Recommendation 6B

Technical regulations etc. for
10-20 kV dry type distribution transformers

1st Edition

DEFU
dansk energi · forskning og udvikling

Recommendation 6B

Technical regulations etc. for 10-20 kV dry type distribution transformers

1st Edition

Dansk Energi
R & D
Rosenørns Allé 9
1970 Frederiksberg C

Tel.: + 45 35 300 770
Fax: + 45 35 300 401
E-mail: info@defu.dk
www.danskenergi.dk

Feb. 2007

DEFU
dansk energi · forskning og udvikling

Contents

1 Scope

2 General requirements
2.1 Location
2.2 Temperature
2.3 Humidity

3 Principal electrical data
3.1 Rated frequency
3.2 Rated power
3.3 Dimensioning of neutral terminal
3.4 Overload capacity
3.5 Thermal class
3.6 Rated voltages
3.7 Tappings
3.8 Connections
3.9 Short-circuit impedance
3.10 Short-circuit withstand requirements
3.11 Insulation level
3.12 Losses

4 Environment, climate and fire class
4.1 Environmental class
4.2 Climate class
4.3 Fire Class

5 Constructional details
5.1 Switching between tapping voltage
5.2 Cooling
5.3 Terminals
5.4 Surface treatment
5.5 Dimensions
5.6 Sound power level

6 Accessories
6.1 Thermometer or thermal sensor
6.2 Transport devices
6.3 Enclosure
6.4 Warning plate
6.5 Marking

7 Tests

8 **Data to be provided in tenders submitted**

9 Data to be provided in tenders submitted

B1 Corrosion protection

B2 Dimensions

1. SCOPE

This recommendation 6B applies for three-phase dry type distribution transformers with normal equipment.

Transformers are used for transmitting power from resonant earthed or isolated 10-20 kV systems to solidly earthed low voltage systems.

The recommendation is published in Danish and English. In case of discrepancy between the two versions the Danish version shall prevail.

2. GENERAL REQUIREMENTS

The transformers shall be in compliance with the general requirements that apply at the time of tendering and the testing specifications in IEC-, CENELEC- and CEN-standards.

With regard to the terminology used in this recommendation, reference is made to the definitions given in the above mentioned standards.

The transformer shall meet the requirements laid down in current environmental legislation.

2.1 Location

The transformer is designed for indoor or outdoor use. Enclosure may be necessary for outdoor use.

2.2 Temperature

The transformer is designed for installation at ambient temperature in the range of:

$-25^{o}C$ … $+40^{o}C$ for outdoors located transformers
$-5^{o}C$ … $+40^{o}C$ for indoors located transformers

Furthermore applies that the monthly average temperature may not exceed $30^{o}C$, and that the annual average temperature may not exceed $20^{o}C$.

2.3 Humidity

The transformers are designed for installation at a relative humidity less than 93 %.
No water drops shall be found on the surface of the transformer windings.

3. PRINCIPAL ELECTRICAL DATA

3.1 Rated frequency

50 Hz

3.2 Rated power

Recommended rated power:

100 – 200 – 400 – 500 – 630 – 800 – 1000 – 1250 – 1600 – 2000 – 2500 kVA

3.2.1 At high ambient temperatures, cf. 2.2, and/or restrictions in the cooling of the transformer the manufacturer of the transformer shall be consulted with regard to a possible reduction of the rated power of the transformer.

3.2.2 A transformer supplied in an enclosure shall accommodate to its rated power. If the transformer originally is supplied without an enclosure and where this is added later, reference is made to IEC 62271-202 and IEC 60905 for the load of the transformer. The manufacturer of the transformer should be consulted with regard to changing the rated power of the transformer.

3.2.3 The total harmonic factor and the even harmonic factor[1] for the load current shall be limited to 5 % and 1 % respectively. If these limit values are exceeded, the harmonic content in the load current shall be taken into account.

The harmonic content shall be taken into account by specifying in the invitations to tender that the transformer shall accommodate to loads pursuant to CENELEC HD 535.3.

Invitations to tender may also specify that the transformer shall be dimensioned to accommodate 100 % of its rated current plus the harmonic content in the load current. E.g. by specifying a K-factor for the transformer, cf. UL 1562[2]. The K-factor for a given load current is determined from the harmonic content in the load current and is defined by the following expression:

$$K = \sum_{h=1}^{h=h_{max}} \left(\left(\frac{I_h}{I_R} \right)^2 \cdot h^2 \right)$$

where

h	=	Harmonic ordinal numbers
h_{max}	=	Maximum harmonic ordinal numbers that are a part of the calculation
I_h	=	The harmonic component of the load current with the harmonic ordinal number h
I_R	=	The rated current of the transformer

If required, see DEFU report RA 532 ”Transformere udsat for harmoniske strømme” in Danish for a detailed description of the load limit of the transformers, when they are exposed to harmonic currents.

3.3 Dimensioning of neutral terminal

The neutral terminal and conductor on the low voltage side shall be dimensioned for the rated current of the low-voltage winding.

3.4 Overload capacity

The overload capacity of the transformer shall be in compliance with IEC 60905.

3.5 Thermal class

The thermal class of the insulation system shall be one of the following

Thermal class[3]	Insulation system temperature. [°C]	Average max. temperature rise for the windings at rated current. [°C]
A	105	60
E	120	75
B	130	80
F	155	100
H	180	125
-	200	135
-	220	150

The table is based on table 2 in CENELEC EN 60076–11.

The windings temperature rise is determined in relation to the maximum ambient temperature for which the transformer is designed, cf. 2.2. If the transformer is installed in ambient temperatures that exceed the temperatures, cf. 2.2, the above mentioned rise in temperature shall be reduced correspondingly.

The manufacturer of the transformer shall be consulted with regard to the load of the transformer if the transformer is installed under conditions with particularly high ambient temperatures or limited possibilities for cooling.

---

[1] The harmonic factor is determined by $H[\%] = 100 \cdot \left[\sum_{h=2}^{h=H} \left(\frac{I_h}{I_1} \right)^2 \right]^{\frac{1}{2}}$.

[2] Standard UL 1562, ”Transformers, Distribution, Dry-type – Over 600 Volts”, Underwriters Laboratories Inc.

[3] The character notification refers to classification in CENELEC EN 60085.

3.6 Rated voltages

	Primary [kV]			Secondary [kV]	
Nominal voltage, U_r	10	15	20	0,4	0.69
System voltage	10.5	15.75	21	0.42	0.69[4]

3.7 Tappings

The high voltage winding shall have five tappings, corresponding to the rated voltage ± 2·2.5 %. A tap-changer for switching between tappings must be provided, cf. 5.1. The transformer shall accommodate a load according to para. 3.4 in all switching positions.

3.8 Vector group

Dyn 5 or Dyn 11. Alternatively, at power ratings lower than or equal to 200 kVA, the vector group may be Yzn 5 or Yzn 11.

3.9 Short-circuit impedance

The transformer shall be designed for the following short-circuit voltage:

Highest voltage for equipment, U_m	Rated power [kVA]	100… 630	630 … 2500
12 kV	Short-circuit impedance, e_k [%]	4	6
24 kV	Short-circuit impedance, e_k [%]	6	6

3.10 Short-circuit withstand requirements

The transformer shall withstand the thermal and mechanical loads arising from external short-circuits and earth faults in all switching positions.

3.10.1 Depending on the thermal class of the insulation system the max. average temperature of the windings in case of a short-circuit shall not exceed:

Thermal class	Temperature of the insulation system, [°C]	Winding temperature [°C]	
		Copper	Aluminium
A	105	180	180
E	120	250	200
B	130	350	200
F	155	350	200
H	180	350	200
	220	350	200

Table is based on table 3 in CENELEC EN 60076 – 5.

The average temperature of the windings after a short-circuiting shall be specified pursuant to CENELEC EN 60075–5.

3.10.2 Invitations to tender shall state the short-circuit power of the network. It is assumed that the short-circuit power of the 10 – 20 kV network is 500 MVA (common practice in Europe. CENELEC EN 60076–5, if the short-circuit power is not known).

3.11 Insulation level

The transformers shall be designed for the following voltages specified in CENELEC EN 60076–11:

Nominal voltage, U_r [kV]	Highest voltage for the equipment, U_m [kV]	1 min. AC voltage	Lightning impulse 1,2/50 μs [kV]
0.4	1.1	3	-
0.69	1.1	3	-
10	12	28	75
15	17.5	38	95
20	24	50	125

The lightning impulse voltage refers to list 2 in table 3 in CENELEC EN 60076–11.

3.12 Loss

Tenders submitted shall be based on the capitalisation factors for the load and no-load losses stated in the invitation to tender.[5]

If the capitalised value of the total losses exceeds the value calculated on the basis of tenders, the purchase price shall be correspondingly reduced. The calculated reduction shall be based on the above-mentioned capitalisation factors. No compensation is made for load and no-load losses lower than those stated.

[4] Unless otherwise agreed.

[5] Refer to TR 12, 3rd Edition "Værdisætning af transformertab ved forskellige tariferingsformer" in Danish.

If a load or no-load loss differs by more than +15%, or the total loss by more than +10% from the loss specified in the tender, the purchaser reserves the right to reject the transformer.

If the purchase covers a batch of transformers, the losses for the individual transformers shall apply.

4. ENVIRONMENTAL, CLIMATE AND FIRE CLASS

4.1 Ambient class

The environmental class of the transformer depends on the environment in which the transformer is installed and determined in relation to humidity, condensation, pollution and ambient temperature.

The following environmental classes are defined in CENELEC EN 60076–11[6]:

Class	Description
Class E0:	No condensation occurs on the transformer, and pollution can be neglected.
Class E1:	Condensation may occur now and then to a minor degree on the transformer, limited pollution may also be found.
Class E2:	Condensation on the transformer and heavy pollution or a combination of both may occur often.

Required environmental class to be specified in the invitation to tender.

4.2 Climate class

The following climate classes are defined in CENELEC EN 60076–11:

Class	Description
Class C1:	The transformer is suitable for operation at ambient temperature down to - 5°C, but may be exposed to ambient temperatures down to - 25 °C under transportation or storage.
Class C2:	The transformer is suitable for operation at ambient temperatures down to - 25 °C.

Required climate class to be specified in the invitation to tender.

4.3 Fire class

The following fire classes are defined in CENELEC EN 60076–11:

Class	Description
Class F0:	There is no special risk of fire that needs to be taken into account. Emission of toxic substances or opaque smoke shall however be kept to a minimum.
Class F1:	The transformer is exposed to risk of fire. Limited flammability is required. Emission of toxic substances or opaque smoke shall however be kept to a minimum.

Required fire class to be specified in the invitation to tender[7].

5. CONSTRUCTIONAL DETAILS

5.1 Switching between voltage tappings

Switching between tappings, cf. 3.7, shall be possible to execute in a no-voltage condition by use of bolted connections, cf. CENELEC EN 60076-11.

5.2 Cooling

The transformer cooling system shall be designed for natural air circulation (AN) or natural and mechanical air circulation (AN/AF).

[6] The environment class of the transformer is also important in relation to storage. The transformer shall therefore not be stored in an environment that does not comply with its environment class.

[7] In the executive order on high-voltage "Stærkstrømsbekendtgørelsen afsnit 2" in Danish from 2003 a fire class F2 is mentioned. This class does no longer exist in CENELEC EN 60076-11.

5.3 Terminals

5.3.1 Low voltage terminals shall be designed as specified in the order/offer.

5.3.2 High voltage terminals shall be designed as specified in the order/offer.

5.3.3 The secondary winding of the transformer (low voltage winding) shall be equipped with a neutral terminal.

5.3.4 The transformer shall be equipped with an earthing terminal placed on the lowest yoke of the transformer for the connection of protective conductors. All dead conducting parts of the transformer shall be connected to this terminal. The earthing terminal shall be designed in accordance with CENELEC EN 50216-4 and shall either be an earthing screw M12, length 35 mm, fitted with two nuts, or a terminal for 240 mm^2 Cu-cable. Screws etc. shall be made of stainless steel or cuprodur.

5.3.5 The clearance for high-voltage terminals between phase-phase, phase-earth, phase-neutral and for low-voltage terminals shall as a minimum be as specified in the table:

Highest voltage for equipment, U_m [kV]	Lightning impulse voltage 1,2/50 μs [kV] peak value	Minimum clearance [mm]
12	75	110
17.5	95	170
24	125	275

The table is based on table 5 in CENELEC EN 60076 – 3.

5.4 Surface treatment

All metallic parts of the transformer shall be surface-treated in compliance with Appendix B1.

5.5 Dimensions

Unless otherwise specified in the invitation to tender, transformers shall be dimensioned within the following limits, see drawing in Appendix B2:

Rated power [kVA]	Length a_1 [mm]	Width b_1 [mm]	Height h_1 [mm]
100	1450	760	1300
200			
400	1650	870	1700
500			
630	1850	1000	1850
800			
1000	2000	1085	2150
1250			
1600	2250	1250	2450
2000			
2500	2550	1400	2650

(NB! Not all conventional prefabricated substations fit the above dimensions.)

By installation of the transformer in an enclosure the superior dimensions shall be specified in the invitation to tender.

5.6 Sound power level

The sound power level shall not exceed:

U_m [kV]	S [kVA]	100	200	400	500	630	800
12	L_{wa}	54	58	63	64	65	66
24	L_{wa}	-	-	63	64	65	66

U_m [kV]	S [kVA]	1000	1250	1600	2000	2500
12	L_{wa}	68	69	71	73	76
24	L_{wa}	68	69	71	73	76

The sound power level shall be documented cf. CENELEC EN 60076 – 10. If the sound power level exceeds the level specified in the invitation to tender or if not specified the above mentioned levels, the purchaser reserves the right to reject the transformer.

If the cooling of the transformer is executed at an AN/AF, cf. 5.2, the addition to the sound power level by AF-cooling of the transformer shall be stated in dB.

6. ACCESSORIES

6.1 Thermometers or thermal sensor

The transformer shall be equipped with a thermometer or a thermal sensor placed in accordance with CENELEC EN 60076-11. The temperature metering shall as a minimum be carried out on the middle limb of the transformer. It shall be possible to change thermometer and temperature sensor, without damaging the transformer.

6.2 Transport arrangements etc.

The transformer shall be provided with rollers for transportation. The rollers shall allow lengthwise and transverse transportation.

The rollers shall be in accordance with CENELEC EN 50216-4 and be selected from the table below:

Diameter of roller [mm]	Thickness of roller [mm]	Max. carrying capacity for each roller [t.]
125	40 or 50	2.5
160	50	3.6
200	70	6.3

The distance between the rollers shall be in accordance with CENELEC EN 50216-4 and determined from the table below:

Rated power [kVA]	Distance between rollers (see drawing in Appendix B2) [mm]
S ≤ 250	520
250 ≤ S ≤ 1250	670
1250 ≤ S ≤ 1600	820
1600 ≤ S ≤ 2500	820 or 1070

The base frame of the transformer shall be equipped with the necessary pulling lugs for transport.

6.3 Enclosure

The transformer may be supplied with an enclosure.

6.3.1 The following three definitions of dry type transformers are to be found in CENELEC EN 60076–11:

Type	Description
Non-enclosed dry-type transformer	Transformer without an enclosure cooled by natural air circulation.
Enclosed dry-type transformer	Transformer in an enclosure cooled by the circulating external air.
Totally-enclosed dry-type transformer	Transformer in an enclosure cooled by the circulating internal air.

The choice will depend on the location of the transformer, and the environment in which it will be installed.

6.3.2 The enclosure shall be designed in accordance with IEC 62271-202.

6.3.3 The degree of protection shall be in accordance with CENELEC EN 60529 and pursuant hereto the degree of protection shall be specified in the tender documents.

6.3.4 If the enclosure is purchased at some other point in time, the class of the enclosure shall be specified and possess one of the following values: class 5, 10, 15, 20, 25 and 30 in accordance with IEC 62271-202.

The class of the enclosure is used to de-rate the transformer in accordance with Appendix D in IEC 62271-202.

6.3.5 If the enclosure is made of metal, it shall be surface treated cf. Appendix B1.

6.3.6 Cabling of high and low-voltage cables into the transformer through the enclosure is specified in the invitation to tender.

6.3.7 Partial discharge test on the transformer in the enclosure shall be executed in accordance with partial discharge test in CENELEC EN 60076-11 and to a satisfactory result.

6.4 Warning plate

Warning plates shall be placed on the transformer in accordance with CENELEC HD 538.1.

6.5 Marking

A climate resistant rating plate shall be placed on the transformer. The plate shall be placed in a conspicuous place on the transformer. If the transformer is encapsulated, the enclosure shall also be fitted with a rating plate. The following information shall be found on the plate::

- Dry type transformer
- Reference to standard
- Manufacture
- Serial number of manufacture
- Year of production
- Winding material (both primary and secondary windings)
- Temperature of the insulation system and thermal class for each winding (i.e. both primary and secondary)
- Number of phases
- Rated power for all types of cooling
- Rated frequency
- Rated voltages incl. tapping voltages
- Rated current for all types of cooling
- Connections
- Short-circuit voltage at reference temperature
- Cooling method
- Weight
- Insulation level
- Degree of protection
- Environment class
- Climate class
- Fire class

If the transformer is designed for both natural and mechanical air circulation (AN/AF), the rating plate of the transformer shall state the rated power and the rated current for both natural and mechanical air circulation.

7. TESTS

The purchaser's approval of the supply is subject to the routine tests stated in CENELEC EN 60076–11 having been carried out on the transformers with a satisfactory result. Furthermore type tests according to CENELEC EN 60076–11 for a transformer representative of the transformer type shall be carried out to a satisfactory result.

Furthermore special tests to document the following features of the transformer, must also be performed:

- Short-circuit withstand requirements cf. CENELEC EN 60076–5
- Sound power level cf. CENELEC EN 60076-10
- Climate class cf. CENELEC EN 60076–11
- Ambient class cf. CENELEC EN 60076–11
- Fire class cf. CENELEC EN 60076-11

Invitation to tender may specify that special partial discharge tests shall be performed on transformers in resonant earthed or isolated systems cf. CENELEC EN 60076–11.

8. DATA TO BE PROVIDED IN INVITATION TO TENDER

Invitations to tender shall contain the following data and particulars:

- Cooling, cf. 5.2.
- Rated power, cf. 3.2.
- Rated frequency, cf. 3.1.
- Rated voltage (primary and secondary), cf. 3.9.
- Highest voltage for winding (primary and secondary), cf. 3.9.
- Insulation level, cf. 3.9.
- Location and specifications for high and low voltage terminals.
- Tappings, cf. 3.7.
- Specification as to how switching between tappings shall be carried out, cf. 5.1.

- Connections, cf. 3.8.
- Capitalisation factors for load and no-load losses, cf. 3.10.
- Outdoor or indoor installation, cf. 2.2 and 2.3.
- Thermal class, cf. 3.5.
- Environment class, cf. 4.1.
- Climate class, cf. 4.2
- Fire class, cf. 4.3
- Any peculiarities of installation, assembly, transport and handling.
- Special restrictions to dimensions and weight, if any.
- Indications as to where various accessories shall be placed.

Special requirements:

- Short-circuit impedance, cf. 3.9
- Short-circuit power of the system, cf. 3.10.
- Special ambient temperature conditions or restrictions in connection with cooling, if any.
- Contents, if any, of harmonic currents in the load current, cf. 3.23.
- Other particulars regarding operating conditions that need to be taken into account
- Other requirements to surface treatment, if any, cf. B1
- Whether the transformer shall have a lower sound power level, cf. 5.6.
- Degree of protection, cf.6.3.3, for transformers supplied with an enclosure.
- For transformers supplied with an enclosure, specification shall be made as to where high and low-voltage cables shall enter the enclosure, cf. 6.3.6
- Special requirements with regards to transportation on rollers.

Commercial information:

- Time of delivery and circumstances of unloading
- Delivery address
- Earliest and latest time of delivery
- Terms of delivery, if relevant. Unless otherwise agreed Carriage Paid To place of delivery, cf. Incoterms 2000)
- Deadline for submission of tender, binding dimensional drawings etc.
- Any requirements in respect of insurance, warranty period, deposits, period for which the tender is open for acceptance, etc.

The commercial terms and conditions should be expanded further.

9. DATA TO BE PROVIDED IN TENDERS SUBMITTED

Tenders shall contain the following information:

- Price of complete supply.
- Any price adjustments.
- Information in respect of customs duties, VAT and exchange adjustments.
- Terms of payment.
- Guaranteed values for no-load losses and no-load current at rated voltage.
- Guaranteed values for load losses and short circuit impedance at rated transformation ratio and reference temperature (20°C plus max. temperature rise for winding).
- Guaranteed sound power level.
- Total weight of the transformer.
- Surface treatment.
- Binding dimensional drawings.
- Binding dimensional drawings for transformers supplied in a casing.
- Time of delivery.
- Warranty period.

In addition, the supplier shall confirm that the requirements specified in the invitation to tender are met. Any deviations shall be detailed.

B1. CORROSION PROTECTION

B1.1 The target service life should be 20 years or more.

B1.2 An ambient impact corresponding to heavy pollution (heavy pollution cf. CENELEC EN 60071-2).

B1.3 All structural parts shall be well-drained. Profile and plate edges shall be rounded, $r \geq 2$ mm or half the metal thickness. Welding deposits and protruding surface flaws shall be completely removed.

All welds shall be fully welded and all welding slag removed before the surface treatment. After welding with coated electrodes, the surface shall be carefully washed with water where subsequent blast-cleaning is to be employed.

B1.4 Treatment of outer surfaces The supplier may choose between the following protective systems:

B1.4.1. Painting.
Surface preparation by blast-cleaning corresponding to min. Sa 2 1/2 according to DS/EN ISO 8501-1

The surface treatment shall be carried out as follows:

Application of base coat: two-component high-zinc epoxy paint or zinc coating:	min. 50 μm
Application intermediate coat: two-component epoxy paint	min. 140 μm
or vinyl or chlorinated-rubber paint	min. 160 μm
Application of finish coat, on epoxy: two-component polyurethane	
or vinyl/acrylic enamel	min. 30 μm

Finish coat, on thermoplastic intermediate coat: thermoplastic finish coat.

Alternative paint treatments may be proposed to the purchaser for evaluation and approval.

Cross-cut test according to DS/EN ISO 2409 shall produce the values Gt 0, Gt 1 or Gt 2. Test requirements shall be met both at the time of delivery and at the end of the warranty period.

The pinhole rating shall be tested with a low-voltage pinhole detector (9V, wet sponge, see for example DS/R 454). Max. acceptable number of pinholes:

- length of edge 3 pinholes/m length of edge
- surface 3 pinholes/m^2 surface

B1.4.2 Hot dip galvanising according to DS/EN 1461, class B.

B1.4.3 Where the metal thickness or the design prevents the use of either hot dip galvanising class B or painting according to 4.1, hot dip galvanising according to DS/EN ISO 1461, class C, is preferable to paint treatment. The reasons for any such deviation shall be stated and explained in the tender.

B1.5 Screws, nuts, washers, etc. shall be made of acid proof stainless steel (AISI 1316). Screw threads shall l be rolled. Threads etc. to be greased.

B1.6 It the supplier offers alternative treatments, the treatments suggested above shall serve as quality references. In general, higher coating thicknesses should be asked for in the case of these alternatives, especially if they do not include a high-zinc base coat. The requirements in respect of pinhole rating and adhesion are the same.

Appendix B2. Dimension drawings