1 Overview

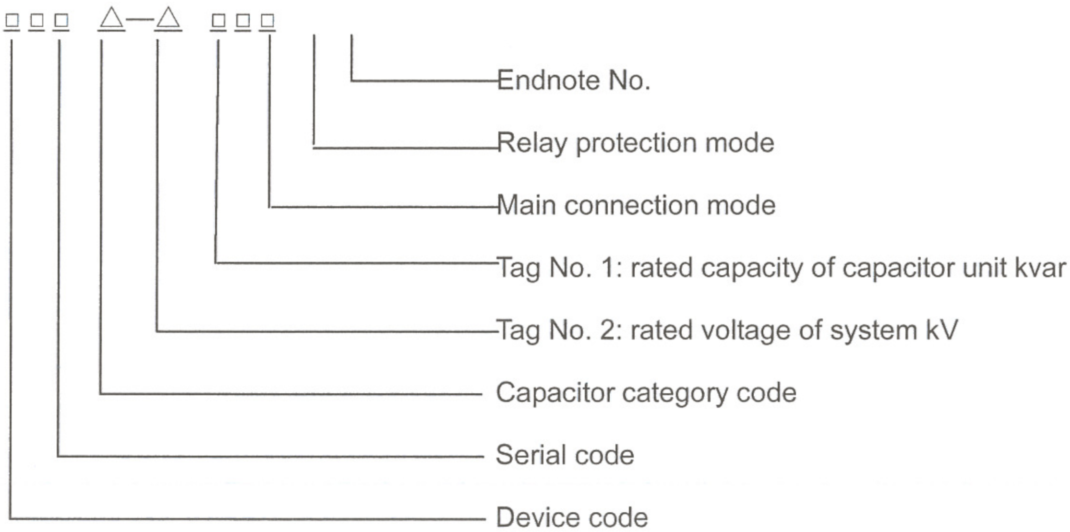
1.1 Main Application and Scope of Application

The Instruction Manual is applicable to 6～110kV power frequency AC power systems, used to increase the power factors, improve voltage quality and reduce line loss for complete HV shunt capacitors.

1.2 Model of HV Shunt Capacitor

Name: Complete HV Shunt Capacitor

Model and Representation of Complete HV Shunt Capacitor



□ - expressed in capitalized Chinese phonetic alphabets

△ - expressed in Arabic alphabets

1.2.1 Device Code: T - complete device

1.2.2 Serial Code: BB - shunt capacitor compensation

1.2.3 Tag No. 1: refers to rated voltage, kV

1.2.4 Tag No. 2: refers to rated capacity/rated capacity of capacitor unit, kvar

1.2.5 Main Connection Mode

A - Represents single-star connection

B - Represents double-star connection

1.2.6 Relay Protection Mode

C - Represents voltage differential protection

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K - Represents open-delta voltage protection

L - Represents neutral wire unbalanced current protection

Q - Represents bridge current differential protection

1.2.7 Endnote No.: indicates the difference in the application environment for products of the same specifications

W - Represents outdoor application (not expressed in letters)

G - Represents application in plateau

TH - represents application in wet tropics

H - Represents application in contaminated areas

1.2.8 Examples

Example 1: TBB 10—10000/334 AKW

Representing: shunt capacitor, with the rated system voltage of 10kV, the rated capacity of 10,000kVar and the rated capacity for a single unit of 334kVar, based on single-star connection, open-delta voltage protection and outdoor application.

Example 2: TBB 35—15000/500 ACW

Representing: HV shunt capacitor, with the rated system voltage of 35kV, the rated capacity of 15,000kVar and the rated capacity for a single unit of 500kVar, based single-star connection, voltage differential protection and outdoor application.

2 Service Conditions

2.1 Altitude

The altitude at the installation and operation location shall be no more than 2,000m.

2.2 Ambient Temperature

The ambient temperature for the capacitor application shall be of -40/B in category.

2.3 Anti-contamination Capability

With a view to the specific creepage distance for external insulation, it shall be no less than 25mm/kV for Grade-III contamination and no less than 31mm/kV for Grade-IV contamination.

2.4 Seismic Capability

The device shall not be damaged under a seismic force of a 0.2g horizontal acceleration and a 0.15g vertical acceleration (with the safety coefficient no less than 1.67).

3 Main Technical Parameters and Technical Performance Index

3.1 Capacitance Tolerance

a) The capacitance tolerance of the capacitor bank shall be 0 ~ +5% of the rated capacity for the device;

b) The ratio of the maximum and minimum capacitances between the terminals for any two lines of the three-phase capacitor bank shall be no more than 1.02;

c) The ratio of the maximum and minimum capacitances for each series section of the capacitor bank shall be no more than 1.01.

3.2 Inductance Tolerance

a) When a series reactor is provided in the device and in case of the rated current, for a reactor with the rated reactance ratio K≥4.5%, the allowable deviation for its reactance value shall be 0 ~ +5%; for a reactor with the rated reactance ratio K≤1%, the allowable deviation for its reactance value shall be 0 ~ +10%.

b) For a three-phase reactor bank consisting of three-phase reactors or single-phase reactors, the reactance value for each phase shall be no more than ±2% of the three-phase average value;

c) For iron-core reactors, the difference between the reactance value and the rated value in case of 1.8 times of the rated current shall be no more than -5%.

3.3 Insulation Level

The withstand voltage specified in Table 1 shall be applicable to the insulation level between each phase and between the phase and ground for the primary circuit (excluding the components) of the device, as well as between the secondary circuit and ground for the device. The time duration for the application of the power-frequency withstood voltage shall be 1min.

Table 1 Insulation Level **kV**

Rated Voltage of Device	Primary Circuit		Power-frequency Withstand Voltage of Secondary Circuit (root mean square value)
	Power-frequency Withstand Voltage (root mean square value)	Impulse Withstand Voltage [(1.2 ~ 5)/50μs, peak value]	
6	32	60	3
10	42	75	
20	68	125	
35	95	185	

66	140	325	
110	185	450	

3.4 Temperature Rise

For a framed device, the temperature rise at the connection point between its busbars and each connection point in the main circuit shall be no more than 50K. The temperature rise of each electrical equipment shall not exceed its own stipulated value.

For a cabinet device, apart from that the temperature rise of each electrical equipment does not exceeds its own stipulated value, all the other equipment shall conform to the relevant regulations.

3.5 Short-circuit Current Withstand Capability

The electrical equipment, connecting wires and mechanisms in the major loop shall withstand short-circuit currents and interelectrode short-circuit discharge currents, with no heat production, mechanical damage and obvious deformation.

The rated short-circuit withstand current value for the substation devices shall be selected from the following values: 12.5 kA, 20 kA, 25 kA, 31.5kA, 40kA.

The rated short-circuit withstand current value for the line devices shall be selected from the following values: 2.5kA, 8kA, 12.5kA, 20 kA.

3.6 Overload Capability

3.6.1 Steady-state Overcurrent

The device shall run continuously when the root-mean-square value of the current is no more than $1.37I_N$. The current is the result of $1.1U_{CN}$, capacitance tolerance and higher harmonics.

3.6.2 Steady-state Overvoltage

The continuous operating voltage of the device is $1.05U_N$. It can run accordingly based on the steady-state overvoltage stipulated in Table 2.

Table 2 Steady-state Overvoltage

Power Frequency Overvoltage	Max. Time Duration	Description
$1.05U_N$	Continuous operation	
$1.10U_N$	Long-term (no more than 8h for every 24h)	Means that the max. long-term operating voltage shall not be more than 1.1 times.

$1.15U_N$	30min in every 24h	The regulation and fluctuation of the system voltage
$1.20U_N$	5min	The voltage rises in case of a light load
$1.30U_N$	1min	

3.6.3 Rush Current

The device shall restrict the rush current generated when putting the capacitor bank into service to less than 20 times of the rated current of the capacitor bank.

3.6.4 Transient Overvoltage

The switching device selected for the device shall not product an interelectrode overvoltage more than $2\sqrt{2}U_n$ (peak value) during operation.

4 Main Structure of Complete Shunt Capacitor

The main circuit and auxiliary equipment of the complete capacitor include: HV circuit breakers, series reactors, discharge components, metal oxide arresters, capacitor banks, HV isolators, earthing switches, electrical fittings and enclosures, etc.

4.1 HV Circuit Breaker

The circuit breaker used to switch the shunt capacitor shall adopt a vacuum circuit breaker or SF_6 circuit breaker (it is suggested to adopt a SF_6 circuit breaker for a device of 35kV and above). The performance of the circuit breaker shall meet the following requirements:

a) The contact shall not bounce when switching on;

b) Re-strike shall not occur when switching off. In order to avoid re-strike the vacuum circuit breaker, the contact shall be treated based on electric burn-in before delivery;

c) It shall withstand switch-on rush current.

d) It shall be capable of disconnecting the short-circuit current quickly.

4.2 Series Reactor

The series reactor is connected in the capacitor loop serially and used to suppress the switch-on rush current and the harmonics, with the following selection principle adopted:

a) When only used to suppress the switch-on rush current, it shall select a reactor with the rated inductive reactance for each phase of (0.1 ~ 1%) Xc (Xc is the rated inductive reactance of each phase of the capacitor bank, the same below);

b) When used to suppress quintuple harmonics or above, it shall select a reactor with the rated inductive reactance for each phase of (4.5 ~ 6%) Xc;

c) When used to suppress triple harmonics or above, it shall select a reactor with the rated inductive reactance for each phase of (12~ 13%) Xc;

4.3 Discharging Device

The discharging device shall adopt a discharge coil special for the capacitor, with the rated voltage no less than the rated voltage of the capacitor bank and the maximum supporting capacity no less than the capacity of its capacitor in parallel. The discharge time of the discharge coil shall reduce the residual voltage on the capacitor bank from the peak rated voltage value to 50V or less in 5 seconds after disconnecting the power supply. In the meantime, it can take the secondary-side coil of the discharge coil as the open-delta voltage protection or voltage differential protection against the internal faults in the capacitor.

4.4 Shunt Capacitor Bank

The capacitor bank generally consists of capacitor units, metal racks, busbars and post insulators, etc. The capacitor bank adopts a single-star or double-star mode for main wiring.

Different from most of other electrical equipment, the shunt capacitor shall operate with full load when connected to the power system.

Since c concentrated capacitance is introduced in the system, it will generate various unflavored operating conditions as follows: after the capacitor is connected to the system, the system voltage will rise; the voltage on the capacitor terminals will rise exceptionally in case of a light load; when the series reactor is connected to the capacitor loop, the voltage on the capacitor terminals will be higher than the operating voltage of the network; if a harmonic source exists in the system (such as large rectifiers, saturated transformer cores, arc furnaces and rolling mills, etc.), it will result in capacitor overcurrent and generate a heat effect greater than the fundamental wave, etc.

If the operating voltage, current and temperature exceeds the specified limits, it will shorten the service life of the capacitor. Therefore, it shall make a proper choice for the operating conditions of the capacitor.

4.5 Metal Oxide Arrester

In order to prevent the device from a damage due to the operating overvoltage, it shall install a metal oxide arrester.

4.6 Earthing Switch

In order to ensure the personal safety during equipment maintenance and overhaul, the device shall be installed with an earthing switch.

5 Protection Mode

Protection modes for the capacitor include internal fuse protection, external fuse protection and relay protection, etc.

5.1 Fuse Protection

Internal fuse protection and external fuse protection are the first protection against internal faults in the capacitor. The fusing can timely isolate the damaged element or the capacitor unit, ensuring the overall safe operation of the capacitor. See the supplementary specifications for the relay protection and setting for complete shunt capacitors.

5.1.1 Allowed overvoltage multiples for complete elements of capacitor banks with an internal fuse: 1.3 (See Annex A for the formula).

5.1.2 Allowed overvoltage multiples for complete elements of capacitor banks with an external fuse: 1.1 (See Annex B for the formula).

5.2 Relay Protection

Relay Protection is the second protection against capacitor faults. Relay protection modes include zero sequence voltage protection, voltage differential protection, neutral wire unbalanced current protection and bridge current differential protection, etc. Overvoltage protection, undervoltage protection, overcurrent protection and short circuit quick-disconnecting protection, etc. shall also be provided for the protection of the device.

5.2.1 Busbar overvoltage protection: the busbar overvoltage protection relay shall be set in such a manner that it can trip upon a 60s time-delay operation, based on 1.1 times of the rated voltage of the device.

5.2.2 Busbar undervoltage protection: the busbar undervoltage protection relay shall be set in such a manner that it can trip upon a quick-disconnecting operation, based on 55% times of the rated voltage of the device.

5.2.3 Overcurrent protection: the overcurrent protection relay shall be set in such a manner that it can trip upon a 0.2 ~ 0.4 s time-delay operation, based on 1.5 times of the rated current of the device.

5.2.4 Overcurrent quick-disconnecting protection: the overcurrent quick-disconnecting protection relay shall be set in such a manner that it can trip upon a quick-disconnecting operation, based on 5 ~ 6 times of the rated current of the device.

6 Packing, Transportation, Acceptance and Storage

6.1 Packing and Transportation

6.1.1 The device shall be packed separately according to the packing list. The outdoor capacitor bank shall be shipped as a whole during transportation with other accessories (reactors, discharge coils and post insulators, etc.) packed and shipped in separate.

6.1.2 When loading, unloading and hoisting the packing case, it shall not damage the equipment.

6.1.3 When hoisting the capacitor bank, it shall hoist according to the Lifting Identifier on the rack and must avoid damaging the casings.

6.1.4 Transport marks shall be provided on the packing case. Measures against rain, moisture and vibration shall be taken during long-distance transportation.

6.2 Acceptance

Upon receiving the product, the User shall check and accept it according to the items for acceptance, which are as follows:

a) To check the appearance of each package and verify that there are no damages and no shortage of any item listed in the packing list;

b) In case of damaged articles or discrepancy between the articles and the packing list, it must report to Shanghai Sieyuan Power Capacitor Co.,Ltd. immediately;

c) In case transfer or long-term storage is required upon the inspection, it shall recover the packing case to its original state.

6.3 Storage

The device shall be stored indoor rather than a place of moisture, dust, high temperature as well as flammable, explosive and corrosive gases.

7 Installation

7.1 The product must be installed as per the general layout and the capacitor bank drawings provided.

7.1.1 The capacitor shall be connected in parallel and then in series, consequently assembled as a capacitor bank with a main connection mode based on a single-star or double-star form. Wiring between the capacitors shall adopt flexible connecting wires. It shall use a proper torque spanner to tighten up the nut on the leading-out terminal of the capacitor during installation (it is suggested to select a moment of 25 ~ 28N·m), in order to ensure that the wire clip grips the connecting wire firmly. It is forbidden to adopt rigid busbar connection in order to prevent mechanical stress or electric stress from damaging the capacitor casing and destroying the seal to cause oil leakage.

7.1.2 Before installing the capacitor bank, it shall balance the capacitance, with the deviation meeting Article

3.1.

7.1.3 The footing and the embedded parts for foundation of the capacitor bank shall be fixed by electric welding or foundation bolts, applied with a rust-inhibitive primer and a polyurethane paint on surface.

7.2 It must ensure the good contact of the electric loop and the earthed part, avoid high-frequency oscillating arc and abnormal heating that are caused by improper contact.

7.3 When installing electric conductors (including busbars, stranded wires, wire clips and terminals, etc.), the connection mode and the moment value of the fasteners shall conform to the relevant installation standard. See the following Table 3. When installing electric non-conductors (including brackets, bases, supports and footing for various accessories), the moment value of the fasteners shall conform to Table 3.

Table 3 Moment Values of Fasteners for Electric Conductors and Non-conductors

Electric Conductor				Electric Non-conductor			
Specification mm	Moment Value N·m	Specification mm	Moment Value N·m	Specification mm	Moment Value N·m	Specification mm	Moment Value N·m
M8	10	M16	80	Up to M6	10	M16	150
M10	20	M18	100	M8	20	M20	350
M12	35	M20	150	M10	35		
M14	55	M24	300	M12	60		

7.4 The insulation distance between the live part and the earthed part and the insulation distance between the live parts shall conform to the relevant design standard.

7.5 Busbar phase colors U(A), V(B) and W(C). The three-phase busbars shall be painted as: Phase U(A) in yellow, Phase V(B) in green, Phase W(C) in red, neutral wire in light blue, earth wire in black, with the connection points not painted.

7.6 Installation of Discharge Coil

7.6.1 It must check whether the polarity and wiring of the discharge coil are correct or not (see the installation instructions for discharge coils), avoiding damage or even explosion due to improper polarity and wiring of the discharge coil.

7.6.2 It shall be forbidden to connect the primary winding of the discharge coil in a triangular or "V"-type mode.

7.6.3 Short circuits shall not be allowed for the outgoing wiring for the secondary winding of the discharge coil.

7.7 Installation of Series Reactor

7.7.1 It shall meet the requirements resisting against electromagnetic induction when installing a dry-type air-core series reactor. The minimum distance between the reactor and the ferromagnetic metal components that do not form a closed loop to its surrounding area and the minimum center distance between the reactors shall meet the relevant technical requirements (see the installation instructions for dry-type air-core series reactors).

7.7.2 The dry-type air-core series reactor supports the mounting plate for the metal base of the insulator. It shall adopt a radial or open ring form.

7.7.3 When installing the dry-type air-core series reactor indoor, it shall keep away from the relay protection and the computer room, avoiding electromagnetic interference to them.

7.7.4 When the dry-type air-core series reactor adopts the three-phase lamination or two-laminated-one-flat mode for installation, the phase sequence of the reactor must be correct during installation, not allowing changing of the laminated phase sequence freely.

8 Precautions before Putting the Device into Service

8.1 Inspection before Power Transmission

8.1.1 Appearance inspection: to check whether the outgoing terminals and the insulators are damaged, whether the external surface of the metalwork are damaged or corroded. It shall check whether oil leakage and deformation occur to the enclosure of each accessory and whether the nameplate is clear and compliant to the relevant requirements.

8.1.2 Measurement of insulation against ground: the reactor shall adopt a 2,500V megger, with a record made.

8.1.3 Capacitance measurement: it shall measure the capacitance in case of (0.9 ~ 1.1) times of the rated voltage and (0.8 ~ 1.2) times of fN. The measurement method adopted shall eliminate the error due to the harmonics and the accessory inside the measurement circuit. The accuracy of measurement shall be no less than 2%.

8.1.4 Inductance (reactor measurement): when the dry-type air-core reactor measures the inductance, it can be conducted by reducing the current and the voltage, or it can be conducted by the bridge method. When measuring the inductance of the dry-type air-core reactor that is vertically laminated, it shall use the three phase power supply to measure the three-phase reactance simultaneously.

8.1.5 It shall check that the connection points between the busbars and each connection point in the main circuit are correct and reliable.

8.1.6 Various protection devices shall be correct and reliable.

8.2 System Harmonic Influence

8.2.1 With a view to the measurement of the background harmonics for the system, when the harmonic content of the system exceeds the relevant regulations, it shall consider to take restrictive measures at the harmonic source.

8.2.2 When subdivided capacitor runs based on various capacity and different reactance ratio combinations, it shall adopt a rational switch combination mode to avoid resonance or harmonic amplification that may be produced.

8.2.3 The switch sequence for capacitors with different reactance ratios: the capacitor bank with a greater reactance ratio shall be switched in first and then switched out. The capacitor bank with a smaller reactance ratio shall be switched out first and then switched out.。

8.2.4 It shall be forbidden to switch the capacitor when the transformer is not loaded.

8.2.5 It shall be forbidden to switch the capacitor bank in insufficient quantity (impedance variation of the system, the harmonic is amplified).

8.2.6 The device shall be forbidden to quit the switching of the series reactor (impedance variation of the system, the harmonic is amplified).

9 Operation, Maintenance and Repair

9.1 Operation

9.1.1 It shall make a record on equipment operation (relevant parameters such as: operating voltage, operating current, active load, reactive load, power factor, time and number of times for counter operation).

9.1.2 It shall make a visual inspection on the capacitor that operates frequently. It shall stop to use them if the capacitor box is detected to expand exceptionally and the abnormal noises occur to the reactor, etc. in order to deteriorate the faults.

9.1.3 When switching in the capacitor, the temperature shall be no less than -40℃. The upper temperature limit during operation shall be no more than the specified value (Class A: +40℃, Class B: +45℃). If the temperature exceeds the value, it shall adopt artificial cooling (by installing fans, etc.) or disconnect the capacitor and the network.

9.1.4 The operating current and voltage of the capacitor shall not exceed the stipulation of Articles 3.5 and

3.6 during application.

9.1.5 It can use an infrared temperature tester to test the maximum temperature at the installation location and on the capacitor enclosure. It must make a record on the temperature (especially in summer).

9.1.6 It will cause the network voltage rise after connecting the capacitor, especially the voltage on the capacitor terminal may be quite high in case of a light load in the system. When the voltage between the capacitor terminals exceeds $1.1U_N$, it shall disconnect the capacitor and the network.

9.1.7 In case of a power factor lead in the system ($\cos\varphi_2 \geq 1$), the system impedance shall be capacitive or resonant, which must result in some abnormal phenomena or faults. It shall disconnect the capacitor and the network immediately.

9.1.8 If the capacitor switch is disconnected due to the relay operation, it shall not be switched in again before finding out the root cause.

9.2 Maintenance

9.2.1 It is suggested to check and clear the capacitor and fuse regularly every year. It must check the contact reliability for all the connection points in the electrical circuits of the capacitor bank carefully (busbars, junctors and switch circuit breakers, etc).

9.2.2 It is suggested to measure the capacitance of the capacitor regularly every year. It is suggested to use a 2,500V megger to measure the insulation against ground for the capacitor.

9.3 Repair

9.3.1 If oil leaks on the enclosure, it can repair it with the tin lead solder.

9.3.2 If oil leaks on the casing, it can repair it with the epoxy resin adhesive.

10 Accident and Fault Handling Plan

10.1 In one of the following cases, it shall switched off the capacitor immediately

a) The capacitor explodes;

b) A lot of heat is produced at the connection point or the wax scale for the capacitor enclosure melts away;

c) The capacitor casing breaks with flashover discharge;

d) The capacitor blows the oil out heavily or is on fire;

e) The capacitor enclosure expands greatly;

f) Three-phase current unbalance is over 5%;

g) Abnormal noises are detected inside the capacitor or the reactor.

10.2 Once the capacitor fails, it shall make a record immediately (voltage, capacitance, load and the capacitance and No. of the capacitor, etc.). It shall not be switched in against before finding out the root cause and conducting treatment correctly.

10.3 See Table 4 for common fault analysis and troubleshooting for capacitors.

Table 4 Common Fault Analysis and Troubleshooting

Symptom	Cause Analysis	Handling
Broken casings, damaged enclosures	Collision due to carelessness during transportation and installation	Minor damages can be repaired by yourself Severely damaged sealed waterproof devices shall be returned to the manufacturer for repair after being treated
Breakdown during the acceptance test	1. The product is damaged during transportation 2. The test voltage is too high or lasts for too long 3. The method to measure the voltage is wrong	To replace the capacitor
Obvious changes in capacitance	The element is broken down and (or) the fuse is broken	To replace the capacitor
Increased loss	The capacitor quality gets worse	To replace the capacitor
Exceptional expansion of the enclosure	1. Partial discharge occurs inside the product. 2. The element is broken down or the pole-to-case breakdown occurs.	To replace the capacitor
Oil leakage	1. Improper seal occurs to the flange since the casing is raised during handling. 2. The nut is tightened with excess force, which damages the casing	Minor leakage can be repaired by yourself Major leakage shall be returned to the manufacturer for repair

	3. A defect occurs during manufacturing 4. The temperature varies greatly	
Temperature rise	1. The ambient temperature is too high, with the capacitors arranged densely 2. The harmonic current is too large 3. Dielectric aging occurs, with the loss increased	1.To improve ventilation 2.To replace the capacitor

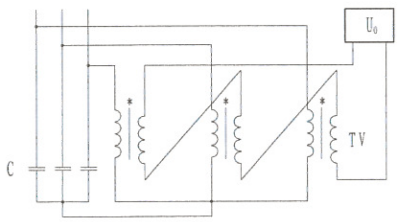
11 Environmental Protection and Others

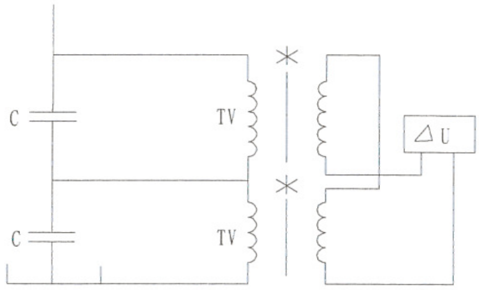
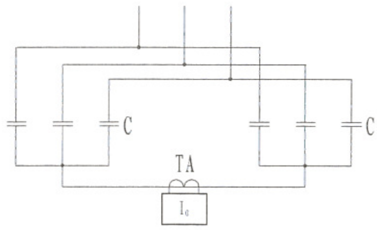
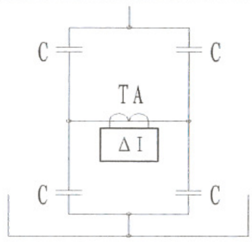
Materials such as membrane, paper and oil (non-toxic, without PCB) as well as other metal materials and electric ceramics used in the product, shall not pollute the environment during production, application and waste treatment, etc.

Electrotechnical products such as capacitors, oil-immersed discharge coils and oil-immersed reactors, etc. must be recovered and treated by a qualified company after they are scrapped.

Environmental-protection materials and packages shall be adopted for the packing of the parts. The environmental-protection materials can be reusable, renewable and degradable, etc. The environmental-protection packing means less materials, least wastes and less energy, easy to recover and recycling. The packing wastes will not pollute the environment.

Annex A Formula for Unbalanced Protection of Capacitor Bank with Internal Fuse

SN	Wiring and Protection Mode	Formula	
1	Single-star Open-delta unbalanced voltage protection	$k=\frac{3MNmn\,(K_V-1)}{K_V\cdot(3MNn-3MN+3N-2)}$ $\Delta U_C=\frac{3k\cdot U_{EX}}{3MNmn-k(3MNn-3MN+3N-2)}$	

2	Single-star Voltage differential protection		
3	Double-star Neutral wire unbalanced current protection	$k = \dfrac{3MNmn\,(K_V - 1)}{K_V \cdot (3MNn - 3MN + 6N - 5)}$ $I_0 = \dfrac{1.5k \cdot I_{EX}}{3MNmn - k(3MNn - 3MN + 6N - 5)}$	
4	Single-star Bridge unbalanced current protection	$k = \dfrac{3MNmn\,(K_V - 1)}{K_V \cdot (3MNn - 3MN + 6N - 8)}$ $I_0 = \dfrac{3k \cdot I_{EX}}{3MNmn - k(3MNn - 3MN + 6N - 8)}$	

$\triangle U_C$ - unbalanced voltage

m - numbers of shunt elements in the unit

n - number of series element in the unit

Elements in parallel first and then in series

M - numbers of shunt units in the phase

N - numbers of series units in the phase

Units in parallel first and then in series

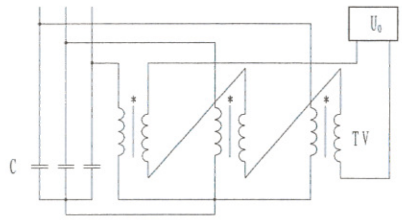
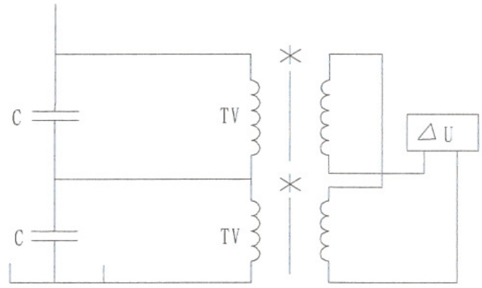
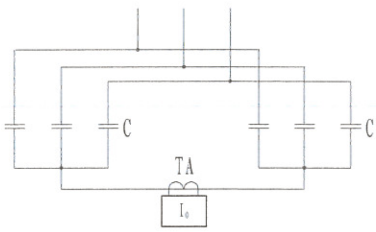
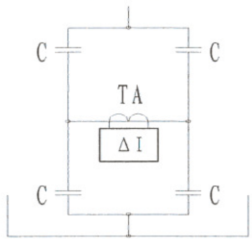
k - numbers of disconnected elements in the section

K_V - allowed overvoltage multiples for complete elements

U_{EX} - rated phase voltage of the capacitor bank

I_{EX} - rated phase current of the capacitor bank

Annex B Formula for Unbalanced Protection of Capacitor Bank with External Fuse

SN	Wiring and Protection Mode	Formula	
1	Single-star Open-delta imbalance voltage protection	$\Delta U_C = \frac{3K \cdot U_{EX}}{3N(M-K)+2K}$ $K = \frac{3MN \cdot (K_V - 1)}{K_V \cdot (3N-2)}$	
2	Single-star Voltage differential protection		
3	Double-star Neutral wire unbalanced current protection	$I_0 = \frac{1.5K \cdot I_{EX}}{3N(M-2K)+5K}$ $K = \frac{3MN \cdot (K_V - 1)}{K_V \cdot (6N-5)}$	
4	Single-star Bridge unbalanced current protection	$I_0 = \frac{3K \cdot I_{EX}}{3N(M-2K)+8K}$ $K = \frac{3MN \cdot (K_V - 1)}{K_V \cdot (6N-8)}$	

$\triangle U_C$ - unbalanced voltage

m - numbers of shunt elements in the unit

n - number of series element in the unit

Elements in parallel first and then in series

M - numbers of shunt units in the phase

N - numbers of series units in the phase

Units in parallel first and then in series

k - numbers of disconnected elements in the section

K_V - allowed overvoltage multiples for complete elements

U_{EX} - rated phase voltage of the capacitor bank

I_{EX} - rated phase current of the capacitor bank

Annex C Calculation of Resonance Capacity

The capacitance of a capacitor with n-th harmonic resonance shall be calculated according to the following approximate computation expression

$$Q_{cx} = S_d \left(\frac{1}{n^2} - K\right)$$

$$\beta = \frac{Q_c}{Q_{cx}}$$

$$F_{ch} = \frac{\beta}{\beta - 1}$$

$$F_{sh} = \frac{1}{1 - \beta}$$

Wherein Q_{CX} - capacitance of a capacitor with n-th harmonic resonance (Mvar)

S_d - busbar short-circuit capacity at the installation location of the capacitor (MVA)

n - harmonic order, that is, the ratio of resonance frequency and mains frequency

A - ratio of the inductive reactance per phase (XL) for the capacitor and the capacitive reactance per phase (XC), that is, A=XL/XC

F_{ch} - amplification of the n-th harmonic current in the branch of the capacitor

F_{sh} - amplification of the n-th harmonic current of the system

Table C.1 Correlation Chart for Harmonic Amplification and β

β	0~0.5	0.5	0.60	0.67	0.71	0.75	0.78	0.80	0.82	0.83	0.85	0.86	0.90	0.95	1.00	1.05
$\|F_{ch}\|$	Minor Amplification Zone	1.00	1.50	2.00	2.50	3.00	3.50	4.00	4.50	5.00	5.50	6.00	9.00	19.00	∞	21.00
$\|F_{sh}\|$		2.00	2.50	3.00	3.50	4.50	4.50	5.00	65.50	6.00	6.50	7.00	10.00	20.00	∞	20.00
β	1.10	1.14	1.15	1.17	1.18	1.20	1.22	1.25	1.29	1.33	1.40	1.50	1.67	2.00	∞	
$\|F_{ch}\|$	11.0	8.00	7.50	7.00	6.50	6.00	5.50	5.00	4.50	4.00	3.50	3.00	2.50	2.00	1.00	
$\|F_{sh}\|$	10.0	7.00	6.50	6.00	5.50	5.00	4.50	4.00	3.50	3.00	2.50	2.00	1.50	1.00	0	

Annex D Calculation of Steady-state Voltage Rise (or Drop)

D.1 After the capacitor (or reactor) is connected to the busbar, the resultant steady-state voltage rise (or drop) value can be calculated according to the following formula

$$\Delta U \approx U_{zM}\frac{Q_C}{S_d}$$

Wherein ΔU - voltage rising value (kV);

U_{zM} - busbar voltage before the connection of the capacitor (or reactor) (kV)

Q_C - total capacity of the capacitor (or reactor) bank connected to the busbar (Mvar)

S_d - busbar short-circuit capacity at the installation location of the capacitor (or reactor) (MVA)

D.2 After the capacitor bank is connected to the series reactor, the terminal voltage of the capacitor will rise, with the value calculated according to the following formula

$$U_C = \frac{U_{eM}}{\sqrt{3}N}\times\frac{1}{1-A}$$

Wherein U_C - operating voltage of the terminals for the capacitor (kV)

U_{eM} - busbar voltage of the capacitor (kV)

N - numbers of series sections for the capacitor in each phase

A - ratio of the inductive reactance per phase (XL) for the capacitor and the capacitive reactance per phase (XC), that is, $A = X_L/X_C$

Annex E Calculation of Capacitor Compensation Capacity

If the load power P, the power factor before compensation $\cos\varphi_1$ and the targeted power factor $\cos\varphi_2$ are known, the required capacity Q of the capacitor shall be calculated according to the following formula:

$$Q = P\left(\sqrt{\frac{1}{\cos^2\varphi_1} - 1} - \sqrt{\frac{1}{\cos^2\varphi_2} - 1}\right)$$

Wherein: P - output active power (kW) when the load power factor $\cos\varphi_1$, P = S× $\cos\varphi_1$;

S - apparent power of the load (kVA).

Annex F Calculation of Altitude Correction Factor

When the altitude is over 2,000m, the test voltage of the complete device shall be multiplied by the altitude correction factor K based on the rated withstand voltage of the equipment, thus correcting the external insulation of the corresponding equipment. The altitude correction factor K shall be calculated based on the following formula:

$$K = \frac{1}{1.1 - H \times 10^{-4}}$$

Wherein: K - altitude correction factor;

H - altitude (m).