise specified, the transformer shall be subject to the following tests. At pre-delivery testing, a test programme shall be set up so that the testing will be carried out in the order listed below:

- Measurement of winding resistance according to SS-EN 60076-1
- Measurement of voltage ratio and check of phase displacement according to SS-EN 60076-1
- Measurement of zero-sequence impedances according to SS-EN 60076-1
- Measurement of short-circuit impedance and load loss according to SS-EN 60076-1
- Temperature rise test according to SS-EN 60076-2
- Lightning impulse test according to SS-EN 60076-3 (also for transformers with highest voltage for equipment 72.5 kV or below)
- Separate source withstand voltage test according to SS-EN 60076-3
- Short-duration induced AC withstand voltage test (ACSD) according to SS-EN 60076-3
- Measurement of no-load loss and no-load current according to SS-EN 60076-1
- Measurement of sound levels according to SS-EN 60076-10
- Tests on on-load tap-changer according to SS-EN 60076-1
- For transformers > 170 kV, chopped wave lightning impulse tests are routine tests for all windings of the transformer. (IEC 60076-3, Cl 7.1).

Standards
Unless otherwise specified, testing shall follow the scope and requirements on test results specified in the relevant SS-EN standard. However, if there are conflicting interpretations between Swedish and international standards, the Swedish standard have precedence.

Requirements
PD
Induced voltage test with simultaneous partial discharge measurement shall be performed according to SS-EN 60076-3.

Lightning impulse
Unless otherwise stated in the specification, a lightning impulse voltage test (1.2/50 μs) shall be performed on all transformers in accordance with the latest revision of the SS-EN standard. All phase bushings shall be tested directly, while the neutral point shall preferably be tested indirectly via the phase bushings with a 1.2/50 surge. The impulse level shall then be measured over an impedance between the neutral point and earth. However, if the neutral point is fully insulated (uniform insulation) or if, for some other reason, an indirect test cannot be carried out at the neutral bushing, a direct surge may be applied.

When testing the phases, the position of the on-load tap-changer shall be changed as the test proceeds. Example:
Phase U is tested in the minimum position of the tap-changer
Phase V is tested in the principal position of the tap-changer and
Phase W in the maximum position of the tap-changer.
If a direct surge at the neutral point is applied during surge voltage testing, the position of the tap-changer shall be selected in consultation between the supplier and E.ON Energidistribution AB.

Current transformers (CT)
Current transformers shall be tested individually on place in the transformer during transformer factory acceptance test to an extent that verifies CT installation. Tests shall also be performed according to following table, but might be performed in separate test bench with a conductor with same dimension and location at current transformer as the one located at transformer. A test report shall be established including at least following tests.

	Tested at	Indicated test result
Current dependence	1, 5, 20, 100 and 120% of In	Current failure (%), angle failure (min)
Burden dependence	1 VA, 25 and 100% rated burden at above % of In	Current failure (%), angle failure (min)
Accuracy limit factor	Type test or routine test	Constants a and b

Table 18. Tests for Current transformers

Measured values shown in test report shall be according to international (SI) System of Units.

Sound
Sound level measurement shall be carried out on all transformers, unless otherwise stated in the specification. The measurement method, background noise and the frequency spectrum of the sound emitted shall be shown in the test report. The measurement shall be carried out according to SS-EN 60076-10.

Zero-sequence impedance
Measurement of zero-sequence impedance shall be carried out for y- and z-connected windings in principal position of tap-changer and both extreme positions. For transformers with reconnectable windings, e.g. 10-20 kV, measurement shall be carried out for both (all) connections. For each y- and z-connected winding in the transformer shall the imaginary- (X0) and real part (R0) of the zero-sequence impedance be determined. For transformers with a design that result in a non-linear impedance shall the current dependence of the zero-sequence be recorded with measurements for at least four different current levels, to have a picture of the impedance current dependence obtained. Applied voltage, recorded current, phase angle and impedance value shall be shown in the test report. Impedance value shall be assigned in ohm per phase.

Gas analysis (DGA)
The transformer oil shall be sampled before, during and after the temperature rise test in order to analyse the level and occurrence of the different gases. The results shall be shown in the test report.
After final assembly at site, an oil sample shall be taken and sent to E.ON Energidistribution AB's framework contract laboratory.

Capacitive total current bushing terminal
At rated voltage and short circuit between a voltage terminal and earth, at least the following capacitive total current shall be obtained from the three phases:

Rated voltage (kV)	Capacitive current (mA)
140/√3	10
77/√3	8
57,5/√3	7
46/√3	6

Table 19. Capacitive current

6 Documentation

All dimensional drawings, signal- and wiring diagrams shall be in A3 format. Disposition of terminals and marking/labelling shall be clearly included on drawings and wiring diagrams etc. The documentation shall be submitted on paper, as dwg files and as pdf files.

The dimensional drawings shall include type of accessories, manufacturer and accessory drawing number. Material in primary terminals, transformer weight and outer dimensions shall be clearly specified in the dimensional drawings. Main data shall at least include rated power, rated voltage and connection group.

A transport drawing shall be included. The transport drawing shall include centre of gravity, positioning of hydraulic jacks, usable wagons and weights.

Scope

Documents for review and approval during execution of the project:

- Rating plate
- Dimensional drawings and list of accessories
- Transport and installation drawings
- Circuit diagrams, list of apparatus, list of cables, lay-out drawings for cubicles and control equipment
- Inspection and test program
- E.ON:s form for technical data

Final documentation shall be delivered 5 days after FAT and shall be submitted in dwg- and pdf format and in paper (one copy in binder) including at least following documents:

- Rating plate
- Dimensional drawings and list of accessories
- Transport and installation drawings
- Circuit diagrams, list of apparatus, list of cables, lay-out drawings for cubicles and control equipment
- Product data sheet for the oil
- Pictures of the active part four different sides

- Test protocols and test results
- Instructions for maintenance and operation
- Assembly instructions
- Instruction for touch-up painting
- List of gaskets with dimensions and material included
- Instruction for opening of welded cover.
- Power transformer datasheet
- E.ON:s form for documentation data.

Annex 1, General specifications for hydrocarbon based oils.

Property	Test method(s)	Limits for Transformer oil
1 – Function		
Viscosity at 40 °C	ISO 3104	Lower than 12 mm^2/s
Viscosity at –30 °C	ISO 3104	Lower than 1 800 mm^2/s
Pour point	ISO 3016	Lower than –40 °C
Water content	IEC 60814	Less than 30 mg/kg
Breakdown voltage	IEC 60156	Higher than 30 kV
Density at 20 °C	ISO 3675 or12185	Lower than 895 kg/m^3
DDF (tan d) @ 90 °C	IEC 60247 or 61620	Lower than 0,005
Particles content	IEC 60970	No general requirement
2 – Refining/stability		
Appearance	--	Clear, free from sediment and suspended matter
Acidity	IEC 62021-1	max. 0,01 mg KOH/g
Interfacial tension	ASTM D971	No general requirement
Total sulphur content	ISO 14596	< 0,005 %
Corrosive sulphur	DIN 51353 & IEC 62535	Not corrosive
Antioxidant additive	IEC 60666	At delivery: 0,30 – 0,40 % (w/w)
2-Furfurals	IEC 61198	Max. 0,05 mg/kg for each individual compound
3 – Performance		
Oxidation stability	IEC 61125 (method C) Test duration: 500 h	
Total acidity		<1,2 mg KOH/g oil
Sludge		< 0,8 %
DDF (tan d) @ 90 °C	IEC 60247	< 0,500
Gassing	IEC 60628	No general requirement
”Stray” gassing		Oils known to cause stray gassing are not accepted
4 – Health, safety and environment (HSE)		
Flash point	ISO 2719	> 135 °C
PCA content	BS 2000 Part 346	< 3 %
PCB content	IEC 61619	< 2 mg/kg

Additional requirement concerning aromatic content

C_A	ASTM D2140	< 4,0 %
C_A	ASTM D3238	< 4,0 %

For hermetically sealed transformers < 1500 kVA

C_A	ASTM D2140	< 6,5 %
C_A	ASTM D3238	< 6,5 %

C_A requirements are motivated by this parameters influence on future maintenance needs as aromatic structures will degrade and form sludge at higher rate than more rigid molecular structures.

A positive side effect is that DGA interpretations are facilitated.

Additional requirement concerning elemental composition.

Hydrocarbon based oil consists of three major elements:

- Hydrogen, atom-wize most abundant but weight-wize second.
- Carbon, atomwize second most abundant but weight-wize most abundant.
- Sulphur is an element in many molecule types but refined to be less than 50 mg/kg in modern transformer oils. Sulfur free oil is the optimum.

Element	Concentration
Carbon	No requirement
Hydrogen	No requirement
Sulphur	< 50 mg/kg
Silicon	< 1 mg/kg
Calcium, Barium, Sodium, Potassium	< 0,1 mg/kg
Chlorine	< 1

Other so called hetero-atoms shall be below concentrations that affect serviceability of the transformer or introduce premature need for maintenance.

Equipment to determine contaminant concentrations shall have sufficient detection limits eg for metals 0.1 mg/kg, for sulphur 5 mg/kg, alkaline earth metals 0.2 mg/kg etc.