



Standard

Protection and Control of HV Capacitor Banks
Standard

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Authorisations

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Responsibilities

This document is the responsibility of the Secondary Systems Asset Strategy Team, Tasmanian Networks Pty Ltd, ABN 24 167 357 299 (hereafter referred to as "TasNetworks").

Please contact the Secondary Systems Asset Strategy Team Leader with any queries or suggestions.

- Implementation All TasNetworks staff and contractors.
- Compliance All group managers.

Minimum Requirements

The requirements set out in TasNetworks' documents are minimum requirements that must be complied with by all TasNetworks team members, contractors, and other consultants.

The end user is expected to implement any practices which may not be stated but which can be reasonably regarded as good practices relevant to the objective of this document.

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Record of revisions

Section number	Details
1.6	Added standards to the reference list including cyber security standards
2.3	Removed the requirement for two relays
2.3	Added cyber security requirements
2.3.1	Clarified that the 699 monitors both A and B trip coils
2.3.1	Removed requirement for IEC 61850 and specified DNP3 as minimum
Error! Reference source not found.	Removed requirement for IEC 61850 and specified DNP3 as minimum
3.2	Removed the section on CB close inhibit specifically for the unbalance protection
3.3.6	Changed the CBF initiation to all protection functions not just neutral unbalance
5	Changed the auto control to not require a separate control relay

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1 General

1.1 Purpose

The purpose of this document is to define the requirements and describe the application philosophy for the protection and control of Shunt Capacitors connected to the HV network under the responsibility of Tasmanian Networks Pty Ltd (hereafter referred to as “TasNetworks”).

1.2 Scope

The document applies to the protection and control facilities for HV Shunt Capacitor Banks located on substation HV busbars (22 kV and 11 kV) in the power system network under the responsibility of TasNetworks. This standard contains requirements for design of protection and control equipment and is to be applied to new installations as well as redevelopment of part or all existing installations.

1.3 Objective

TasNetworks requires design as covered in this standard to ensure:

- (a) personnel and public safety;
- (b) safety of TasNetworks’ assets;
- (c) reliability and continuity of power supply to the power transmission network;
- (d) that relevant Australian legal requirements are met;
- (e) that the requirements of the National Electricity Code are met;
- (f) ease in operation and maintenance;
- (g) minimum disruption to the HV supply system following a fault;
- (h) that the requirements of TasNetworks’ business plan are met;
- (i) that the exposure of TasNetworks’ business to risk is minimised; and
- (j) that TasNetworks’ responsibilities under connection agreements are met.

1.4 Precedence

Any apparent conflict between the requirements of this standard and the law, mandatory requirements, industry standards, project specifications, non-statutory standards or guidelines, and any other associated documents should be brought to the immediate attention of TasNetworks for resolution and no action must be taken that might result in a breach of law or mandatory standard.

Where there may be a conflict between the requirements of this standard and any:

- (a) law, mandatory requirement or industry standard, then that law or statutory requirements will prevail over this standard;
- (b) non-mandatory standard, or guideline, then this standard will prevail over that standard or guideline;
or
- (c) project specification, then a deviation must be specifically requested and approved in writing by TasNetworks’ Secondary Systems Asset Strategy Team Leader.

Approval for a deviation to this standard may only be accorded if it does not reduce the quality of workmanship, pose a safety risk to personnel or equipment and does not deviate from the intent of this standard.

1.5 Abbreviations

CB	Circuit Breaker
CBF	Circuit Breaker Failure
CT	Current Transformer
CTS	Current Transformer Supervision
DC	Direct Current
HMI	Human Machine Interface
IEC	International Electrotechnical Commission
MCB	Miniature Circuit Breaker
NOCS	Network Operational Control System
OLTC	On-Load Tap Changer
R.M.S.	Root Mean Square
SOE	Sequence of Events
TCS	Trip Circuit Supervision
THD	Total Harmonic voltage Distortion
VT	Voltage Transformer

1.6 References

As a component of the complete specification for a system, this standard is to be read in conjunction with other standards and documents as applicable. In particular this includes the project specifications and the literature mentioned below.

- HV Shunt Capacitor Bank Standard (R522695)
- AC Distribution System Standard (R565984)
- DC Distribution System Standard (R522693)
- General Substations Requirements Standard (R522687)
- High Voltage System Standard (R565983)
- Secondary Equipment Testing Standard (R244782)
- Protection of HV Busbars and Feeders Standard (R246419)
- SCADA System Standard (R246439)
- Secondary Systems – General Requirements Standard (R246444)
- Secondary Cable and Wiring Standard (R1744962)
- Testing Commissioning and Training Standard (R246497)
- Technology Asset and Change Management Standard (R1400111)
- Security Event Logging and Monitoring Standards (R1313426)

1.6.1 Other references

IEEE Guide for the Protection of Shunt Capacitor Banks – IEEE Standard C37.99-2000

Australian Standard for Power Capacitors – Shunt-Rated Voltages above 660V AC - AS2897-1986

1.7 TasNetworks drawings

No standard design drawings have been developed for the HV capacitor bank protection and control panel.

The last HV capacitor bank protection and control scheme installation design drawings, based on this standard shall be used.

New design drawings shall only be developed with prior approval from TasNetworks.

2 Policy

2.1 Design policy

The capacitor bank protection and control scheme shall be designed to ensure that:

- (a) the protection schemes shall be adaptable and adequate for the protection of the entire capacitor bank;
- (b) the protection scheme must comply with the National Electricity Rules (**NER**), specifically section S5.1.9 for fault clearance times; and
- (c) the control system is capable of switching the capacitor bank 'in' and 'out' of service based on MVAR and/or Voltage control if included in TasNetworks' project specification.

2.2 HV shunt capacitor bank arrangement

The configuration of the HV capacitor bank will normally be arranged:

- (a) as per TasNetworks' HV Shunt Capacitor Bank Standard; and
- (b) so that each phase of the capacitor bank is physically separated from the other phases in order to reduce the possibility of phase to phase faults.

2.3 Protection and control scheme arrangement

The protection scheme for HV capacitor banks shall:

- (a) use a proven relay from a reputable supplier that is fit for purpose with standard capacitor bank protection and control features;
- (b) use device naming '699' including the bay designation for the single protection relay;
- (c) have a separate DC supply derived from the 'A' battery, unless the backup protection is supplied from the 'A' battery in which the capacitor bank protection shall utilise the 'B' battery supply;
- (d) initiate circuit breaker (CB) tripping via hard wiring direct to both circuit breaker 'A' and 'B' trip coils;
- (e) have the 699 relay fed from a protection core of the capacitor bank current transformers (CT), and the CT located between the two star connected sections of the capacitor bank, and use a voltage transformer (VT) secondary circuit for its voltage input; and
- (f) The following software controls and monitoring are to be implemented:

- (i) Change the device default password;
- (ii) Disable or remove unused interfaces; and
- (iii) Disable built-in or default user accounts.
- (iv) If possible, record:
 - a. What activity was performed (e.g. setting changes on protection relay);
 - b. Who performed the activity (e.g. engineer or operator); and
 - c. When the activity was performed (e.g. time and date).

2.3.1 699 protection and control relay

The 699 relay shall consist of:

- (a) phase overcurrent protection and earth fault protection;
- (b) multistage overvoltage and undervoltage protection together with VT fuse failure detection logic;
- (c) multistage neutral unbalance protection;
- (d) phase harmonic overload protection;
- (e) circuit breaker failure (CBF) protection;
- (f) operational metering;
- (g) operational CB open and close;
- (h) trip circuit supervision of both A and B trip coils;
- (i) time delayed CB close interlocking to ensure that the capacitor bank is not energised until the capacitors have discharged to a safe voltage level based on manufacturer recommendations;
- (j) disconnecter and earth switch interlocking;
- (k) CB, disconnecter and earth switch status for transmission via SCADA to NOCS;
- (l) numerical operation including self-supervision;
- (m) inbuilt disturbance recorder with time and date tagging; and
- (n) communications via Ethernet RJ45 or fibre connections using DNP3.0 protocols as a minimum. Where IEC 61850 communications is required, it will be specified in the project documentation.

3 Capacitor Bank Protection

3.1 General

The following section provides more detail for the required protection functionality.

3.2 Functional requirements

The following functionality of the capacitor bank protection shall be provided:

- (a) Overcurrent and earth fault protection.
 - (i) The protection shall detect all high current faults (phase to phase and phase to earth faults), located on or near to the terminals of a shunt capacitor bank.

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- (ii) The protection shall provide phase segregated measurement and phase identification of the faulted phase.
 - (iii) The relay shall operate from 1 Amp CT secondary connections, with a separate input for the neutral.
 - (iv) In addition to time delay characteristics that shall be selectable as definite time or inverse time, instantaneous phase fault elements and an instantaneous earth fault element shall be provided.
 - (v) The protection shall be sensitive only to fundamental frequency.
- (b) Harmonic overload protection.
- (i) The protection shall detect overload, due to prevailing system harmonics from the fundamental to the 13th harmonic, that may cause damage to the capacitor bank.
 - (ii) The protection shall provide phase segregated measurement and phase identification of the faulted phase.
 - (iii) The protection connections shall be made from a 1 Amp CT secondary, with a separate input for the neutral current.
 - (iv) The tripping time delay characteristics on the protection shall be capable of being set to match the overvoltage withstand characteristic of the capacitor bank.
 - (v) The alarm function shall have a definite time delay characteristic.
- (c) Neutral unbalance protection.
- (i) The protection shall detect low level unbalance current caused by the failure of the capacitor cans on one of the star configurations.
 - (ii) The protection shall only respond to the fundamental component of the unbalance current.
 - (iii) The protection connections shall be made from a 1 Amp or 5 Amp secondary of a CT connected between the two star points of the connected banks.
 - (iv) The neutral unbalance protection shall be equipped with two stages, alarm and trip, and adjustable compensation for amplitude and phase angle to cater for the natural unbalance between the two wye-connected non-earthed capacitor banks.
 - (v) The time delay element for the alarm stage shall be definite time and the time delay element for the tripping stage shall be inverse time.
- (d) Overvoltage and undervoltage protection.
- (i) The protection shall detect overvoltage and undervoltage conditions. The output of the protection shall trip the capacitor bank CB following an appropriate definite time delay.
 - (ii) The overvoltage protection shall be equipped with an alarm setting and a trip setting.
 - (iii) The relay shall be connectable for 110 Volts (phase to phase), and $110/\sqrt{3}$ Volts (phase to earth), VT secondary connections, normally $110/\sqrt{3}$ Volt VT secondary windings per phase are applied.
 - (iv) VT fuse failure supervision with separate monitoring of individual phases shall be provided. The fuse failure protection shall block the operation of the undervoltage relay and shall provide an alarm following a settable time delay.
- (e) The 699 relay shall have a local Human Machine Interface (HMI) to read on line parameters of primary data, setting parameters and self-diagnosis details.
- (f) Event and disturbance recording capability.
- (i) As a minimum, the 699 relay must have the capability of capturing sequence of events and waveforms of capacitor bank disturbances that trigger the protection elements.

- (ii) The 699 relay must provide self-health and protection alarms, and status indications locally and remotely.

3.3 Protection application and settings

3.3.1 Overcurrent protection

The following principles shall be applied to the overcurrent protection:

- (a) The overcurrent protection shall be arranged in two stages – stage 1 shall have an IEC inverse time characteristic enabled and stage 2 shall have a definite time characteristic enabled.
- (b) Stage 1 shall detect low level faults and the current setting shall be set to a value of 1.2 times the maximum permissible current for the capacitor bank. The time multiplier setting for the inverse characteristic shall be such that the relay shall not operate during capacitor inrush current conditions.
- (c) Stage 2 shall detect high level faults and the current setting shall be greater than the maximum inrush current during energisation of the capacitor bank but preferably less than the minimum fault level. The definite time characteristic shall be set to a value that allows a maximum clearance time of 120ms for all high level faults.
- (d) Where a capacitor bank is connected as per figure 2, the protection settings shall also be applied with consideration to the settings on the feeder CB and the requirements outlined in the Protection of HV Busbars and Feeders Standard related to capacitor banks.

3.3.2 Earth fault protection

The following principles shall be applied to the overcurrent protection:

- (a) The earth fault protection shall also be arranged in two stages – stage 1 shall have an IEC inverse time characteristic and stage 2 shall have a definite time characteristic enabled.
- (b) Stage 1 shall detect low level faults and shall have a current setting capable of detecting a low phase to earth fault located on the line side terminals of the last set of capacitors before the neutral connection (preferably in the range of 40A primary).
- (c) Stage 2 shall detect high level faults located on the busbar side on the reactor side of the capacitor. The current setting shall be approximately 0.5 times the minimum phase to earth fault level and the definite time delay shall be set to affect a clearance time not exceeding 120ms.
- (d) Where a capacitor bank is connected as per figure 2, the protection settings shall also be applied with consideration to the settings on the feeder CB and the requirements outlined in the Protection of HV Busbars and Feeders Standard related to capacitor banks.

3.3.3 Harmonic overload protection

In order to prevent overloading of the capacitor banks due to system harmonics and overvoltage, the following settings should be applied on harmonic protection elements:

- (a) An alarm signal shall be issued if the measured R.M.S. current flow to the capacitor bank exceeds 120 per cent of the nominal rated current of the capacitor bank. The alarm definite time delay shall be set to 10 seconds.
- (b) A trip signal shall be issued if the measured R.M.S. current flow to the capacitor bank exceeds 130 per cent of the nominal rated current of the capacitor bank. The inverse time characteristic selected shall match the overload withstand characteristic of the capacitor bank.

- (c) If applicable, an alarm signal shall be issued if the total harmonic voltage distortion (THD) as measured at the connected HV bus exceeds 3 per cent. The alarm definite time delay shall be set to 10 seconds.

3.3.4 Overvoltage and undervoltage protection

3.3.4.1 Overvoltage protection

The overvoltage tripping function shall have the following two settings:

- (a) The short-time setting shall be set to operate at 120 per cent of the nominal system voltage with a time delay of 1 second.
- (b) The long-time setting shall be set to operate at 110 per cent of the nominal system voltage with a time delay of 5 seconds.

The overvoltage relay shall be connected phase to earth and the logic shall be arranged such that high voltage of any one phase shall cause operation.

3.3.4.2 Undervoltage protection

The following principles shall be applied to the undervoltage protection:

- (a) The undervoltage tripping shall be set to operate at 20 per cent of nominal voltage with a suitable time delay to ensure the capacitor bank trips before auto-close of the associated feeder CB or HV bus coupler.
- (b) The logic shall be arranged such that the low voltage must occur on all phases for operation to occur. The undervoltage element shall not operate or send an unnecessary alarm signal when the CB or VT MCB is opened.
- (c) In order to prevent unnecessary tripping of the capacitor bank for feeder phase to earth faults, the undervoltage connections shall be phase to phase.
- (d) The purpose of the undervoltage protection is to initiate tripping of the shunt capacitor bank in the event of loss of supply to the substation.
- (e) An HV capacitor bank may be installed at a substation where the bus coupler CB is normally open and is automatically closed when supply is lost to one bus section. Under such circumstances, a capacitor bank on the interrupted bus section will have significant trapped charge and shall not be energised until discharged to a safe level. Therefore the capacitor bank CB status must be incorporated into the auto close scheme and the bus coupler CB only allowed to close when the capacitor bank CB has opened.

3.3.5 Neutral unbalance protection

The neutral unbalance protection shall be arranged to detect a small imbalance between two star connected sections of the capacitor bank. The protection shall have an alarm stage and a tripping stage. The capacitor manufacturer shall be consulted in regard to the current settings and the tripping time to be applied to the unbalance protection.

3.3.6 Circuit breaker failure protection (CBF)

CBF protection shall be applied to the HV capacitor bank CB with initiation by all associated protection elements.

The following principles shall be applied to the CBF protection:

- (a) The CBF shall be enabled in the 699 relay and shall trip all CB(s) directly upstream of the capacitor bank CB.

- (b) The CB status shall be derived from overcurrent check with a threshold of 20 per cent of load current of the capacitor bank.
- (c) The CBF timer shall be set to 250ms.

4 Control, indication and metering

The required protection functionality of the 699 was mentioned in section 3. This section outlines the required control, metering and monitoring functionality of the 699 relay.

4.1 Functional requirements

The following lists the relevant control, indications and metering functionality to be provided in the 699 relay:

- (a) Local and remote control of CB trip and close.
- (b) Local and remote control enabled and disabled (local control should override remote control).
- (c) The facility to monitor the status of the CB.
- (d) The facility to monitor the bay disconnectors and other relevant disconnectors to provide logic for the interlocking scheme and to provide logic for the voltage selection between VTs.
- (e) The capacitor bank shall be capable of being controlled locally using the HMI on the 699.
- (f) Electrical interlocking of associated disconnectors and the associated earth switch shall be derived by means of the open and close outputs of 699.
- (g) 699 shall be capable of power quality metering measurements as well as measurements of amps, volts and MVAR together with outputs indicating quantities, including harmonic level alarms beyond acceptable values.
- (h) Where necessary, voltage selection of the appropriate VT supplies shall be provided in 699.
- (i) Remote supervision and control shall be provided by the 699.
- (j) Upon opening of the capacitor bank CB, the CB shall be prevented from being reclosed for a period sufficient to allow the trapped charge on the capacitors to decay to an acceptable level. The duration of this period shall be adjustable from 5 minutes to 15 minutes.
- (k) The ability to be connected to the station SCADA system for alarms and monitoring and for CB control. Local and remote open commands shall be connected to the CB trip coil which has the same battery supply as the 699.
- (l) Blocking facility for VT MCB trip and/or fuse failure condition on the associated protection.
- (m) Condition monitoring functions including CB condition monitoring, maintenance planning information, internal supervision and self-diagnosis features.
- (n) Providing all required signals with respect to controls, alarms and status indications locally and remotely.
- (o) 699 shall provide Trip Circuit Supervision (TCS) to monitor and alarm the associated trip circuits and CB trip coils.

5 Automatic control of capacitor banks

Automatic control of the capacitor bank shall be provided where requested in the project specification.

Where requested, the following control features and operating conditions shall be applicable:

- (a) The automatic control feature for the switching of the capacitor bank shall be via the MVAR control according to the total reactive demand of the substation.
- (b) For multiple capacitor bank installations, automatic control and operation shall be coordinated so that duty cycling can be shared between capacitor banks.
- (c) The capacitor bank automatic control feature shall be capable of being overridden locally and remotely.

5.1 Capacitor bank control philosophy

The substation SCADA system shall provide automatic switching of capacitor banks in accordance with the following criteria:

- (a) Setting parameters (i.e. MVAR threshold limits, time delays and dead-bands etc.) must be selected to prevent anti-hunting with the automatic voltage regulation scheme of the transformers.
- (b) The automatic energisation of the capacitor bank shall not override the normal de-energise time delay for discharging such that the auto close signal to the 699 relay shall be treated similarly to a manual close of the capacitor bank CB.
- (c) In order to equally share the duty-cycle of all capacitor banks at a site, logic shall be applied to determine which capacitor bank will be 'next on' and 'next off'. This logic shall be designed to account for each capacitor bank's CB status, control mode and availability. It shall also check which CB was 'last on' or 'last off'.
- (d) The automatic MVAR control shall be based on the normal status of the bus coupler CB, where the normal status of the bus coupler CB can be open or closed. It shall not be possible to manually operate a capacitor bank CB when it is selected to automatic mode.
- (e) If the bus coupler CB is detected in the abnormal status, the capacitor bank control must be automatically switched from automatic to manual mode.