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NTS

OUR REFERENCE
TR01-17E

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CONSULTATIONS
NTA, NTP, NAS,
SDA, GHH

TECHNICAL GUIDELINE

REVISION
4

APPROVED
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SHUNT CAPACITORS BANKS

Introduction

These guidelines are based on the Swedish standard SS-EN 60871-1. The guidelines do state preferred alternatives where the standard allows for such selections. They also include additions to and clarifications of the standard. The guidelines may be as part of a contract made compulsory for the Supplier and in such cases they will specify requirements that will in addition to the standard be applicable for manufacture and testing of high voltage capacitor units.

Revisions

Revision	Note	Date
B	Rated voltage explained. Appendix 2 replaced. Alternative solutions for connection discussed. Pollution class b and d added for insulators. Demand for Geotextile removed.	2010-12-21
3	Collaboration with Vattenfall removed	2013-02-25
4	Multiple major updates related to much more detailed definitions of previously missing design and other technical requirements. Updated references to current international and national standards.	2022-01-10

Contents

1	General.....	5
1.1	Applicable standards.....	5
2	Service conditions	7
2.1	Ambient temperature	7
2.2	Pollution	7
2.3	Wind and ice loads.....	7
2.4	Altitude	7
3	Ratings	8
3.1	Standard insulation level	8
3.2	Rated voltage	8
3.3	Rated frequency	8
3.4	Rated output.....	8
4	Design of shunt capacitor banks	8
4.1	General	8
4.2	Design requirements	9
4.3	Foundations and support structures	9
4.4	Corrosion protection	10
4.5	Environment	10
4.5.1	Insulating liquids	10
4.6	Capacitor units.....	10
4.6.1	Balancing.....	10
4.6.2	Overload capacity	11
4.6.3	Fuses.....	11
4.6.4	Discharge resistors	11
4.6.5	Containers	11
4.7	Unbalance current transformer	11
4.8	Damping reactor	12
4.8.1	Design	12
4.8.2	Rated inductance.....	13
4.8.3	Terminals.....	13
4.8.4	Protective surge arrester	13

4.9	<i>Insulators</i>	14
4.10	<i>Earthing</i>	14
4.11	<i>Protective fencing</i>	14
5	Rating plates and labels	15
5.1	<i>General</i>	15
5.2	<i>Capacitor unit rating plate</i>	15
5.3	<i>Capacitor rack rating plate</i>	15
5.4	<i>Capacitor bank rating plate</i>	15
5.5	<i>Damping reactor rating plate</i>	15
6	Lifting devices	16
7	Spare parts.....	16
8	Testing	16
8.1	<i>Type tests</i>	16
8.2	<i>Routine tests</i>	16
8.3	<i>Site acceptance tests</i>	17
8.3.1	<i>Thermal vision measurements</i>	17
9	Documentation.....	18
9.1	<i>General</i>	18
9.2	<i>Documentation included in tender</i>	18
9.3	<i>Documentation included in delivery</i>	18
9.4	<i>Documentation and spare parts after delivery</i>	19
	Appendix 1.....	20

1 General

The design and installation shall comply with applicable requirements of SS-EN 61936-1 with amendments and additional requirements of TR01-01 and TR01-21.

The protection of shunt capacitor shall be in accordance with TR02-05-06.

1.1 Applicable standards

Applicable Swedish standards (SS) shall be used. When these do not exist, European standards (EN) and international standards (IEC) are applicable. The latest edition of each standard shall be used.

If equipment does not, in all respect fulfil the applicable standards as well as any additional requirements stated in this document, the deviations shall be clearly presented.

Applicable standards and specifications:

SS-EN 60529	Degrees of protection provided by enclosures (IP-code)
SS-EN-ISO 1461	Hot dip galvanized coatings on fabricated iron and steel articles - Specifications and test methods
SS-EN ISO 12944-2	Färg och lack – Korrosionsskydd av stålkonstruktioner genom målning – Del 2: Miljöklassificering
SS-EN ISO 10684	Varmförzinkade gängade ståldetaljer
SS 14 23 03	Rostfritt stål – SS-stål 2303
SS-EN 50522	Starkströmsanläggningar med nominell spänning överstigande 1kV AC – Del 1: Jordning
SS-EN 61238-1	Kablar – Förbindningsdon för kraftkablar med märkspänning upp till 36 kV (Um = 42 kV) utförda genom kontaktpressning eller annan mekanisk metod – Del 1: Fordringar och provning
SS-EN 61869-1	Mätransformatörer – Del 1: Allmänna fördringar
SS-EN 61869-2	Mätransformatörer – Del 2: Tilläggfördringar för strömtransformatörer
SS-EN 61936-1	Starkströmsanläggningar med nominell spänning överstigande 1 kV AC Del 1: Allmänna fördringar
SS 421 01 66	Mekanisk dimensionering av utomhusställverk
SS 421 01 67	Dimensionering av utomhusställverk – Vind och islaster
SS-IEC 60168	Tests on indoor and outdoor post insulators of ceramic material or glass for systems with nominal voltages greater than 1000 V.
SS-IEC 60273	Characteristics of indoor and outdoor post insulators for systems with nominal voltages greater than 1000 V
SS-EN 60437	Radio interference test on high-voltage insulators
SS-IEC 62231	Composite station post insulators for substations with a.c. voltages greater than 1 000 V up to 245 kV - Definitions, test methods and acceptance criteria
SS-EN 60060-1	High voltage test techniques – Part 1: General definitions and test requirements
SS-EN 60071-1	Insulation co-ordination – Part 1: Definitions, principles and rules
SS-EN 60071-2	Insulation co-ordination – Part 2: Application guide

SS-EN 60076-6	Krafttransformatorer – Del 6: Reaktorer
SS EN 60076-1	Krafttransformatorer – Del 1: Allmänt
IEC 60099 all parts	Surge arresters
SS-EN 60549	Yttre enhetssäkringar för shuntkondensatorer
IEC/TS 60815: all parts	Guide for the selection of insulators in respect of polluted conditions
SS-EN 60076-11	Power transformers – Part 11: Dry-type transformers
SS-EN 60871-1	Shuntkondensatorer för högspänning – Del 1: Allmänt
IEC TS 60871-2	Shunt capacitors for a.c. power systems having a rated voltage above 1 000 V – Part 2: Endurance testing
IEC TS 60871-3	Shunt capacitors for a.c. power systems having a rated voltage above 1 000 V – Part 3: Protection of shunt capacitors and shunt capacitor banks
SS-EN 60871-4	Shuntkondensatorer för högst 1000 V – Del 4: Inre säkringar
SS-EN 61936-1	Power installations exceeding 1 kV a.c. – Part 1: Common rules

The following guidelines and recommendations are applicable:

TR01-01	Stamnätsstationer
TR01-02E	Cable Current Transformers 7.2 – 420 kV
TR01-04	Fristående strömtransformatorer 7,2-420 kV
TR01-08	Effektbrytare 245-420 kV
TR01-09	Frånskiljare i utomhus-utförande 12-420 kV
TR01-13	Stamnätsstationer jordning
TR01-16	Skyltar i ställverk 7.2 – 420 kV
TR01-21	Stamnätsstationer Bygg och mark
TR02	Kontrollanläggningar
TR02-05-06	Shuntkondensatorskydd
TR13-04-01E	Requirements concerning environment and health
TR13-04-02E	Svenska kraftnät's chemicals prohibition list
VAST-Vattenfall	Jordningsanvisningar, ställverk, 1987
EBR KJ 60:4	Stängsel för kraftanläggningar

2 Service conditions

2.1 Ambient temperature

The shunt capacitors shall be classified by standard temperature categories in accordance with SS-EN 60871-1 and TR01-01 as -40/A and -50/A which correspond to minimum ambient temperatures of -40°C and -50°C, respectively and maximum ambient temperature of +40°C.

Capacitors for indoor installations shall normally be classified -25/A. If installed in a normally heated room, category -5/A may be used.

2.2 Pollution

Site pollution severity class (SPS) shall be specified in the request for tender and determined in accordance with TR01-01, Sub.cl. 4.4.2.2.

2.3 Wind and ice loads

The shunt capacitor bank shall be designed to withstand wind pressures specified in SS 421 01 66 and SS 421 01 67.

2.4 Altitude

Service altitude is <1000 m.a.s.l.

3 Ratings

3.1 Standard insulation level

The standard insulation levels are presented in **Table 1 – Standard insulation levels**.

Table 1 – Standard insulation levels

Highest voltage for equipment (kV _m)	Standard rated lightning impulse withstand voltage (kV _{peak})	Standard rated switching impulse withstand voltage (kV _{peak})		Standard rated short-duration power frequency withstand voltage (kV _{rms})
		Phase-to-earth	Phase-to-phase	
245	950	-	-	395
420	1425	1050	1575	See ¹

3.2 Rated voltage

The rated voltage of the shunt capacitor bank shall be equal to the highest voltage for equipment, in accordance with TR01-01, Sub.cl. 4.2, unless, a higher voltage is specified in the tender document.

3.3 Rated frequency

The rated frequency is 50 Hz.

3.4 Rated output

Rated output of the shunt capacitor bank in MVar is defined at rated voltage of the shunt capacitor bank unless otherwise specified.

4 Design of shunt capacitor banks

4.1 General

The shunt capacitor bank shall, unless otherwise specified herein, be designed, rated and tested in accordance with SS-EN 60871-1 and SS-EN 60871-4.

¹ In accordance with admissible voltage levels in service stated in SS EN 60871-1.

All components, which are required in order to fulfil the required function of the capacitor bank, shall be included in the delivery. This includes: capacitor units, racks, post insulators as required, current transformers for unbalance protection, damping reactor if such is required, tubes/stranded conductors for high voltage connections and interconnection of the units to a completed bank.

The shunt capacitor bank shall be designed to have at least two strings of capacitor units and provisions made for connection of an unbalance current transformer, at approximately middle potential.²

All three phases of the shunt capacitor bank shall connect to a common bus before being connected to earth. The common bus shall be of a tube type mounted on post insulators with a rated lightning withstand voltage level of 125 kV_{peak}. Further details of earthing arrangement are given in TR01-13, Appendix 1.

Data sheet for a specific delivery shall contain at least the information given in Appendix 1.

4.2 Design requirements

All structural elements of a rack shall be electrically connected to each other in order to ensure adequate earthing of the rack during maintenance and the rack itself shall have connections for adequate earthing during maintenance. The rack components shall not be used as a load current bus.

The capacitor units shall be fixed to the racks by screws and nuts. Each capacitor unit shall be mounted such that it can be easily replaced without removing other capacitor units. The units shall have provisions for lifting.

All post insulators with the same rated voltage, shall be of such dimensions that they can be interchanged without requiring any special adapters or removing and/or rearranging of capacitor units.

4.3 Foundations and support structures

Capacitor banks and current-limiting reactors shall be placed on support insulators with supports bolted to concrete foundations.

Design requirements and applicable standards for steel supports, support insulators and concrete foundations are given in TR01-01 and TR01-21.

If concrete foundations of damping reactors are designed and constructed with metallic reinforcements they shall not form electrically closed loops.

² Should capacitor bank design be more efficient with a design of a single string of capacitor units, an alternative unbalance protective scheme must be proposed for the approval of the Svenska kraftnät. The capacitor units of such a capacitor bank arrangement must be of a fuseless design.

4.4 Corrosion protection

All structural elements of the capacitor stacks and any other external details shall be of galvanized structural steel, stainless steel or aluminum. In case structural steel is used, the galvanizing and corrosion protection shall be in accordance with TR01-01 and no drilling permitted after galvanizing.

If an increased corrosion protection is specified the installation shall be designed for a corrosion class C5-I as per SS-EN ISO 12944-2.

4.5 Environment

The requirements as per TR13-04-01E and TR13-04-02E shall be fulfilled.

4.5.1 Insulating liquids

Insulating liquids shall not contain any PCB.

Specific measures against spread of oil on surface or leakage into earth such as protective covering of the geotextile type beneath the shunt capacitor bank will be specified if required.

The chemical properties of the insulating oil must be such that it is biologically degradable and that the toxicological levels are minimal in case of leakage.

4.6 Capacitor units

Selection of rated voltage, rated current and rated output of capacitor units as well as the number of units in parallel and series groups shall be done such to achieve the rated output of the shunt capacitor bank.

The rated voltage of the capacitor unit shall be $\frac{U_{Nb}}{S}$ where U_{Nb} is the maximum continuous voltage across the capacitor bank and S is the number units connected in series.

4.6.1 Balancing

The placement of the included capacitor units shall be made such that the highest measured unbalance in a healthy capacitor bank must not be more than 10% of the trip level of the unbalance protection, when measured at $1.1xU_N$.

The allocation of units shall be supported by documentation showing:

- Serial number and measured capacitance of all units
- Physical location of each unit
- The resulting total capacitance of each parallel group, for each leg of the unbalance measurement and for each phase.

4.6.2 Overload capacity

Shall be in accordance with SS-EN 60871-1.

4.6.3 Fuses

The capacitor units shall be of an internally fused design or of fuseless design. The manufacturer shall provide protection levels for the unbalance protection. Protection of the units against case rupture due to damage of external insulation occurring on-load shall be ensured by the unbalance protection.

4.6.4 Discharge resistors

4.6.5 Each capacitor unit shall be equipped with an internal discharge resistor, designed according to SS-EN 60871-1, Sub.cl. 21. Containers

The manufacturer shall show that the container will withstand the overpressure caused by the most unfavorable combination of fault current and fuse tripping time.

When the container is filled with insulating liquid there must be no air bubbles left once the container is sealed.

The container, shall be manufactured in accordance with the corrosion protection requirements given in TR01-01.

4.7 Unbalance current transformer

The unbalance current transformer shall, unless otherwise specified herein, be designed, rated and tested in accordance with TR01-04E.

The design shall be in accordance with TR01-04E, Clause 3.

The unbalance current transformer, shall be designed such that it can handle the steep current impulse such as from a capacitor bank discharging at a fault. If primary winding must be protected a surge arrester shall be used.

The unbalance current transformers and unbalance protection shall ensure that the shunt capacitor bank is tripped in case of a ground fault across one string of the capacitor bank as shown on Figure 1.

The damping reactor shall be located between each phase of the capacitor bank and the common bus, see Figure 2.

A surge arrester may be required to protect the reactor from overvoltages. In case the damping reactor is not equipped with protective surge arrester it shall be designed and type tested to withstand given Lightning Impulse Withstand Level stated in Table 1.

In case the damping reactor is equipped with protective surge arrester it shall be designed and type tested for an insulation margin of at least 15% for switching surges and 25% for lightning surges.

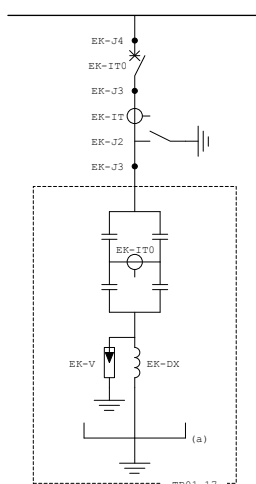


Figure 2 – Single line diagram of a shunt capacitor bank with the damping reactor

4.8.2 Rated inductance

Rated inductance of the damping reactor shall be selected from the following series of values: 0.25 mH; 0.5 mH; 1.0 mH; 1.5 mH etc. in 0.5 increments.

4.8.3 Terminals

The design of terminals shall reduce eddy current related losses such that the temperatures are below the maximum values given in Table 1 of SS-EN 60076-6.

4.8.4 Protective surge arrester

The damping reactor protective surge arrester shall be designed, rated and tested in accordance with chapter 9 of IEC TS 60871-3. The surge arrester should also be in accordance to SS-EN-60099-4: 2014.

The surge arrester shall withstand the stresses caused by a capacitor bank discharge through a close or remote ground fault in the AC substation or adjacent AC system. The capacitor bank discharge shall be assumed to take place when the capacitor bank is charged to a voltage, U_0 , not less than:

- $U_0 = 820$ kV for nominal AC system voltage of 400 kV,
- $U_0 = 440$ kV for nominal AC system voltage of 220 kV.

The surge arrester shall be able to handle an impulse energy not less than $\frac{1}{2}CU_0^2$ where C is the rated capacitance of the capacitor bank.

The surge arrester shall be equipped with a surge counter. The minimum surge arrester protective level shall be selected such that the surge counter shall not tick a current below that obtained at a breaker closing synchronization error of about 30° , i.e. at about $\frac{1}{2}\sqrt{\frac{2}{3}}U_m$ where U_m is the Highest Voltage for equipment given in **Table 1**

– **Standard insulation levels.**

4.9 Insulators

Insulators shall be selected and dimensioned in accordance with TR01-01.

4.10 Earthing

Earthing shall be designed and installed in accordance with TR01-13.

Earth connections to supports shall be made by cable lugs with two c/c 40mm holes. Cable lugs shall be type tested in accordance with SS-EN 61238-1, Class A.

Earth wires with diameter <120 mm² can have cable lugs with only one hole. The earth wires shall be installed such that the risks of corrosion, abrasion damages and burns through contacts with other materials are eliminated.

4.11 Protective fencing

All live equipment, located less than 2500 mm above ground surface, shall be surrounded by a protective fence. Please see also chapter 7 of TR01-01 and SS-EN 61936-1 that TR01-01 is based on.

5 Rating plates and labels

5.1 General

All rating plates shall be made of 1,2 mm engraved steel with lettering in baked enamel or a 25µm thick layer of anodized aluminum. All rating plates shall be in Swedish language. Any other design must be approved by the purchaser.

Other signs and markings shall be supplied in accordance with TR01-16.

5.2 Capacitor unit rating plate

All capacitor units shall be provided with rating plates in accordance with SS-EN 60871-1 and measured capacitance indicated in absolute value.

5.3 Capacitor rack rating plate

Each rack shall be provided with a rating plate stating the physical location within the bank and the total weight of the rack with installed capacitors.

5.4 Capacitor bank rating plate

The complete capacitor bank shall be provided with a rating plate, installed at a suitable location, easily accessible while the capacitor bank is energized. The rating plate shall include the information in accordance with SS-EN 60871-1 and in addition the rated capacitance of each capacitor bank in µF.

5.5 Damping reactor rating plate

The information on the rating plate shall be in accordance with SS-EN 60076-6.

6 Lifting devices

The delivery shall include a simple device for lifting, removing and replacing faulty capacitor units in the bank.

7 Spare parts

The following spare parts shall be included in the delivery of a capacitor bank:

- Capacitor units: 2,5% of the total number of the units supplied;
- Support insulators: at least one of each type supplied.

8 Testing

8.1 Type tests

Type tests are required in accordance with the standards IEC 60871-1 and IEC 60871-4.

The following type tests apply for the damping reactors:

- Measurement of inductance (SS-EN 60076-6 sub-clause 9.10.5).
- Measurement of loss and quality factor (SS-EN 60076-6 sub-clause 9.10.6).
- Temperature rise test (SS-EN 60076-6 sub-clause 9.10.8) - the maximum allowed hot-spot temperature is 120°C for class B and 130°C for class F insulation, i.e. chosen from SS-EN 60076-11 as one class lower than the actual insulation system temperature of the reactor.

If the inrush current peak value is greater than 50 times the r.m.s. value of the rated current the inrush current performance shall be verified through calculations based on earlier performed test.

8.2 Routine tests

Routine tests shall be performed in accordance with the standards listed under Item 1 above.

In addition, a routine test demonstrating that internal connections of capacitor units are consistent, shall be performed on all capacitor units including units of fuseless design. Proposed test procedure is as per IEC 60871-4, clause 5.1.2, however, other test may be proposed - subjected for approval by Svenska kraftnät.

The following routine tests apply for the damping reactors:

- Measurement of winding resistance (SS EN 60076-1);
- Measurement of inductance (SS-EN 60076-6 sub-clause 9.10.5);
- Measurement of loss and quality factor (SS-EN 60076-6 sub-clause 9.10.6)
- Winding overvoltage test (SS-EN 60076-6 sub-clause 9.10.7). The lightning impulse tests shall be performed with both positive and negative polarities.

8.3 Site acceptance tests

8.3.1 Thermal vision measurements

All connectors and conductor joints on capacitor units and the completed bank, shall be subjected to thermal vision measurements before the final acceptance.

9 Documentation

9.1 General

Instructions, dimension drawings and schematics that are included in the delivery shall have all text written in the Swedish language.

9.2 Documentation included in tender

With the tender the following documents shall be provided:

- Data sheet, dimension drawings, electrical circuit and schematic diagrams, instructions for erection, operation and maintenance, type test certificates and also other documents needed for the technical evaluation.
- Bases for evaluation of the need and costs for maintenance, such as:
 - The interval for condition control and other measures of maintenance and the time necessary for these works.
 - List of spare parts, special tools and accessories.
 - Environmental information in accordance with TR 13-04-01E.
 - Inspection and maintenance intervals and the time necessary for these activities.

9.3 Documentation included in delivery

If not agreed otherwise, the following documentation shall be submitted in paper and electronic form, together with the delivery of the equipment:

- Sensitivity analysis³
- Assembly drawings with drawing lists
- Instructions for transport, storage, installation, maintenance, commissioning, inspection and adjustments.
- List of chemicals and safety information for all chemical products according to TR13-04-01E
- Environmental product declaration as given in TR13-04-01E, chapter 4.1.1
- List of special tools and accessories for installation and maintenance
- List of commissioning and inspection equipment
- Spare parts list
- List of repair material
- Final dimension drawings and connection diagrams
- Routine test reports
- Data sheet containing information in accordance with Appendix 1

³ Detailed calculation for the number of internal fuse element failure to be considered for safe operation and the setting to be adopted for unbalance protection relay alarm and tripping. A table showing the number of units that can be lost per phase and per series group for a certain period of time without derating of the capacitor bank and without reduction in the designed life of the capacitor.

On behalf of the maintenance organization of the purchaser a set of documentation, clearly defined for each delivery, shall be submitted. The technical documentation shall enable the purchaser to establish a base of spare parts within its own service organization. It shall also be possible to use the documentation for training of supervisors, storage and service staff.

The documentation shall specify prerequisites for inspection intervals and evaluation criteria, as well as description and instructions for performing of maintenance activities. The list of documentation shall cover assembly drawings valid for the equipment in question. Details of and applicable data for a specific device or a series of devices of the same type shall be identifiable through the documentation list. This means that the valid version of documents shall be clearly stated in the documentation list.

It shall be possible to identify standardized mechanical components for purchase in Swedish specialist stores.

At the time of the first delivery, the documents presented in the list, shall be submitted in one printable version, collected in one set that can be used by the purchaser to create a service handbook. For additional supplies, only amended drawings, documents and instruction, together with advice for insertion, need to be supplied.

9.4 Documentation and spare parts after delivery

The supplier shall upon request provide the purchaser with required information and during at least ten years after delivery, be able to provide spare parts required for maintenance. Design changes or modified instructions, applicable to the supplied equipment shall after delivery be submitted in the form of service bulletins.

Appendix 1

Description	Value	Unit	Remarks
Site/Substation	*	-	Given by the contractor i.e. Hagby, CT65
Object id/Littera	*	-	Given by the contractor i.e. EK1
Manufacturer	*	-	i.e. ABB
Order number	*	-	
Serial number	*	-	
Year of manufacture	*	year	i.e. 2021
Standard, Guideline	*	-	i.e. SS-EN 60871-1, TR01-17E Rev.4
Type designation of Capacitor bank	*	-	i.e. QBANK-A
Type designation of Capacitor unit	*	-	i.e. CHDB182
Use/Installation	*	-	Outdoor or indoor
Standard insulation level:			
Lightning impulse withstand level	*	kV _{peak}	See Table 1 – Standard insulation levels 125 kV _{peak}
Switching impulse withstand level	*	kV _{peak}	
Power frequency withstand voltage	*	kV _{rms}	
Common bus insulation level	*	kV _{peak}	
Insulation level of the neutral (if isolated)	*	kV _{peak}	
Creepage distance	*	mm/kV	[Class b-normal/d-increased] ⁴
Temperature class	*	-	-40/A or -50/A
Rated Voltage	*	kV	245 kV or 420 kV
Reactive Power at Rated voltage	*	MVA	i.e. 300 MVar
Total weight	*	ton	
Volume of insulating fluid	*	kg	
Type of insulating fluid	*	-	i.e. Faradol
Spraying permitted	*	-	Yes/No/optional
Rated Voltage Unit*	*	kV	
Capacitance (for series capacitors)	*	mF	i.e. 50mF
Rated current (for series capacitors)	*	A	
Tolerance for capacitance value	*	%	
Number of units connected in series	*	no	i.e. 80
Connection type	*	-	Bridge connection (YoH) with a current transformer/phase connected between midpoints of the two branches for separate unbalance measurement for each phase. [Isolated / Solid earth]
Neutral connection	*	-	
Summary drawing	*	Doc. No	
Dimension drawing	*	Doc. No	
Installation and maintenance instructions	*	Doc. No	
Circuit diagram	*	Doc. No	
Technical data of the capacitor unit	*	Doc. No	

⁴ Pollution class in accordance with IEC/TS 60815-1



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Applikation

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