Standard

Protection and Control of EHV Capacitor Banks Standard

R245701

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Authorisations

Action	Name and title	Date
Prepared by	Anthony Januba, Senior Asset Strategy Engineer	23/05/2018
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Review cycle	30 months	

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.

Record of revisions

Section number	Details
1.4	Wording for precedence of the project specification over this standard has been changed

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List of figures

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 EHV capacitor banks connected to the transmission 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 capacitor banks energised at voltages of 110 kV and 220 kV operating in the transmission 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 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 Rules are met;

(f) ease in operation and maintenance;

(g) minimum disruption to the EHV supply system following a fault;

(h) that the requirements of TasNetworks' corporate plan are met;

(i) that the exposure of TasNetworks' business to risk is minimised; and

(j) that TasNetworks' responsibilities under connection agreements are met.

1.1 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.

1.1 Abbreviations

CB	Circuit Breaker
CBF	Circuit Breaker Failure
CT	Current Transformer
DNP3.0	Distributed Network Protocol version 3.0
EHV	Extra High Voltage
HMI	Human Machine Interface
IEC	International Electrotechnical Commission
I/O	Inputs and Outputs
LAN	Local Area Network
MCB	Miniature Circuit Breaker
NOCS	Network Operational Control System
POW	Point On Wave
SCADA	Supervisory Control And Data Acquisition
SOE	Sequence Of Events
TCS	Trip Circuit Supervision
VT	Voltage Transformer

1.2 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.

1.2.1 TasNetworks standards

HV and LV Cable System Standard	R590630
EHV Current Transformer Standard	R522690
EHV Voltage Transformers Standard	R586391
Extra High Voltage System Standard	R586386
General Substation Requirements Standard	R522687
SCADA Systems Standard	R246439
Protection of EHV Busbars Standard	R246414
Testing, Commissioning and Training Standard	R246497
Secondary Equipment Testing Standard	R244782

1.2.2 Other standards

IEEE Guide for the Protection of Shunt Capacitor Banks – IEEE Standard C37.99-2000 was used in the production of this standard. Reference to the communications protocol standards IEC60870 and IEC61850 may be used throughout this document but are referring to the physical use of the protocol not the standard for defining the protocol.

1.2.3 TasNetworks drawings

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

The last EHV 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 Secondary Systems Asset Strategy Team Leader.

2 Policy

2.1 Design policy

The EHV 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) faults on any part of the capacitor bank will be detected by at least two protection schemes that have the capability of initiating fault clearance;

(c) all high current faults within the capacitor banks shall be detected by at least two independent protection devices that have the capability of initiating fault clearance within the critical clearance times specified within clause S5.1a.8 of the National Electricity Rules (NER);

(d) the protection scheme shall utilise current transformer (CT) cores that are positioned to provide overlapping zones of protection with adjacent protection schemes;

(e) control for each of the primary bay equipment including status, interlocking, metering and signalling functions shall be integrated into the scheme;

(f) the control system is capable of switching the capacitor bank 'in' and 'out' of service based on MVAr / Voltage control; and

(g) where possible, the protection and control functions shall be arranged to meet the requirements above within multifunction devices to reduce the number of installed components.

2.1 Capacitor bank arrangement

(a) The configuration of capacitor banks in the Tasmanian transmission network will be an unearthed symmetrical double star configuration.

(b) Figure 1 shows the outline of the protection and control scheme for an EHV capacitor bank.

(c) For EHV installations, each phase of the capacitor bank will be physically separated from the other phases in order to reduce the possibility of phase to phase faults.

(d) In order to limit inrush currents to the capacitor bank and to detune harmonics that will impact on the capacitor bank, a three phase iron-cored reactor is provided in series with the capacitor bank.

2.1 Protection and control scheme arrangement

The EHV capacitor bank protection scheme shall consist of two independent protection relays designated the '699A' and '699B' – see Figure 1. The EHV capacitor bank protection relays shall:

(a) employ devices from different suppliers or models to achieve redundancy and diversity;

(b) have a separate DC supply derived from the 'A' and the 'B' batteries respectively;

(c) initiate Circuit Breaker (CB) tripping via hard wiring direct to the 'A' and 'B' trip coils respectively;

(d) be fed from two independent cores of the capacitor bank CT and shall use independent voltage transformer (VT) secondary circuits for their voltage input. The voltage input to the protection devices shall be routed via Miniature Circuit Breakers (MCB); and

(e) be connected, in addition to all other control devices, into the substation remote engineering network via the substation Local Area Network (LAN).

The EHV capacitor banks control scheme shall consist of one relay designated as '699C' – see Figure 1. The EHV capacitor bank control relay shall:

(f) be a numerical multifunction device;

(g) be configurable and accommodate more than anticipated bay I/O;

(h) be capable of communicating all parameters including protection settings and recorded events to the substation SCADA system and shall be capable of being programmed and interrogated remotely;

(i) be capable of multiple communications protocols such as DNP3, IEC60870 and IEC61850;

(j) be capable of communicating on the SCADA network via Ethernet RJ45 or fibre connection; have heavy duty output contacts for direct connection to CB trip and close coils;

(k) have a separate DC supply derived from the 'A' battery; and

(l) initiate CB tripping via hard wiring direct to the 'A' trip coil.

2.1.1 699A protection relay

The 699A protection relay shall consist of:

(a) phase overcurrent protection and earth fault protection sensitive to the fundamental frequency current;

(b) phase harmonic overload protection – where the phase current is proportional to the voltage across the capacitor;

(c) thermal overload protection;

(d) neutral unbalance protection sensitive only to the fundamental frequency current;

(e) overvoltage and undervoltage protection, together with fuse failure detection logic;

(f) overcurrent elements and timers suitable for use in a circuit breaker failure (CBF) scheme;

(g) a local Human Machine Interface (HMI) to read on line parameters of primary data, setting parameters and self-diagnosis details;

(h) Trip Circuit Supervision (TCS) to monitor the associated trip circuit and CB trip coil;

(i) operation from 1 Amp or 5 Amp CT secondary connections, with a separate input for the neutral; and

(j) operation from 110 Volt and $110/\sqrt{3}$ Volt VT secondary connections – normally $110/\sqrt{3}$ Volt VT secondary windings per phase are applied.

2.1.1 699B protection relay

The 699B protection relay shall consist of:

(a) phase overcurrent protection and earth fault protection sensitive to the fundamental frequency current;

(b) phase harmonic overload protection – where the phase current is proportional to the voltage across the capacitor;

(c) thermal overload protection;

(d) neutral unbalance protection sensitive only to the fundamental frequency current;

(e) overvoltage and undervoltage protection, together with fuse failure detection logic;

(f) overcurrent elements and timers suitable for use in a CBF scheme;

(g) a local HMI to read on line parameters of primary data, setting parameters and self-diagnosis details;

(h) TCS to monitor the associated trip circuit and CB trip coil;

(i) operation from 1 Amp or 5 Amp CT secondary connections, with a separate input for the neutral; and

(j) operation from 110 Volt and 110/√ 3 Volt VT secondary connections – normally 110/√ 3 Volt VT secondary windings per phase are applied.

Notes:

(a) Where a single relay is not capable of providing all the functions required above, a number of relays may be required to implement the various functions.

(b) In addition to the protection mentioned above, the capacitors shall be equipped with internal fuses to disconnect a faulted element.

2.1.1 699C capacitor bank control device

As with the protection relays the capacitor bank control may consist of a number of discrete devices rather than a single device. The following capability shall be included in the control device:

(a) Voltage control – see section 4.3;

(b) Point On Wave (POW) switching for capacitor energisation;

(c) Operational metering;

(d) Operational CB tripping;

(e) Uncontrolled CB closing (this function bypasses the POW switching for the CB and is only used for closing the CB for maintenance and emergency procedures);

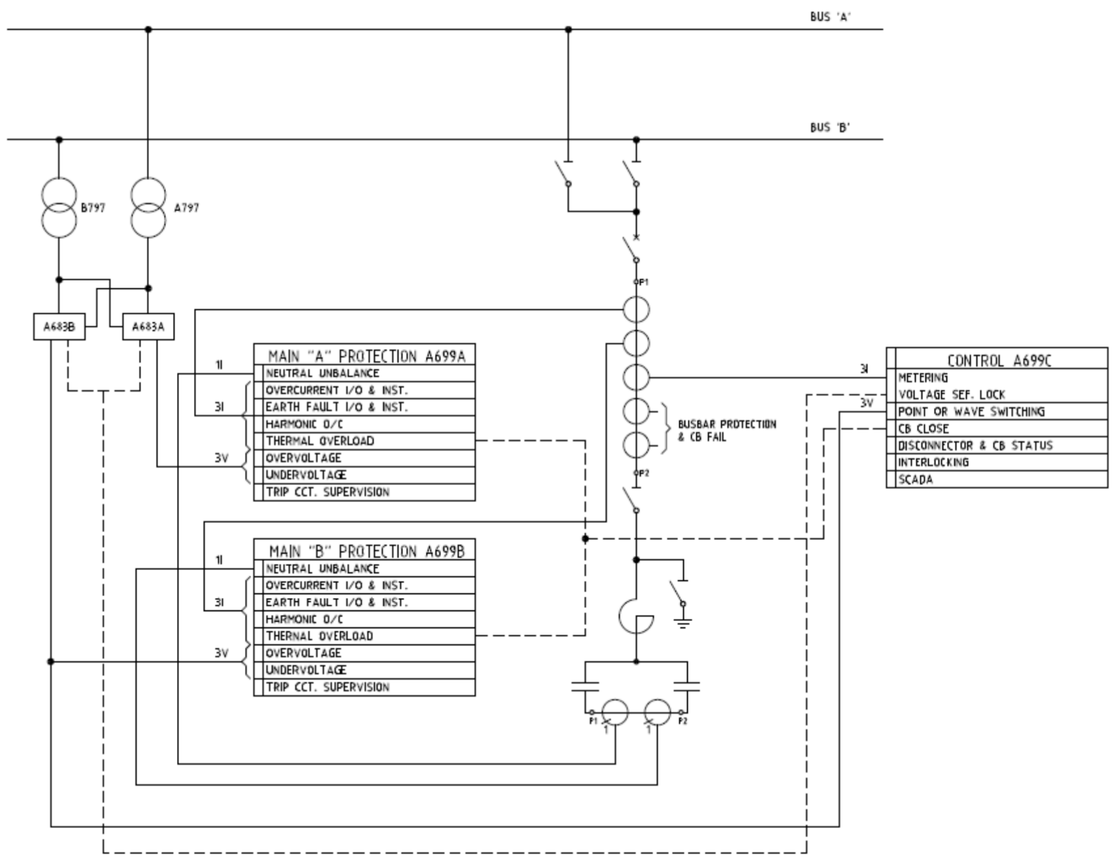
(f) Time delayed circuit breaker close inhibition to ensure that the capacitor bank is not energised until the capacitors have discharged to a safe level - the delay time depends on the capacitor bank design and shall be specified by the capacitor manufacturer;

(g) The ability to be connected to the station SCADA system via Ethernet RJ45 or fibre using communication protocols such as DNP3,IEC 60870 and IEC 61850 for alarms and monitoring and for CB control;

(h) Disconnector and earth switch interlocking; and

(i) Transmission of CB and disconnector status via SCADA to NOCS.

Figure 1 Protection arrangement for an EHV capacitor bank



3 Capacitor bank protection

3.1 Functional requirements

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

(a) Overcurrent and earth fault protection sensitive to fundamental frequency

(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 capacitor bank when the fault current contains a significant fundamental frequency content;

(ii) The protection shall provide phase segregated measurement and phase identification of the faulted phase; and

(iii) In addition to time delay characteristics on the protection that shall be selectable as definite time or inverse time, instantaneous phase fault elements and an instantaneous earth fault element shall be provided.

(b) Thermal overload protection

(i) The thermal protection tripping function shall be capable of being set to the maximum permissible current of the capacitor bank;

(ii) The time constant of the inverse time characteristic shall be capable of matching the thermal time constant of the capacitor bank; and

(iii) Two setting stages, one of which will provide an alarm and the second will provide a CB trip. The alarm shall be set at the value of maximum rated current and the trip function should match capacitor bank damage limit and shall be set to coordinate with upstream and downstream overcurrent protection.

(c) Harmonic overcurrent protection

(i) The protection shall detect all high current faults and current containing significant harmonics, at least from the fundamental to the 13th harmonic, that may cause damage to the capacitor bank – the protection operating quantity shall be proportional to the voltage across the capacitor bank;

(ii) The protection shall provide phase segregated measurement and phase identification of the faulted phase;

(iii) The time delay characteristics of the protection shall be settable as definite time or inverse time;

(d) Neutral unbalance protection

(i) The protection shall detect low level unbalance current caused by the failure of a capacitor element on one of the star configurations;

(ii) The protection shall only respond to the fundamental component of the unbalance current;

(iii) The neutral unbalance protection shall be duplicated 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; and

(iv) 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.

(e) 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) VT fuse failure supervision with separate monitoring of individual phases shall be provided; the fuse failure protection shall block the operation of the undervoltage protection and shall provide an alarm following a settable time delay.

(f) Disturbance recording

(i) All measured and calculated analogue values and protection elements are to be captured upon operation of any protection element.

3.1 Protection application and settings

3.1.1 Overcurrent protection settings

The overcurrent protection shall be arranged in two stages as follows:

(a) Stage 1 shall detect low level faults and the current setting shall be an IEC inverse time characteristic set to a value of 1.2 times the maximum permissible current for the capacitor bank. The time multiplier setting for the inverse time characteristic shall be such that the protection shall not operate during capacitor inrush current conditions; and

(b) Stage 2 shall detect high level faults and the current settings shall be a definite time characteristic greater than the maximum inrush current during energisation of the capacitor bank but less than the minimum fault level. The definite time characteristic shall be set to a value that allows a maximum clearing time of 120ms for all high level faults.

3.1.1 Earth fault protection settings

The earth fault protection shall also be arranged in two stages as follows:

(a) Stage 1 shall detect low level faults and shall be an IEC inverse time characteristic and have a current setting suitable to detect a phase to earth fault on the line side terminals of the last set of capacitors before the neutrals on both star connections; and

(b) Stage 2 shall detect high level earth faults located on the busbar on the reactor side of the capacitor. The protection setting shall be a definite time characteristic approximately 0.5 times the minimum phase top earth fault level and the definite time delay shall be set to affect a clearance time not exceeding 120ms.

3.1.1 Thermal overload protection settings

The thermal protection shall have a trip and an alarm function enabled.

The thermal overload protection current setting for the trip function shall be set to a value approximately equal to the maximum permissible current of the capacitor bank but not less than that value. The thermal time constant of the capacitor, as supplied by the capacitor manufacturer, shall be applied.

The thermal alarm shall be set to 50% of the tripping value.

3.1.2 Harmonic overcurrent protection settings

The current setting for the alarm shall be 105% of the fundamental frequency rated current of the capacitor bank. The definite time delay shall be set to 10 seconds.

The current setting of the harmonic overcurrent protection for the trip function shall be set to start operation at a current level of 110% of the fundamental frequency rated current of the capacitor bank. The inverse time characteristic selected shall match the overvoltage withstand characteristic of the capacitor bank.

Note: The operating quantity shall be the integrated value of the input current which is proportional to the applied voltage.

3.1.3 Overvoltage and undervoltage protection

(a) Overvoltage protection

- (i) The overvoltage alarm and trip shall be set to operate at 120% the capacitor bank rated voltage;
- (ii) The trip time delay shall be 5 seconds; and
- (iii) The logic shall be arranged such that high voltage of any one phase shall cause operation.

(b) Undervoltage protection

- (i) The undervoltage setting shall be set to operate at 50% of nominal voltage;
- (ii) The definite time delay shall be 5 seconds;
- (iii) The logic shall be arranged such that the low voltage must occur on all phases for operation to occur.

3.1.1 Unbalance protection settings

The unbalance protection shall be arranged to detect a small imbalance between the 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 to be applied to the unbalance protection. The alarm time delay shall be 0.5 seconds and the tripping time delay shall be 0.1 seconds.

3.1.2 Circuit Breaker Failure (CBF) protection application

CBF protection shall be applied to the CB controlling the capacitor installation. The CBF protection shall consist of one of the following configurations:

(a) Where the substation EHV busbar protection scheme provides CBF protection, the capacitor CBF protection shall be provided by the EHV busbar protection.

(b) If CBF protection is not provided by the EHV busbar protection, the capacitor bank CBF protection shall be provided by an overcurrent check element and timer tripping into the appropriate CBs.

(c) Where it is necessary to provide the CBF protection in the capacitor protection scheme, two overcurrent check elements and timers, one in the 699A and one in the 699B protection relay shall be provided. Should the substation be equipped with one CBF protection scheme, the output of each of the capacitor bank relays shall be connected in parallel to trip into the single CBF scheme.

(d) For CBF setting guidance refer to the Protection of EHV Busbars Standard.

4 Bay control, indication and metering

The CB for the capacitor bank shall be equipped with a bay control device. The capacitor bank controller may be a separate device from the bay controller.

4.1 Functionality

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

(a) The facility to monitor the status of the CB;

(b) 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 bus voltage transformers;

(c) Blocking facility for VT MCB trip and / or fuse failure condition on the associated protection;

(d) Condition monitoring functions including CB condition monitoring, maintenance planning information, internal supervision and self-diagnosis features;

(e) The facility to control the capacitor bank including Point on Wave (POW) switching; and

(f) Capacitor bank metering.

4.1 Application

The capacitor bank bay controller shall:

(a) derive current from the metering CTs associated with the capacitor bank;

(b) derive the metering voltage supply from the selected voltage of either the 'A' bus or 'B' bus VTs; and

(c) remotely and manually control the CB operations, derived from the 'A' battery, via the associated CB 'A' trip and close coils only.

4.1 Control of capacitor banks

Automatic control and operation of the capacitor bank shall be provided in the bay controller for the capacitor bank CB.

(a) The automatic control feature shall provide for the following modes of operation:

  (i) MVAr or reactive power control; and

  (ii) Voltage Control;

(b) For normal system conditions the switching of the capacitor bank shall be via the MVAr control according to the reactive demand of the load;

(c) Under conditions when the system voltage is below the nominal value, the capacitor bank shall be controlled by the Voltage Control which will attempt to restore the voltage to an acceptable range;

(d) Under conditions where the system voltage is above the acceptable value, the Voltage Control shall again override the function of the MVAr control and shall switch the capacitor bank out of service in order to attempt restoration of the voltage to acceptable levels;

(e) The capacitor bank automatic control feature shall be capable of being overridden by the NOCS;

(f) The capacitor bank shall be capable of being controlled locally by the HMI on the bay controller;

(g) Electrical interlocking of associated disconnectors and the associated earth switch shall be derived by means of the open/close output of the bay controller;

(h) The bay controller shall be capable of power quality metering measurements as well as measurements of amps, volts and MVAr together with alarm outputs indicating quantities, including harmonic levels, beyond acceptable values.

(i) Voltage selection of the appropriate VT supplies shall be provided in the bay controller;

(j) Upon opening of the capacitor bank, 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 continuously adjustable from 5 minutes to 15 minutes; and

(k) POW switching is to be implemented within the bay controller or a dedicated POW device, and a bypass POW CB close command is to be provided.

4.1 Trip circuit supervision

The following TCS facilities shall be provided:

(a) The 699A and the 699B protection relays shall be equipped with TCS facilities.

(b) TCS in the 699A relay monitors the health of the 'A' trip coil and associated circuitry.

(c) TCS in the 699B relay monitors the health of the 'B' trip coil and associated circuitry.

(d) The circuitry shall be arranged such that the TCS covers as much tripping circuitry as possible. To this end, the TCS shall be located at the end of the tripping circuit such that an interruption in the tripping supply to the isolating links of the various functions will be detected by the TCS device.

(e) Failure of one of the trip circuits shall block the operational closing function of the CB.

5 Testing

General testing requirements are detailed in the Testing, Commissioning and Training Standard and Commissioning and Recommissioning of Secondary Equipment Standard.

Appendix 1 – Standard secondary equipment

Where possible standard equipment must be used to ensure the most efficient design and maintenance practices are able to be undertaken. The following table shows the standard equipment types that are currently used by TasNetworks in EHV capacitor bank protection installations.

Device number	Manufacturer	Model	Order code	TasNetworks standard drawings
699A	GE	C70	C70-UB3-HEH-F8L-H6D-M6N-P6E-U6	Under development
699B	Siemens	7SJ82	7SJ82-JAAA-AA0-0AAAA0-AL0411-1	Under development
699C	GE	RPH3	TBA	Under development