Fundamentals

SuperTAPP SG

Voltage Control & Monitoring Relay

User Documentation

Part 2 Technical Reference

Applicable to Basic, Advanced and Ultimate relays

About this manual

This document is one part (highlighted in bold below) of the complete user documentation set, which comprises three parts in total:

- Part 1 Installation, Operation and Maintenance Guide
- **Part 2 Technical Reference**
- Part 3 SCADA Communication Guide

Manufacturer and Publisher

SuperTAPP SG is manufactured by, and this manual is published by:

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Document Reference FP1034-U-11 v4.5

Scope

This document is applicable to SuperTAPP SG relay types with Basic, Advanced and Ultimate function levels.

The relay type is printed in the form ‘FP1034-XXXXXXXXXX-Xnn-**F**X’, and the digit in the position ‘F’ represents the function level.

Version Information

Document Issue

Issue	Issue Date	Description of Main Changes	Applicable relay version
Published as part of FP1034-U-2 User Manual			
1.0	April 2016	First issue	h/w 00, s/w v4.x
2.0	Sept 2016	Substantial changes to section 15. Subsections renumbered and subsections 15.6, 15.8 and 15.9 added to support new features. Improved description in most other subsections with function diagrams added. Minor updates throughout.	h/w 01 s/w v5.x
2.1	January 2017	17 Settings lists updated to reflect new functionality 18.1.3 ENA TS 48-6-5 reference added 18.2.1 Frequency response h/w version clarified	h/w 01,02 s/w v5.x
2.2	June 2017	Hardware and software version tables added 15.1.1 Description of time delays extended and consolidated from 15.3 15.4.3 Description expanded 15.4.8 New section on power calculations 15.10 New section added: general inputs and outputs 17 New settings added (Tables 2-14, 2-16, 2-17, 2-18, 2-19, 2-20, 2-21, 2-25)	h/w 03,04 s/w v6.0, v6.1
Converted to separate document FP1034-U-11 Technical Reference			

Issue	Issue Date	Description of Main Changes	Applicable relay version
3.0	May 2018	14.2 Table 2-2 clarifies VT/CTs at basic function level 15.3.3 Added description of motor current sense 15.3.4 Added section for step-by-step function 15.8.2 Clarified reset and pickup times on Voltage Offset B 15.10.3 Added description for setting group selection 15.10.8 Added description for I/O timers 17 New settings added (Tables 2-15, 2-20, 2-21, 2-24)	h/w 04,05 s/w v6.6 – v6.8, v7.3, v7.4
3.1	July 2019	15.1.1 Added description of settings to modify bandwidth hysteresis 15.4.7 Added description of extra tranformer to list of current input functions 15.4.10 New section for Pseudo-VT 15.6 Added description of automatic busbar topology detection 17 Updated settings list	h/w 04,05 s/w v8.1-8.2
3.2	Nov 2019	15.3.3 Changed table 2-3 to show VT fuse failure blocking raise and immediate alarm time 17 Updated settings list	h/w 04,05 s/w v8.3-8.3.1
3.3	Nov 2020	Updated logo on cover page 15.3.1 Added new version of "Figure 2-59 Typical connection diagram for power supply and scheme logic module" for 'B' LV PSU stating positive and negative power supply connections. 16.2.3 Created new version of "Figure 2-59 Typical connection diagram for power supply and scheme logic module" for 'B' LV PSU stating positive and negative power supply connections. 16.2.5 Updated "Figure 2-44 Inter-relay connections" to reflect correct high and low terminals	h/w 04,05 s/w v8.3-8.5

Issue	Issue Date	Description of Main Changes	Applicable relay version
4.0	January 2021	15.10 Added Transformer temperature monitoring and control Figure 2-12 Connection arrangements for tap position module edited Table 2-2 updated with module L Figure 2-42 Optional I/O module allocation to terminal blocks edited 15.11 Analogue DC Input and Output Modules Type K and L edited Table 2-6 Analogue DC module I/O provision added Figure 2-45 Connection arrangements for type L DC analogue I/O module added 15.11.5 mA Inputs edited Table 2-8 mA Input Functions and Ranges added 15.11.6 mA Outputs 15.11.7 RTD (Pt100) Inputs edited Table 2-23 Thermal management added Table 2-24 Binary inputs submenu edited Table 2-25 Binary outputs submenu edited Table 2-26 Milliamp and Pt100 inputs submenu added 18.3.1 Energising and Output Quantities edited Figure 2-67 Connection diagram for tap position input module	h/w 05 s/w v9.1
4.1	June 2021	15.3.3 Tap position input customisation added 15.3.4 Position indication added 15.3.5 Tap changer monitoring customisation added Table 2-24 Tap changer settings edited	h/w 05 s/w v9.2
4.2	Nov 2021	20 Locations added Table 2-1 Network settings edited 18.3.1 Updated electrical characteristics	h/w 05 s/w v9.3
4.3	May 2022	Terms and conditions Table 2-2 Alarms settings edited Table 2-3 Communications menu removed IED name 18.5.2 Weight Unpackaged edited 20 Locations updated	h/w 05 s/w v9.4

Issue	Issue Date	Description of Main Changes	Applicable relay version
4.4	March 2023	15.9.4 Added Extended voltage range Figure 2-15 Additional 5-8 VT inputs added Table 2-23 Additional 5-8 VT inputs added Table 2-4 Features added Table 2-5 Added Module D to AC input options	h/w 05 s/w 9.5-10.0.2
4.5	Sept 2023	Updates related to SW V10.1 changes and document rebranding Table 2 32 Binary outputs submenu - Added comms loss alarm New Table 2 38 Communications link monitoring menu Table 2 26 Voltage target adjustments settings - Added B5 to B8 voltage target offsets Table 2 29 Network services settings - Added tap stagger reset time	h/w 05 s/w 10.1

Hardware Version

Version	Release Date	Description of Main Changes	
00	April 2016	First release	
01	Sept 2016	Module type P Module type S	Tap position input connections changed Orientation of Ethernet ports changed Serial communication terminating resistor moved
02	January 2017	Module type D	Frequency measurement response time reduced
03	May 2017	Module type G	Ability to reject AC signals added (selectable in software)
04	June 2017	Case height marginally reduced to meet 4u cutout standard SFP removal warning added	
05	June 2018	Real time clock lithium backup battery replaced with capacitor Module type A	 Voltage range of tapchanger interface extended

Note. The hardware version of the relay may be determined from the label in the bottom left-hand corner of the front panel. The relay type is printed in the form 'FP1034-XXXXXXXXXX-X**HH**', and the digits in the position 'HH' represent the hardware version.

Software Version

Version	Release Date	Description of Main Changes
v4.0	April 2016	First release
v5.0	December 2016	New features added: • General voltage offset group B • Load response • Frequency response • Tap stagger • Frequency tripping
v6.0	March 2017	Some features (load response, frequency response, frequency tripping) moved to correct feature level (Ultimate)
v6.1	May 2017	New features added: • 3-phase and 2-wattmeter power measurements • Tap change impact calculations
v6.6	Sept 2017	New features added: • Input/output timers • CT Trim added Adjustments to behaviour of some features in non-availability or activation fail conditions (load response, frequency response, tap stagger, frequency tripping)
v6.7	October 2017	Fixes to the following issues: • handling of transfer taps in step-by-step mode • handling of Auto command from SCADA • possibility of relay reboot when current is zero.
v6.8	Nov 2017	New features added: • Configurable deadbands for reporting of analogues over SCADA communications Fixes to the following issues: • Internal driver error which causes loss of event and command handling
v7.3	February 2018	New features added: • Addition of master-follower functionality • Ability to upgrade SCADA communications software via Ethernet
v7.4	April 2018	Fixes to the following issues: • A driver error which can cause lock up of the SD card which records measurement and event data, and also prevent comms event reporting

Version	Release Date	Description of Main Changes
v7.5	June 2018	New features added: ● "Automatic" option for inter-tap time delay setting ● Adjustable bandwidth hysteresis Fixes to the following issues: ● Possible incorrect tap position displayed during tap changer lockout
v7.7	October 2018	New features added: ● Alarms information screen
v8.1	April 2019	New features added: ● Automatic busbar topology detection ● Measurement and control of voltages on either side of the transformer ● Pseudo-VT ● Real time clock monitoring ● Block SCADA control input ● Reset lockout by SCADA command
v8.2	July 2019	New features added: ● Support for IEC 60870-5-103 SCADA communications
v8.3.1	Sept 2019	New features added: ● Nominal transformer voltage settings default to be the same as nominal system voltages ● Inter tap time delay and tap pulse time settings now default to 'automatic' Fixes for the following issues: ● Feeder measurements were assigned to the wrong bus section when busbar grouping was controlled by CB statuses or was automatic
v9.1	January 2021	New Features added: ● Transformer thermal monitoring and control
v9.2	June 2021	New Features added: ● Tap position customisation
V9.3	Nov 2021	New feature added: ● Network circulating current factor setting can be set to "disabled". Fixes for the following issues: ● Issue accessing settings over USB on v9.2 Basic relays.
V9.4	March 2022	Updates to IEC 61850 implementation
V10.0.2	January 2023	New Features added: ● Extended voltage range ● Compatibility for additional module type D

Version	Release Date	Description of Main Changes
V10.1	August 2023	New Features added: ● Added detection of loss of DNP3 communications link ● Added timeout function on tap stagger ● Added voltage target offsets B5 to B8 Fixes for the following issue: ● Repeated Select Before Operate command failures

> Note. The software version of the relay may be determined from within the menu structure in 'Instruments/Diagnostics/Relay Info (7/xx)'. The software version is the displayed on the first line of the display.

Table of Contents

Sections 1 to 12 can be found in part 1 of the user manual.

Conventions and Definitions

Text Conventions

Important information in the text may be in the form of either Warnings or Notes:

WARNING

A Warning contains information about situations that could result in personal injury to yourself or other persons, or risk damaging the relay or associated equipment.

NOTE: A note gives significant additional information about the use of the product.

Glossary

Primary	(VT, CT related) refers to the winding of a VT or CT which receives the voltage or current to be measured
Pseudo-VT	Feature which calculates the voltage and current on the opposite side of the transformer from that on which it is measured.
Secondary	(VT, CT related) refers to the winding of a VT or CT which produces the transformed voltage or current

Abbreviations

AVC	Automatic Voltage Control
AT	Ampere-turns
CT	Current Transformer
DSS	Directional Sequence Switch – signals whenever a raise or lower operation occurs at the tap changer
ESD	Electrostatic Discharge
HV	High Voltage (see Voltage Conventions)
IED	Intelligent Electronic Device – a device that monitors components of electrical power supplies and issues control commands based on the data received
LSS	Local Selector Switch – controls whether the tap changer is operated locally (at the mechanism itself) by an operator, or remotely by the AVC system
RFI	Radiofrequency Interference
SFP	Small Form-factor Pluggable – refers to a communication transceiver standard for pluggable Ethernet communications modules
VT	Voltage Transformer

Voltage Conventions

There are a variety of phrases indicating particular voltage levels in use in different contexts, such as low voltage (LV), medium voltage (MV), high voltage (HV) and extra high voltage (EHV). Some of these have IEC definitions attached to them and some are accepted as 'industry standard' for a particular situation.

Since the SuperTAPP SG can be applied at many voltage levels and in different countries we have avoided the use of any of these phrases to indicate an absolute level or a part of a transmission or distribution network.

However, since SuperTAPP SG is primarily concerned with transformers, it is useful to identify different voltage levels connected to the transformer and for this we use the following convention:

- HV (or high voltage) is used to indicate the higher (or highest) voltage level connected to a transformer, or the winding itself.
- LV (or low voltage) is used to indicate the lower voltage level(s) connected to a transformer, or the winding itself (ignoring any auxiliary windings). In a 3-winding transformer all the windings (again ignoring auxiliary windings) may have different voltage levels in which case the phrase LV will be applicable to all but the HV winding.

Power and Current Flow Conventions

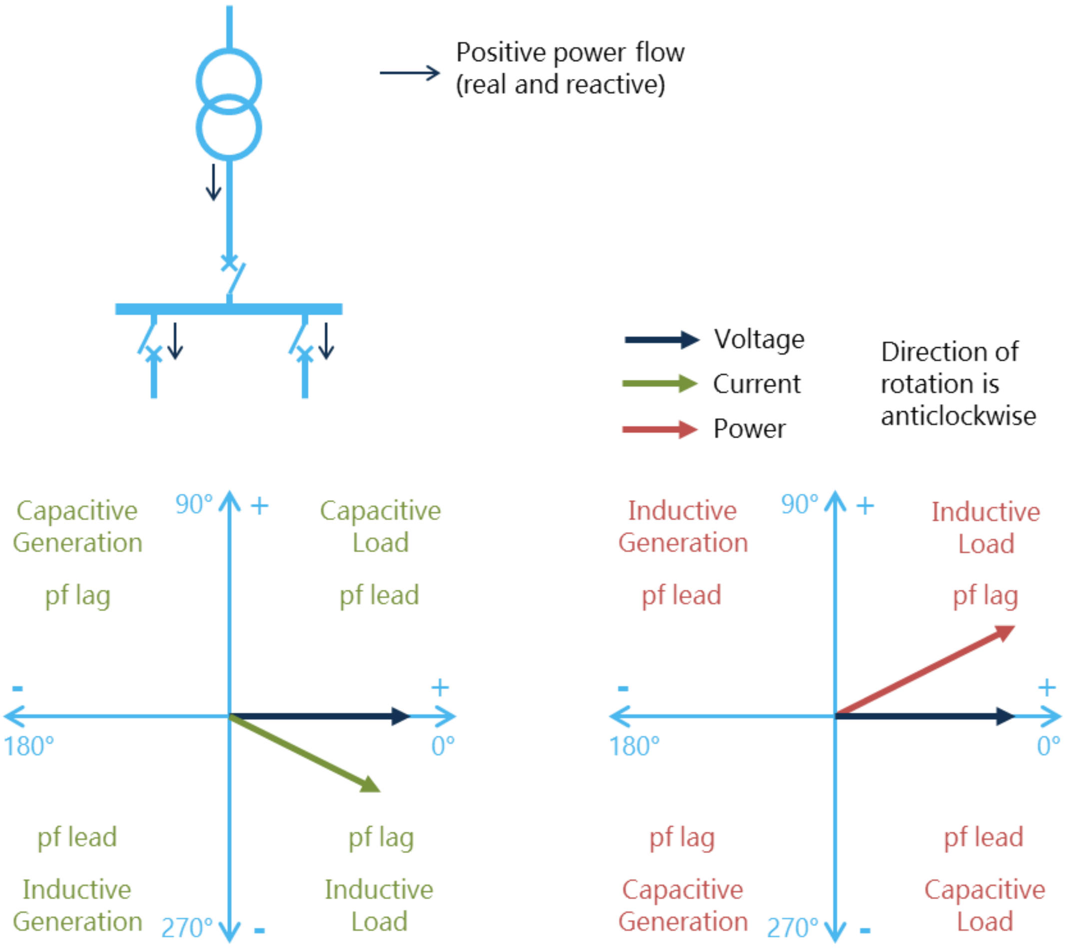
In this manual and within the SuperTAPP SG the following conventions are used.

The flow of real and reactive power will usually be given context by directional arrows within a diagram. If the arrow is pointing towards a resistive load the real power flow will be a positive number, while if it is pointing towards a generator the real power flow will be a negative number. Similarly if the arrow is pointing towards an inductor the imaginary (or reactive) power flow will be a positive number, while if it is pointing towards a capacitor the imaginary (or reactive) power flow will be a negative number.

In the absence of explicit directional arrows the implicit directional sense will be towards the busbar on transformer incomers, and away from the busbar on all other feeders, as per Figure 2-1.

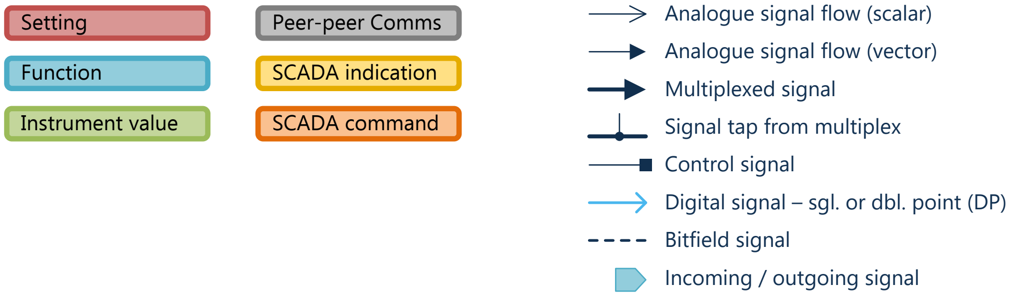
Power is defined as $P + jQ = V.I^*$ where V and I are complex numbers and * is the conjugation operator.

Figure 2-1 Sign Conventions for Power and Current Flow



Functional Diagram Conventions

In this manual the following drawing conventions are used.



13 Introduction to SuperTAPP SG

The SuperTAPP SG is the fourth generation of AVC relay designed by Fundamentals, building on a rich history and heritage gained from direct experience of working with the fundamentals of power system operation. Previous relays in the line of succession include the original TAPP, SuperTAPP, MicroTAPP and SuperTAPP n+.

13.1 Purpose

The SuperTAPP SG is designed for automatic voltage control of power systems via transformers with on-load tap-changers. It can cater for all voltage control applications from the straightforward to the complex and difficult to solve. Situations which it can handle include two-winding transformers, three-winding transformers, distributed or embedded generation, fluctuating load power factors, differing voltage sources, transformers and tap spacings, paralleling across networks, transfer taps and many more.

13.2 Physical Overview

The SuperTAPP SG is designed for fitting in the front panel of a 19” rack-mounting system and occupies ¾ width of a 4U subrack, allowing a complete voltage control for one transformer and test blocks to be fitted in a single subrack.

SuperTAPP SG is a modular relay. Ordering options allow the user to select the hardware functions which are required for the particular scheme and these are easily built into the relay. Additional hardware can be added later if required.

SuperTAPP SG is a withdrawable relay. Once the relay is wired into the panel the relay chassis can be withdrawn from the case without disturbing the wiring.

14 Ordering Options and Configuration

An Option is a phrase we use to describe a choice which the user must make at time of ordering. Where we use the word Configuration or Settings it refers to adjustments and setup which the user can carry out.

SuperTAPP SG is designed and constructed in a modular format. This allows tailoring to each user’s requirements and avoids provision of unnecessary and unused functionality. Before ordering the user should ensure that the options are right for their needs. Fundamentals can provide selection advice if required.

14.1 Function Levels

Three levels of relay function are available: basic, advanced and ultimate which define the voltage and current measuring and voltage control functionalities of the relay. A variety of I/O options are then available to customise the relay to the scheme requirements.

The functions included at each level are defined in Table 2-4. Each of these functions is described within this part of this user manual.

Table 2-4 Function level

Function Level	Included Functions
Basic SG	Measurement of three-phase VT and CT AVC for 2-winding transformers with: LDC Paralleling using Enhanced TAPP (which incorporates negative reactance compounding and true circulating current) with support for master-follower Integrated control panel Tap Position Indication Tap-changer control, monitoring and runaway prevention Busbar configuration using settings or CB status Voltage offsets A Prepare for switchout TPI customisation
Advanced SG	All Basic SG functions + Measurement of 4 three-phase VTs and 3 CTs (total) AVC for 3-winding transformers Busbar configurations using automatic busbar topology Use of additional current inputs for generation feeder, generation, load correction, load exclusion, load inclusion, interconnected substations Voltage offsets B Thermal management Binary I/O timers
Ultimate SG	All Advanced SG functions + Autonomous algorithms for frequency- and load-based voltage offsets Frequency-based tripping of parallel transformers Bottom tap transfomer triping (extending voltage range) Tap stagger Pseudo VT

14.2 Ordering Options and Product Codes

Ordering of a SuperTAPP SG is usually made up of 2 separate line items:

- the relay, including the plug-in comms modules, known as SFPs, and
- interposing CTs for connection of current inputs.

The product code for the relay is defined in Table 2-5, including the various I/O options which may be selected. Each of these elements is described within section 0 of this user manual.

Table 2-5 SuperTAPP SG product code

Product Code	FP1034	-								P	D		-		vv	-		
Power Supply																		
110/230 V AC/DC			A															
24/48 V DC			B															
Digital I/O																		
Scheme I/O only (4I & 7O)				0	0	0	0											
Scheme I/O + 5I & 4O (1 c/o)				G	0	0	0											
Scheme I/O + 10I & 8O (2 c/o)				G	G	0	0											
Scheme I/O + 15I & 12O (3 c/o)				G	G	G	0											
Scheme I/O + 20I & 16O (4 c/o)				G	G	G	G											
Analogue DC																		
None								0										
mA 2I & 3O + PT100 input								K										
mA 1I & 1O + 3PT100 inputs								L										
AC Input Options																		
2 x 3ph. VTs & 3CTs *									0									
2 x 3ph. VTs & 10CTs *									F									
4 x 3ph. VTs & 6CTs*									D									
SCADA Communications																		
None												R		0				
IEC 61850, IEC 60870, DNP3												S		L				
Function Level																		
Basic SG																	1	
Advanced SG																	2	
Ultimate SG																	3	
Ethernet																		
None																		0
100base-T RJ45																		A
100base-SX (850nm MM) LC																		B
100base-T RJ45 x2																		C
100base-SX (850nm MM) LC x2																		D
100base-FX (1300nm MM) LC																		E
100base-FX (1300nm MM) LC x2																		F
100base-LX (1300nm SM) LC																		G
100base-LX (1300nm SM) LC x2																		H

* If Basic SG function level is selected only 1 x 3ph VT and 1 CT will be usable.

Note. 'vv' in the product code is a 2-digit number indicating the hardware version. This issue of the manual is applicable to the hardware versions indicated in the Version Information on page ii.

15 Description of Functions

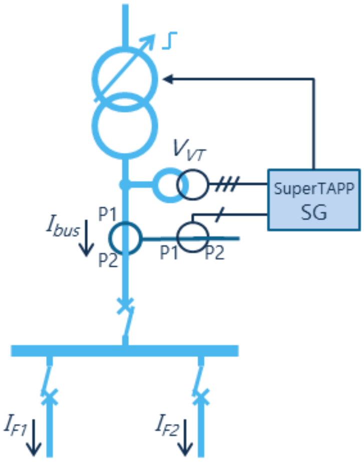
15.1 Voltage Control for 2-Winding Transformers

15.1.1 Basic Voltage Control

Applies to: all function levels and options

Basic relay operation can be described with reference to Figure 2-2 which shows a single tap changing transformer supplying a busbar with two outgoing feeders. Normally, the tap changer is on the HV winding of the transformer and the VT and CT are on the LV side between the transformer and the circuit breaker.

Figure 2-2 Simplified AVC operation



The measured voltage (V_{VT}) is compared with the target voltage of the relay (V_{tgt}). If the difference exceeds the bandwidth setting, a tap changer operation is initiated to adjust the transformer voltage to a satisfactory level.

Voltage target and deviation

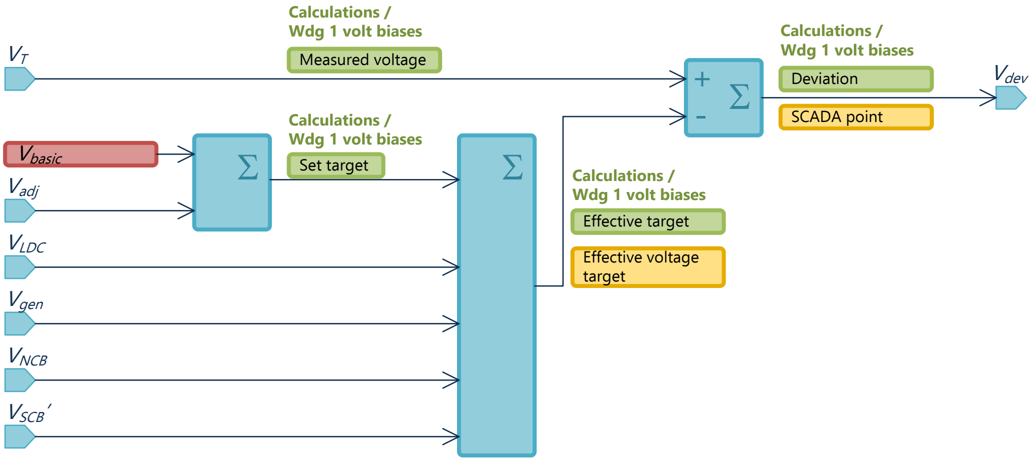
The target voltage is a dynamic quantity and is affected by several bias quantities associated with the voltage control system. The calculation of the effective target voltage, and its use for calculating the voltage deviation is shown in Figure 2-3.

where
V_T = transformer measured voltage of LV winding
V_{basic} = relay basic target voltage setting
V_{adj} = voltage target adjustments (see section 15.8)
V_{LDC} = load drop compensation bias voltage (see section 15.1.2)
V_{gen} = embedded generator bias voltage *
V_{NCB} = network circulating bias voltage
V_{SCB} = site circulating bias voltage

* available only with an advanced model

These quantities are all expressed in % values where 100% voltage is the nominal voltage of the network which the transformer is supplying.

Figure 2-3 Function diagram for calculation of target voltage and voltage deviation



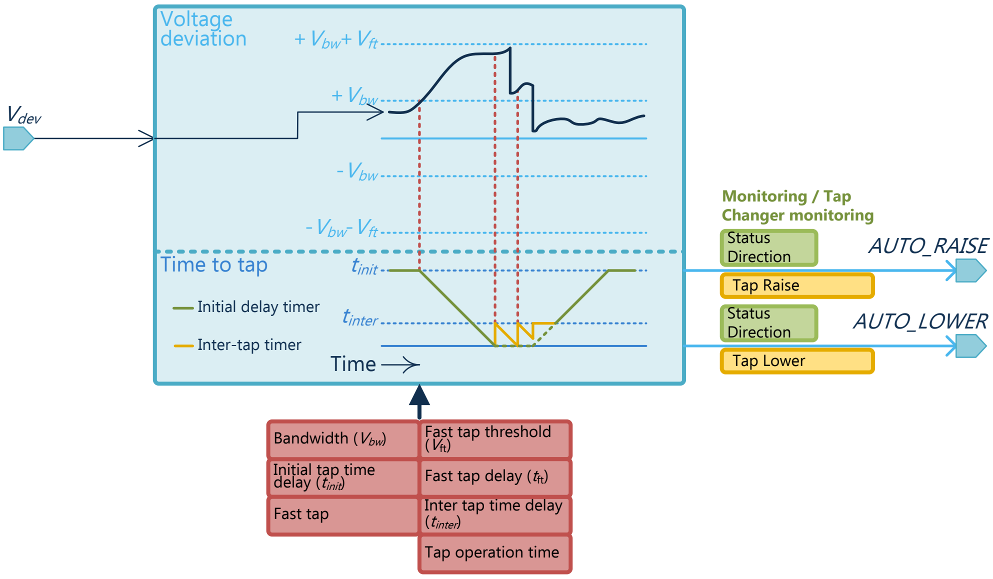
Deadband

The bandwidth or deadband setting, V_{bw} in

Figure 2-4, defines the sensitivity to voltage fluctuations. Reducing the bandwidth setting will maintain the voltage closer to the target level (i.e. increase the voltage control accuracy), but will increase the number of tap changer operations. It is represented by a ±% value based on the system nominal voltage.

If the deviation of the measured voltage from the target voltage (V_{dev}) is less than the bandwidth (i.e. within the deadband), no tap changes will occur.

Figure 2-4 Function diagram for tap changer time delays



Initial tap time delay

When the deviation exceeds the bandwidth, an initial time delay takes place before the relay issues the raise/lower command. This initial time delay is included

- to ensure that unnecessary operations do not occur for transient voltage deviations,
- to prevent an excessive number of tap operations which increases tap-changer maintenance costs,
- to allow grading of AVC relays 'top to bottom', i.e. allow tap changers at higher voltage levels to operate first, correcting the voltage across a wide area, before a more localised operation at a lower voltage level which may subsequently be reversed.

The delay is presented on the relay screen as 'time to tap', which counts down from the initial time delay setting to zero, at which point a tap changer operation is initiated. During the timing cycle, if the voltage returns to normal, the 'time to tap' count will increase at the same rate back to the initial time delay setting (although this won't be visible on the screen). If the voltage swings through the deadband to the other side, the timer is reset and starts to count down again from the initial time delay setting.

Successive Tap Operations

Following a tap changer operation, if further corrections are required, an inter-tap time delay is used. A tap-change operation usually requires a number of seconds to complete, and the inter-tap delay allows for this before requesting further operations.

If the inter tap time delay is configured to be less than the tap operation time, successive taps are delayed until the previous tap operation completes. As long as the measured voltage is still out of band the SuperTAPP SG will display 'Time to tap 0s' until the tap occurs.

Fast Tap

Under some circumstances the normal initial time delay is bypassed and a corrective tap changer operation is initiated after a fast tap time delay. The conditions under which fast tapping can take place are as follows:

- High voltage above fast tap threshold
- Low voltage below fast tap threshold
- Following a change to the relay basic target voltage or application of the voltage target adjustments (-3%, -6% etc.).
- When preparing for switch-out

The delay used for fast tap is also configurable using the fast tap time delay setting.

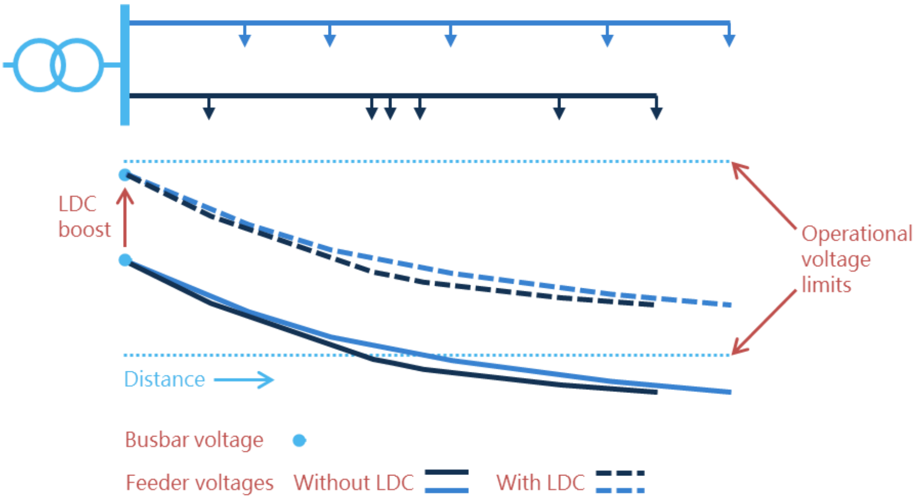
The settings relating to basic voltage control are listed in Table 2-20. Advice on the selection of appropriate setting values is provided in the Applications section 16.

15.1.2 Load (or Line) Drop Compensation (LDC)

Applies to: all function levels and options

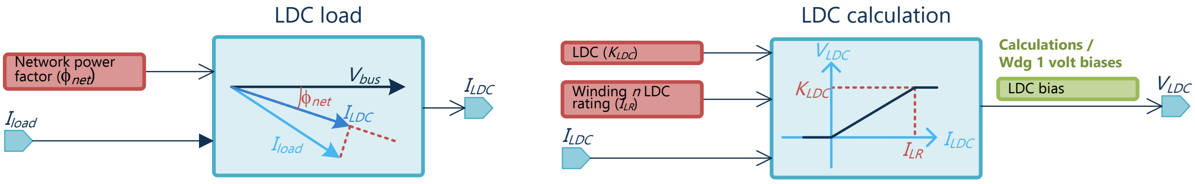
Load drop compensation (LDC) is used to offset voltage drops across a network caused by load current, as shown in Figure 2-5.

Figure 2-5 Load drop compensation (LDC)



The voltage bias for LDC (V_{LDC}) is applied in proportion to the load current (I_{load} in Figure 2-6) and is expressed as a percentage boost at full load. For example, an LDC setting (K_{LDC}) of 10% means that at full load the voltage boost applied to the relay will be 10% of nominal. At half load, the boost will be 5%. Full load is defined by the LDC rating setting (I_{LR})

Figure 2-6 Function diagram for load drop compensation (LDC)



LDC is applied according to the assumed load power factor to minimise the effects of purely reactive network components such as capacitor banks, heavy industrial loads etc. The effect of this is shown in Figure 2-6. The applied LDC voltage bias is capped at the setting level; it cannot exceed the setting level even if the LDC load is above the LDC rating.

The related settings can be found in Table 2-20.

15.1.3 Parallel Transformers

Applies to: all function levels and options

The above description of voltage control is correct for simple substations with a single two-winding transformer. Parallel transformers introduce two factors which require some modification to the operating methods described above. Firstly a method is required to ensure that the transformers "keep in step" appropriately, and secondly multiple transformers affect the load seen by one transformer and hence the impact of LDC.

SuperTAPP SG employs the enhanced TAPP method to "keep in step" and apply LDC. Inherent in this method is the ability to handle parallel transformers with

- Different transformer capacities, impedances and tap spacing,
- Different source voltages and source feeding arrangements, and
- Generation teed into the HV winding incoming feeder.

All of this is capable of operating without needing to know any circuit breaker positions or setting master or slave transformers which makes a SuperTAPP SG scheme extremely easy to design, implement, commission and operate.

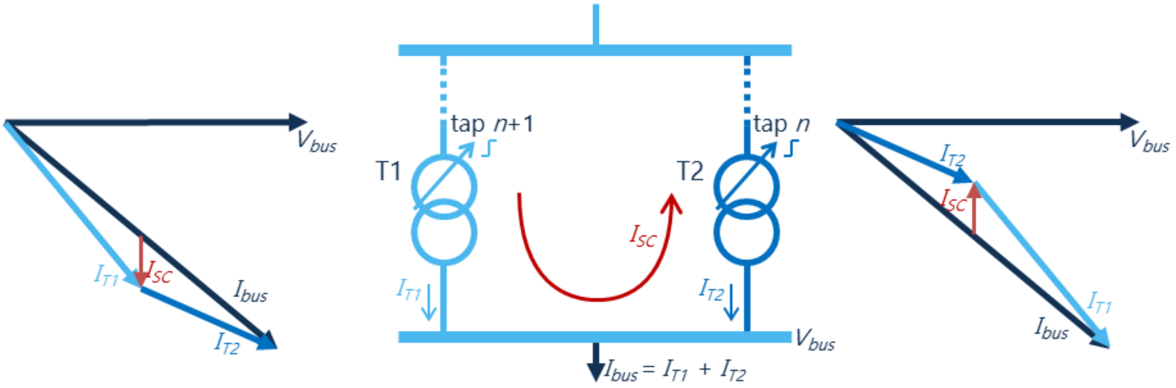
15.1.3.1 Circulating Current Minimisation

If the open circuit terminal voltages of paralleled transformers are not identical, a circulating current will flow between them (at a site or across the network). This current will be highly reactive since the transformers are essentially inductive. Figure 2-7 shows two paralleled identical transformers at a site, T1 and T2, on different tap positions with corresponding vector diagrams. T1, being on a higher tap position, will attempt to produce a higher output voltage than T2 and therefore exports circulating current into T2. The bus-bar voltage, V_{bus}, will be the average output voltage of the transformers.

Any voltage control relay must include a method to maintain the tap position to the point where circulating current is minimised, otherwise the tap changers will drift apart and, while the voltage will be the average of their terminal voltages, a high amount of circulating current will flow between them. This will cause an unnecessary power loss within the transformers and the network, reducing their useful capacity and their efficiency. In a worst case this may lead to transformers tripping on high winding temperature or directional overcurrent, and a complete loss of voltage control.

The SuperTAPP SG employs the 'enhanced TAPP' method to calculate the circulating current and convert it into a circulating current voltage bias, V_{circ}. The voltage bias modifies the target voltage of the relays in order to promote tap changer operations which will reduce the circulating current to a minimum. An export of circulating current, as seen by T1 in Figure 2-7, results in a negative V_{circ} which decreases the effective target voltage, making the relay tend to tap down. An import of circulating current, as seen by T2 in Figure 2-7, results in a positive V_{circ} which increases the effective target voltage, making the relay tend to tap up.

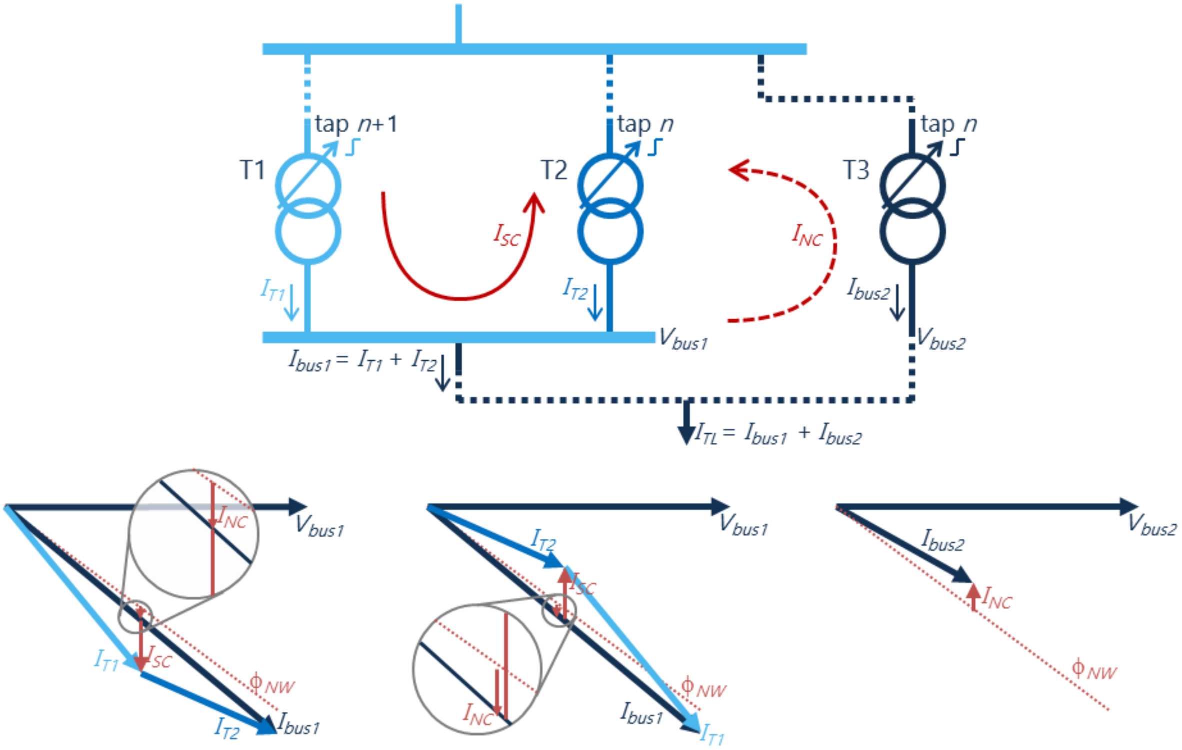
Figure 2-7 Parallel transformers at a site



The circulating current voltage bias is made up of two components: a bias arising from site circulating current, and a bias arising from network circulating current. The site circulating current is calculated using the 'true circulating current' method, which is dependent on the individual transformer load and the summed load of paralleled transformers, as exhibited in Figure 2-7.

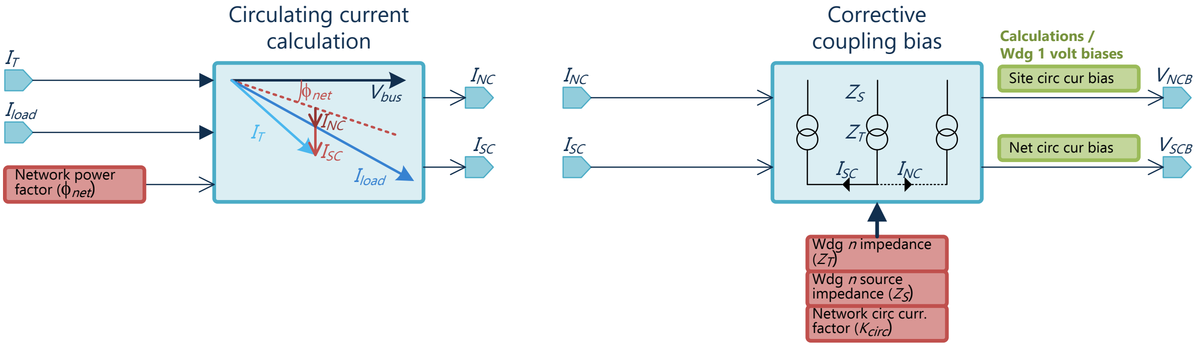
Figure 2-8 shows a situation involving paralleling across the network and includes site circulating current I_{SC} and network circulating current I_{NC}. The network circulating current is calculated using the 'TAPP' method (Transformer Automatic Paralleling Package). This is the circulating current exported from (or imported to) the site. Since it is not possible to measure an overall load setting across the network, the network power factor setting is used as the basis for the calculation (typically around 0.96 lagging). The network circulating current is the circulating current of the site, with respect to the network power factor, I_{NC} in Figure 2-8.

Figure 2-8 Parallel transformers across a network



The logic diagram of Figure 2-9 includes the circulating current calculations. The related settings can be found in Table 2-21 and Table 2-22.

Figure 2-9 Function diagram for circulating current calculation



15.1.3.2 LDC on Multi-transformer Busbars

On busbars fed by multiple transformers, as exhibited in Figure 2-7, the total load on the busbar is the sum of the loads on all the transformers connected to the busbar. It is this summated load which is applied as I_{load} in Figure 2-9 for the calculation of the LDC effect.

The loads of multiple transformers on a busbar are summated using inter-relay communications, which can connect together multiple SuperTAPP SG relays on a site. The use of the inter-relay communications is discussed in greater detail in section 15.12.1.

15.1.3.3 Master-Follower

In a very few circumstances SuperTAPP SG may be applied to parallel transformers when it is not possible to use the TAPP method to keep transformers in step, for example if there are no CTs which are able to provide transformer current measurements. For these circumstances SuperTAPP SG is equipped with master-follower mode.

Fundamentals do not recommend the use of master-follower mode except in situations where it is unavoidable, because it is an inferior method of keeping transformers in step and the constraints it imposes:

- Transformers (capacity, impedance, tap spacing) must be identical; and
- They must be fed from the same voltage source, with the same source impedance and no tees on the incoming lines.

If master-follower must be used it is selected with the Voltage control mode setting (Table 2-20). A setting is also available to define the delay for the follower after the master taps.

The master-follower behaves as follows:

- When a relay is set in master-follower mode, or is powered up in master-follower mode it looks to see if there are any other relays in the same busbar group (and also in master-follower). If not, it will become the master; if there are it will become a follower of the master.
- When a follower relay is switched from manual to auto, or is powered up in auto, it will tap to the same tap position as the master.
- If a master relay taps, whether it is in auto or manual, all follower relays in the same busbar group which are in auto will tap to maintain the same tap position, following a short delay as defined by their 'Follower delay' settings.
- Whenever one of the follower relays has a different tap position to the master, the master and the relevant follower will indicate out of step, and the master will inhibit further automatic tapping until the follower relays have caught up.
- If, for any reason, a follower remains out of step for the defined Alarm time (Table 2-27), an alarm will be generated (on SCADA comms and on binary outputs as defined by the 'Out of step alarm' setting - Table 2-30). When the situation is corrected further automatic taps will be allowed again.

The master relay can be selected locally or through SCADA as follows:

- When in This Panel mode by pressing and holding the 'Auto' button for 3 seconds on the relay which is required to be the master;
- When in SCADA mode using SCADA communications; or
- In either mode using the 'Select master' binary input.

The currently selected master is indicated locally on the main screen and to SCADA by the SCADA communications, and also a binary output as defined by the 'Master' setting (Table 2-30).

15.2 Integrated Control Panel

Applies to: all function levels and options

Figure 2-10 Front panel features

15.2.1 Control Points

The SuperTAPP SG accommodates three points of control for tap-changers:

- Local, i.e. local to the tap-changer
- This Panel, i.e. on the SuperTAPP SG integrated control panel or adjacent panel switches
- SCADA, via the relay by SCADA communications (DNP3, IEC 61850 etc)

15.2.2 Modes of Operation

There are two modes of operation for the relay as follows:

- Auto – SuperTAPP SG AVC algorithm controls the tap changer
- Manual – an operator controls the tap changer

These modes of operation can exist independently of the control point giving the following combinations:

- This Panel-Auto – tap changer controlled by the relay
- This Panel-Manual – tap changer manually controlled by an operator at the control panel/relay
- SCADA-Auto – tap changer controlled by the relay but influenced by SCADA communications (DNP3, IEC 61850 etc.)
- SCADA-Manual – tap changer controlled by an operator via remote raise and lower commands over SCADA communications (DNP3, IEC 61850 etc.)
- Local to tapchanger (AVC disabled) – tap changer manually controlled by an operator at the tap changer

15.2.3 Manual Mode

In this mode the relay maintains measurements and indications according to the operational state, but does not issue tap changer operations or operational alarms. Normally this would represent situations where the tap changer is operated by an operator.

15.3 Tap-changer Control, Monitoring and Runaway Prevention

Applies to: all function levels and options

15.3.1 Tapchanger Control

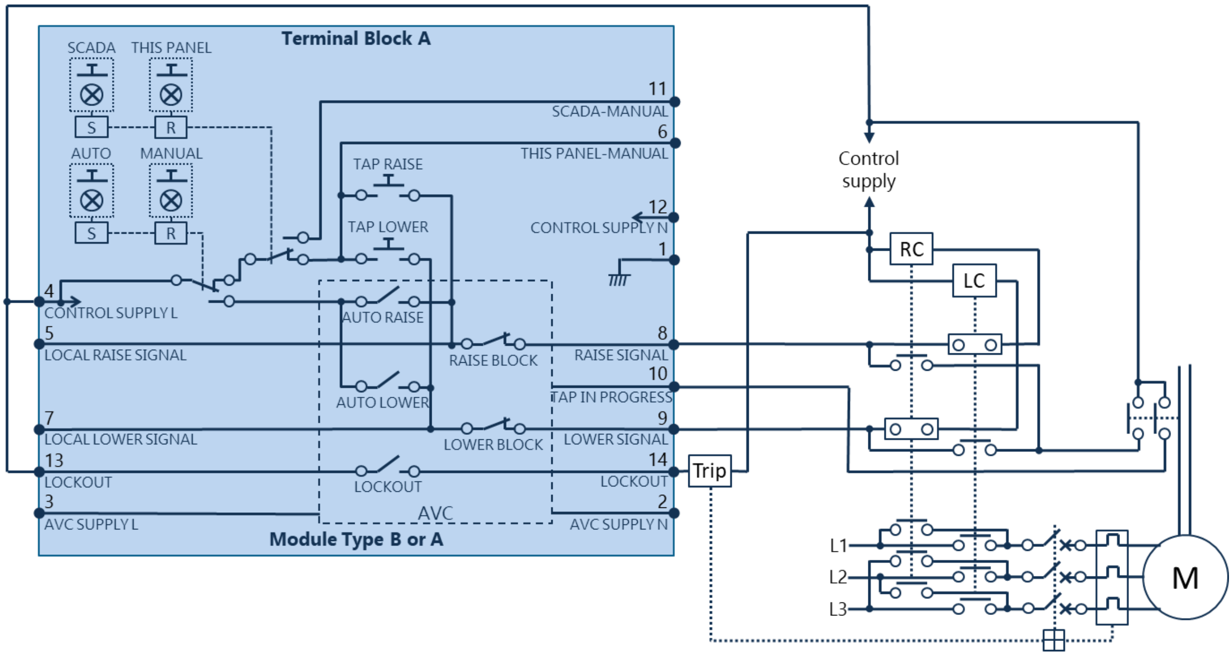
All connections to the tapchanger control circuits are made to the scheme logic module. A basic control scheme is shown in Figure 2-11. This assumes a 3-phase tapchanger motor; single-phase motors are as easily catered for.

Manual tap operations (described in section 15.2) are generated within this module, as are automatic tap operations. They both feed through blocking contacts which are a check-balance to prevent operation in the wrong direction when the voltage is high or low, and when an overcurrent situation arises.

This module also allows monitoring of the tapchanger operation with the raise, lower and tap in progress signals. There is also the ability to generate a 'lockout' output which is normally wired to trip the tapchanger motor, and is described further below.

The positive and negative AVC supply connections for Module Type A can either be on terminals 2 and 3 or terminals 3 and 2. The positive and negative AVC supply connections for Module Type B are on terminals 3 and 2, respectively.

Figure 2-11 Connection arrangements for the power supply and scheme logic module



15.3.2 Tap Position Inputs

The tap position input module (Figure 2-12, supplied as standard, comes with inputs for all tap position sender units:

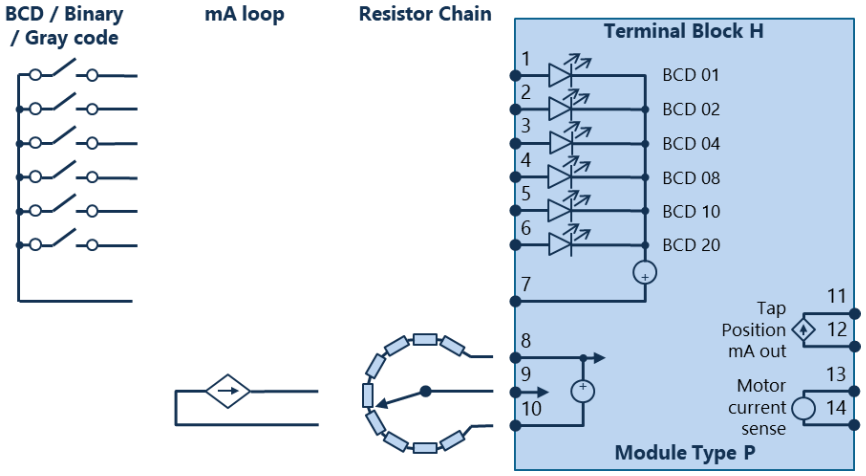
- Resistor chain
- Binary coded decimal (BCD), binary, Gray code
- mA loop

The SuperTAPP SG has a number of settings which tell it how to interpret the inputs, including tap position indicator type, number of tap positions, the minimum and maximum tap position, whether the taps are reversed (highest position corresponds to the lowest voltage, rather than the usual highest voltage) and whether there are transfer taps. The settings can all be found in Table 2-25.

The resistor chain sender unit is the most challenging to work with since it is susceptible to measurement errors with age. The SuperTAPP SG has a number of features within it designed to overcome these errors and prevent poor operation while maintaining a high degree of confidence in the tap position and good runaway prevention (see the following section).

- Additional top and bottom resistors – allow the detection of open circuit sender unit contacts
- Dead reckoning – provides a degree of intelligence that the measured tap position corresponds with the expected tap position

Figure 2-12 Connection arrangements for tap position module



15.3.3 Tap Position Input (TPI) customisation

The default SG operation is configured to accept a one-to-one relationship between tap position indication and transformer ratio. Therefore, for tap changer control and monitoring, only one discrete change in tap position indication is expected per tap command. Due to the operation of some tap changers one discrete change in tap position indication per tap command is not always the case, for example where a tap changer has a transfer tap arrangement. A transfer tap performs additional tap operations to increase the range of transformer ratios available using the same winding. During this transfer tap operation, the tap position sender can indicate different discrete positions where no change in transformation ratio exists between primary and secondary windings, assuming a two winding transformer. Without tap position input customisation, the SG would interpret this as a tap position indication failure under default behaviour.

Two solutions are supported by the SG, the first being to modify the tap position sender unit on the tapchanger itself. If this is supported by the sender unit this is usually by use of electrical links but is dependent on the manufacturer of the tapchanger on how to achieve this. The second solution would be to use the tap position input customisation settings described below.

To describe how the TPI customisation settings are used, an extract from an example rating plate is shown in Table 2-6. This example shows a 19 position tapchanger with discrete positions for each transfer tap operation where two transfer tap positions exist in the indicated position range 9 to 11. It can be seen that there are 17 distinct voltage ratios against a 19 position indicator with the nominal voltage ratio at indicated positions 9, 10 and 11.

Table 2-6 HV Rating plate example for customised TPI settings

Indicated Position	HV		LV	
	Voltage(V)	Current (A)	Voltage(V)	Current (A)
1	36776	358.9	11000	1200
2	36304	363.6		
3	35832	368.4		
4	35360	373.3		
5	34888	378.4		
6	34416	383.5		
7	33944	388.9		
8	33472	394.4		
9	33000	400		
10	33000	400		
11	33000	400		
12	32528	405.8		
13	32056	411.8		
14	31584	417.9		
15	31112	424.3		

Indicated Position	HV		LV	
	Voltage(V)	Current (A)	Voltage(V)	Current (A)
16	30640	430.8		
17	30168	437.5		
18	29696	444.5		
19	29224	451.7		

In this example the tapchanger performs an automatic transfer tap when tapping up from indicated positions 8 or 10 or when tapping down from indicated positions 12 or 10. Tapping from 9 to 10 or from 11 to 10 does not result in a change in voltage ratio and positions 9 and 11 are transitory, where the tapchanger, under normal operation, never remains in these positions. The use of the setting "number of consecutive transfer taps" (as seen in Table 2-7) defines the number of additional transitory tap operations allowed which if exceeded will result in a runaway being issued.

Table 2-7 shows the relevant settings for TPI customisation for the example. The TPI customisation menu lists the TPI inputs labelled as "TPI tap" against the expected winding ratio tap position. The winding ratio tap setting describes the distinct transformer ratio step between the configured top tap voltage and bottom tap voltage in the transformer settings. Each TPI tap input setting can be configured with its corresponding ratio position. The number of tap positions setting determines the number of tap positions expected on the TPI input. The minimum and maximum tap position setting relates to the displayed tap position (see 15.3.4) and represents where tap blocking should be applied.

Table 2-7 TPI customisation settings example

Setting Menu >Tapchanger	Setting Name (Parameter)	Value
Tap position indicator submenu		
	Number of tap positions	19
	Minimum tap position	1
	Maximum tap position	19
	Number of consecutive transfer taps	1
	Display	Indicated TPI tap pos

Setting Menu >Tapchanger	Setting Name (Parameter)	Value
TPI customisation submenu		
	Tpi tap 1 : wdg ratio tap	1
	Tpi tap 2 : wdg ratio tap	2
	Tpi tap 3 : wdg ratio tap	3
	Tpi tap 4 : wdg ratio tap	4
	Tpi tap 5 : wdg ratio tap	5
	Tpi tap 6 : wdg ratio tap	6
	Tpi tap 7 : wdg ratio tap	7
	Tpi tap 8 : wdg ratio tap	8
	Tpi tap 9 : wdg ratio tap	9
	Tpi tap 10 : wdg ratio tap	9
	Tpi tap 11 : wdg ratio tap	9
	Tpi tap 12 : wdg ratio tap	10
	Tpi tap 13 : wdg ratio tap	11
	Tpi tap 14 : wdg ratio tap	12
	Tpi tap 15 : wdg ratio tap	13
	Tpi tap 16 : wdg ratio tap	14
	Tpi tap 17 : wdg ratio tap	15
	Tpi tap 18 : wdg ratio tap	16
	Tpi tap 19 : wdg ratio tap	17

Within the TPI customisation menu any tap position indication setting that is not configured with an associated Xfer setting is expected to only take one tap operation. If the associated Xfer setting is configured, then the maximum number of tap operations expected at the Xfer position is set by the "Number of consecutive transfer taps" setting. This setting signifies the maximum taps allowed through the discrete positions but if the setting is too high it will result in inefficient detection of runaways throughout the transfer. Whereas fewer taps will not generate a runaway or tap incomplete error and the setting may be increased to allow for correct functional in asymmetric tap changers. Where no associated Xfer setting is configured against a winding ratio tap value then the number of tap operations as set by the "Number of consecutive transfer taps" is expected anywhere within the tapping range before a lockout due to runaway is issued. Where TPI failures occurs, a lack of tap position indication causes tap customisation to be not applicable. The relay will then regress to the "Number of consecutive transfer taps" expected anywhere within the tapping range.

The relay will detect if the transfer and tap customisation has been entered incorrectly. An error message will be displayed on the relay LCD screen indicating "TPI Settings error". This should be observed through commissioning or setting changes and does not have any application to comms.

15.3.4 Voltage Control and Tapchanger Monitoring and Alarms

The most important function of the tapchanger monitoring is runaway prevention. The SuperTAPP SG has a comprehensive runaway prevention function which has been developed from decades of experience of our staff working with tapchangers of many makes and vintages.

Runaway prevention

The runaway prevention function includes within it monitoring of

- the control signals (raise, lower, in progress),
- the tap position, and
- tapchanger motor current.

These are combined with the expected characteristics of the tapchanger such as operating time to detect if the tapchanger is running away (i.e. carrying out more than one tapping operation for a single instruction). If a runaway, or an incomplete tapchange is detected a 'lockout' output can be generated to trip the tapchanger, and settings are provided for this in Table 2-25.

The 'motor current sense' inputs on the Tap Position Inputs module type P allows the tap changer motor current to be monitored using a standard SuperTAPP interposing CT (type FP1030). This is a more robust method of determining if the tapchanger motor runs for an excessive period, and if it is available it is used as the definitive indication of operation of the tapchanger.

If the voltage cannot be corrected (e.g. tap changer mechanism fault or end of range), the relay will stop issuing raise/lower signals and may additionally trip the tapchanger motor MCB. Additionally after a common alarm time the associated AVC alarm will be raised. A list and description of each monitored condition is given in Table 2-8 and the associated settings can be found in Table 2-22, Table 2-26 and Table 2-30.

Blocking and inhibiting tapping operations

The term 'blocking' refers to a physical prevention of tapping by opening blocking contacts which are in series with the auto relay and the manual pushbuttons, affecting both auto and manual operation. The term 'inhibit' refers to a temporary stopping of auto operation, until the condition is removed, but allowing manual operation to be carried out.

SuperTAPP SG monitors for a number of conditions and blocks or inhibits tapping to prevent potential damage to the tapchanger or incorrect voltages being applied to the network. These conditions are all listed in Table 2-8 and some of them and their uses are further described below:

- Overcurrent limit – blocks tapping when the current exceeds the tapchanger rating. The limit level is specified by setting (Table 2-22).
- Reverse current limit – blocks tapping when the current exceeds the tapchanger rating in the reverse direction. Some tapchangers (particularly those with an asymmetrical pennant cycle) can have a lower rating when current flow is in the reverse direction. The limit level is specified by setting (Table 2-22).
- Voltage high limit – blocks tapping in the raise direction when the voltage is higher than the setting less half the bandwidth (Table 2-26)
- Voltage low limit – blocks tapping in the lower direction when the voltage is lower than the setting plus half the bandwidth (Table 2-26)
- Low volt inhibit level – inhibits automatic tapping when the voltage is lower than the setting level since this indicates a dead bus (Table 2-26).

- External blocking – an external digital input can be used to manually block tap operations, or to generate the block from another relay, as specified by the Tap block setting (Table 2-29).

Table 2-8 Monitored conditions and alarms

Condition	Description	Blocking	Alarm	SCADA point
VT fuse failure	When a 3-phase VT is used excessive difference between phase measurements are present.	Raise blocked	Immediate	VT Fuse Failure
End of tap range	When the tapchanger is on top or bottom tap.	In relevant direction	Immediate	Highest (Lowest) Tap Position Reached
Target not achievable	A lower is requested when on bottom tap, or a raise when on top tap.		Immediate	Tap Not Achievable
CAN bus failure	Communication failure between relays using inter-relay communications.		After alarm time	CAN Bus Failure
Overload	The transformer load is above the overcurrent limit.	Both directions	After alarm time	Overload Alarm
Reverse current limit exceeded	The transformer load is above the overcurrent limit in the reverse direction.	Both directions	After alarm time	Reverse Current Overload
Voltage high	The measured voltage is above the voltage high limit.	Raise blocked	After alarm time	Voltage High Indication
Voltage low	The measured voltage is below the voltage low limit.	Lower blocked	After alarm time	Voltage Low Indication
Phase reference alarm	No voltage is available to provide a phase reference.	Both directions	After alarm time	Loss of Phase Reference
Voltage out of band alarm	The voltage deviation has been outside the bandwidth for the alarm time.		After alarm time	Voltage out of Band Alarm
Tap changer runaway	Signals from the tap changer indicate the tapchanger executes multiple tapping actions for a single command.	Tap changer motor may be tripped	Immediate	Tap Changer Runaway
Tap incomplete	Signals from the tap changer indicate the tapchanger never completes the tapping action.	Tap changer motor may be tripped	Immediate	Tap Change Incomplete
Out of step	(Master-follower only) Indicates that a follower is not on the same tap position as the master	**	After alarm time	Out of step alarm

** No blocking, but further auto tapping of the master is inhibited until the out of step is corrected

15.3.5 Step-by-step Control

Figure 2-11 shows a basic tap change control scheme which works as follows:

When a raise or lower control signal is generated (terminals 8 or 9 respectively) the relevant contactor is energised which operates the motor in the appropriate direction. The contactor also opens a series contact on the opposite contactor to prevent both raise and lower being energised together. Once the motor is running, the in-progress switch provides an in-progress signal to the SuperTAPP SG and maintains the supply to the appropriate (raise or lower) contactor until the tapchange is complete. This allows the scheme to operate with a pulse control signal from the SuperTAPP SG, which may have been generated by the AVC function or from manual pushbutton or manual SCADA input.

If a raise or lower button is held in through the complete tapchange, when the tapchange is complete a second tapchange will start and this will continue as long as the button is held (until the tapchanger reaches its endstop). To prevent this, it is normal to employ the use of a step-by-step relay which, once energised by the control signal and the motor is running, blocks further control signals from latching the raise and lower contactors until the first signal is removed. This enforces the behaviour of one tapchange for one button press.

SuperTAPP SG has the maintaining signal and step-by-step functionality built in, although this is not enabled by default, since many installations already have this as part of the hardwired scheme.

The Tap changer scheme setting (Table 2-25) allows selection between Basic and Step-by-step. If basic is chosen the hardwired scheme must provide all maintaining and step-by-step functionality. If Step-by-step is chosen the SuperTAPP SG will provide step-by-step functionality and external step-by-step relays are not required.

15.4 Measurement of AC Voltage and Current

15.4.1 AC Input Module Type D

Applies to: all function levels and options

The AC Input module type D included in all relays provides

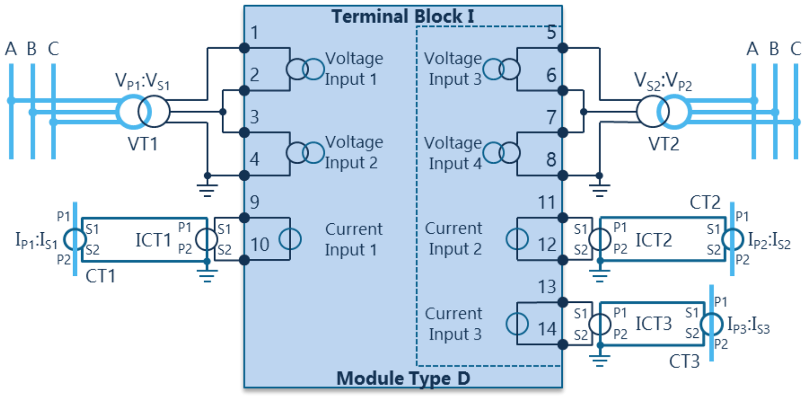
- 4 voltage inputs, which between them are capable of measuring two 3-phase voltages
- 3 current inputs

The Basic function level gives access to 2 voltage inputs and 1 current input. Purchase of the Advanced or Ultimate function level is necessary to access the full functionality of the module.

The voltage and current inputs are very flexible in the way they can be connected. The VT & CT Settings allow the connection arrangements to be specified.

The normal connection details for the type D module are shown in Figure 2-13. In a simple configuration it is expected that VT1 and CT1 would be wired to measure the voltage and current on the transformer LV winding. Different arrangements of the various VT and CT inputs are discussed in greater detail in the Applications section of the manual (section 16).

Figure 2-13 Connection arrangements for type D AC input module



Voltage

Figure 2-13 assumes that a 3-phase VT is available. If this is not the case alternative connection arrangements are possible with some reduction in functionality. The SuperTAPP SG provides complete flexibility over which voltage inputs to use with which VT and which phases. The relevant settings are provided in Table 2-23.

Current

The current is measured with the use of an interposing CT. The primary CT should have a nominal 0.2A, 0.5A, 1A or 5A secondary winding. This is wired through an interposing CT which is supplied with the SuperTAPP SG relay, ICTx as shown in Figure 2-13. It is the secondary windings of the interposing CT which are wired to the relay terminals.

There are a number of advantages of using the interposing CT method of current measurement.

- Since the output and rating of the interposing CT is very low (mA) it removes the dangers associated with open circuit CTs.
- No CT shorting is required if it is necessary to remove the SuperTAPP SG relay for any reason.
- The interposing CTs have low burden and can be installed around protection secondary cores of existing CTs. This is useful when measuring currents in feeders which do not have spare CTs.

15.4.2 AC Input Module Type F

Applies to: SuperTAPP Advanced and Ultimate SG function levels

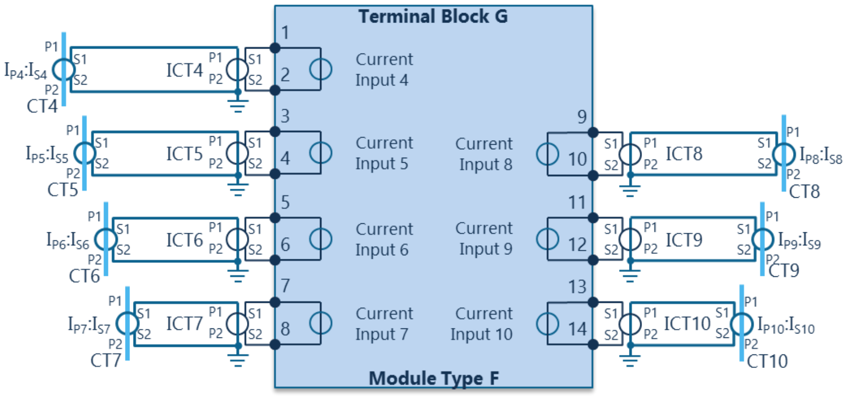
The AC Input module type F is available as an option and provides

- 7 additional current inputs

As with the main analogue input module these can be used to measure the current on outgoing feeders and applied in many different ways.

The use of this module gives a total of 10 current measurement inputs per transformer. If one of these is used to measure the LDC CT then in a 2 transformer substation it is possible to measure the current on 18 outgoing feeders.

Figure 2-14 Connection arrangements for type F AC input module



15.4.3 Voltage Measurements and Calculation

Applies to: all function levels and options

Figure 2-15 shows the signal flows for voltage measurement and calculation. The measured quantities are associated with different VTs and phases according to the settings in the relevant Voltage Input settings menu. Voltage measurements can be phase-phase (which is the norm) or sometimes phase-neutral.

If a 3-phase VT is used the measurement inputs are normally set to measure two sets of phase-phase voltages (e.g. A-B and B-C in Figure 2-13) and calculate the remaining phase-phase voltage (C-A) as per the phasors of Figure 2-16.

The measured values are secondary voltages. The setting of VT Ratio is then used to calculate the appropriate primary voltages which are propagated through the relay and used for SCADA values.

Figure 2-15 Function diagram for voltage measurement and calculation

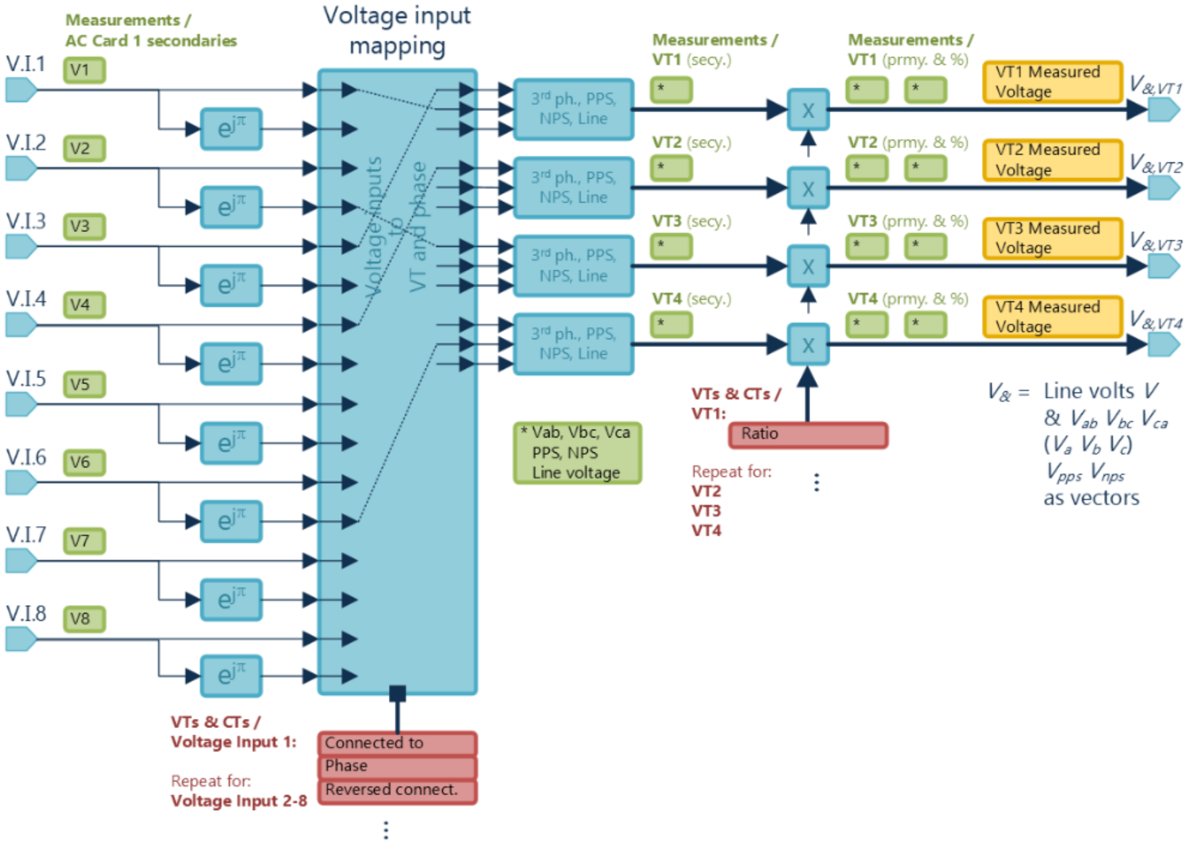
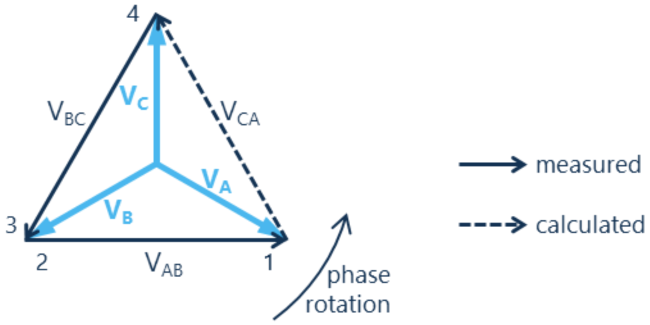


Figure 2-16 Example of measured and calculated voltage phasors



A single 'line voltage' is also determined, which is used in all voltage control algorithms. The following methodology is used to determine the line voltage:

- If two or three phase-phase voltages are measured, the line voltage is the average of the three (after calculation of the third if necessary).
- If one phase-phase voltage is measured, it is used as the line voltage
- If two or three phase-earth voltages are measured the line voltage is the average multiplied by root three.
- If one phase-earth voltage is measured it is assumed to be a single phase system and will be the line voltage (no multiplication by root three)

The positive phase sequence angle is used as the reference for load angle calculations.

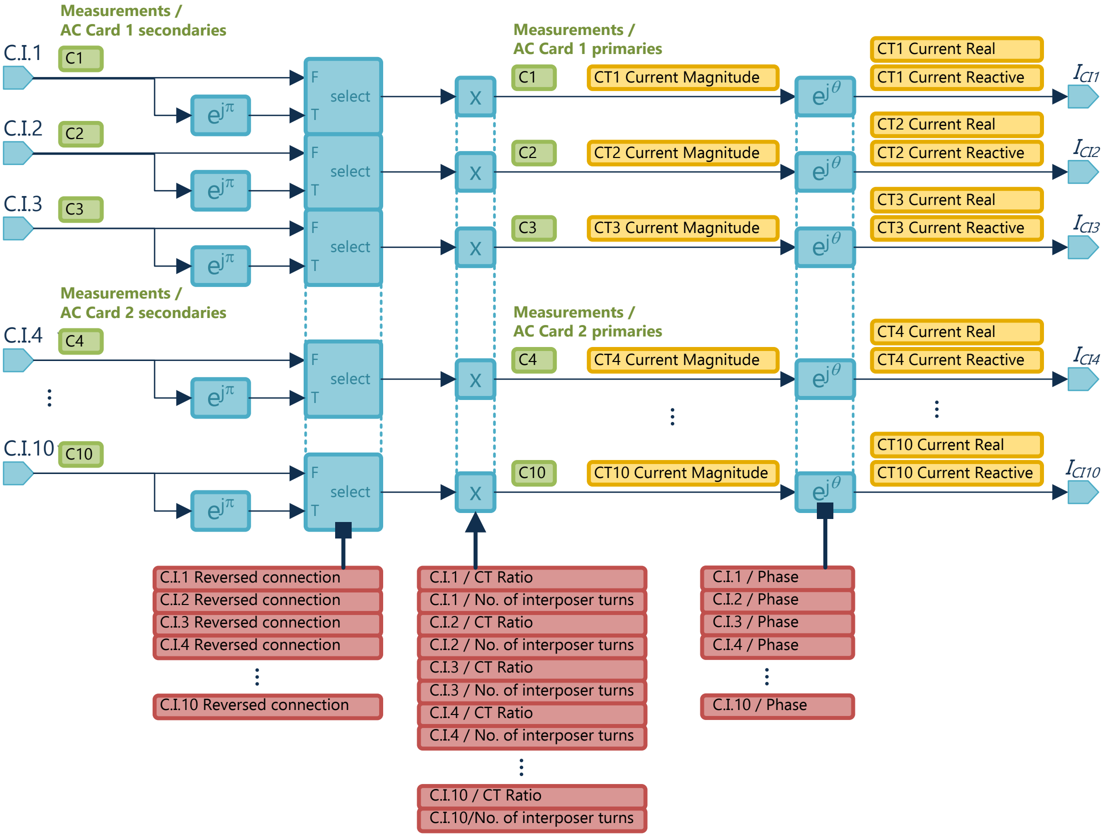
15.4.4 Current Measurements and Calculation

Applies to: all function levels and options

The current measurement can be taken from any phase selected by the user. The phase used is identified by setting along with the CT Ratio and number of primary turns applied to the interposing CT. In addition sometimes the primary or interposing CT can be installed in the reverse direction. In this case it is possible to reverse the sense in software using the sense setting.

For correct calculation of real and reactive components, the phases of VT and CT inputs must be configured correctly in the settings. The relay uses the phase configurations to make the appropriate adjustments to measured angles between the voltage and current, Figure 2-17.

Figure 2-17 Function diagram for current measurement and calculation



Correct selection of the voltage/current phase relationship is critical for operation of the relay. Comprehensive instrumentation is available to aid this including:

- Secondary values of all current measurements with magnitude and angle with respect to the voltage reference
- Primary values of all current measurements with magnitude and power factor

15.4.5 Principle of Bus Sections and Bus Groups

Applies to: all function levels and options

SuperTAPP SG uses the concept of bus section as the common basis for their communication. SuperTAPP SG can accommodate up to 15 separate bus sections, identified 1 to 15. When setting up a system a common bus section numbering scheme should be used across all relays at a substation. Other numbering (for instance winding number, and VT number) has the individual SuperTAPP SG as the scope of relevance, and this is not shared across other relays.

This is discussed in greater detail in section 15.6.

15.4.6 Use of Voltage Measurements

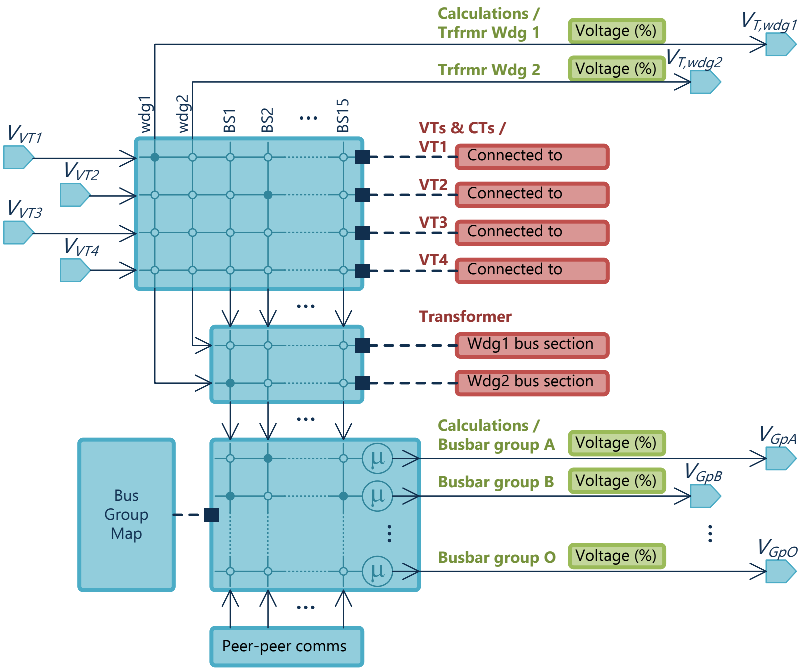
Applies to: all function levels and options

Voltage measurements are used principally for voltage control, but have other uses also:

- For power calculations (for instruments and SCADA),
- For angle references (for current angle and power factor), and
- For frequency measurement.

Because it is possible to measure up to 8 voltages, from up to 4 different primary VTs, it is important for the SuperTAPP SG to know which VT is connected where.

Figure 2-18 Function diagram for voltage measurement mapping to transformer winding and bus group



The ‘Connected to’ setting for each VT (Figure 2-18) has options of:

- ‘Transformer winding 1’ – the main option used for the transformer under control of this SuperTAPP SG,

- 'Transformer winding 2' – used to specify a second secondary winding on 3-winding (double secondary) transformers,
- 'Bus section 1' to 'Bus section 15' – for all other connections, using the relevant bus section number to indicate where in the substation the VT is connected.

Separate settings (in the 'Transformer' menu) tell the SuperTAPP SG which bus section the transformer windings are connected to.

Figure 2-19 gives an example, with the relevant settings for each SuperTAPP SG in Table 2-9.

Figure 2-19 Example of VT allocations

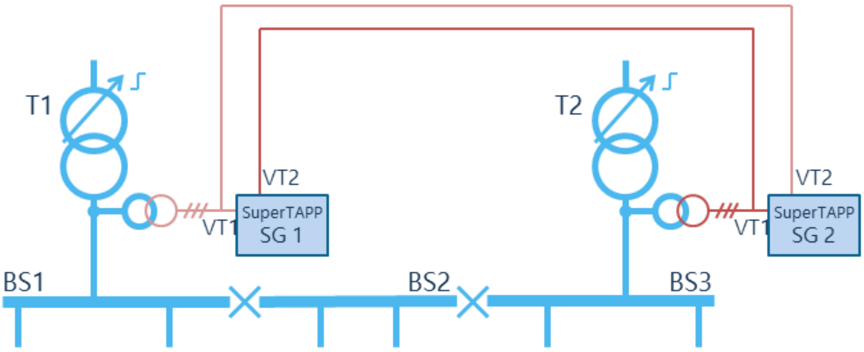


Table 2-9 Example settings for VT allocations

Setting	SuperTAPP SG 1	SuperTAPP SG 2
Winding 1 bus section	1	3
VT1 / Connected to	Transformer winding 1	Transformer winding 1
VT2 / Connected to	Bus section 3	Bus section 1

15.4.7 Use of Current Inputs

Applies to: all function levels and options

The current inputs can be assigned to different purposes. On a SuperTAPP SG with Basic level functionality the purpose of the single CT will be fixed as 'Transformer winding 1', however the Advanced level functionality, with multiple CTs, offers the ability to freely assign CTs to different measurements, see Table 2-23. The options available are as follows:

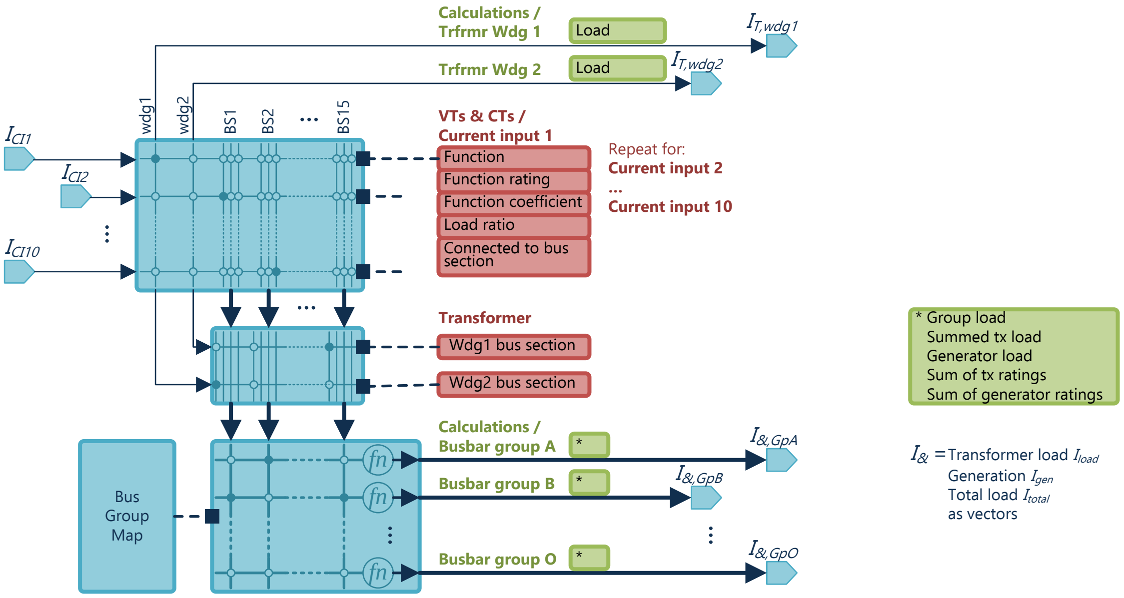
- Transformer winding – measurement of the load through the transformer
- Generator – measurement of the output of a generator connected to the busbar (with no load on the feeder), see section 15.5.1
- Generator feeder – measurement of the net load into a feeder which has a generator embedded within it. The SuperTAPP SG will extract the generation element from the net measured load, see section 15.5.1
- Included for load ratio, Corrected load and Excluded load – the use of these types are described more in section 16.4
- Monitor – the measured load on this feeder is used for instrument purposes only
- Interconnector – this feeder is a tie-line to a parallel substation. The SuperTAPP SG acts to maintain the power factor of this feeder at the same power factor as the substation load.

- Extra transformer – measurement of the load through another transformer, whose voltage control relay is not connected to this SuperTAPP SG's Inter-relay CAN bus. This enables accurate calculation of site and network circulating currents and load drop compensation by the SuperTAPP SGs which are connected to the Inter-relay CAN bus.

Referring to Figure 2-20 if the current input function is a transformer winding measurement it is set as the transformer load for that winding, and also added as transformer load for the relevant bus section.

If the current input is used for any other function it is allocated to a bus section but each function type is kept separate for further calculation. The SuperTAPP SG allocates each bus section's currents to the appropriate bus group and carries out further calculations according to the current input functions, indicated by the fn block in Figure 2-20.

Figure 2-20 Function diagram for current calculations and mapping to transformer winding and bus group



Advice on when and how to use and apply these options is given in the Application Guidance in section 16.4.

15.4.8 Power Calculations

Applies to: all function levels and options

SuperTAPP SG uses current for all its bias and adjustment calculations, with the exception of load response offset (see section 15.8.3) which uses power. For this purpose and also for indication, communication and data recording SuperTAPP SG calculates power associated with each transformer winding and any measured feeder. The calculations are performed on the following basis:

- If all three phase-phase voltages and all three phase currents are measured the power is calculated as: $\mathrm{S} = \frac{1}{3}[\mathrm{V_{AB}}.(\mathrm{I_A} - \mathrm{I_B}) + \mathrm{V_{BC}}.(\mathrm{I_B} - \mathrm{I_C}) + \mathrm{V_{CA}}.(\mathrm{I_C} - \mathrm{I_A})]$.
- If two phase-phase voltages and two phase currents are measured the power is calculated using the two wattmeter method: $\mathrm{S} = \mathrm{V_{AB}}.\mathrm{I_A} + \mathrm{V_{CB}}.\mathrm{I_C}$. If the wrong phase-phase voltages are measured the correct third voltage is calculated on the basis that $\mathrm{V_{AB}} + \mathrm{V_{BC}} + \mathrm{V_{CA}} = 0$.
- If all three phase voltages and all three phase currents are measured the power is calculated as: $\mathrm{S} = \mathrm{V_A}.\mathrm{I_A} + \mathrm{V_B}.\mathrm{I_B} + \mathrm{V_C}.\mathrm{I_C}$.
- If a single phase voltage and single phase current are measured, a single-phase system is assumed and the power is calculated as: $\mathrm{S} = \mathrm{V_{line}}.\mathrm{I}$
- Otherwise a three-phase system is assumed and the power is calculated as: $\mathrm{S} = \sqrt{3}.\mathrm{V_{line}}.\mathrm{I}$.

15.4.9 CT Trimming

Applies to: SuperTAPP Advanced and Ultimate SG function levels

Figure 2-13 and Figure 2-14 show the use of SuperTAPP SG with inputs of voltage from VTs, and inputs of current from CTs employing the use of interposing CTs. In most instances the SuperTAPP SG makes use of the ring-core CT Fundamentals type FP1030 delivered with the SuperTAPP SG relay. This CT has an inherent phase shift which changes with current magnitude and the SuperTAPP SG is calibrated assuming this.

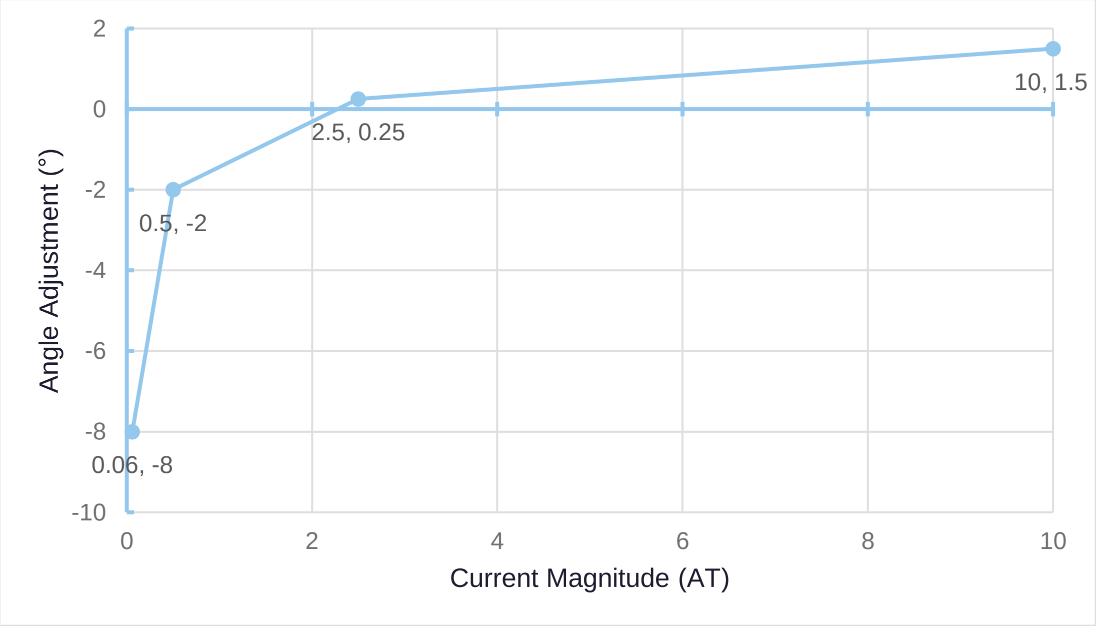
On occasion an alternative interposing CT may be required to be used and, to maintain accuracy, the measured current angle can be adjusted to accommodate different phase shifts using a 3-piece linear curve. The settings related to measurement trimming can be found in Table 2-23. The defaults for these settings are for the Fundamentals CT type FP1030 so in most cases no further adjustment will be required, although they can be trimmed on site if required.

The piece-wise curve is defined using three points, specified in terms of an angle adjustment at a particular Ampere-turn (AT) input to the interposing CT. The curve is linearly interpolated between the specified points. The impact of this phase correction is shown in Figure 2-21 for the default setting values.

The major impact on SuperTAPP SG of different CT characteristics is in angle measurement, but another factor in measurement accuracy is the constancy of CT transformation ratio across the measurement range. The SuperTAPP SG is tuned for the type FP1030 interposing CTs (with a transformation ratio of 1000:1 when one primary turn is used) and a feature to adjust it for other CTs is provided through settings of magnitude zero offset (I_{offset}) and magnitude gradient ($I_{k,grad}$), with effects as follows (referring to Figure 2-13 and Figure 2-14):

$$\text{C.I.}x_{corrected} = (1 + I_{k,grad}) \times \text{C.I.}x_{raw} + I_{offset}$$

Figure 2-21 Effect of CT angle correction (using default setting values)



15.4.10 Pseudo-VT

Applies to: SuperTAPP Ultimate SG function level

SuperTAPP SG is capable of calculating the voltage and current on the opposite side of the transformer to the VT and CT, taking into account the tap position and voltage drop due to load through the transformer.

If the configured controlled voltage location or busbar location is on one side of the transformer and the VT and CT are on the other side then the Pseudo-VT function is activated. The voltage or current on the opposite side of the transformer is calculated and used as if it was measured at that location. The mimic on the main data screen is updated to show the new locations, with the VT and CT drawn dotted to indicate that the values have been calculated using the Pseudo-VT function. The controlled side of the transformer can be changed as necessary using setting groups.

When using Pseudo-VT it is critical that the tap position is measured accurately. If a problem is detected with the tap position indicator, tapping is blocked and an alarm is raised.

15.5 Distributed or Embedded Generation

Distributed generation (DG) can affect regulation of voltage in the network in the following ways:

- DG can cause voltage rise in the network as a result of power flowing from the network into the substation (the reverse of the normal direction of flow).
- DG reduces the substation load, impacting on LDC.

Within the applications guidance section 16.4.2 describes this in greater detail. This section describes some functions which exist specifically to support applications with distributed generation.

15.5.1 Generator Current

Applies to: SuperTAPP Advanced and Ultimate SG function levels

Section 15.4.7 described two feeder measurement types, Generator and Generator Feeder, which contribute their measurements to a determination of generator current. Generator current is determined for each bus section and then added together for the bus group.

Generator current I_G is added to the transformer current I_T to determine the total load current I_{load} for the bus group, and it is this total load which is used for LDC bias in Figure 2-6.

15.5.2 Generator Bias

Applies to: SuperTAPP Advanced and Ultimate SG function levels

Generator bias is the generation equivalent to LDC with two important differences:

- It is applied to the total calculated generator current, and
- It acts negatively on the target voltage, i.e. as the generator current increases the effective target voltage is reduced.

Generator bias is used to counteract the effects of voltage rise to allow more generation than would otherwise be possible. The generator current for the bus group as calculated above is divided by the total of the generator ratings for the bus group and multiplied by the Generator bias setting to reach an overall Generator Bias.

It is important that an assessment of each network is carried out in order that voltage regulation on non-generator feeders is not adversely affected.

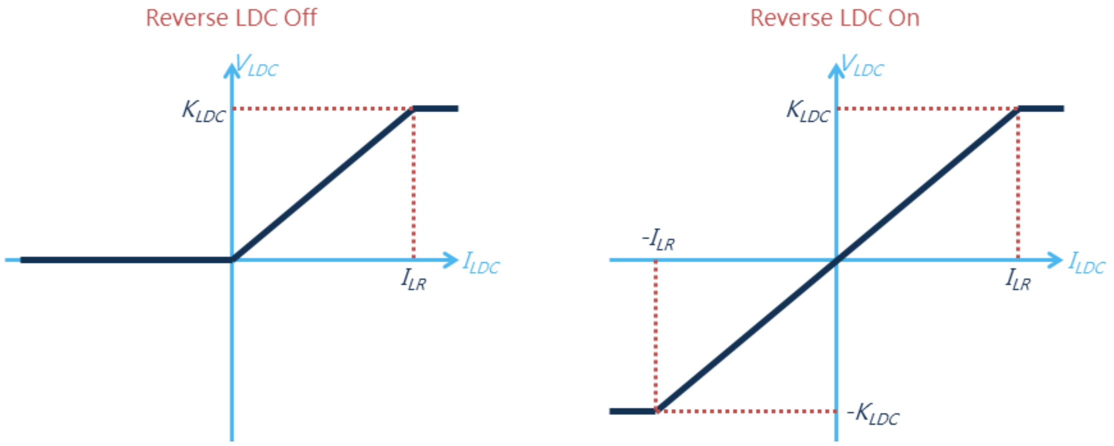
15.5.3 Reverse LDC

Applies to: SuperTAPP Basic SG function level only

Figure 2-6 shows the profile of LDC boost as the current rises from zero. It is capped at the rating for the winding and is zero for reverse current flow. However the setting Reverse LDC (Table 2-20) allows LDC to be applied equivalently in the reverse direction (Figure 2-22).

This allows for the situation where, if a substation is exporting power into its HV network, it might be generally required to depress the substation voltage to address voltage rise issues, even if no feeder currents are being measured. Reverse LDC can be considered a cruder form of generator bias which can be applied without additional feeder measurements.

Figure 2-22 LDC boost profiles with Reverse LDC off and on

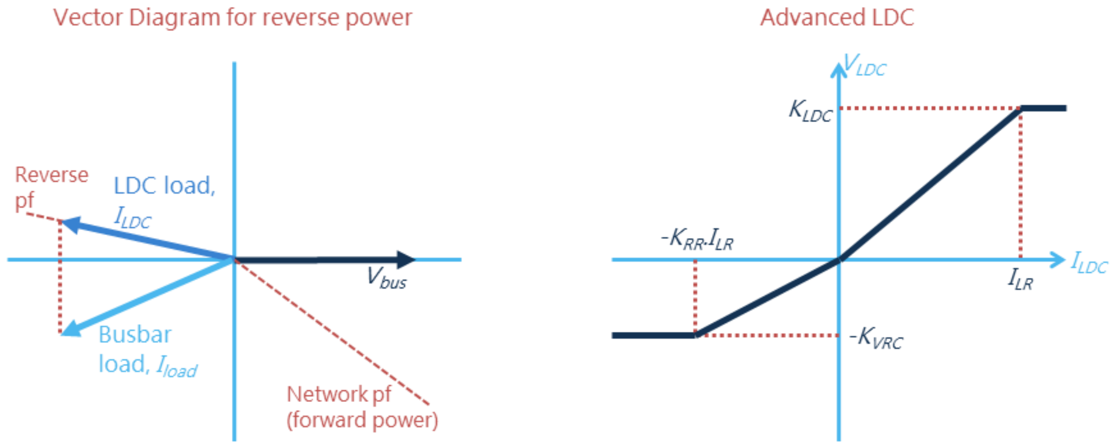


15.5.4 Advanced LDC

Applies to: SuperTAPP Advanced and Ultimate SG function levels

Reverse LDC assumes that the bias in the reverse direction is the same as that in the forward direction. Advanced LDC allows an alternative bias characteristic to be applied, since it is likely that the buck required for current in the reverse direction is somewhat less than the boost for forward current.

Figure 2-23 LDC boost profiles with Reverse LDC off and on



15.6 Busbar Configurations

Applies to: SuperTAPP Basic, Advanced and Ultimate SG function levels

This section describes advanced busbar configuration handling. SuperTAPP SG is also capable of using setting groups to handle simple alternative busbar configurations, and the application of this is described in section 16.3.5.

SuperTAPP SG is capable of simple and effective voltage control, assuming that the busbar is operated closed at all times. Even if the bus section is open, in most cases voltage regulation remains satisfactory. However, there are occasions where recognition and handling of different bus configurations is necessary to maintain adequate regulation, particularly if the bus arrangements are complex, if the bus sections have quite different loadings, or with distributed generation.

SuperTAPP SG has a busbar configuration module capable of handling:

- 2 secondary windings per transformer, with a circuit breaker for each;
- 15 individual bus sections at each substation (numbered 1 to 15) which are arranged in upto 15 individual bus groups (identified A to O); and
- 8 bus section circuit breakers monitored by each SuperTAPP SG, with each bus section circuit breaker connecting any two bus sections.

The result of this is that substation bus arrangements of extreme complexity can be handled, with SuperTAPP SG understanding which bus sections are grouped together and which transformer windings are connected to which bus section group.

The allocation of bus sections to groups can be carried out through one of three methods:

- Manually, through the use of settings to allocate bus sections to groups (Figure 2-24).
- Automatically, by the SuperTAPP SG monitoring circuit breaker auxiliary contacts to allocate bus sections to bus groups (Figure 2-25). All SuperTAPP SGs at a substation share their information on which bus sections are joined by the circuit breakers which they monitor. Therefore, it is only necessary to monitor each circuit breaker by one SuperTAPP SG and each SuperTAPP SG then independently determines the bus groupings.
- Automatically, by the SuperTAPP SG monitoring changes in transformer voltage and current during tap changes to allocate bus sections to bus groups (Advanced and Ultimate function levels only). When a tap change occurs the SuperTAPP SG shares its observations of the change in transformer voltage and current with all the other SuperTAPP SGs at the substation. The other SuperTAPP SGs compare the shared observations with their own to determine whether they are in parallel with the tapping transformer and therefore in the same bus group. When using this method only one transformer may have 2 secondary windings.

If the allocation is done automatically, the bus group letter used for each grouping is determined by SuperTAPP SG and will have no bearing on voltage control settings which are set for the transformer winding. The group letter chosen is that corresponding to the lowest numbered bus section in each group. So the group containing sections 2, 3 and 5 is allocated the letter B and the group for sections 4, 6 and 7 is allocated the letter D.

Whichever method is used, the resulting bus group map is used in Figure 2-18 and Figure 2-20 to correctly aggregate the data from the correct bus sections to form the bus group data. It is important to ensure that consistent bus group settings are applied to all the SuperTAPP SGs at a substation.

Figure 2-24 Function diagram for manual allocation of bus sections to bus groups by setting

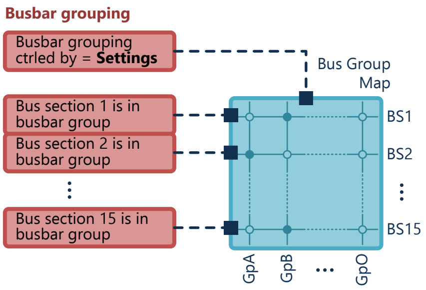
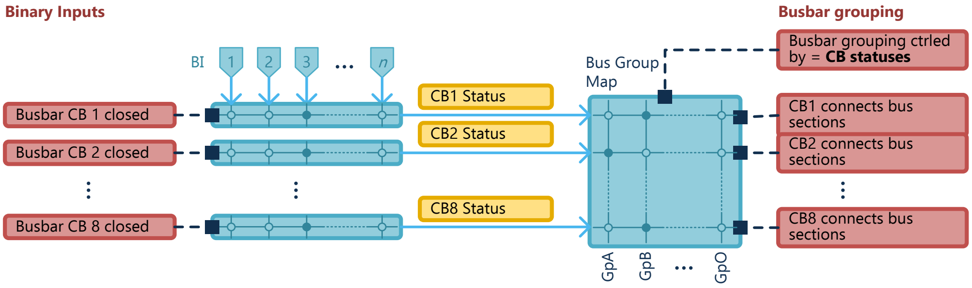


Figure 2-25 Function diagram for automatic allocation of bus groupings from circuit breakers

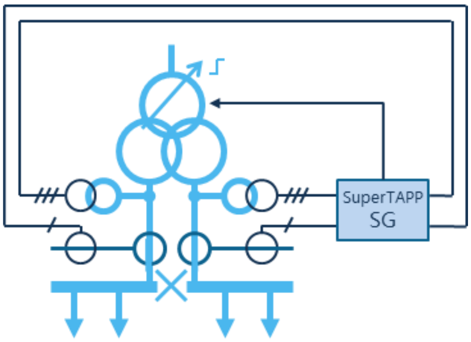


15.7 AVC for 3-Winding Transformers (Double Secondary Winding)

Applies to: SuperTAPP Advanced and Ultimate SG function levels

Since the tap changer is normally located on the HV side of the transformer, regulation of transformers with two secondary windings requires the calculation of an optimum taking into account the voltage and load on each winding. Two VT inputs and two CT inputs are therefore required for control of double-secondary winding transformers, as shown in Figure 2-26.

Figure 2-26 Double secondary winding transformer



In order to implement voltage averaging, each VT and current input must be configured as being connected to the correct winding in the settings, see Table 2-23. The biases, targets and deviations for each winding are calculated separately. The deviations are then averaged and compared against the bandwidth.

Where the measured voltage on a VT input falls below 80% nominal voltage (for example in the event of a fuse failure), the relay will automatically revert to using the remaining VT for voltage control. Averaging will resume once the other VT input recovers back to above the 80% level.

15.8 Adjustments to Target Voltage

Applies to: all function levels and options

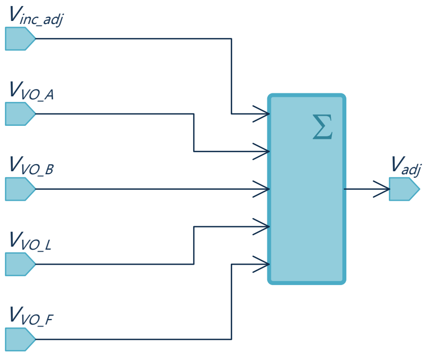
Target adjustments within SuperTAPP SG are made relative to the basic target voltage and correspond to the quantity V_{adj} in Figure 2-3. Adjustments to the voltage target can be positive (increases to the basic target) or negative (decreases to the basic target).

Upto five different adjustments can be present in the SuperTAPP SG, depending on the function level of the relay:

- General voltage offset A – applied manually, usually as a command from SCADA
- General voltage offset B – applied manually, usually as a command from SCADA
- Frequency response – a voltage offset applied automatically in response to system frequency, referred to as voltage offset F
- Load response – a voltage offset applied automatically in response to substation load, referred to as voltage offset L
- Incremental voltage adjustments – applied manually, usually as a command from SCADA

Each of these adjustments is added together to form an overall adjustment to the target voltage, Figure 2-27.

Figure 2-27 Function diagram for voltage adjustments



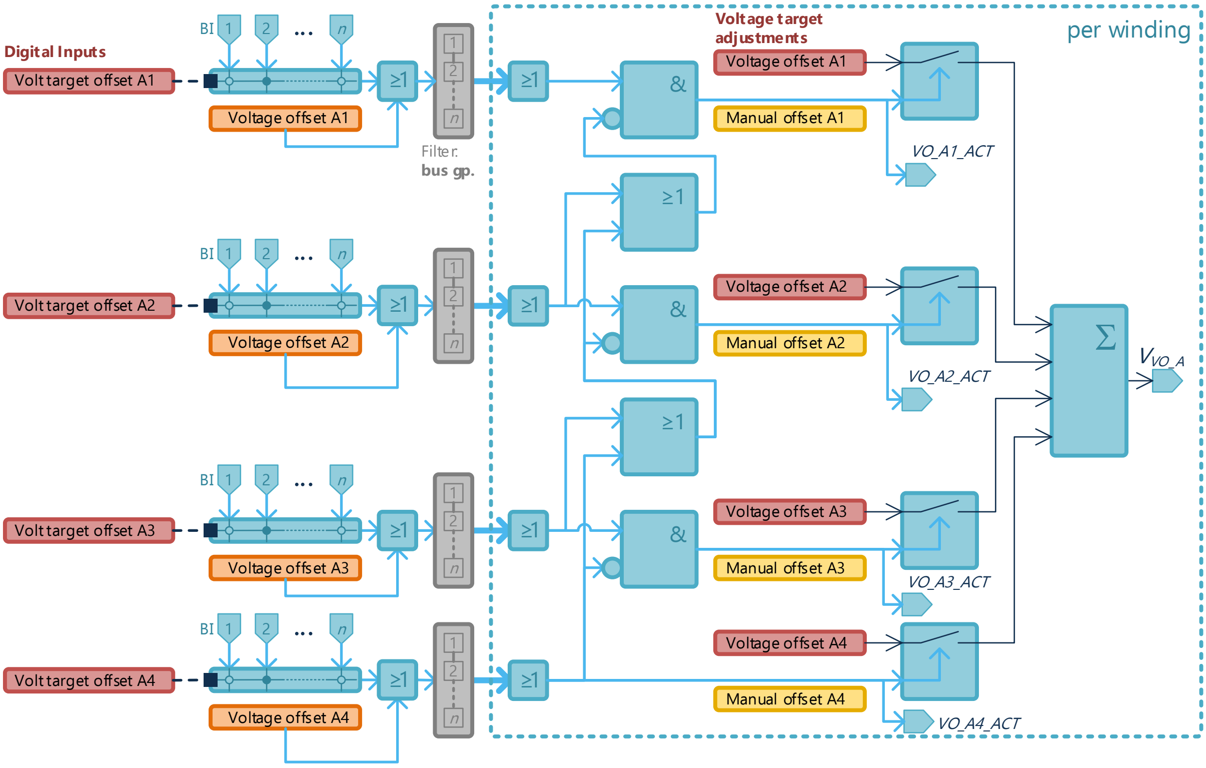
15.8.1 General Voltage Offset A

Applies to: all function levels and options

General voltage offset A provides four different offset levels (A1, A2, A3 and A4) of which only one is active at a time. An offset level can be activated through digital inputs or through SCADA communications. If the activation is through SCADA communications it remains active until it is subsequently deactivated (although not through a restart). If the activation is through digital inputs it remains active until the input is removed.

Only one level may be applied at a time as general voltage offset A. If multiple levels are selected the priority order is A4, then A3, A2 and A1; activation of lower priority levels will be ignored until higher priority levels have been deactivated. Each SuperTAPP SG ORs together the activated general voltage offset A levels of all the relays in the bus group, before carrying out the priority logic, in order to ensure that each applies the same offsets.

Figure 2-28 Function diagram for general voltage offset A



15.8.2 General Voltage Offset B

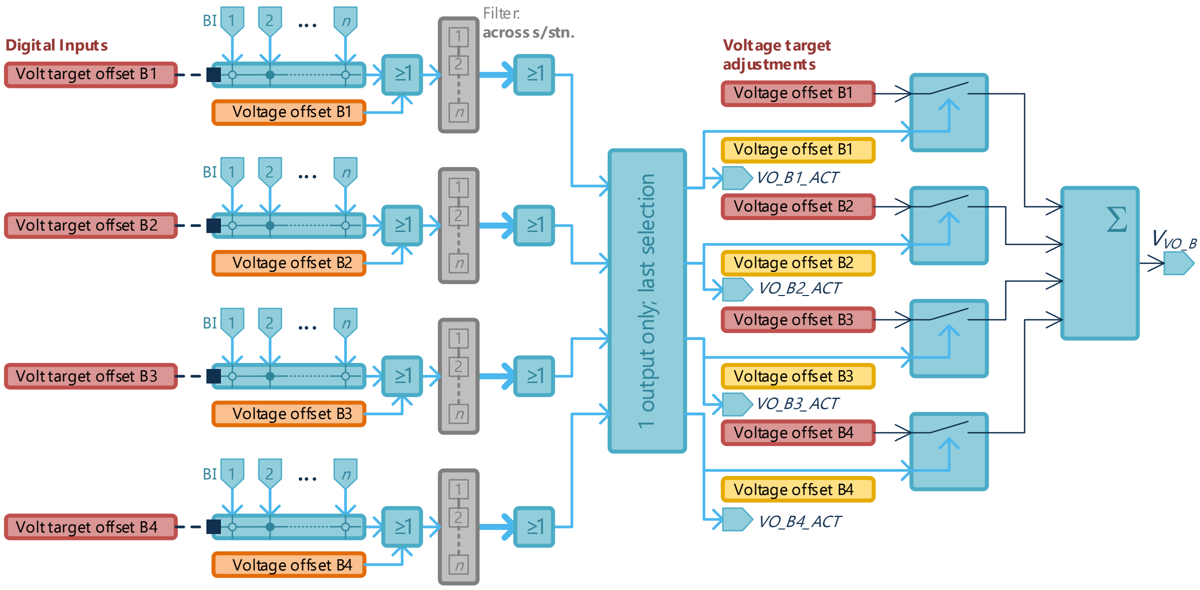
Applies to: SuperTAPP Advanced and Ultimate SG function levels

General voltage offset B provides eight different offset levels (B1 – B8) of which only one is active at a time. An offset level can be activated through digital inputs or through SCADA communications. If the activation is through SCADA communications it remains active until it is subsequently deactivated (although not through a restart) or until the Offset group B reset time has expired. If the activation is through digital inputs it remains active until the input is removed or until the Offset group B reset time has expired.

Only one level may be applied at a time as general voltage offset B. Offset group B, in contrast to offset group A, uses the last instruction as the priority, hence if a digital input corresponding to B3 is energised, and while it is energised an input corresponding to B2 is energised, the active level will switch from B3 to B2. The active offset will be removed when B2 is de-energised, even if B3 remains energised. Each SuperTAPP SG ORs together the activated general voltage offset B levels of all the relays at the substation, before carrying out the priority logic, in order to ensure that each applies the same offsets.

When a group B offset is applied the normal Initial tap time delay is bypassed and the Fast tap time delay setting is instead used to determine the time delay. This allows a group B offset to take effect more quickly.

Figure 2-29 Function diagram for general voltage offset B



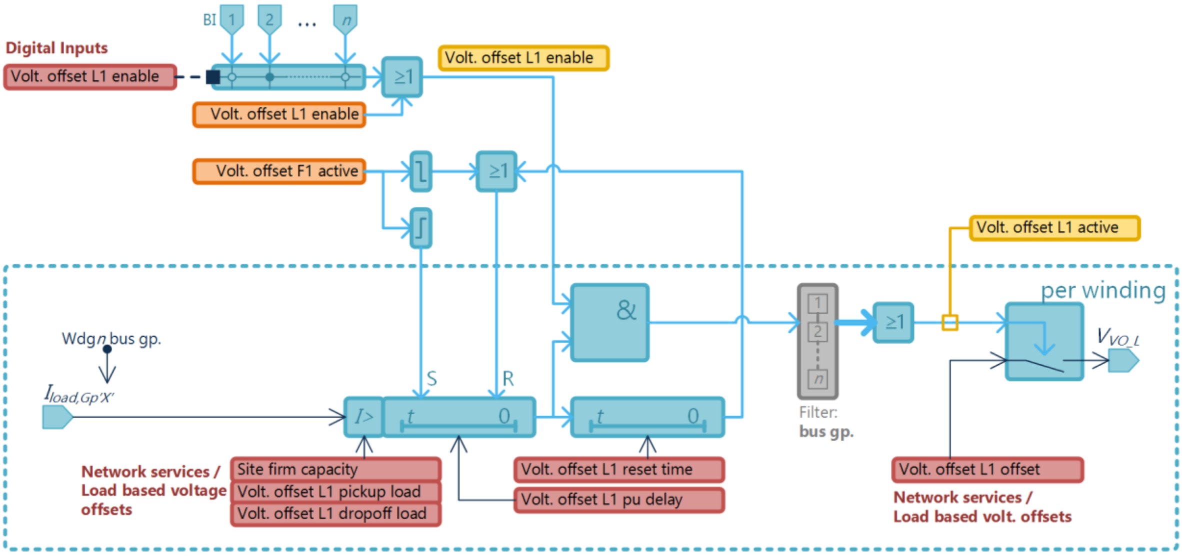
15.8.3 Load Response Offset

Applies to: SuperTAPP Ultimate SG function level only

There is one load response element which provides a definite time lag (DTL) characteristic, with settable pick-up and drop-off levels, a settable pick-up delay and instantaneous drop-off. The pick-up and drop-off levels are for the bus group and are evaluated separately for each winding. If the response is activated (i.e. on expiry of the pick-up delay) this is communicated to the other relays in the bus group which will also act on it.

When a load response is activated the settable load response offset (L1) is applied to the voltage adjustment.

Figure 2-30 Function diagram for load response



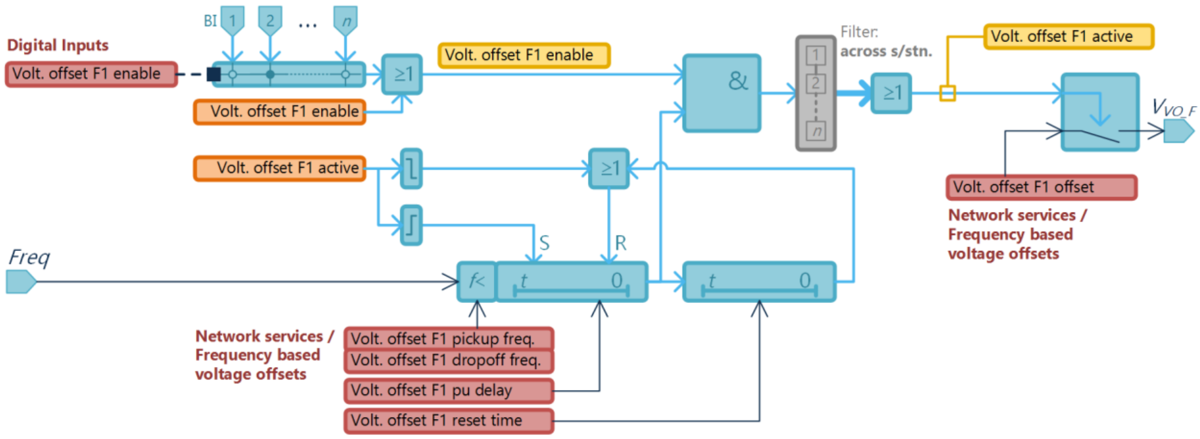
15.8.4 Frequency Response Offset

Applies to: SuperTAPP Ultimate SG function level only

There is one frequency response element which provides a definite time lag (DTL) characteristic, with settable pick-up and drop-off levels, a settable pick-up delay and instantaneous drop-off. If the response is activated (i.e. on expiry of the pick-up delay) this is communicated to the other relays in the bus group which will also act on it.

When a frequency response is activated the settable frequency response offset (F1) is applied to the voltage adjustment.

Figure 2-31 Function diagram for frequency response



15.8.5 Response Factors

In order that the operator can determine how much response should be called for the SuperTAPP SG continuously calculates the effect of tap changes on real and reactive load. Two exponents are calculated, which are unique for each bus grouping and will be re-initialised after a change to the bus grouping.

The factors are displayed as calculated values for the bus group, and made available through SCADA communications as

- Real power voltage exponent K_P, and
- Reactive power voltage exponent K_Q.

15.8.6 Common Busbar Group Target Adjustments

It is important that all SuperTAPP SG relays which are controlling transformers connected to the same busbar group apply the same adjustment, otherwise unintended circulating current may result, along with poor voltage control performance. Since SuperTAPP SG ensures that all relays at a substation apply the same voltage offset levels, it is important when configuring the relays that the same offsets are applied across all relays at the substation.

15.9 Functions Acting on Multiple Transformers

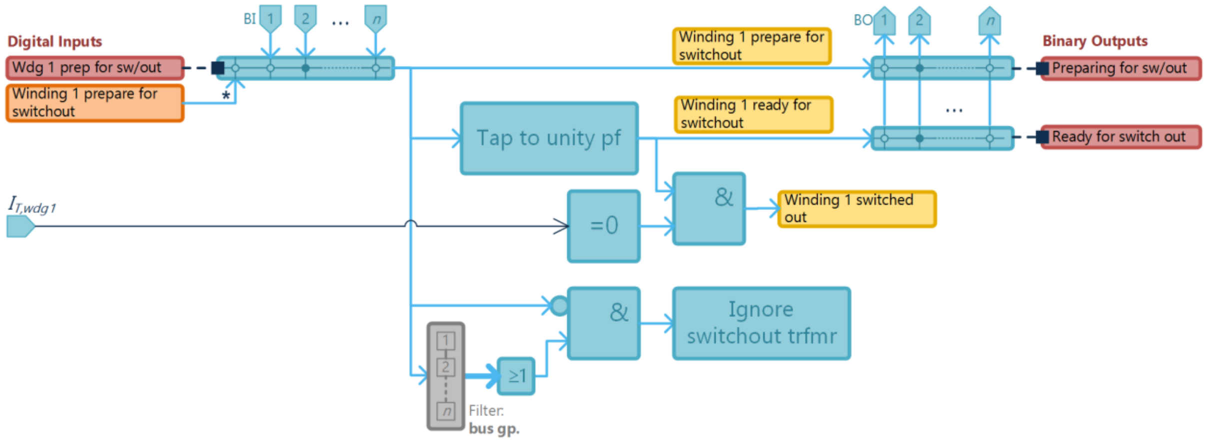
These functions require at least two transformers connected to a bus group in order to operate.

15.9.1 Prepare for Switchout

Applies to: all function levels and options

If two or more transformers are feeding a common busbar and one transformer is switched out while on load, the busbar will experience a step change in voltage due to the step increase in load, and hence voltage drop of the transformer(s) that remain in service. To avoid this SuperTAPP SG provides a 'Prepare for Switchout' function which, when activated, will tap the transformer to unity power factor and cause the other transformer(s) to provide all the reactive power. This will minimise the voltage drop when this transformer is switched out of service.

Figure 2-32 Function diagram for prepare for switchout



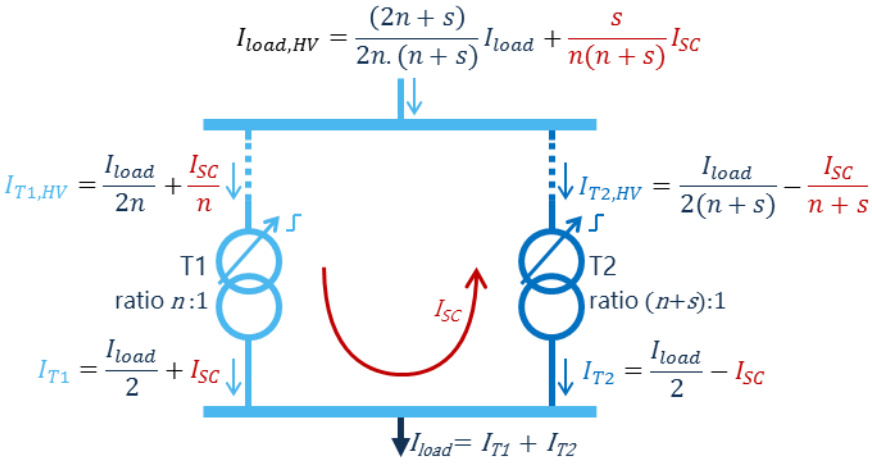
15.9.2 Tap Stagger

Applies to: SuperTAPP Ultimate SG function level only

Normally voltage control attempts to maintain parallel transformers on equivalent tap positions to minimise circulating current between transformers. However, if transformers are deliberately driven so that circulating current flows there is a side effect of the mismatch of transformer ratios (due to the different tap positions) that results in the substation absorbing additional VArs from the network of the HV winding. This can be used as an additional network control function by the network operator.

Figure 2-33 demonstrates the effect, where the ratio of the two transformers are $n{:}1$ and $(n+s){:}1$, where s is the amount of the stagger. The total load I_{load} seen on the transformers' LV windings is reflected through to the HV windings, with the average of the two ratios. There is also an additional term, reflecting a proportion of the circulating current I_{SC}. Since circulating current is almost entirely reactive this results in an additional reactive load on the network which is a function of the transformers and the tap difference, and immune to load current.

Figure 2-33 Effect of applying tap stagger to parallel transformers



Four different tap stagger levels (S1, S2, S3 and S4) are provided of which only one can be active at a time. A tap stagger level can be activated through digital inputs or through SCADA communications. If the activation is through SCADA communications it remains active until it is subsequently deactivated (although not through a restart). If the activation is through digital inputs it remains active until the input is removed.

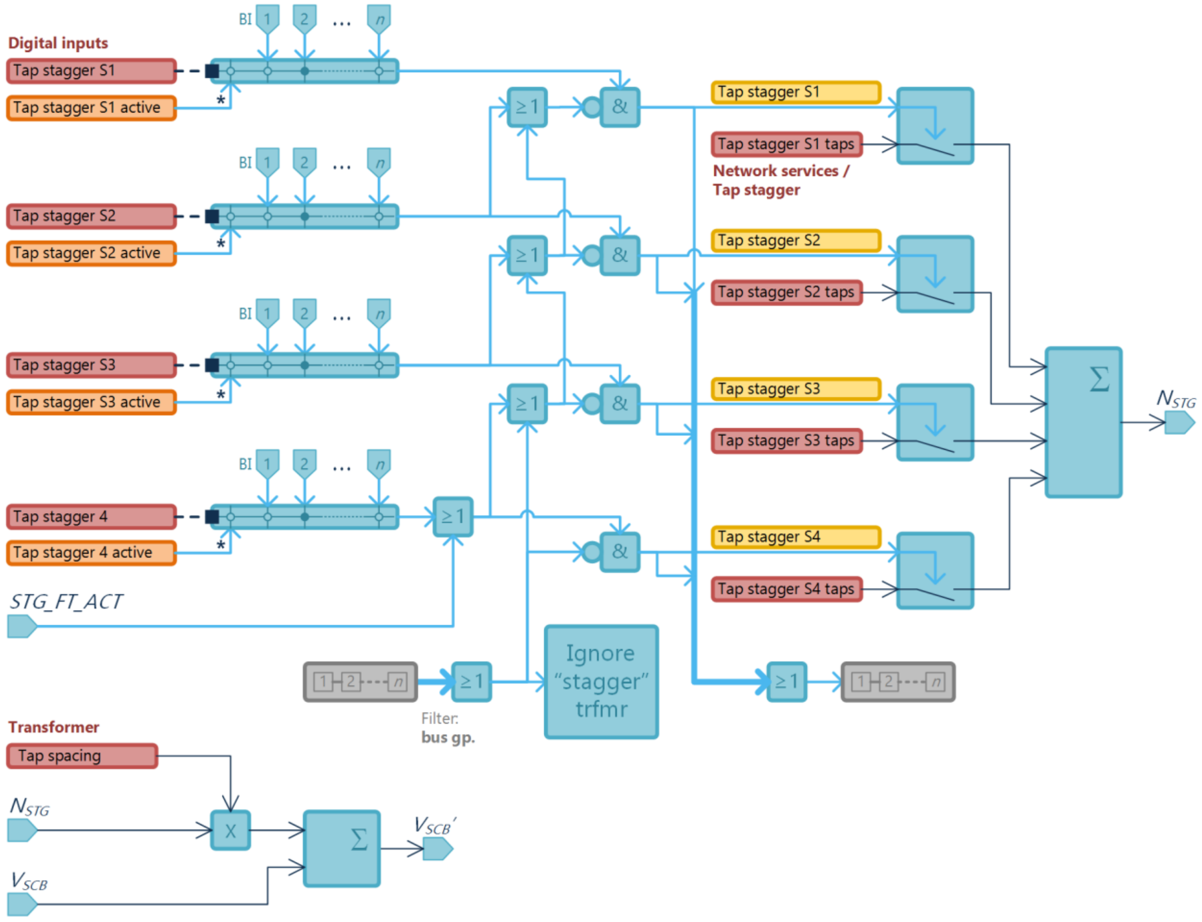
Only one tap stagger level may be applied at a time. If multiple levels are selected the priority order is S4, then S3, S2 and S1; activation of lower priority levels will be ignored until higher priority levels have been deactivated. SuperTAPP SG requires multiple transformers in parallel to operate, and if not tap stagger will be unavailable. The SuperTAPP SG requested to provide the stagger will communicate with the other SuperTAPP SGs in order to deliver the function and maintain voltage regulation.

The setpoint for the stagger level is in terms of no. of taps, and the SuperTAPP SG converts this into equivalent offset which it adds to the site circulating bias used by the voltage control algorithm.

If necessary (e.g. the end of the tapping range is reached) the requested tap stagger will be delivered at the expense of maintaining the dead band, however the upper and lower alarm levels will never be breached.

Tap stagger S4, the highest priority level, has an additional activation input from the fast frequency response function, and this is described in section 15.9.3.

Figure 2-34 Function diagram for tap stagger



15.9.3 Frequency Tripping

Applies to: SuperTAPP Ultimate SG function level only

Section 15.8.4 describes a function which aids system operation by applying voltage target offsets in the event of low system frequency. The frequency tripping function takes this further by, in the event of low system frequency, tripping one transformer where parallel transformers feed a busbar. This has the effect of doubling the transformer voltage drop and immediately imposing a step voltage reduction on the busbar, which in turn causes a step reduction in load.

A diagram of the function is shown in Figure 2-35 and has two main parts. The upper part of the diagram shows the "pre-activation" functionality which consists of a number of checks to ensure it would be appropriate to trip the circuit breaker. These include:

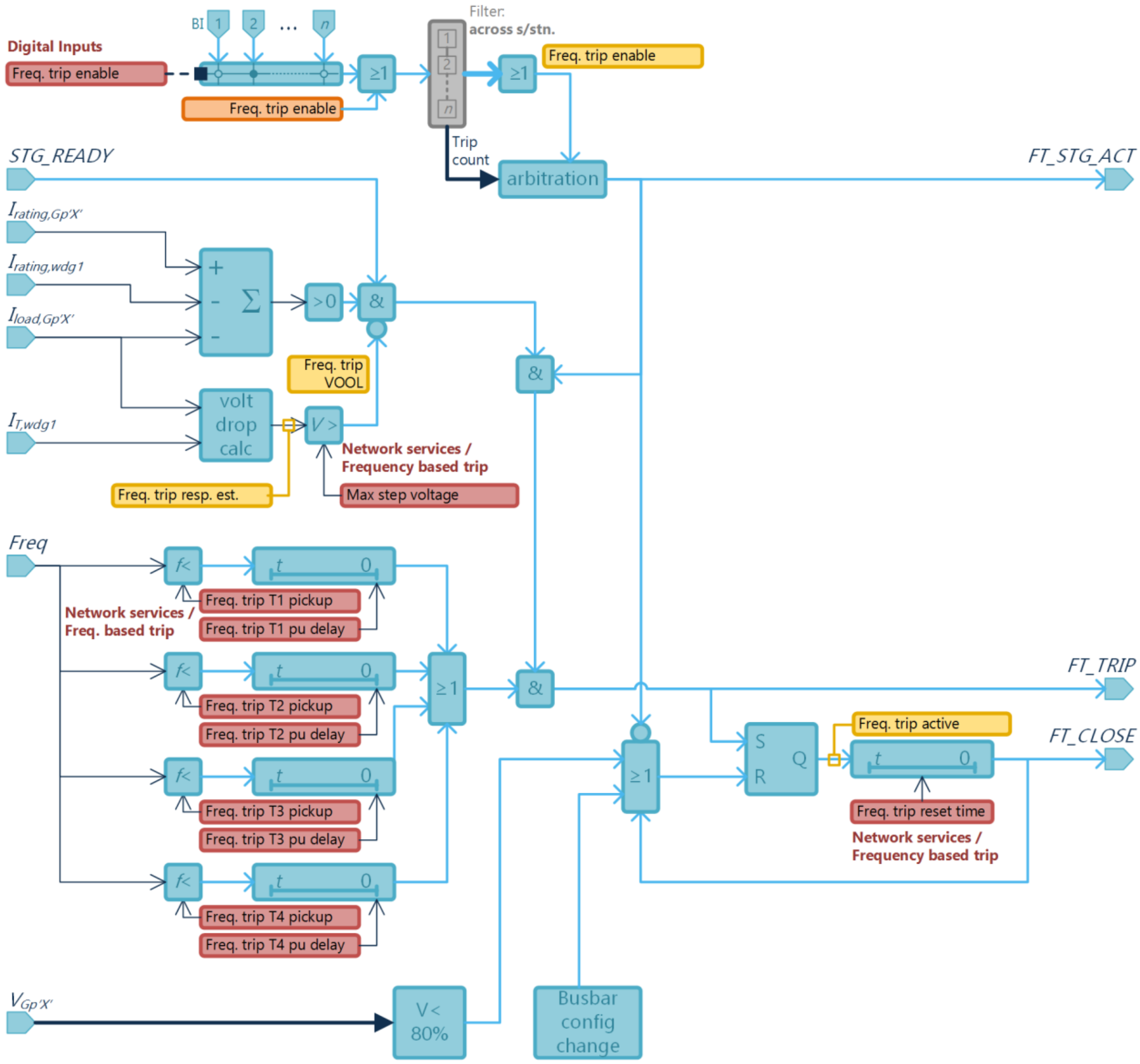
- That there is at least one other on-load transformer connected to the busbar(s),
- That the other transformer(s) can support the current load, and
- That the resultant voltage drop would not cause an excessive step voltage change.

When the Function is enabled on a SuperTAPP SG it is shared with all other SuperTAPP SG at the substation and they together select a transformer which will be the "trip" transformer based on the number of trips previously issued (the lowest is selected). The trip transformer will then activate tap stagger element S4 and ensure that it staggers in the upward direction, in order to maximise the voltage drop when it trips.

When the frequency is beneath the pickup setting level for the pickup delay the function is activated and, if the above checks are positive a trip is issued. After a settable time period a close command is then issued.

During the trip period the other SuperTAPP SGs refrain from operating in order that the voltage offset is not reversed.

Figure 2-35 Function diagram for frequency tripping



15.9.4 Extended Voltage Range

Applies to: SuperTAPP Ultimate SG function level only

Extended voltage range attempts to provide additional voltage reduction during network conditions that result in no further tap range available on an individual tap changer or at the substation. In order to obtain extra voltage range from the transformer and tap changers within the substation some non-standard running arrangements are adopted via the extended voltage range automated control feature. These running arrangements in order of priority are:

- Ignore pre-set voltage limits
- Application of tap stagger as the result of ignoring circulating current reduction
- Opening of an LV circuit breaker, taking a transformer off load, to increase the volt drop across the remaining transformer(s) at the substation

In response to an adjustment in target voltage the conditions under which extended voltage range is required are summarised but not limited to high source voltage, differing source voltages and dissimilar transformers or tap ranges. When a voltage adjustment is activated the first action taken is to adhere, adjust or ignore the pre-set voltage limits depending on the voltage offset setting as described.

The voltage offsets that the extend voltage range functionality applies to are: General voltage offsets Group A, General voltage offsets Group B and the frequency response offsets Group F.

15.9.4.1 Voltage limits setting

The alarm limits setting is designed to prevent the busbar voltage going out of the set limits. However, some functions are required to reduce the voltage where no limit on voltage reduction applies. The voltage limits setting for "Alarm limits for A offsets", "Alarm limits for B offsets", "Alarm limits for L offset" and "Alarm limits for F offsets" settings determine the action taken on the alarm limits for the Group A, Group B, Load Response offset and Frequency response offset respectively. The setting can be configured to:

1. **Use**. Configured alarm limits will be obeyed for these offsets, no further reduction is allowed if the offset it activated.
2. **Adjust**. The configured alarm limit will be adjusted to "Voltage low limit" minus the activated offset setting value.
3. **Ignore**. No low voltage alarm limit will be applied onto the busbar allowing an unconstrained target voltage reduction.

For example, if the voltage low limit was configured to 95% and the target voltage prior to activating an offset was 96%, an offset of -3% with the "Alarm limits" setting configured to "Use" would result in a 1% voltage reduction resulting in 95%. Configured for "Adjust" the alarm limit will be 92% resulting in a reduction to 93% after applying the offset. A further applied offset configured for "Use" would only be able to apply a further 1% voltage reduction. Set to "Ignore" the resulting reduction would still be 93% but any subsequent voltage offset reduction activation would allow an unlimited reduction in voltage.

15.9.4.2 Application of tap stagger, ignore circulating current

Following the application of the alarm limits setting and a further tap to reduce voltage is required however the transformer tap changer has reached the physical limit of its tap range any other transformers in parallel are permitted to ignore the circulating current in order to reach the target voltage, provided the "Bottom tap tripping" setting is set to "Enabled". This is prioritising lowering the voltage over minimising circulating current. There is no risk of tapping apart because the other relays have indicated that they are unable to tap and are still attempting to control site circulating current as usual.

When the voltage target is increased the voltage controller will tap the transformers back in line with minimising circulating current.

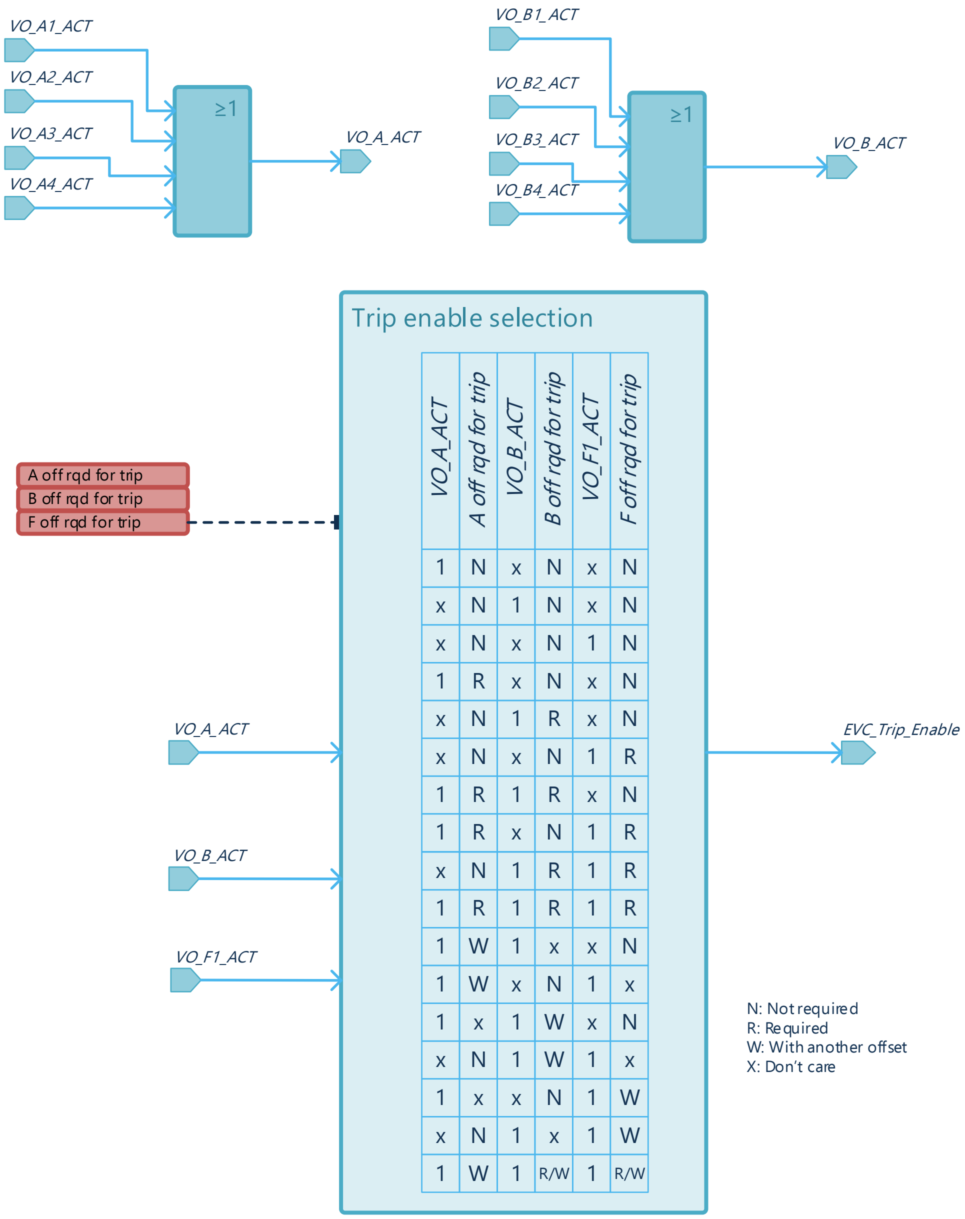
15.9.4.3 Opening an LV Circuit Breaker

When all parallel relays have indicated that they have reached the physical tap changer limits and a further tap to reduce the busbar voltage is required, then opening of a transformer LV circuit breaker is considered, provided the "Bottom tap tripping" setting is set to "Enabled".

In order for an LV circuit breaker to be opened the bottom tap tripping setting and the offset required setting need to be configured. The offset required setting determines if a function or multiple functions need to activate before an open command to the LV circuit breaker is issued. This is configured by the "offset required for trip" setting.

An offset group that is set to "Required" must be activated for the open command to be considered. If multiple offset groups are set to "Required" they all must be active before an open command is considered. Where an offset group is set to "With another offset" that group must be active with another offset group that is active, however, all required offsets must be active to fulfil the "Required" criteria. See Figure 2-36 for a comprehensive list of trip enable conditions.

Figure 2-36 Extended voltage control trip enable function diagram



Trip enable selection

VO_A_ACT	A off rqd for trip	VO_B_ACT	B off rqd for trip	VO_F1_ACT	F off rqd for trip
1	N	x	N	x	N
x	N	1	N	x	N
x	N	x	N	1	N
1	R	x	N	x	N
x	N	1	R	x	N
x	N	x	N	1	R
1	R	1	R	x	N
1	R	x	N	1	R
x	N	1	R	1	R
1	R	1	R	1	R
1	W	1	x	x	N
1	W	x	N	1	x
1	x	1	W	x	N
x	N	1	W	1	x
1	x	x	N	1	W
x	N	1	x	1	W
1	W	1	R/W	1	R/W

N: Not required
R: Required
W: With another offset
X: Don't care

The decision on which transformer LV CB to open will be based on network conditions. The transformer that will result in the greatest drop in voltage, when all tap changers that are at bottom tap, will be opened, subject to the following conditions:

- The trip block input "Block EVR CB trip" must not be energised on the chosen transformer.
- The predicted reduction in voltage should be greater than the minimum step size setting value.
- The maximum trip step size and voltage limits checks should be done in accordance with the currently activated voltage offset function settings (do the same voltage checks for tripping as would be done for tapping, plus trip step size).
- "Bottom tap tripping" setting is set to "Enabled".

- Parallel transformers would not be overloaded.

When a transformer has been chosen following the above criteria it will be tripped after the "Bottom tap trip timeout" setting if set, if not immediately.

If a voltage offset group has been set as "required" for tripping and the "Bottom tap trip timeout" is set, then the CB will be tripped only if the conditions are met within the set timeout period after the required voltage offset has been activated. If the conditions are not satisfied within this period then tripping will be disabled until the offset is next reactivated.

15.9.4.4 Reclosing an LV Circuit Breaker

When extended voltage range has commanded an open of on LV circuit there are conditions under which the extended voltage range feature will reclose the transformer LV circuit breaker. Providing the "Block EVR CB reclose" input is logically off and that there is winding voltage on the selected off load transformer a close command will be issued to the selected transformer LV CB.

The conditions under which the reclose command is given are as follows:

- The required voltage offsets are no longer active
- If the load on any parallel transformer exceeds its rating or a thermal alarm is triggered
- The voltage reduces such that the transformer open circuit voltage of the selected transformer is in band and that the resulting tap position is not at the limit of travel.

The conditions under which the reclose function ceases to operate after the open command has been issued are:

- Topology change of the substation, for example another on load transformer is tripped or connected in parallel.
- The selected transformer CB is closed via another function outside of the voltage controller, for example via SCADA.
- No open circuit voltage present at the time a reclose is issued preventing back feed of the transformer.

Once a reclose has been performed and the initial conditions that caused the trip have reset the extended voltage range feature continues to revaluate whether a new trip operation is required.

15.10 Transformer temperature monitoring and control

15.10.1 Transformer oil and winding temperature monitoring

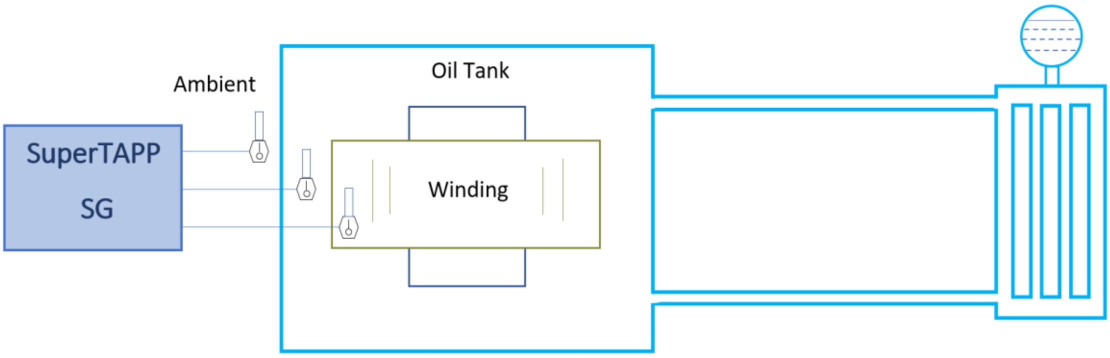
Applies to: relays with optional module type K or L

Measurement of temperature is made using temperature sensors which produce analogue signals that can be fed to the relay as displayed in Figure 2-37. These signals will be connected directly to the inputs of the relay. In order to do this at least one module type K or L needs to be fitted in the relay. The analogue input types used for temperature measurement are mA input and RTD input.

These inputs are defined as:

- Ambient temperature
- Transformer oil temperature
- Transformer winding temperature
- Tap changer temperature

Figure 2-37 Simplified transformer oil and winding temperature measurement



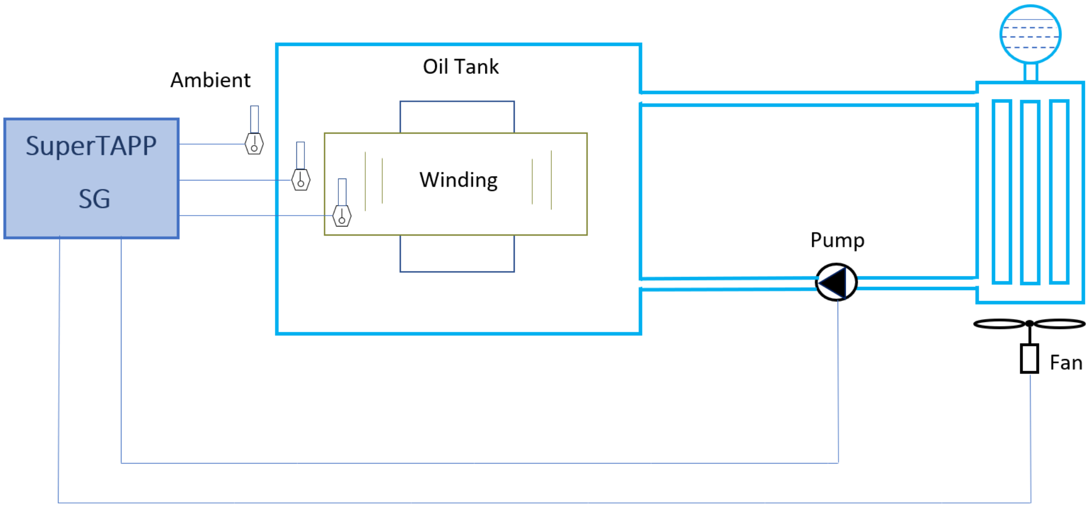
The winding "hot-spot" temperature can either be measured or be calculated from the oil temperature and measured load current in accordance with IEC 60076-7:2018.

15.10.2 Oil pump and radiator fan monitoring

Applies to: Advanced and Ultimate relays with optional module type K or L

SuperTAPP SG can monitor the state of energisation of oil pumps and fans taking inputs from the equipment contactor auxiliary contacts or scheme relays into the digital inputs. A simplified version of transformer thermal management has been shown in Figure 2-38.The digital inputs must be allocated for oil pump and radiator fan monitoring in the relay settings by the user. An alarm will be raised if the SuperTAPP SG requests a pump or fan to run but none is sensed as running.

Figure 2-38 Simplified transformer thermal management



15.10.3 Transformer Top Oil Temperature Estimation

Applies to: Advanced and Ultimate relays with optional module type K or L

SuperTAPP SG uses the IEC 60076-7 model, with ambient temperature, current and state of pumps/fans to estimate the temperature of the oil in the transformer. The function is designed in a way to switch between ONAN, ONAF and OF models as the state of pumps and fans changes, as shown in Figure 2-39. The transformer parameters for each model are customizable to user needs, however predefined transformer parameters according to Table 4 of IEC 60076-7:2018 are available in the relay settings as default values.

Figure 2-39 Oil pump and radiator fan state matrix

x y	k_{11}	k_{21}	k_{22}	τ_o	τ_w	$\Delta\theta or$	$\Delta\theta hr$
ONAN	…	…	…	…	…	…	…
ONAF	…	…	…	…	…	…	…
OF	…	…	…	…	…	…	…

15.10.4 Hotspot Temperature Estimation

Applies to: Advance and Ultimate relays with optional module type K or L

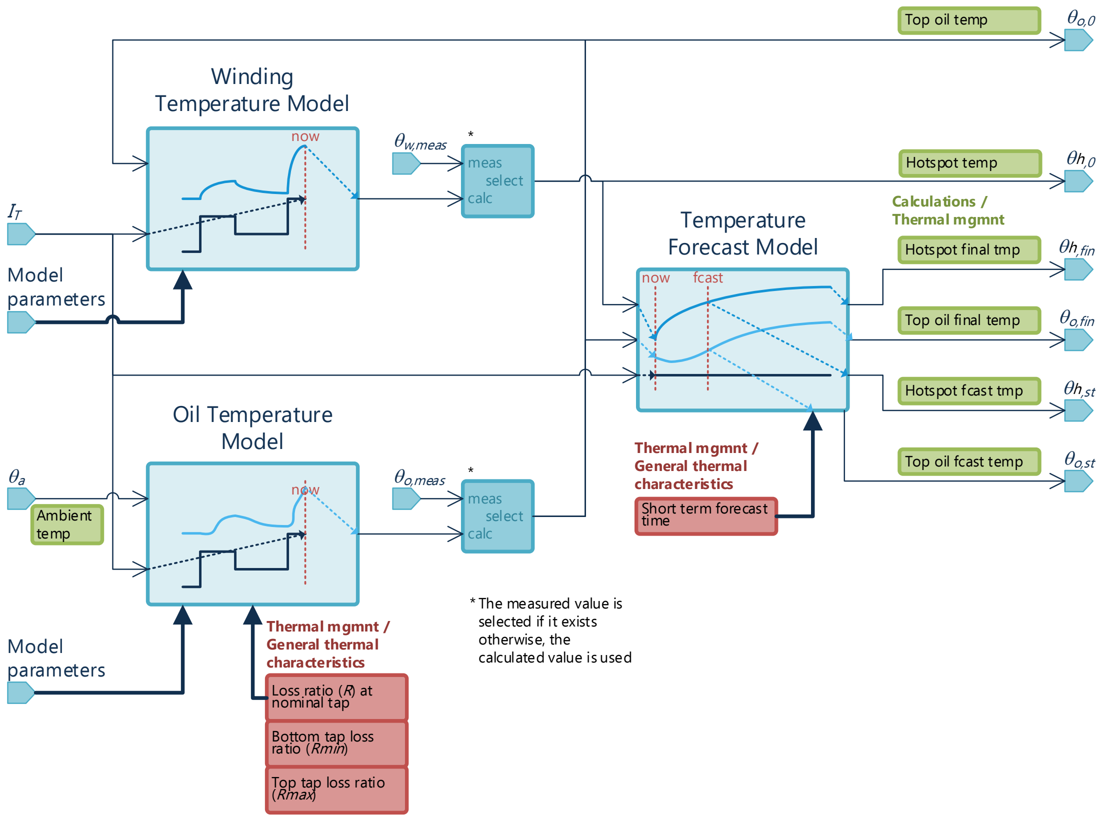
SuperTAPP SG uses the IEC 60076-7 model, with top oil temperature, current and state of pumps/fans to estimate the hot spot temperature of the transformer. The top oil temperature can be a measured temperature, or the calculated temperature as described above.

In the event that a comprehensive set of temperature sensors are not available, the temperature modelling function is capable of estimating internal oil and hotspot temperatures using IEC 60076-7 transformer thermal models with an ambient temperature sensor as shown in Figure 2-40.

- If a measurement of winding hotspot is available, it is used directly for cooling and monitoring
- If a measurement of oil temperature is available, but no winding hotspot measurement, the model will estimate winding hotspot temperature from transformer current.
- If neither oil nor winding measurements are available, the model will use ambient temperature together with transformer current to estimate oil and hotspot temperatures.

The model can also forecast a short-term future temperature and the final temperature for the current flowing using the ambient temperature.

Figure 2-40 Thermal model



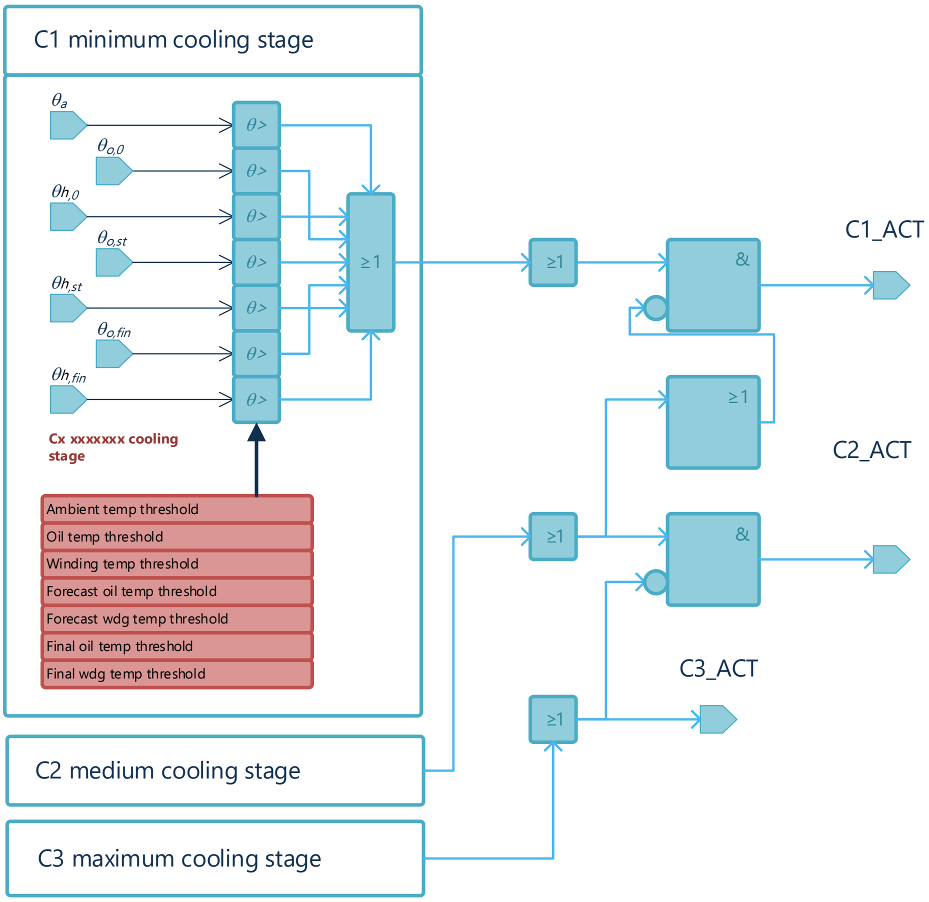
* The measured value is selected if it exists otherwise, the calculated value is used

15.10.5 Transformer Temperature Management

Applies to: Advanced and Ultimate relays with optional module type K or L

Transformer temperature management is described with reference to Figure 2-41 and comprises three separate cooling stages, each of which is configured to operate a different number of pumps and fans. SuperTAPP SG compares measured or calculated and forecasted temperatures with setpoints to activate each cooling stage, and also to raise alarms. SuperTAPP SG applies hysteresis to the temperature settings for deactivation of cooling stages. The temperature setpoints and hysteresis values can be adjusted by the user in the settings.

Figure 2-41 Transformer thermal management function diagram



15.10.6 Cooling stages

Once a cooling stage is activated, the required quantity of configured outputs will be energised until the temperature has dropped below the threshold temperature value and hysteresis when the cooling stage will be deactivated. Figure 2-42 displays the operation of one cooling stage.

In case of further temperature increase, the next cooling stage will be activated, and this could mean multiple equipment will be running at the same time, or/and different cooling device types will be energised. This process continues until the temperature level drops below the set threshold and hysteresis value. There are three cooling stages available and only once is activated at a time.

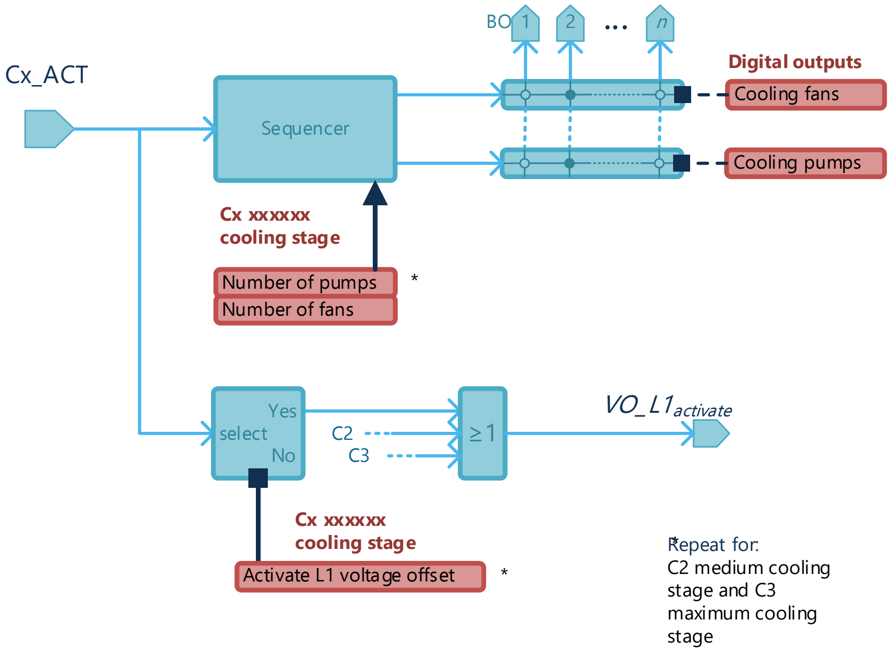
During each cooling stage, a number of pumps and fans can be running at the same time which is configurable by the user in the cooling stage settings, this has been displayed in Figure 2-42. Forecast and final temperature thresholds for oil and winding can also be configured in the cooling stage settings.

As shown in Figure 2-41, a variety of temperature quantities can be considered, and these are described in Table 2-10. Temperature thresholds can be disabled, if the user wishes to stop SuperTAPP SG from reacting to one or more temperature quantities.

Table 2-10 Temperature quantities

Item	Description
Ambient temperature (qa)	The measured ambient temperature currently
Oil temperature (qo,0)	The measured or calculated oil temperature currently
Winding temperature (qh,0)	The measured or calculated winding temperature currently
Forecast oil and winding temperatures (qo,st)	The oil and winding temperature it is forecast the transformer will reach in the number of minutes specified by the Short term forecast time setting (assuming no change to the current or cooling stage) using the IEC thermal model
Final oil and winding temperatures (qo,fin)	The oil and winding temperature it is forecast the transformer will stabilise at (assuming no change to the current or cooling stage) using the IEC thermal model
Oil and winding temperature hysteresis (qh,fin)	Dependency on previous temperatures.

Figure 2-42 Transformer cooling function diagram



Within each cooling stage, there are sequences to ensure different pumps and fans are activated each time. This is done automatically by the relay as described below:

- When a new cooling stage is activated, outputs which have not been selected during the previous active cooling stage will be favoured by the sequencer.
- Similarly, the sequencer will de-energise the longest running devices when a decrease in cooling devices is requested by exiting a cooling stage.
- In the case of a long-lasting cooling stage; a max runtime timer for each pump and fan device type will energise the next idle output(s) and de-energise the original one(s).
- The number of configured output(s) for each fan and pump in a cooling stage will always be satisfied unless the number of digital outputs configured does not allow it. For instance, for a given cooling stage requiring 4 pumps to run but only 2 digital outputs have been configured for pumps, only 2 pumps would be selected by the sequencer.

The sequencing is suitable for sites with multiple fans or pumps and provides alternation in the deployment of equipment.

15.10.7 Periodic running

If this function is activated, the relay will periodically energise the outputs to operate a fan and/or pump for a certain amount of time. Periodic running for pumps and fans can be configured in the relay settings. This is an optional feature and when activated it can be either a daily or weekly operation and the user can decide the duration of these operations.

There are dedicated settable timers to manage the maximum running time of the pumps and fans. This function would periodically schedule outputs to be energised as specified, however it would not trigger in the event that both fans and pumps have run since the last periodic run was scheduled.

15.10.8 Thermal management Alarms

There are two levels of alarms (H1 and H2) that can be configured to trigger in different situations. The alarm thresholds and time delays can be adjusted in H1 and H2 alarm settings. Once the measured/calculated temperature reached the threshold, an alarm would be raised after a time delay and with consideration of alarm temperature hysteresis.

The logic for each alarm stage is similar to the cooling stage logic for one stage as shown in Figure 2-41.

Digital outputs can be configured to send a signal in alarm conditions. The following output functions can be configured for thermal management alarms:

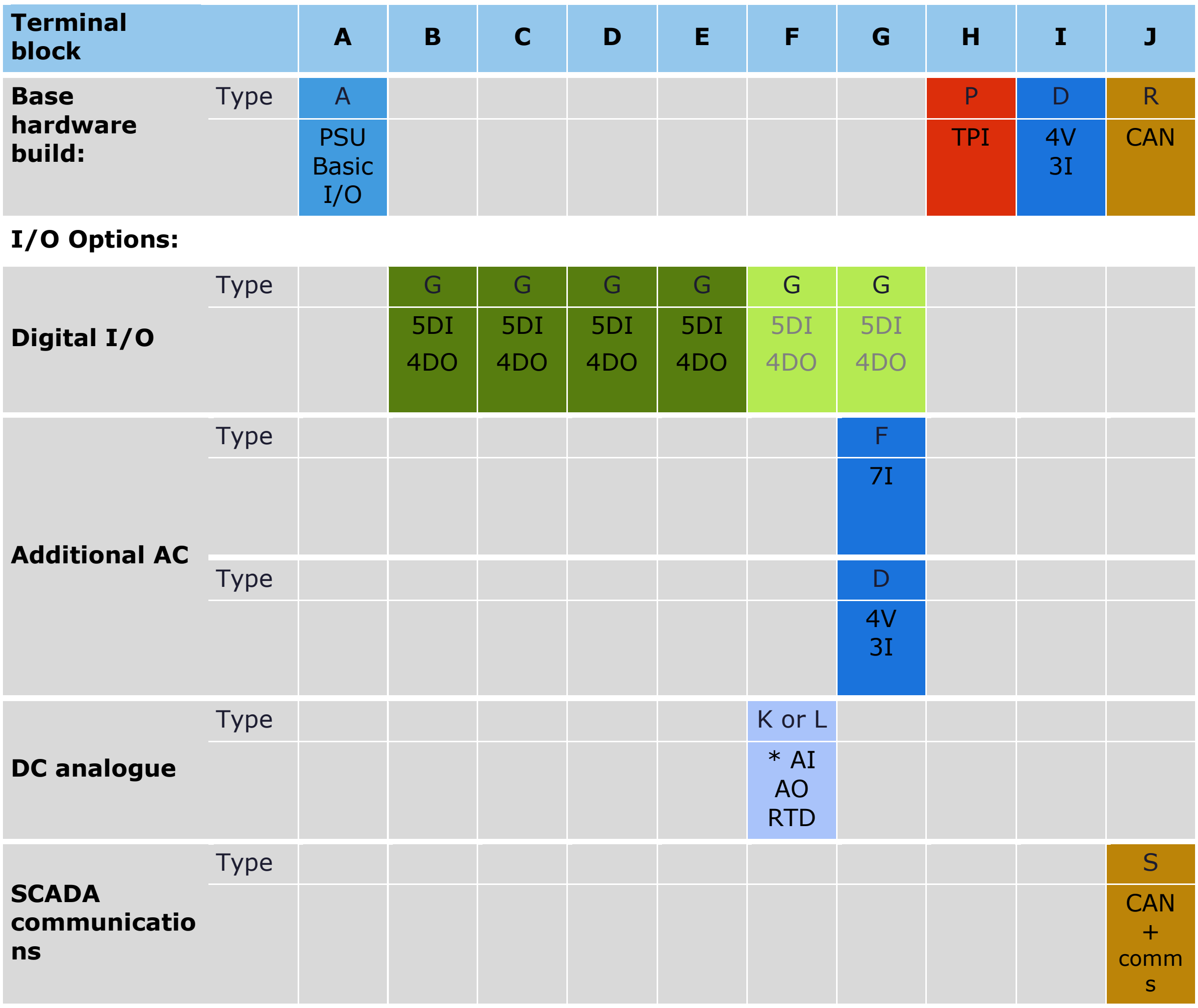
- Cooling device faulty – for when an activation signal was sent to a pump/fan and no return signal has been received;
- mA/PT100 faulty alarm – for when there is a problem with the input signal or the mA card; and
- Thermal alarm H1 and H2 – to indicate temperature higher than the set thresholds.

15.11 General Inputs and Outputs

Applies to: all function levels and options

In addition to the base hardware SuperTAPP SG can accommodate up to 6 additional digital and analogue I/O modules to provide interfacing to other substation plant and SCADA (terminal blocks B to G, see Figure 2-13).

Figure 2-43 Optional I/O module allocation to terminal blocks



Terminal block		**A**	**B**	**C**	**D**	**E**	**F**	**G**	**H**	**I**	**J**
Base hardware build:	Type	A							P	D	R
		PSU Basic I/O							TPI	4V 3I	CAN
I/O Options:											
Digital I/O	Type		G	G	G	G	G	G			
			5DI 4DO	5DI 4DO	5DI 4DO	5DI 4DO	5DI 4DO	5DI 4DO			
Additional AC	Type							F			
								7I			
	Type							D			
								4V 3I			
DC analogue	Type						K or L				
							* AI AO RTD				
SCADA communications	Type										S
											CAN + comms

* Module type K has 2AI, 3AO and 1RTD; module type L has 1AI, 1AO and 3RTD.

15.11.1 Digital Input and Output Module Type G

Applies to: relays with optional module type G

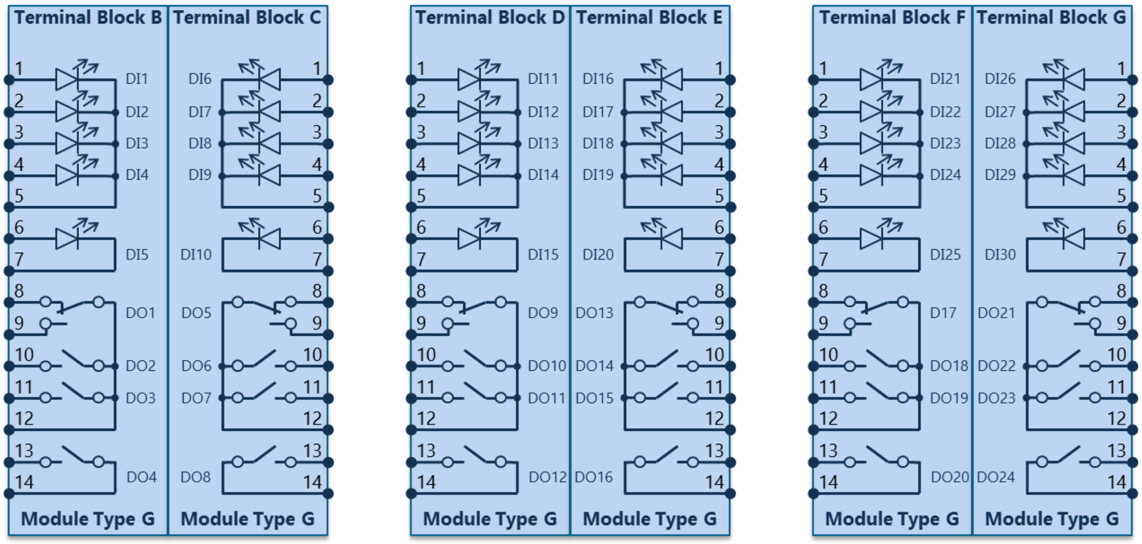
Each digital input and output module type G provides

- 5 digital (status) inputs, with a commoned group of 4, and a separately isolated input
- 4 digital outputs (relays), with a commoned group of 2 normally open and 1 changeover contact, and a separately isolated normally open contact

The digital inputs and outputs are sequentially numbered from left-to-right looking at the back of the relay (i.e. terminal block B, C, etc.) and from the top of the terminal block downwards. The terminal blocks are normally populated with digital I/O in sequential order B, C etc. Then if new I/O is subsequently added the I/O numbering will not be disrupted.

If this pattern is followed then the I/O numbering will be as per Figure 2-44. This diagram should be used indicatively and reference made to the wiring diagram for the actual relay type for the correct allocations.

Figure 2-44 Connection arrangements for type G digital I/O module



15.11.2 Analogue DC Input and Output Module Type K and L

Applies to: relays with optional modules type K or L

The DC analogue modules provide mA inputs and outputs and RTD inputs as indicated in Table 2-11.

Table 2-11 Analogue DC module I/O provision

Module type	Type K	Type L
DC analogue (mA loop) passive inputs	2	1
DC analogue (mA loop) active outputs	3	1
Three-wire RTD (PT100) inputs	1	3

The type K or L module would normally be expected to be located at terminal block F, as per Figure 2-45 and Figure 2-46. However, if terminal block F is required for digital I/O, then it could be located in terminal block G. Therefore, this diagram should be used indicatively and reference made to the wiring diagram for the actual relay type for the correct allocations.

The mA inputs are passive and require an external source to energise the loop. The mA outputs are active, i.e. they provide the energisation for the loop, in addition to controlling the current flow. Therefore no other sources should be added to the loop to avoid overvoltages and potential damage to the relay and other equipment.

The RTD inputs is of the 3-wire type which provides compensation for lead length between the sensor and the SuperTAPP SG.

Figure 2-45 Connection arrangements for type K DC analogue I/O module

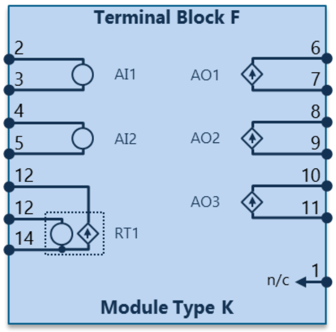
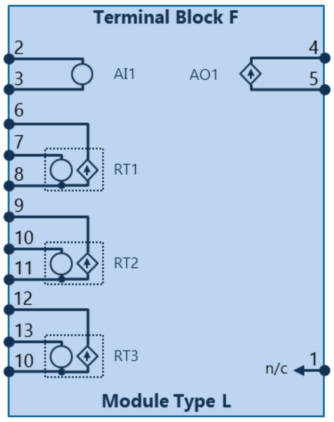


Figure 2-46 Connection arrangements for type L DC analogue I/O module



15.11.3 Digital (Status) Inputs

Applies to: relays with optional module type G

The digital inputs are general purpose inputs which can be mapped to a variety of purposes using a matrix approach. Table 2-29 lists all the functions to which the inputs can be mapped. Multiple physical inputs can be mapped to each function and, with the exception of circuit breaker status (see below), this is on an 'OR' basis. For instance if digital input 1 and digital input 3 are both mapped to the 'tap block' function, then the function is activated whenever digital input 1 or digital input 3 are energised.

It is possible to invert the sense of the digital inputs and the first setting in the list allows inverted inputs to be identified. Most inputs are sensitive to DC or AC energisation, however it is possible to set any inputs to reject AC and the second setting in the list allows AC rejection inputs to be identified.

SCADA inputs

Most of the input functions are 'activation' or 'enable' type which would typically be received from SCADA using hardwiring from a substation RTU. As an alternative to this, all of these functions can also be accessed using SCADA communications (see section 15.12.2).

Plant inputs

Most of the interface with substation plant is carried out via the dedicated scheme I/O card (see section 15.3.1) which does not require any configuration. However additional plant input functions may be allocated to the general purpose digital inputs. These are limited in number and listed below.

- T/C motor overload – an input typically driven from the tap change motor MCB to indicate that the tap change motor has tripped
- Winding 1/2 CB closed – indicates the position of a transformer circuit breaker and is required for some functions such as frequency tripping (ultimate function level only) which needs to be certain about circuit breaker position.
- Busbar CB n closed – indicates the position of a bus section circuit breaker and is required for some functions such as frequency tripping (ultimate function level only) which needs to be certain about circuit breaker position.

For the input functions which relate to circuit breaker position it is possible to create a double point input using two inputs, one wired to the circuit breaker 'a' or NO contact and one wired to the 'b' or NC contact. The input wired to the 'b' contact should be inverted and all inputs indicating circuit breaker position should be supplied from DC and their inputs set to reject AC. An example of how this should be set up is given in Table 2-12.

Table 2-12 Setting up CB inputs

Functions	1	2	3	4	5
Invert input		x		x	
AC Rejection	x	x	x	x	
Winding 1 CB closed	x	x			
Busbar CB 1 closed			x	x	

When the inputs are set in this way, if the two inputs are inconsistent then the input will be flagged as invalid and any functions which make use of this signal will “fail safe”. The behaviour of individual functions in the event of an invalid input is included in the description for that function.

Activating setting groups

An input function is provided for each of the 8 settings groups (‘Alt settings group n’). These functions are ‘edge triggered’ rather than ‘level triggered’, so the relay will act on the last trigger, which may also be via SCADA communications, even if a previous input is still active.

15.11.4 Digital (Relay) Outputs

The digital outputs are general purpose outputs which can be mapped to a variety of purposes using a matrix approach. Table 2-30lists all the functions for which the outputs can be mapped. A function can be mapped to energise multiple physical outputs and. For instance if digital output 1 and digital output 3 are both mapped to the ‘Relay healthy’ function, then digital output 1 and digital output 3 are energised when the relay is healthy.

It is possible to invert the sense of the digital outputs and the first setting in the list allows inverted outputs to be identified.

SCADA outputs

Most of the outputs are reporting the status of functions or alarms which would typically be received by SCADA using hardwiring to a substation RTU. As an alternative to this, all of these functions can also be accessed using SCADA communications (see section 15.12.2).

Plant outputs

Most of the interface with substation plant is carried out via the dedicated scheme I/O card (see section 15.3.1) which does not require any configuration. The only additional plant output functions which may need to be allocated to the general purpose digital outputs are:

- Winding 1/2 CB trip/close – trip and close commands to circuit breakers as part of the frequency tripping function (ultimate function level only).

15.11.5 mA Inputs

Applies to: relays with optional module type K or L

Milliamp inputs are mainly used for transformer thermal monitoring and control functions and to facilitate the connection of measured temperatures to the relay. SuperTAPP SG then uses this information for display and calculation purposes. There is always at least one mA input (Input 1) located on the TPI module (type P). If a type K DC Analogue module is fitted, three additional mA inputs (2, 3 and 4) are available. Similarly, if a type L DC Analogue module is fitted, one additional mA input is available.

For each one of the milliamp input three settings are presented:

- the function of the input,
- the real world value at the minimum and associated mA input (0 to 24 mA), and
- the real world value at the maximum and the associated mA input (0 to 24 mA).

Each one of the milliamp inputs can be assigned to any of the temperature measurements. Table 2-14 lists the functions which are available for milliamp input, and the real world values which can be applied to the minimum and maximum value settings.

Table 2-13 mA Input Functions and Ranges

Input Function	Maximum Range
Ambient temperature	-100 °C to +300 °C
Oil temperature	-100 °C to +300 °C
Winding temperature	-100 °C to +300 °C
Tapchanger (oil) temperature	-100 °C to +300 °C

15.11.6 mA Outputs

Applies to: all function levels and options

There is always at least one mA output (Output 1) located on the TPI module (type P). If a type K DC Analogue module is fitted, three additional mA outputs (2, 3 and 4) are available. It is generally assumed that output 1 (on the TPI module) will be used for tap position, but this isn't fixed and the user can choose otherwise.

For each output three settings are presented:

- the function of the output,
- the real world value at the minimum and associated mA output (0 to 24 mA), and
- the real world value at the maximum and the associated mA output (0 to 24 mA).

Table 2-14 lists the functions which are available for milliamp output, and the real world values which can be applied to the minimum and maximum value settings.

Table 2-14 mA Output Functions and Ranges

Output Function	Maximum Range
Fixed output	n/a
Tap position	0 to 39
Target voltage	0 to 140 %
Actual voltage	0 to 200 %
Transformer real power	-300 to +300 MW
Transformer reactive power	-300 to +300 MVAr
Transformer apparent power	0 to 300 MVA

15.11.7 RTD (PT100) Inputs

Applies to: relays with optional module type K or L

Similar to milliamp inputs, SuperTAPP SG is able to take RTD (Pt100) inputs for transformer thermal monitoring and management. If a type K DC Analogue module is fitted, one Pt100 input will be available, and if a type L DC Analogue module is fitted, three Pt100 inputs will be available.

RTD (Pt100) inputs can be assigned to the following:

- Ambient temperature
- Oil temperature
- Winding temperature
- Tapchanger (oil) temperature

15.11.8 Timers

Applies to: SuperTAPP Advanced and Ultimate SG function levels

Three general purpose pickup and dropoff timers are provided which can be mapped to digital inputs and outputs. When a mapped input is activated for the pickup time then the timer output is activated, which can be mapped to a digital output. After the digital input is deactivated for the dropoff time then the timer output is deactivated.

The settings to map the digital inputs and outputs are shown in Table **2-29** and Table 2-30 respectively. The time delay settings are shown in Table 2-33.

15.12 Communications and Data Storage

15.12.1 Inter-relay Communications

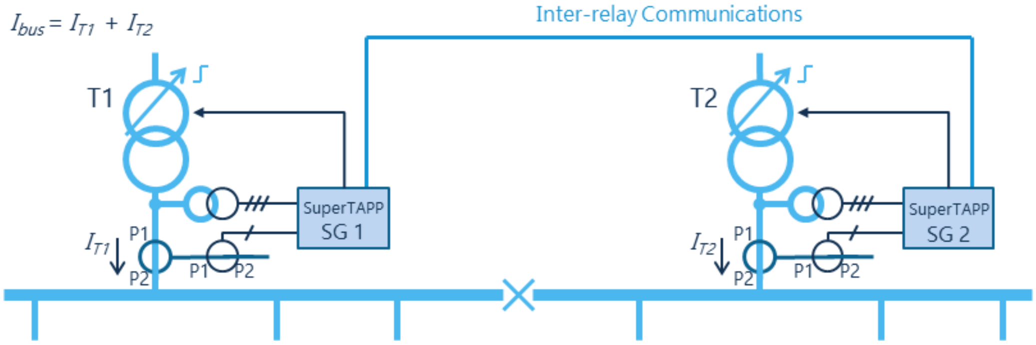
Applies to: all function levels and options

SuperTAPP SG can accommodate parallel operation of up to eight units using the Inter-relay Communications system. Units operating together should have the same software version to ensure compatibility.

In order to aid understanding of relay operation, some terminology is introduced by reference to Figure 2-47 which shows multiple SuperTAPP SG relays as a typical voltage control scheme with peer-to-peer communications.

Advice on connection of Inter-relay Communications is provided in section 16.2.5.

Figure 2-47 Inter-relay communications



The inter-relay communications system is used to exchange a number of information types, for example:

- Transformer and feeder currents for LDC and minimisation of circulating current
- Checking that voltage measurements and targets are consistent across the busbar group
- Sharing of target adjustments to ensure correct operation across the busbar group
- Cooperative functions such as prepare for switchout and tap stagger
- Identification of busbar groups and circuit breaker switch positions

15.12.1.1 Group load

Each relay reports measurement and status information which is received by all relays connected by inter-relay communications. Each relay has a transformer ID and a busbar no. which are configured in the settings. Relays connected to the same busbar will use measurement data to calculate the group load as follows:

$$I_{group} = I_{TL\text{-}1} + I_{TL\text{-}2} + \ldots I_{TL\text{-}n}$$

where transformers 1 to n are in the same group*

The group load is important for operational calculations and is displayed with the individual transformer measured current on the default screen of the relay.

Each unit on the CAN bus should have a unique transformer ID, otherwise there will be communication errors which could result in load summation inaccuracy.

15.12.1.2 Monitoring Inter-relay Communications

Inter-relay communications (CAN communications) are continuously monitored by the SuperTAPP SG and it is able to detect the following conditions:

- Multiple SuperTAPP SGs with the same address, resulting in communication conflict
- Unexpected loss of communication with another SuperTAPP SG
- Another SuperTAPP SG being powered down

The first two conditions are failure conditions which are alarmed and which cause SuperTAPP SG to move to a safe mode of operation with the following actions.

- The use of site circulating bias is temporarily suspended as it can no longer be relied upon.
- Network circulating bias continues to be applied to parallel operation which ensures transformers cannot run apart.
- Any functions which relay on multiple transformers or a known busbar group or circuit breaker positions or feeder currents from the 'lost' SuperTAPP SG are suspended.

The error status remains until it is manually reset, ensuring that any problem has been rectified. The error status is reset using the 'Reset CAN data' setting, Table 2-38 Communications link monitoring menu

This setting menu will not always be visible, depending on relay configuration

Setting	Range	Default	Section
Lost comms link timeout	15 – 3600 s	60 s	
Change to settings group	Disabled, 1 – 8	Disabled	
Reset setpoints	Disabled, Enabled	Disabled	
Deactivate A offsets	Disabled, Enabled	Disabled	
Deactivate B offsets *	Disabled, Enabled	Disabled	
Disable frequency offsets *	Disabled, Enabled	Disabled	
Disable frequency tripping *	Disabled, Enabled	Disabled	
Disable load based offsets *	Disabled, Enabled	Disabled	
Deactivate tap stagger *	Disabled, Enabled	Disabled	

* This setting will not always be visible, depending on relay configuration

Table 2-36.

15.12.2 SCADA Communications

Applies to: relays with the SCADA communications option, with or without Ethernet

SCADA communications with SuperTAPP SG can be used to:

- Receive inputs to the SCADA system for indication of events such as tap change operations, alarms, setting changes;
- Receive inputs to the SCADA system of status such as relevant circuit breaker positions, operation modes (auto/manual etc.);
- Send outputs from the SCADA system for commands such as manual tap, mode change;
- Receive inputs to the SCADA system of any of the measured voltages or currents, and many internally calculated values such as frequency, MW, MVAr, MVA;
- Receive inputs to the SCADA system of internal counters such as no. of taps;
- Receive inputs to the SCADA system of currently applied setpoint values
- Send outputs from the SCADA system to change the active settings group; and
- Send outputs from the SCADA system to change current setpoint values.

SuperTAPP SG provides the following commonly used substation communication protocols:

- IEC 60870-5-101 (serial), IEC 60870-5-103 (serial), IEC 60870-5-104 (Ethernet)
- DNP3 (serial or Ethernet)
- IEC 61850 (Ethernet)

Serial communications is over RS485 and the interface includes a terminating resistor for the end of the chain which can be wired if required. Ethernet communications is provided through the use of Small Form-factor Pluggable (SFP) modules which can provide Ethernet using a number of copper and fibre standards, as listed in Table 2-5.

The settings associated with SCADA Communications are listed in Table 2-35. Unlike other settings in the relay the communication settings are not immediately applied on a setting change, since this requires an internal restart of the communications module. Rather the last item in the communication settings list is an 'APPLY' option and when this is selected the communications module is restarted and the settings applied.

Interoperability profiles with full data point lists for each of the protocols supported are provided separately.

15.12.3 Event Logging

All command, event and status information which is provided through SCADA communications is also stored internally and can be accessed through the front USB port and the PC software, described in part 1 of the user manual.

The length of time the data is stored is a function of the frequency of event generation, but is measured in months and is likely to be over 1 year.

15.12.4 Analogue Data Storage

All measured, calculated and counter values which are provided through SCADA communications are also stored and can be accessed through the front USB port and the PC software, described in part 1 of the user manual.

The length of time the data is stored is a function of the number of analogue inputs in operation and the logging interval setting (see Table 2-38 Communications link monitoring menu

This setting menu will not always be visible, depending on relay configuration

Setting	Range	Default	Section
Lost comms link timeout	15 – 3600 s	60 s	
Change to settings group	Disabled, 1 – 8	Disabled	
Reset setpoints	Disabled, Enabled	Disabled	
Deactivate A offsets	Disabled, Enabled	Disabled	
Deactivate B offsets *	Disabled, Enabled	Disabled	
Disable frequency offsets *	Disabled, Enabled	Disabled	
Disable frequency tripping *	Disabled, Enabled	Disabled	
Disable load based offsests *	Disabled, Enabled	Disabled	
Deactivate tap stagger *	Disabled, Enabled	Disabled	

* This setting will not always be visible, depending on relay configuration

Table 2-36), but is measured in months and may be up to 1 year.

16 Application Guidance

16.1 Fundamentals Application Support

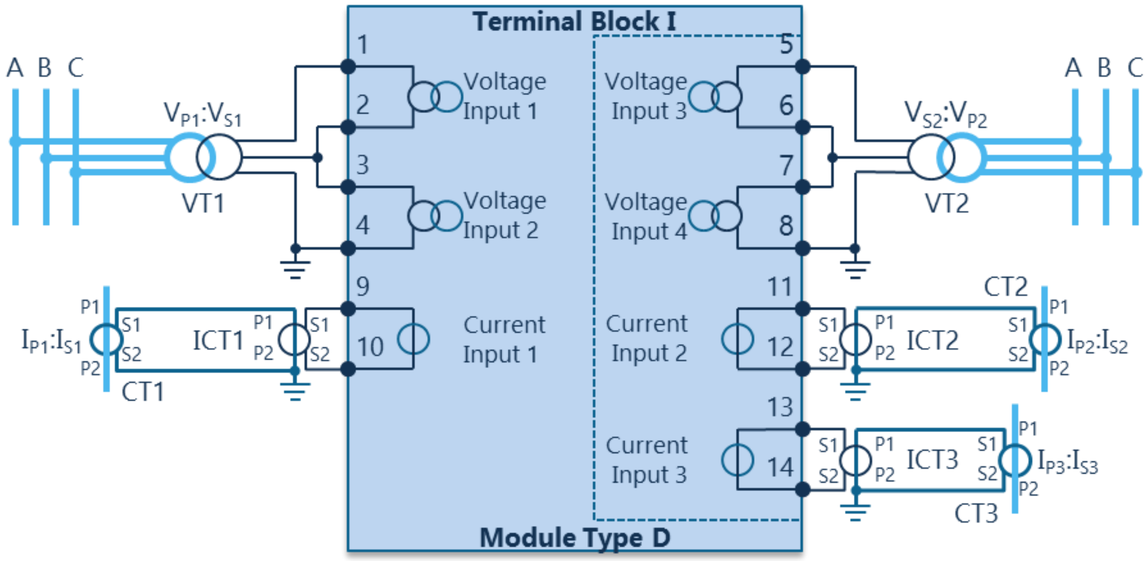
When you buy a Fundamentals product you can expect to receive expert assistance to apply your relay. Please contact your sales office or agent and we will do our best to advise you. We will gladly provide you with advice on an ad hoc basis, or if you have an extensive requirement for support we can offer services for scheme design, panel build, installation and commissioning.

Our global partners are carefully chosen to ensure that they have application support capabilities which are backed up by Fundamentals voltage control experts.

16.2 Basic Control Scheme Design

16.2.1 Voltage and Current Inputs

Figure 2-48 Voltage and current connections



16.2.1.1 Voltage measurement inputs

Four low burden voltage inputs are provided and can be arranged to measure two sets of 3-phase voltages, Figure 2-48. An additional four low burden voltage inputs can be obtained by introducing an additional module type D in terminal block G, potentially providing four sets of 3-phase voltages. In most schemes only a single 3-phase voltage will be measured (and only one is available with the SuperTAPP Basic SG function level).

The second, third and fourth 3-phase measurement becomes available with the Advanced and Ultimate function levels and is used for applications involving 3-winding (double-secondary) transformers where voltage averaging and load summation is required. It will also be used for applications where a 'back-up' phase reference is required for feeder current measurements. These applications are described in more detail in section Part 21.1.1.

However it is possible to use the four voltage inputs to make single-phase or phase-phase measurements of four separate voltages, e.g. all four secondary windings of two 3-winding transformers.

The settings for each voltage input (such as VT ratio and VT phase) need to be configured appropriately in order that the relay can convert measurements into the correct primary values (see section 15.4.3).

16.2.1.2 Current measurement inputs

SuperTAPP SG is designed to measure feeder currents in addition to the transformer current. Normally, feeder current measurements are only possible using protection CTs. In order that the protection scheme is not compromised, low burden interposing CTs are used to interface with the relay. The use of such interposing CTs gives the following additional advantages:

- Safety – no risk of high voltages for open-circuit (clamped at around 11 V)
- Flexibility – accuracy can be ‘tuned’ by additional interposer turns

The SuperTAPP SG is designed for use with low burden interposing CTs for all current measurements, feeder and transformer. Interposing CTs are supplied with the SuperTAPP SG, and are described in more detail in section 16.2.2.

The settings for each current input (such as CT ratio and CT phase) need to be configured appropriately in order that the relay can convert measurements into the correct primary values (see section 0).

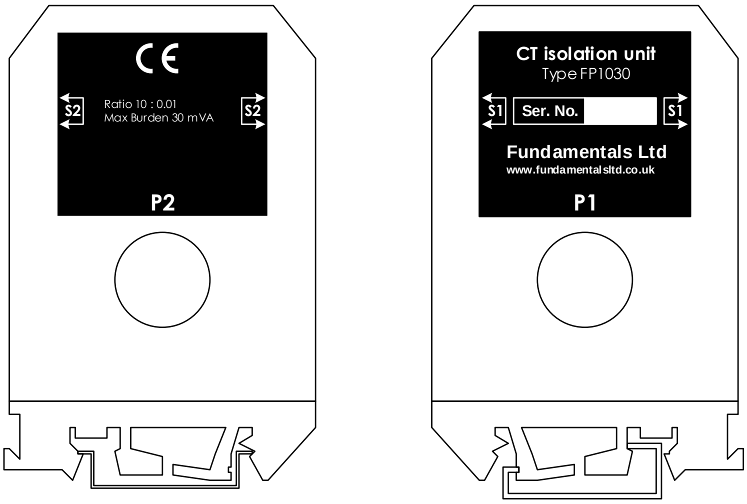
16.2.2 Interposing CT

The interposing CT designed for use with the SuperTAPP SG provides a high level of electrical isolation between the source current circuitry and imposes virtually no burden upon the measurement current transformer.

Figure 2-49gives an external view of the interposing unit, shown from each side. The enclosure is mounted on a reversible universal foot that will allow fixing onto either a G-rail or top hat rail mounting arrangement. Screwed terminal output connections are available from either side of the unit.

The primary conductor (S1 from the primary CT) is passed through a central hole in the casing as shown in Figure 2-49 and Figure 2-50.

Figure 2-49 Interposing CT



The interposing CT should be mounted in a convenient position such that the distance between the unit and the SuperTAPP SG is at a practical minimum. If there is substantial distance between the unit and the device, a twisted-pair cable should be used. This may be the case where a protection CT is utilised. In this instance the interposing CT should be mounted as close as possible to the primary CT secondary wiring and in any event in the same panel. The electrical specification for the interposing CT is shown in Table 2-15.

Figure 2-50 Interposing CT connections

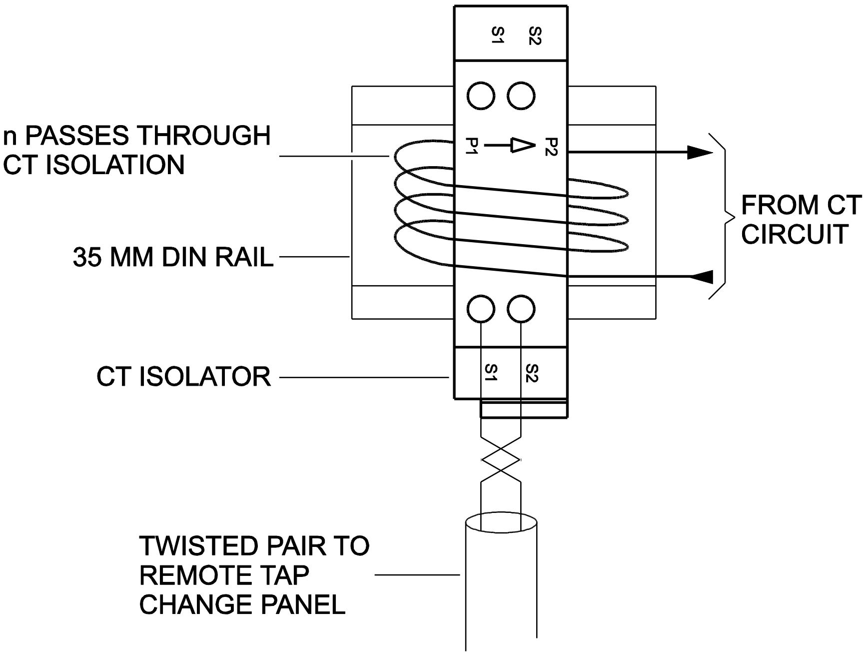


Table 2-15 Interposing CT specification

Parameter	Specified value
Ratio	10A : 0.01 A
Maximum primary current	10 A
Burden	0.03 VA
Isolation	> 3 kV
Material	UV 94-V-0 polyamide 66/6

The maximum current that the device can measure with accuracy is 10 amps. Depending on the use of the interposing unit, turns can be added to the primary side in order to increase the sensitivity of the output. It is recommended that the number of turns should give '5 Amp turns' at rated current as shown in Table 2-16 and Figure 2-50.

Table 2-16 Interposing CT turns

CT Secondary Rating	Recommended Turns on Interposing CT
5 A	1
1 A	5
0.5 A	10

In situations where the loading on the CT is low compared to the rating, accuracy can be compromised. The number of turns on the interposer can be increased to improve the accuracy, but care is required and in any case it is not recommended to increase the number of turns above 5 Amp-turns at the normal maximum loading level. The maximum non-fault overload level should be less than 10 Amp-turns.

For example, a feeder breaker CT (ratio 1000:5) would normally have a single interposer turn. If the maximum loading of the feeder is 200 A, the number of turns could be increase to 5 to give more accuracy.

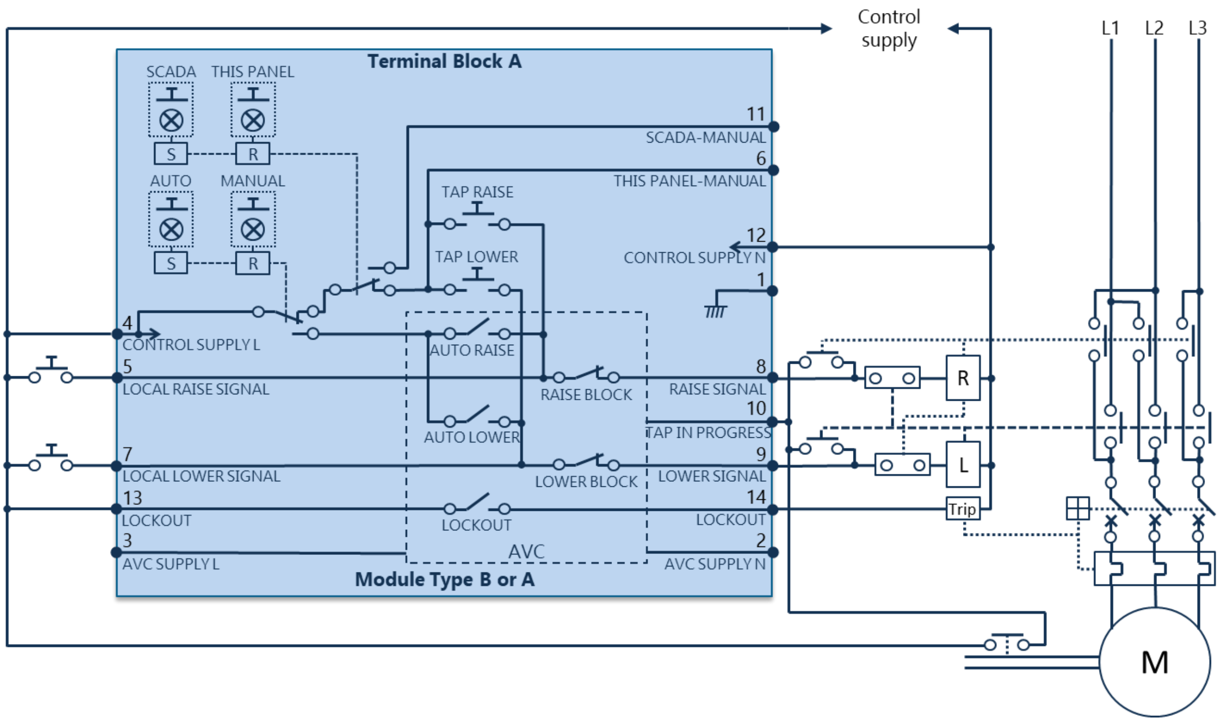
The settings for each CT input need to be configured appropriately in order that the relay can convert the measurements into the correct primary values (see CT settings in section 0).

16.2.3 Interfacing with the Tapchanger

The raise and lower outputs are used to initiate a tap change when the measured voltage is outside of the 'dead band'. Normally a raise will increase the tap position and the measured voltage, and a lower vice-versa. However, tap changers can sometimes work in the opposite direction where an increase in tap position will produce a lower voltage. The outputs should be wired such that raise produces a higher voltage.

All the hardwired I/O required to interface with a tapchanger is provided on the Power Supply / Scheme Interface module. A typical scheme arrangement for Module Types A and B are shown in Figure 2-51. The positive and negative AVC supply connections for Module Type A can either be on terminals 2 and 3 or terminals 3 and 2. The positive and negative AVC supply connections for Module Type B are on terminals 3 and 2, respectively.

Figure 2-51 Tapchanger connections



16.2.4 Hardwired SCADA Interface

In addition to the interface with the tapchanger it is usual for further I/O to be used to interface with other plant and with hardwired SCADA RTUs. Since this additional I/O is freely programmable it provides for a flexible deployment.

16.2.4.1 Digital outputs (relay outputs)

The I/O modules can provide changeover relay contacts and normally-open contacts. Some of these are commoned together so care should be taken that the functions are allocated appropriately where different sources are used. For instance, 110V AC or DC may be used for plant interface while a 48 VDC battery is used for SCADA.

At a minimum it is usual to use:

- a changeover contact for SuperTAPP SG healthy,
- a changeover contact for auto/manual status,
- normally open contacts for alarm indications such as tap changer failure and voltage control alarm.

It is recommended to separate the alarms to indicate problems with the SuperTAPP SG, problems with the tap changer and issues with controlling the voltage. This enables the control engineer to determine the required response.

16.2.4.2 Digital inputs

The digital inputs on the I/O modules can be used to modify the operating parameters of the voltage control system. The inputs are wired to the SCADA RTU and have wide operating voltage range.

The typical uses of these inputs in most schemes for are for

- remote auto/manual selection,
- remote manual tap raise and tap lower, and
- selection of voltage target adjustments as part of load management.

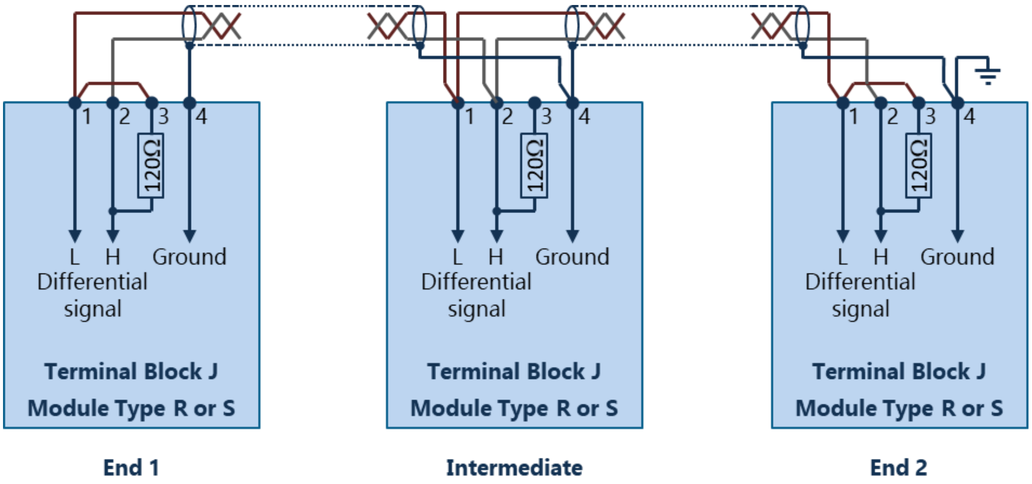
16.2.5 Inter-relay Communications

Inter-relay communications take place using a CAN bus (Controller Area Network) connected between the SuperTAPP SGs as shown in Figure 2-52. The cable used should be twisted-pair with a characteristic impedance of 120Ω and individually-screened pairs with drain wire.

If there are more than two SuperTAPPs they should be daisy-chained together directly on to the SuperTAPP SG terminals (i.e. no stub tee). The SuperTAPP SGs at each end of the chain require a terminating resistor, which is provided within the relay and simply requires a connection between terminals J1 and J3 (Figure 2-47). The screen of the twisted pair cables, in addition to being terminated onto terminal J4 of each SuperTAPP SG, must be earthed at one point only to avoid earth loops.

If there are only two SuperTAPP SGs then each one is treated as an 'End' device. If there is only one SuperTAPP SG no communication connections are required, however it is advised to earth the CAN Ground terminal (J4).

Figure 2-52 Inter-relay connections



The Inter-relay communications can accommodate a maximum of eight SuperTAPP SGs. Previous relays MicroTAPP and SuperTAPP n+ also use CAN as a means of providing inter-relay communications, however the implementations differ and a mix of relays cannot be used on a single CAN network.

Instrumentation is available to show the number of units communicating with corresponding groupings to check correct configuration.

Inter-relay communications are very important for correct operation of the SuperTAPP SG system and should therefore be set up correctly. Faults and errors with suggested fixes are shown in Table 2-17.

Table 2-17 Inter-relay communication errors

Relay display message	Remedy
Communications error	Check diagnostic instruments and CAN bus wiring
Comms ID clash	Check transformer ID setting
Comms data missing	Check diagnostic instruments and for errors or power fail on other relays
DAM error	Check for errors on connected DAM units

16.3 Determination of Settings

16.3.1 Distribution Voltage Settings – Basic Voltage Target and LDC

The allowable range of permissible voltage at each point of connection determines to a large extent, the operational voltages that can be applied at each voltage level on the network. Using typical voltage ranges it will be useful here to examine the maximum typical design voltage drops that can occur across a distribution system at extreme loading conditions.

Figure 2-53 Effect of load on system voltages

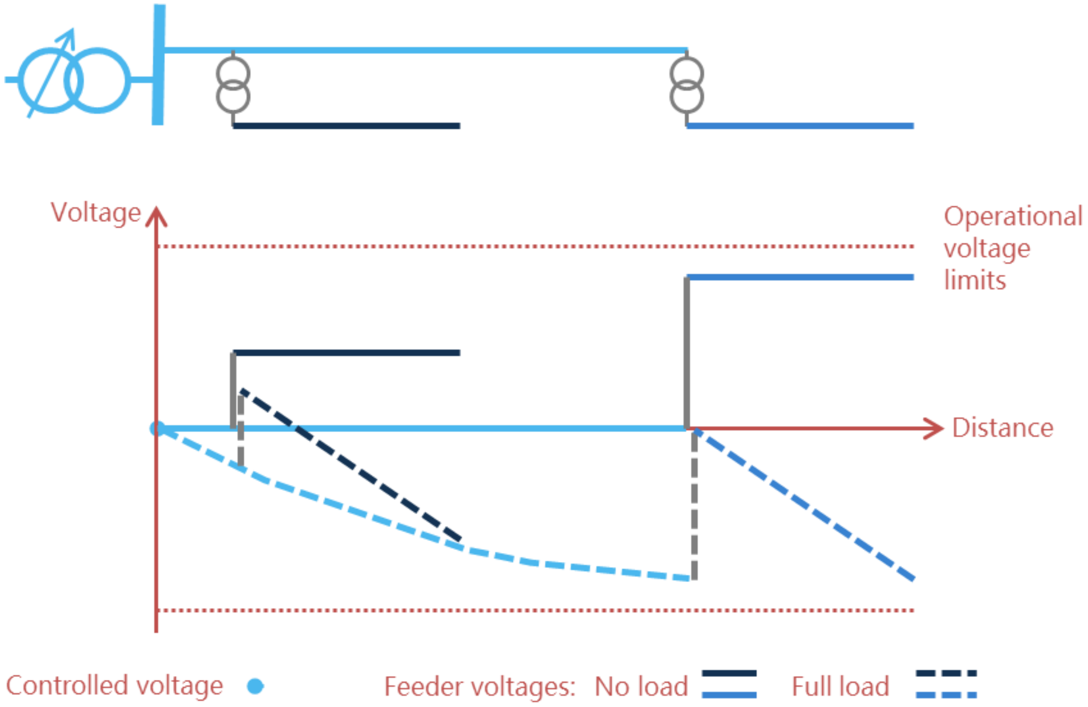


Figure 2-54 Effect of load with LDC on system voltages

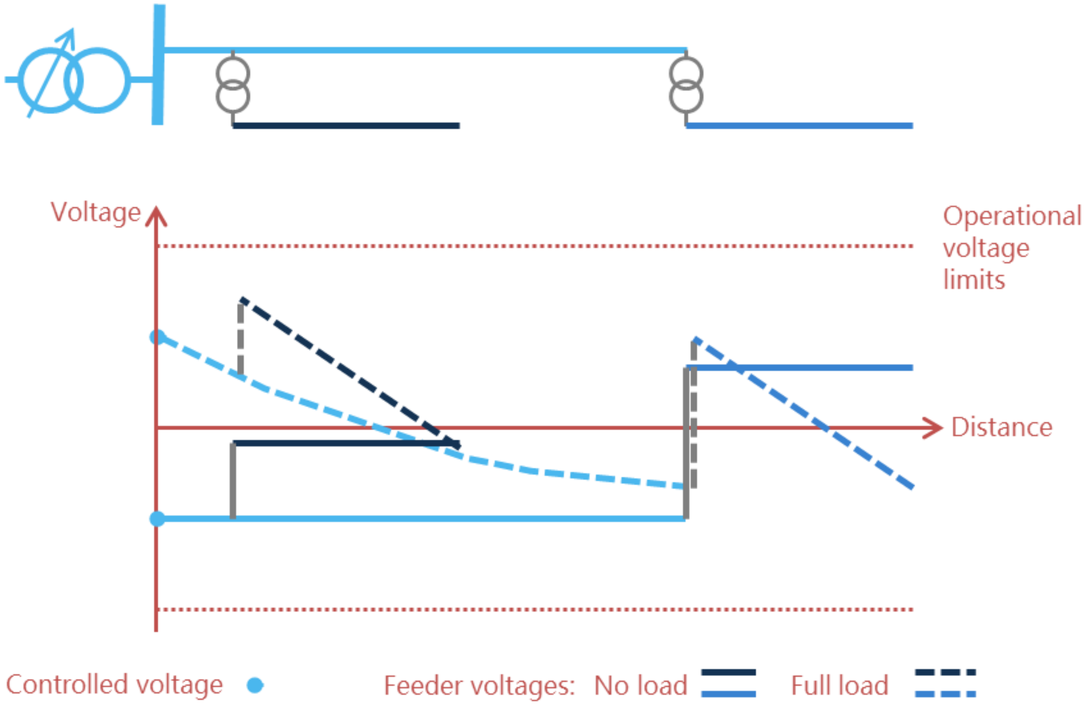


Figure 2-53shows an example network of a primary transformer, secondary distribution network, distribution transformers and LV distribution with one point of voltage control at the primary substation. In this example the basic voltage setting is set at nominal voltage, 100% or "level bar", and the distribution transformers have their fixed taps set at +2.5% and +5% (the voltage graphs are scaled in per units and assume a ±6% limit across all voltages). The additional boost on transformers remote from the primary substation allows for the additional voltage drop at full load (shown by the dashed lines on the voltage graph). It can be seen from the graphs that this approach accommodates all connections within the voltage limits in all situations but it is not without its disadvantages:

- There is very little voltage legroom at full load to allow for any load increases or alternative feeding arrangements
- There is very little voltage headroom at low load to allow for distributed generation
- There is no opportunity for additional connections or increased feeder lengths at the primary substation

Improved voltage regulation with increased voltage headroom and legroom can be achieved by reducing the basic voltage setting by 3% and applying a +6% LDC voltage boost (Figure 2-54). Using this method the no-load / full-load voltage variation is minimised across the network.

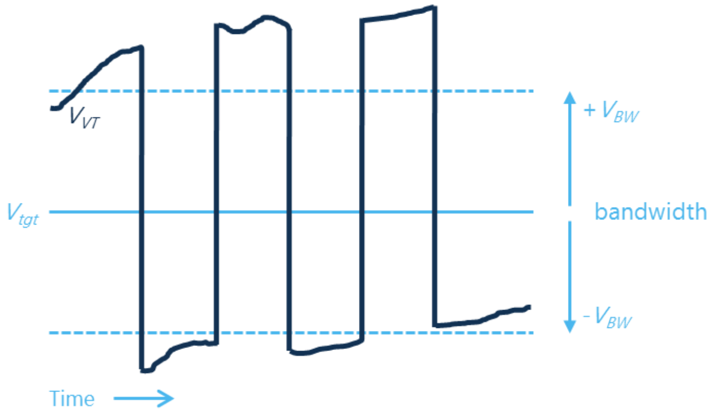
Theoretically the use of LDC will improve the situation to the ideal point where the absolute voltage variation is the same at both the source and remote ends of all feeders.

While abnormal network running and disparate feeder load profiles may cause the use of LDC to be reduced from the ideal, advantage can still be gained by the use of these settings, including those networks where voltage drops occur only on the LV system.

16.3.2 Bandwidth and Hunting

The permissible bandwidth setting is determined by the voltage step of the tap changer. To optimise the number of tap changer operations it should be set to approximately one tap step (as shown in Figure 2-3). Care should be taken not to set the bandwidth lower than half a tap step since this will result in 'hunting', where one tap operation can cause the voltage to move across the full bandwidth and result in a call for another tap operation in the opposite direction (see Figure 2-55).

Figure 2-55 Tapchanger 'hunting'



16.3.3 Tap delays

The inter-tap time should be set to longer than the operation time of the tap changer (for safety at least 25% longer than the tap changer operation time). This is to avoid attempted raise/lower operations while the tap changer is already in operation.

16.3.4 Circulating Current

The calculations for circulating current described in section 15.1.3.1 depend on the busbar group load which makes use of inter-relay communications. In the event that inter-relay communications are not possible, either temporarily or by design, circulating current will be calculated using the TAPP mode. If this is a permanent arrangement the Network Circ Current Factor (Table 2-21) should be set to 100%.

Alternatively, relays may directly measure the group load using a special CT type.

16.3.5 Settings Groups

Many of the settings in SuperTAPP SG are duplicated in 8 individual settings 'groups' (see section 17). Digital inputs can be programmed to switch the SuperTAPP SG to use a different setting group as defined in the 'Set dig input terminals' menu.

Alternative settings are intended to offer flexibility for abnormal operating conditions such as:

- Topology changes – where transformers which are normally operated in parallel are temporarily switched apart by opening of a bus section for example. In this situation it will be necessary to alter the group ID of at least one unit.

- Network changes – where the configuration of outgoing feeders is changed and require different settings (e.g. LDC settings).

The alternative settings may be particularly useful for the more ‘advanced’ applications where extra CT and VT measurements are in use and where ‘safe AVC’ can be applied in the event of abnormal conditions.

16.4 Feeder Current Measurements

Conventional voltage control uses the measured transformer current, usually via the LDC CT, for load drop compensation and/or circulating current control. These functions have been discussed in sections 16.3.1 and 16.3.4 respectively.

Modern networks have increasing levels of electrical plant connected which can compromise conventional voltage control due to the injection of real and reactive power (for example embedded generation, capacitor banks and other reactive support devices). Different types of highly reactive load can also add to voltage control problems (for example heavy industrial loads which are on in the day and off at night).

Normally, these items of 'problem plant' are confined to individual outgoing feeders, while other feeders are unaffected. Despite this, the voltage control effect is experienced by all feeders. The SuperTAPP SG has functions available to solve these problems, which rely on the implementation of extra current measurements on the outgoing feeders which have connected 'problem plant'.

16.4.1 Implementation

The feeder current measurements are facilitated by feeder protection CTs. In order that this does not compromise the protection scheme, very low burden interposing CTs are used to interface with the SuperTAPP SG relay. These CTs are 1000:1 ratio wedding ring type with burden < 0.05 VA. The CTs are described in detail in section 16.2.2.

All relay measurements are transmitted on the CAN bus to make them available for peer units. Functions which make use of these measurements must be applied in the same way to all relays in the busbar group, otherwise the desired effects will not be realised and voltage errors can occur. Special attention therefore needs to be given to relays which are configured for feeder current measurements so that the data can be available even when the transformers to which they are connected are switched out (e.g. for maintenance), namely:

Power supply

The relay must be powered to continue transmitting measurement data. Normally the auxiliary AC supply for tap changer control is used to power the control relays and this may be disconnected if the transformer is switched out, so an alternative is required. The best solution is to use the DC supply (if available) to power the relay. The SuperTAPP SG has a flexible AC/DC power supply available with an input range of 88 – 253 V AC/DC.

Voltage reference.

The relay uses the VT input as a reference for calculation of real and reactive components of current. The second VT input of the relay can be configured to use a VT from another transformer in the group as a voltage reference when the main VT input is lost due to a transformer switch out. This will be considered in detail in section 16.3.5, 'VT Switching'.

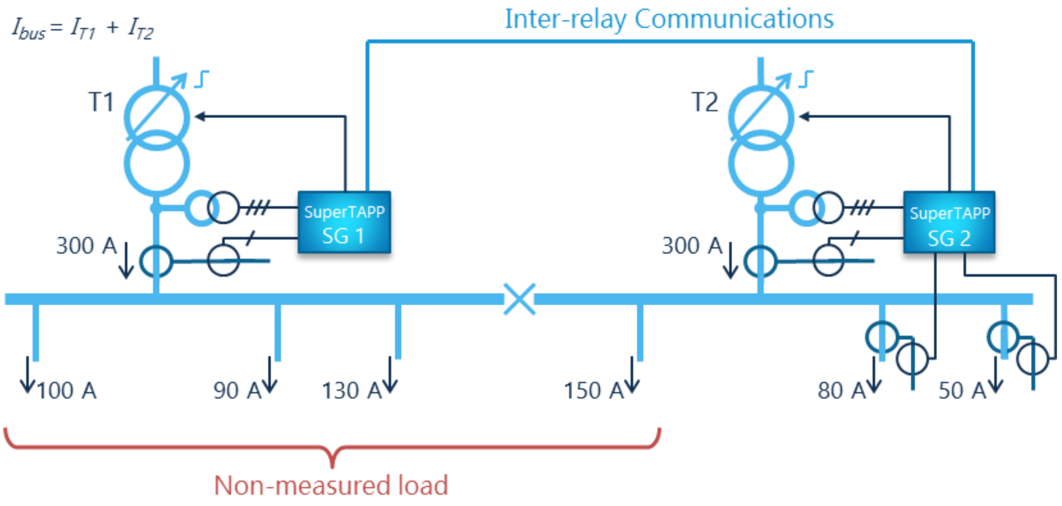
16.4.1.1 Definitions

The important relay definitions are as follows:

- Measured currents – transformers and feeders.
- Non-measured load – sum of the load on feeders which are not being measured.

These values can be understood by reference to Figure 2-56which shows an application with feeder measurements on two of the six feeders.

Figure 2-56 Definition of non-measured load



In this case both relays would show the following values in the instruments screens (see section 11.3.1):

Summed transformers	=	600 A
Summed feeder measurements *	=	130 A
Non-measured load	=	470 A

*this data will be presented according to how the CT inputs are configured (see below).

Each CT input used for feeder current measurement must be configured in the settings for a specific use. There are many uses to choose from, but broadly they can be split into three types, relating to:

- Embedded Generation
- Reactive Sources / Loads
- Special Applications

Each of these types is described in detail in individual sections below.

16.4.2 Distributed Generation

Distributed or embedded generation is defined here as generation of any type connected to the network which the transformer is supplying. The generation can be connected directly to the busbar via one or more dedicated feeders, or remotely to one or more outgoing feeders. In either case the embedded generation can cause the following voltage control issues:

- Reduction in the applied LDC due to reduced transformer current.
- Voltage rise along feeders to the point of connection when in reverse power flow (i.e. when the generation exceeds the load on the feeder).
- Voltage error incurred by inaccurate network circulating current control due to power factor variations on the transformer current.

In order to solve the above problems the relay has functions available which utilise feeder current measurements:

1. Accurate LDC based on the 'true' group load.

With generation present the summed transformer currents do NOT represent the group load. The relay can determine generation output(s) based on feeder current measurements and use it to calculate the 'true' group load.

2. Generation compensation – Vgen in Figure 2-3.

This is a reduction in relay target voltage in proportion with calculated generation output levels:

$$V_{gen} \quad = \quad [\Sigma(I_G)/\text{Rating}] \times \text{Genbias}$$

where

$\Sigma(I_G)$	is the measured/calculated generation output (Amps)
Rating	is the maximum generator output rating (Amps)
Genbias	is the %voltage reduction to target at full generator output.

3. Enhanced TAPP circulating current control using the 'true' group load.

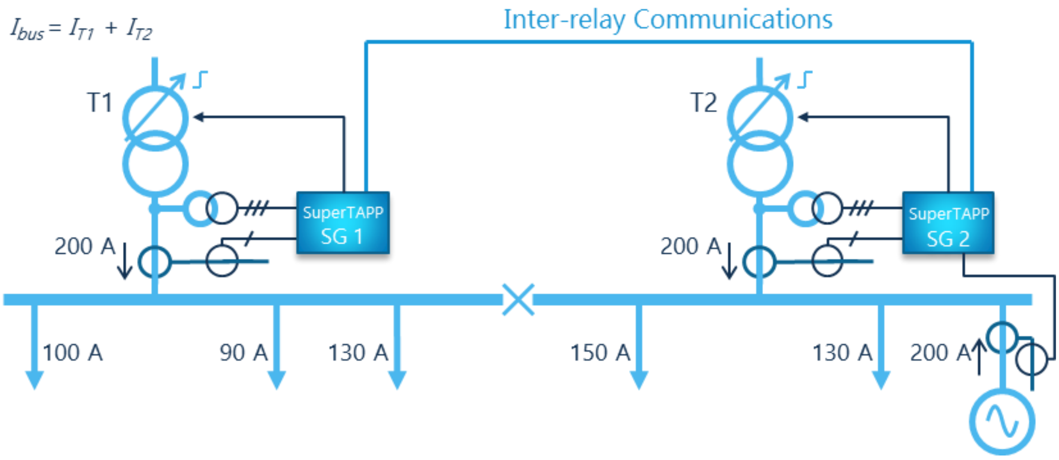
All of the above-mentioned functions rely on the real-time calculation of the 'true' group load and the generation output. There are two methods for this in respect of how the generation itself is connected and how the corresponding feeder current measurement inputs are configured in the relay:

- Direct generator connection – CT input configured as 'generator'.
- Indirect generator connection – CT input configured as 'generator feeder'.

16.4.2.1 Direct generator connection

An example of this application is shown in Figure 2-57 where two transformers supply a network via 6 feeders and a generator connected directly to the busbar. There is one voltage control relay per transformer, each of which uses one VT input for voltage measurement and one CT input for transformer current measurement. One of the relays also uses a CT input for the generator measurement. All measurement data is available to all relays connected on the CAN bus.

Figure 2-57 Direct generator connection



Relay 1 and Relay 2

Transformer current	=	200 A
Summed transformer currents	=	400 A
Summed feeder measurements	=	-200 A
Non-measured load	=	600 A
Generator output	=	200 A
Group Load	=	600 A

If the bus section is open, the situation changes* as follows:

Relay 1

Transformer current	=	320 A
Summed transformer currents	=	320 A
Summed feeder measurements	=	0 A
Non-measured load	=	320 A
Generator output	=	0 A
Group Load	=	320 A

Relay 2

Transformer current	=	80 A
Summed transformer currents	=	80 A
Summed feeder measurements	=	-200 A
Non-measured load	=	280 A
Generator output	=	200 A
Group Load	=	280 A

* the group ID of the relays must change to reflect the new configuration (see section 16.2.4.2 for ‘alternative settings’).

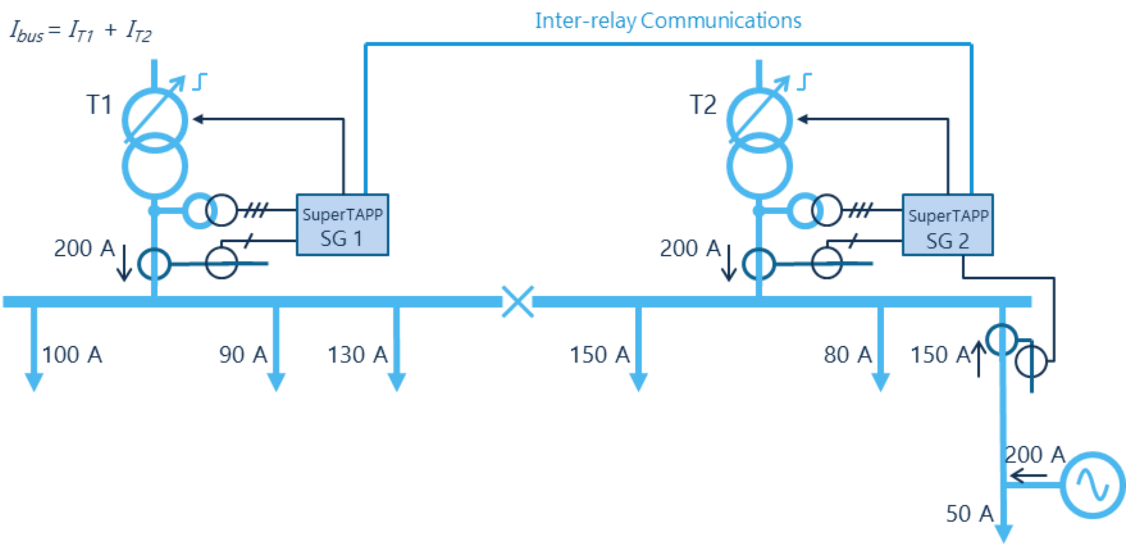
In order to accommodate all applications to include any number of transformers and generator connections, the above calculations can be summarised as follows:

Summed transformer currents = $\sum(I_{Tn})$
Generator output = $\sum(I_G)$
Group Load = $\sum(I_{Tn}) + \sum(I_G)$

16.4.2.2 Indirect generator connection

An example of this application is shown in Figure 2-58which shows the same network as presented in Figure 2-57 but with the generator connected remotely (e.g. several km’s away) to one of the feeders (called the ‘generation feeder’).

Figure 2-58 Indirect generator connection



The generator feeder has connected load and generation but the feeder current measurement, I_F, cannot discern between them. The example network shows this where the measured feeder current is -150 A, with 50 A of load and 200 A generation present.

The relay has a generation estimation function which can calculate load and generation present on the network. The generator estimation function depends on the following:

- Current Measurements
    - Summed Transformer
    - Generator Feeders
- Load Ratio

The Load Ratio is a relay setting which is expressed as a percentage and defined as follows:

$$\text{Load Ratio} = \frac{\text{'true' load on generation feeders}}{\text{load on 'non-measured' feeders}}$$

The load ratio of the example network shown in Figure 2-58 is 9% (50 A / 550 A).

The relevant calculations for the two relays shown in the example network are as follows (all data presented in the relay instruments to aid troubleshooting):

Relay 1 and Relay 2

Transformer current	=	200 A
Summed transformer currents	=	400 A
Summed feeder measurements	=	-150 A
Non-measured load	=	550 A
Estimated load	=	50 A
Estimated generation	=	200 A
Group Load	=	600 A

If the bus section is open, the situation changes* as follows:

Relay 1

Transformer current	=	320 A
Summed transformer currents	=	320 A
Summed feeder measurements	=	0 A
Non-measured load	=	320 A
Estimated load †	=	0 A
Estimated generation	=	0 A
Group Load	=	320 A

Relay 2

Transformer current	=	80 A
Summed transformer currents	=	80 A
Summed feeder measurements	=	-150 A
Non-measured load	=	230 A
Estimated load †	=	50 A
Estimated generation	=	200 A
Group Load	=	280 A

*the group ID of the relays must change to reflect the new configuration (see section 16.2.4.2 for 'alternative settings').

† this is dependent on a new load ratio of 0% for T1 and 22% for T2 in the new settings group

In the event of a network configuration change or fault, it is possible to switch the relay to use 'alternative settings'. This gives added flexibility so that the relay can be configured appropriately for abnormal operating conditions. Some examples of how the relay could be configured for abnormal situations are as follows:

- Revert to 'safe' operating mode where feeder current measurements and generator estimation are ignored
- Adopt a new load ratio for a specific configuration

In order to accommodate all applications to include any number of transformers and generator connections, the above calculations can be summarised as follows:

Estimated load = Non-measured load x Load Ratio

Estimated Generation current = Estimated load – Generator feeder

Group Load = Non-measured load x (1 + Load Ratio)

The load ratio can be determined from historical load data or from direct measurements. If historical data is used, the load ratio should be taken as an average value from a period of time over which the extent of seasonal variations can be observed. If direct measurement is used to determine the load ratio it must be ensured that the generation is not running so that the measurement represents the 'true' load.

Once the load ratio has been calculated it is configured into the relay settings. It is clear that the actual load ratio will vary over time due to seasonal variations and network events (outages, faults etc.). For this reason, the relay settings should be regularly checked to ensure that errors associated with these variations are kept to a minimum.

The accuracy of the generation estimation algorithm will vary throughout a year and across a network. Each application will demand an extent of network analysis to optimise the system and minimise errors.

Generation estimation can be adversely affected by 'troublesome loads' connected to the non-generation feeders. The effect can be mitigated by the use of functions associated with reactive loads and sources which are described in the next section.

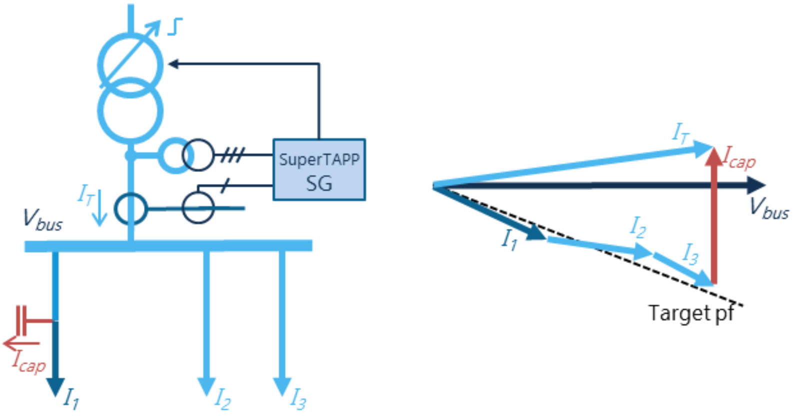
16.4.3 Reactive Loads and Sources

The presence of a load which varies significantly in power factor from the 'normal' (target) system power factor can cause the following issues:

- Voltage errors incurred by inaccurate LDC.
- Voltage errors incurred by inaccurate network circulating current control.
- Generator estimation errors.

Examples of such loads are capacitor banks, heavy industrial loads and embedded generators. Figure 2-59 shows the power factor effect of a capacitor bank.

Figure 2-59 Power factor effect of a capacitor bank



In order to solve these problems the relay has functions available which utilise feeder current measurements to calculate the 'true' load power factor as accurately as possible and thus minimise errors. There are options for how these current measurements are configured and used in the relay:

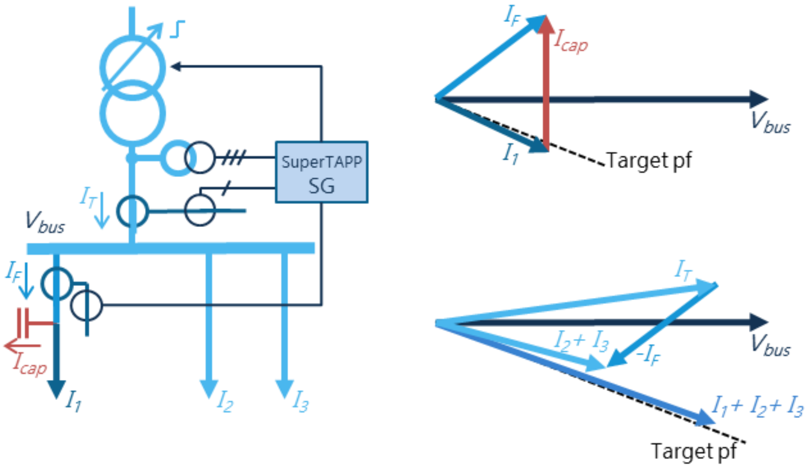
- Excluded Load
- Corrected Load

16.4.3.1 Excluded load

The simplest solution to power factor problems is to exclude the 'troublesome' load completely from the system as shown in Figure 2-60. The drawback of doing this is a reduced group load (c.f. the vectors I_2+I_3 and $I_1+I_2+I_3$), so care needs to be taken where LDC is applied that full boost is applied to the relay at an amended site capacity.

If the relay is configured for generator estimation, the load ratio calculation must exclude feeders configured as excluded loads.

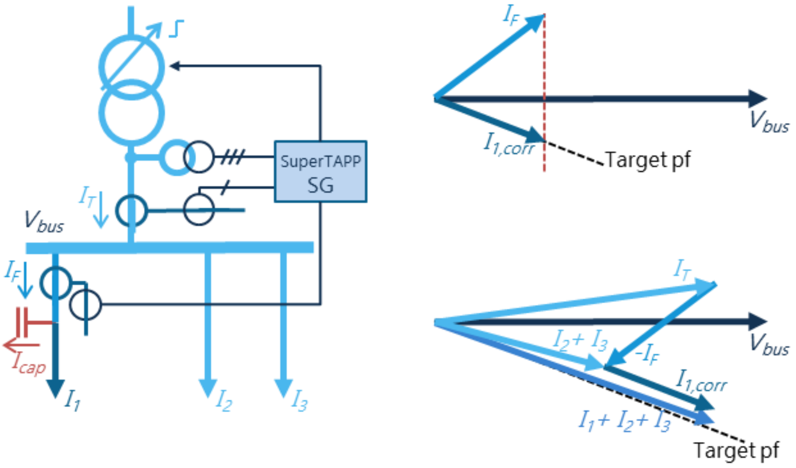
Figure 2-60 Load exclusion



16.4.3.2 Corrected load

This type is similar to the excluded load type considered above, except that instead of excluding the measured current, the measurement is ‘adjusted’ to the relay target power factor as shown in Figure 2-61.

Figure 2-61 Load correction



In this way, the voltage accuracy of the relay is not impaired by the troublesome load, and also the load information (if any) is maintained for LDC purposes.

If the relay is configured for generator estimation, the load ratio calculation must exclude feeders configured as corrected loads.

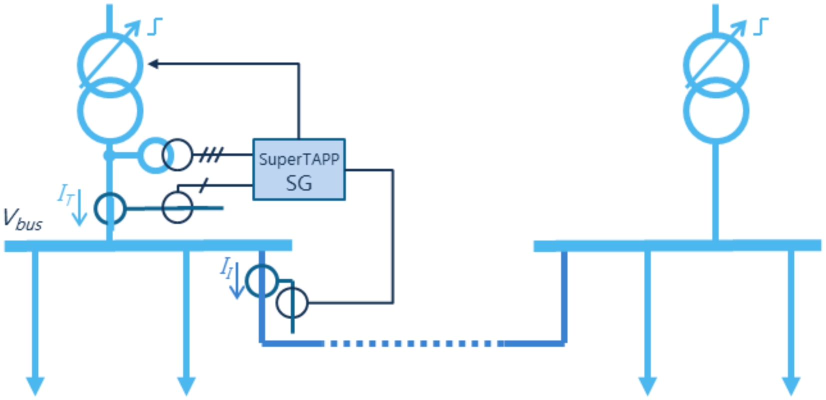
16.4.4 Special Applications

16.4.4.1 Interconnector

This type is used where it is not possible to calculate the summed loads using Inter-relay Communications, for instance if there is a strongly interconnected, but remote, parallel transformer.

The 'Interconnector' measurement enables the summed load calculation as shown in Figure 2-62.

Figure 2-62 Interconnector Measurement



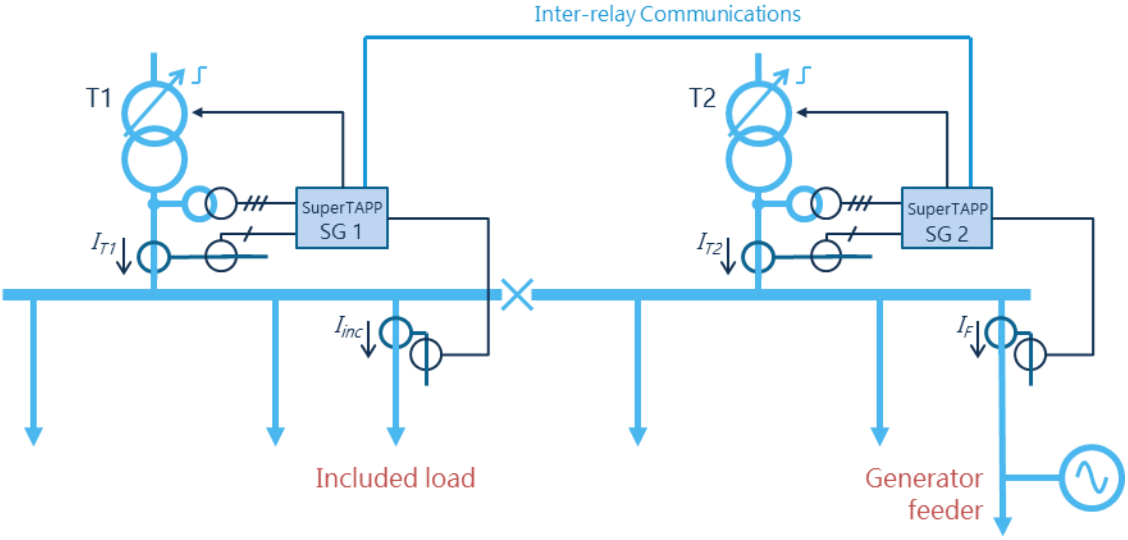
16.4.4.2 Included load

As presented earlier, the actual load on generator feeders can be calculated using the non-measured load and the load ratio setting according to the following for the example network shown in Figure 2-58:

Estimated load = Non-measured load x Load Ratio

In some situations it may be that the non-measured load is not truly representative of the load on the generator feeders. An alternative is to select the most representative feeder(s) to use to calculate the load on generator feeders. This is shown in Figure 2-63for the same example network.

Figure 2-63 Load Inclusion



The actual load on the generator feeder is now as follows:

Estimated load (as part of I_F) = I_{inc} x Load Ratio

This approach gives added flexibility to the application of generator estimation.

16.4.4.3 Monitor

This feeder measurement type is used for monitoring purposes only. The CT input measurements are displayed in the instruments and are available as SCADA measurands but are not used for any operational purposes.

1.1.1 VT Switching

Each current measurement requires a voltage reference for calculation of the real and reactive components. Normally this comes from the VT on the transformer which the relay uses for regulation.

Relays which are configured for feeder current measurements require an alternative voltage source to use as a reference for when the transformer to which it is connected is switched out (for maintenance etc.) and the regulation VT input is lost. It is possible to use the VT from another transformer (if available) for this use, where it is wired to the second VT input of the relay and configured as 'Busbar 2'. If no back-up voltage source is available, the feeder current measurement information will be lost during a transformer outage and a corresponding error message and alarm will result.

Figure 2-64 shows an example scheme where each relay uses the VT from the paralleled transformer as a back-up voltage reference. Table 2-18 shows how the voltage inputs are configured on each relay. Table 2-19 shows which voltage source is used on each relay according to the transformer status. The voltage level at which the voltage source switches from one VT input to another is 80% nominal.

Figure 2-64 Extra VT input from paralleled transformer

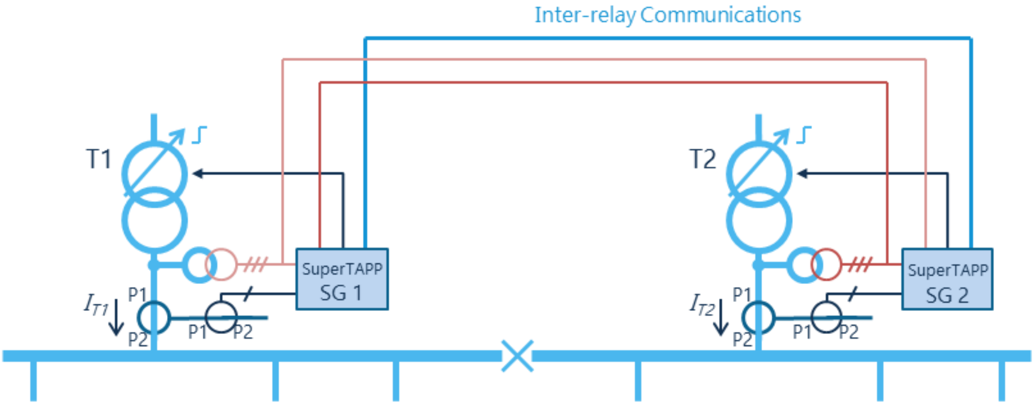


Table 2-18 Voltage input configurations

	SuperTAPP SG 1		**SuperTAPP SG 2**	
	Connected to	Which is connected to	Connected to	Which is connected to
Voltage Input 1 & 2	VT1 (T1 VT)	Transformer wdg 1 (T1)	VT1 (T2 VT)	Transformer wdg 1 (T2)
Voltage Input 3 & 4	VT2 (T2 VT)	Busbar 2	VT2 (T1 VT)	Busbar 1

Table 2-19 VT used for voltage reference

Active Transformers	**SuperTAPP SG 1 Voltage Ref**	**SuperTAPP SG 2 Voltage Ref**
T1 & T2	VT1 (T1 VT)	VT1 (T2 VT)
T1 only	VT1 (T1 VT)	VT2 (T1 VT)
T2 only	VT2 (T2 VT)	VT1 (T2 VT)

17 Settings List

Table 2-20 Voltage target settings

Setting	Range	Default	Section
Target voltage	90.0 – 110.0 %	100 %	15.1.1 (V_{basic})
Bandwidth	±0.5 – 10.0 %	±1.5 %	15.1.1 (V_{bw})
Bandwidth 2 type *	Off, Target change only, On	Off	15.1.1
Bandwidth 2 *	±0.0 – 5.0 %	±0.0 %	15.1.1
Initial tap time delay	10 – 120 s	60 s	15.1.1 (t_{init})
Fast tap	Disabled, Down, Up/down	Down	15.1.1
Fast tap threshold *	±0.5 – ±5.0 %	±2.0 %	15.1.1
Fast tap time delay *	3 – 120 s	5 s	15.1.1, 15.8.2
Generator bias *	0.0 – 10.0 %	0.0 %	15.5.2
LDC	0.0 – 20.0 %	5.0 %	15.1.2 (K_{LDC})
Reverse LDC *	Disabled, Enabled	Disabled	15.5.3
Winding 1 LDC rating	50 – 10000 A	1575 A	15.1.2 (I_{LR})
Winding 2 LDC rating *	50 – 10000 A	1575 A	15.1.2 (I_{LR})
Reverse LDC level *	Use fwd LDC, 0.0 – 20.0 %	0.0 %	15.5.4 (K_{VRC})
Wdg1 rev LDC rating *	Wdg1 fwd rating, 50 – 10000 A	Wdg1 fwd rating	15.1.2 (I_{RR})
Wdg2 rev LDC rating *	Wdg2 fwd rating, 50 – 10000 A	Wdg2 fwd rating	15.1.2 (I_{RR})
Voltage control mode	Enhanced TAPP, Master-follower	Enhanced TAPP	15.1.3.3
Follower delay *	3 – 60 s	5 s	15.1.3.3
Exclusive tapping *	Disabled, Enabled	Disabled	
Bottom tap tripping *	Disabled, Enabled	Disabled	15.9.4
Bottom tap trip timeout *	Disabled, 10 – 3600 s	Disabled	15.9.4
Min trip volt step size *	0 – 5.0 %	1.0 %	15.9.4

* These settings will not always be visible, depending on relay configuration

Table 2-21 Network settings

Setting	Range	Default	Section
Nominal system LV voltage	1.0 – 500.0 kV	11 kV	
Nominal system HV voltage	3.0 – 500.0 kV	33 kV	
Controlled voltage location *	LV, HV	LV	
Busbar location *	LV, HV	LV	
Network circ current factor	Disabled, 10 – 100 %	10 %	15.1.3.1 (K_{circ})
Phase rotation	Normal, Reverse	Normal	
Network power factor	0.50 lag – 1.00 – 0.90 lead	0.97 lag	15.1.3.1 (ϕ_{net})
Reverse power factor *	Use Network PF, 0.50 lag – 1.00 – 0.90 lead	Use Network PF	15.5.4

* These settings will not always be visible, depending on relay configuration

Table 2-22 Transformer settings

Setting	Range	Default	Section
Transformer ID	1 – 8	1	
Winding 1 rating	1.00 – 1000 MVA	30.0 MVA	
Winding 2 rating *	1.00 – 1000 MVA	30.0 MVA	
Winding 1 impedance	5.0 – 50.0 %	30.0 %	15.1.3.1 (Z_T)
Winding 2 impedance *	5.0 – 50.0 %	30.0 %	15.1.3.1 (Z_{T2})
Winding 1 source impedance	0.0 – 20.0 %	0.0 %	15.1.3.1 (Z_S)
Winding 2 source impedance *	0.0 – 20.0 %	0.0 %	15.1.3.1(Z_{S2})
Winding 1 bus section	1 – 15	1	15.4.6, 15.4.7
Winding 2 bus section *	1 – 15	2	15.4.6, 15.4.7
Tx nominal HV voltage	Nom sys HV volt, 3.0 – 500.0 kV	Nom sys HV volt	
Tx nominal LV voltage	Nom sys LV volt, 1.0 – 160.0 kV	Nom sys LV volt	
Top tap voltage	1000 - 599999 V	27337 V	
Bottom tap voltage	1000 - 599999 V	34888 V	
Tap changer location	LV, HV	HV	

* These settings will not always be visible, depending on relay configuration

Table 2-23 VTs & CTs settings

Setting	Range	Default	Section
Voltage input 1 submenu			
Connected to	Not used, VT1, VT2†, VT3†, VT4†	VT1	15.4.3
Phase	A-B, B-C, C-A, A-E, B-E, C-E	A-B	15.4.3
Reversed connection	No, Yes	No	15.4.3
Voltage input 2 submenu			
Connected to	Not used, VT1, VT2†, VT3†, VT4†	VT1	15.4.3
Phase	A-B, B-C, C-A, A-E, B-E, C-E	B-C	15.4.3
Reversed connection	No, Yes	No	15.4.3
Voltage input 3 to 8 submenus *			
Connected to *	Not used, VT1, VT2, VT3, VT4	Not used	15.4.3
Phase *	A-B, B-C, C-A, A-E, B-E, C-E	C-A	15.4.3
Reversed connection *	No, Yes	No	15.4.3
VT 1 submenu			
Ratio	1.0 – 500.0 kV : 50.0 – 130.0 V	11.0 kV : 110 V	15.4.3
Connected to *	Not used, Transformer wdg 1, Transformer wdg 2, Bus section 1 – 15	Transformer wdg 1	15.4.6
Location ‡	LV, HV	LV	
VT 2, VT 3 and VT 4 submenus *			
Ratio *	1.0 – 500.0 kV : 50.0 – 130.0 V	11.0 kV : 110 V	15.4.3
Connected to *	Not used, Transformer wdg 1, Transformer wdg 2, Bus section 1 – 15	Not used	15.4.6
Location ‡	LV, HV	LV	
Current input 1 submenu			
Function *	Unused, Transformer winding 1, Transformer winding 2, Generator, Generator feeder, Included for load ratio, Excluded load, Corrected load, Interconnector, Extra transformer, Monitor	Transformer winding 1	15.4.7
Number of interposer turns	1 – 25	5	15.4.4
Ratio	50 – 6000 A : 0.2, 0.5, 1.0, 2.0, 5.0 A	1600 A : 1.0 A	15.4.4
Phase	A, B, C	A	15.4.4

Fundamentals

Setting	Range	Default	Section
Connected to bus section ‡	1 – 15	1	15.4.7
Location ‡	LV, HV	LV	
Reversed connection	No, Yes	No	15.4.4
Function rating ‡	50 – 5000 A	500 A	15.4.7
Function coefficient ‡	0.0 – 100.0 %	10.0 %	15.4.7
Load ratio ‡	0 – 200 %	20 %	15.4.7
Current input 2 to current input 10 submenus *			
Function	Unused, Transformer winding 1, Transformer winding 2, Generator, Generator feeder, Included for load ratio, Excluded load, Corrected load, Interconnector, Extra transformer, Monitor	Unused	15.4.7
Number of interposer turns	1 – 25	5	15.4.4
Ratio	50 – 6000 A : 0.2, 0.5, 1.0, 2.0, 5.0 A	1600 A : 1 A	15.4.4
Phase	A, B, C	A	15.4.4
Connected to bus section ‡	1 – 15	1	15.4.7
Location ‡	LV, HV	LV	
Reversed connection	No, Yes	No	15.4.4
Function rating ‡	50 – 5000 A	500 A	15.4.7
Function coefficient ‡	0.0 – 100.0 %	10.0 %	15.4.7
Load ratio ‡	0 – 200 %	20 %	15.4.7
CT trim *			
Magnitude zero offset	-100 – +100 mAT	+14 mAT	15.4.9
Magnitude gradient	-5.00 – +5.00 %	-0.75 %	15.4.9
Angle correction 1	0.000–10.000 AT, -30.00 – +30.0°	0.060AT, -8.00°	15.4.9
Angle correction 2	0.000–10.000 AT, -30.00 – +30.0°	0.500AT, -2.00°	15.4.9
Angle correction 3	0.000–10.000 AT, -30.00 – +30.0°	2.500AT, +0.25°	15.4.9
Angle correction 4	0.000–10.000 AT, -30.00 – +30.0°	10.000AT,+1.50°	15.4.9

* This setting or submenu will not always be visible, depending on relay configuration

† These setting values will not always be visible, depending on relay configuration

‡ This setting will not always be visible, depending on the associated connection or function settings

Table 2-24 Voltage target adjustments settings

Setting	Range	Default	Section
Offset A1	-10.0 – +10.0 %	-3.0 %	15.8.1
Offset A2	-10.0 – +10.0 %	-6.0 %	15.8.1
Offset A3	-10.0 – +10.0 %	+3.0 %	15.8.1
Offset A4	-10.0 – +10.0 %	+1.5 %	15.8.1
Alarm limit for A offsets *	Use, Adjust, Ignore	Use	15.9.4
A off rqd for trip *	Not required, Required, With another offset	Not required	15.9.4
Offset B1 *	-10.0 – +10.0 %	-2.0 %	15.8.2
Offset B2 *	-10.0 – +10.0 %	-3.0 %	15.8.2
Offset B3 *	-10.0 – +10.0 %	-4.0 %	15.8.2
Offset B4 *	-10.0 – +10.0 %	-5.0 %	15.8.2
Offset B5 *	-10.0 – +10.0 %	+2.0 %	15.8.2
Offset B6 *	-10.0 – +10.0 %	+3.0 %	15.8.2
Offset B7 *	-10.0 – +10.0 %	+4.0 %	15.8.2
Offset B8 *	-10.0 – +10.0 %	+5.0 %	15.8.2
Offset group B reset time *	Disabled, 30 – 7200 s	900 s	15.8.2
Alarm limit for B offsets *	Use, Adjust, Ignore	Use	15.9.4
B off rqd for trip *	Not required, Required, With another offset	Not required	15.9.4
Target inc/dec step size *	0.5 – 3.0 %	1.0 %	15.8

* This setting or submenu will not always be visible, depending on relay configuration

Table 2-25 Tapchanger settings

Setting	Range	Default	Section
Tap changer operation submenu			
Inter tap time delay	Automatic, 5 – 120 s	Automatic	15.3.1
Tap pulse time *	Automatic, 0.50 – 5.00 s	Automatic	15.3
Tap operation time	2 – 120 s	5 s	15.3.1
Overcurrent limit	50 – 200 %	130 %	15.3.4
Reverse current limit	Disabled, 0 – -100 %	Disabled	15.3.4
Tap changer scheme	Basic, Step-by-step	Basic	15.3.5
Disable lockout for tap incomplete	No, Yes	No	15.3.4
Disable lockout for t/c runaway	No, Yes	No	15.3.4
Tap position indication submenu			
Number of tap positions	5 – 39	17	15.3.2
Minimum tap position	1 – 39	1	15.3.2
Maximum tap position	1 – 39	17	15.3.2
Tap position indicator type	Resistor, BCD, Gray code, Binary, Milliamp	Resistor	15.3.2
Number of consecutive transfer taps	0 – 3	0	15.3.2
Extra bottom rstor equiv to *	0.00 – 4.00 taps	0.00 taps	15.3.2
Extra top resistor equiv to *	0.00 – 4.00 taps	0.00 taps	15.3.2
TPI mA input value 1 *	Tap 0 - 39 : 0.0 - 25.0 mA	Tap 0:0.0 mA	15.3.2
TPI mA input value 2 *	Tap 0 - 39 : 0.0 - 25.0 mA	Tap 17:20.0 mA	15.3.2
Display	Winding ratio tap pos, Indicated TPI tap pos	Winding ratio tap pos	15.3.3
TPI customisation submenu			
TPI tap 1 : wdg ratio tap	1 – 39 , Xfer pos	1	15.3.3
TPI tap 2 : wdg ratio tap	1 – 39 , Xfer pos	2	15.3.3
TPI tap 3 : wdg ratio tap	1 – 39 , Xfer pos	3	15.3.3
TPI tap 4 : wdg ratio tap	1 – 39 , Xfer pos	4	15.3.3
TPI tap 5 : wdg ratio tap	1 – 39 , Xfer pos	5	15.3.3
TPI tap 6 : wdg ratio tap	1 – 39 , Xfer pos	6	15.3.3
TPI tap 7 : wdg ratio tap	1 – 39 , Xfer pos	7	15.3.3

Setting	Range	Default	Section
TPI tap 8 : wdg ratio tap	1 – 39 , Xfer pos	8	15.3.3
TPI tap 9 : wdg ratio tap	1 – 39 , Xfer pos	9	15.3.3
TPI tap 10 : wdg ratio tap	1 – 39 , Xfer pos	10	15.3.3
TPI tap 11 : wdg ratio tap	1 – 39 , Xfer pos	11	15.3.3
TPI tap 12 : wdg ratio tap	1 – 39 , Xfer pos	12	15.3.3
TPI tap 13 : wdg ratio tap	1 – 39 , Xfer pos	13	15.3.3
TPI tap 14 : wdg ratio tap	1 – 39 , Xfer pos	14	15.3.3
TPI tap 15 : wdg ratio tap	1 – 39 , Xfer pos	15	15.3.3
TPI tap 16 : wdg ratio tap	1 – 39 , Xfer pos	16	15.3.3
TPI tap 17 : wdg ratio tap	1 – 39 , Xfer pos	17	15.3.3
TPI tap 18 : wdg ratio tap	1 – 39 , Xfer pos	18	15.3.3
TPI tap 19 : wdg ratio tap	1 – 39 , Xfer pos	19	15.3.3
TPI tap 20 : wdg ratio tap	1 – 39 , Xfer pos	20	15.3.3
TPI tap 21 : wdg ratio tap	1 – 39 , Xfer pos	21	15.3.3
TPI tap 22 : wdg ratio tap	1 – 39 , Xfer pos	22	15.3.3
TPI tap 23 : wdg ratio tap	1 – 39 , Xfer pos	23	15.3.3
TPI tap 24 : wdg ratio tap	1 – 39 , Xfer pos	24	15.3.3
TPI tap 25 : wdg ratio tap	1 – 39 , Xfer pos	25	15.3.3
TPI tap 26 : wdg ratio tap	1 – 39 , Xfer pos	26	15.3.3
TPI tap 27 : wdg ratio tap	1 – 39 , Xfer pos	27	15.3.3
TPI tap 28 : wdg ratio tap	1 – 39 , Xfer pos	28	15.3.3
TPI tap 29 : wdg ratio tap	1 – 39 , Xfer pos	29	15.3.3
TPI tap 30 : wdg ratio tap	1 – 39 , Xfer pos	30	15.3.3
TPI tap 31 : wdg ratio tap	1 – 39 , Xfer pos	31	15.3.3
TPI tap 32 : wdg ratio tap	1 – 39 , Xfer pos	32	15.3.3
TPI tap 33 : wdg ratio tap	1 – 39 , Xfer pos	33	15.3.3
TPI tap 34 : wdg ratio tap	1 – 39 , Xfer pos	34	15.3.3
TPI tap 35 : wdg ratio tap	1 – 39 , Xfer pos	35	15.3.3
TPI tap 36 : wdg ratio tap	1 – 39 , Xfer pos	36	15.3.3
TPI tap 37 : wdg ratio tap	1 – 39 , Xfer pos	37	15.3.3
TPI tap 38 : wdg ratio tap	1 – 39 , Xfer pos	38	15.3.3
TPI tap 39 : wdg ratio tap	1 – 39 , Xfer pos	39	15.3.3

* This setting or submenu will not always be visible, depending on relay configuration

Table 2-26 Alarms settings

Setting	Range	Default	Section
Voltage high limit	90.0 – 125.0 %	110.0 %	15.3.4
Voltage low limit	75.0 – 110.0 %	90.0 %	15.3.4
Alarm time	Disabled, 180 – 900 s	300 s	15.3.4
Low volt inhibit level	50 – 90 %	80 %	15.3.4

Table 2-27 Network services settings

This menu and these settings and submenus will not always be visible, depending on relay configuration

Setting	Range	Default	Section
Tap stagger submenu			
Tap stagger reset time	Disabled, 30 – 7200 s	Disabled	15.9.2
Tap stagger controlled by	Current, Voltage	Current	15.9.2
Tap stagger 1 offset	0.0 – 50.0 %	5.0 %	15.9.2
Tap stagger 2 offset	0.0 – 50.0 %	10.0 %	15.9.2
Tap stagger 3 offset	0.0 – 50.0 %	15.0 %	15.9.2
Tap stagger 4 offset	0.0 – 50.0 %	20.0 %	15.9.2
Frequency based voltage offset submenu			
Volt offset F1 pickup freq	Disabled, 45.0 – 65.0 Hz	Disabled	15.8.4
Volt offset F1 dropoff freq	45.0 – 65.0 Hz, Disabled	46.00 Hz	15.8.4
Volt offset F1 pickup delay	0 – 7200 s	60 s	15.8.4
Volt offset F1 reset time	Disabled, 30 – 7200 s	60 s	15.8.4
Volt offset F1 offset	-10.0 – +10.0 %	-3.0 %	15.8.4
Alarm limit for F offsets	Use, Adjust, Ignore	Use	15.9.4
F off rqd for trip	Not required, Required, With another offset	Not required	15.9.4
Load based voltage offset submenu			
Load offset capacity	1.0 – 1000.0 MVA	30.0 MVA	15.8.3
Volt offset L1 pickup load	50.0 – 200.0 %, Disabled	Disabled	15.8.3
Volt offset L1 dropoff load	50.0 – 200.0 %	90.0 %	15.8.3
Volt offset L1 reset delay	0 – 3600 s	900 s	15.8.3
Volt offset L1 voltage offset	-10.0 – +10.0 %	-5.0 %	15.8.3
Alarm limit for L offsets	Use, Adjust, Ignore	Use	15.9.4
Frequency based tripping submenu			
Pickup frequency 1	Disabled, 45.00 – 65.00 Hz	Disabled	15.9.3

Setting	Range	Default	Section
Pickup frequency 2	Disabled, 45.00 – 65.00 Hz	Disabled	15.9.3
Pickup frequency 3	Disabled, 45.00 – 65.00 Hz	Disabled	15.9.3
Pickup frequency 4	Disabled, 45.00 – 65.00 Hz	Disabled	15.9.3
Activation delay 1	0.00 – 1800.00 s (step 0.25 s)	15.00 s	15.9.3
Activation delay 2	0.00 – 1800.00 s (step 0.25 s)	15.00 s	15.9.3
Activation delay 3	0.00 – 1800.00 s (step 0.25 s)	15.00 s	15.9.3
Activation delay 4	0.00 – 1800.00 s (step 0.25 s)	15.00 s	15.9.3
Activation reset time	2.00 – 1800.00 s (step 0.25 s)	30.00 s	15.9.3

Table 2-28 Thermal management

Setting	Range	Default	Section
General thermal characteristc submenu			
Loss ratio R at nominal tap	1.00 – 20.00	Current	
Buttm tap loss ratio Rmin use nom	Use nom tap R, 1.00 – 20.00	5.0 %	
Top tap loss ratio Rmax use nom	Use nom tap R, 1.00 – 20.00	10.0 %	
Short term forecast time	10 min – 180 min	15.0 %	15.10.6
Thermally upgraded paper insulation	No, Yes	20.0 %	
ONAN thermal characteristic submenu			
Oil exponent x	0.50 – 2.00	0.80	
Winding exponent y	1.00 – 2.50	1.30	
Constant k11	0.20 – 2.00	0.50	
Constant k21	0.50 – 5.00	2.00	
Constant k22	0.50 – 2.50	2.00	
Oil time constant τo	30 min – 360 min	210 min	
Winding time constant τw	1.00 min – 30.00 min	10.00 min	
Oil temperature rise	0.0 K – 100.0 K	52.0 K	
Winding temperature rise Δϴhr	0.0 K – 50.0 K	26.0 K	
Thermal rating 50% of wdg rating	10 % of wdg rating set – 200 % of wdg rating set	50 % of wdg rating set	

Setting	**Range**	**Default**	**Section**
ONAF thermal characteristic submenu			
Oil exponent x	0.50 – 2.00	0.80	
Winding exponent y	1.00 – 2.50	1.30	
Constant k11	0.20 – 2.00	0.50	
Constant k21	0.50 – 5.00	2.00	
Constant k22	0.50 – 2.50	2.00	
Oil time constant τo	30 min – 360 min	150 min	
Winding time constant τw	1.00 min – 30.00 min	7.00 min	
Oil temperature rise Δθor	0.0 K – 100.0 K	52.0 K	
Winding temperature rise Δθhr	0.0 K – 50.0 K	26.0 K	
Thermal rating 50% of wdg ratnig	10 % of wdg rating set – 200 % of wdg rating set	70 % of wdg rating set	
OF thermal characteristic submenu			
Oil exponent x	0.50 – 2.00	1.00	
Winding exponent y	1.00 – 2.50	1.30	
Constant k11	0.20 – 2.00	1.00	
Constant k21	0.50 – 5.00	1.30	
Constant k22	0.50 – 2.50	1.00	
Oil time constant τo	30 min – 360 min	90 min	
Winding time constant τw	1.00 min – 30.00 min	7.00 min	
Oil temperature rise Δθor	0.0 K – 100.0 K	56.0 K	
Winding temperature rise Δθhr	0.0 K – 50.0 K	22.0 K	
Thermal rating 50% of wdg rating	10 % of wdg rating set – 200 % of wdg rating set	100 % of wdg rating set	
General alarm submenu			
Oil/tap chg temp hysteresis	1 °C - 20 °C	5 °C	15.10.6
Winding temp hysteresis	1 °C - 20 °C	5 °C	15.10.6
Cooling effectiveness limit	Disabled, 10 °C - 50 °C	Disabled	
H1 alarm submenu			
Oil temperature threshold	Disabled, 70 °C - 180 °C	Disabled	15.10.8
Winding temperature threshold	Disabled, 70 °C - 180 °C	Disabled	15.10.8
Tapchanger temperature threshold	Disabled, 70 °C - 120 °C	Disabled	15.10.8
Oil temp delay	0 min – 30 min	0 min	15.10.8

Setting	Range	Default	Section
Winding temp delay	0 min – 30 min	0 min	15.10.8
Tapchanger temp delay	0 min – 30 min	0 min	15.10.8
H2 alarm submenu			
Oil temperature threshold	Disabled, 70 °C - 180 °C	Disabled	15.10.8
Winding temperature threshold	Disabled, 70 °C - 180 °C	Disabled	15.10.8
Tapchanger temperature threshold	Disabled, 70 °C - 120 °C	Disabled	15.10.8
Oil temp delay	0 min – 30 min	0 min	15.10.8
Winding temp delay	0 min – 30 min	0 min	15.10.8
Tapchanger temp delay	0 min – 30 min	0 min	15.10.8
General cooling sequences submenu			
Oil temp hysteresis	1 °C - 20 °C	5 °C	15.10.6
Winding temp hysteresis	1 °C - 20 °C	5 °C	15.10.6
Max pump runtime	Disabled, 1 hr – 48 hr	Disabled	15.10.6
Max fan runtime	Disabled, 1 hr – 48 hr	Disabled	15.10.6
Periodic day of the week	Disabled, Sun, Mon, Tues, Wed, Thur, Fri, Sat, Every day	Disabled	15.10.7
Periodic time of the day	0 – 23:0 - 59	0:0	15.10.7
Periodic run number of pumps	0 - 12	0	15.10.7
Periodic run number of fans	0 - 12	0	15.10.7
Periodic run pump runtime	1 min – 120 min	30 min	15.10.7
Periodic run fan runtime	1 min – 120 min	30 min	15.10.7
C1 Cooling stage submenu			
Number of pumps	0 - 12	0	15.10.6
Number of fans	0 - 12	0	15.10.6
Ambient temperature threshold	Disabled, 20 °C - 70 °C	Disabled	15.10.6
Oil temperature threshold	Disabled, 50 °C - 200 °C	Disabled	15.10.6
Winding temperature threshold	Disabled, 50 °C - 200 °C	Disabled	15.10.6
Forecast oil temp threshold	Disabled, 50 °C - 200 °C	Disabled	15.10.6
Forecast wdg temp threshold	Disabled, 50 °C - 200 °C	Disabled	15.10.6
Final oil temp threshold	Disabled, 50 °C - 200 °C	Disabled	15.10.6
Final wdg temp threshold	Disabled, 50 °C - 200 °C	Disabled	15.10.6
Active L1 voltage offset	No, Yes	No	15.10.6

Setting	Range	Default	Section
C2 Cooling stage submenu			
Number of pumps	0 - 12	0	15.10.6
Number of fans	0 - 12	0	15.10.6
Ambient temperature threshold	Disabled, 20 °C - 70 °C	Disabled	15.10.6
Oil temperature threshold	Disabled, 50 °C - 200 °C	Disabled	15.10.6
Winding temperature threshold	Disabled, 50 °C - 200 °C	Disabled	15.10.6
Forecast oil temp threshold	Disabled, 50 °C - 200 °C	Disabled	15.10.6
Forecast wdg temp threshold	Disabled, 50 °C - 200 °C	Disabled	15.10.6
Final oil temp threshold	Disabled, 50 °C - 200 °C	Disabled	15.10.6
Final wdg temp threshold	Disabled, 50 °C - 200 °C	Disabled	15.10.6
Active L1 voltage offset	No, Yes	No	15.10.6
C3 Cooling stage submenu			
Number of pumps	0 - 12	0	15.10.6
Number of fans	0 - 12	0	15.10.6
Ambient temperature threshold	Disabled, 20 °C - 70 °C	Disabled	15.10.6
Oil temperature threshold	Disabled, 50 °C - 200 °C	Disabled	15.10.6
Winding temperature threshold	Disabled, 50 °C - 200 °C	Disabled	15.10.6
Forecast oil temp threshold	Disabled, 50 °C - 200 °C	Disabled	15.10.6
Forecast wdg temp threshold	Disabled, 50 °C - 200 °C	Disabled	15.10.6
Final oil temp threshold	Disabled, 50 °C - 200 °C	Disabled	15.10.6
Final wdg temp threshold	Disabled, 50 °C - 200 °C	Disabled	15.10.6
Active L1 voltage offset	No, Yes	No	15.10.6

Table 2-29 Binary inputs submenu

Setting	Range	Default	Section
Invert input	1 – no. of inputs fitted		15.11.3
Reject AC input	1 – no. of inputs fitted		15.11.3
SCADA auto ctrl	1 – no. of inputs fitted		15.2.2
SCADA manual ctrl	1 – no. of inputs fitted		15.2.2
SCADA raise tap	1 – no. of inputs fitted		15.2.2
SCADA lower tap	1 – no. of inputs fitted		15.2.2
Wdg 1 prep sw/out set	1 – no. of inputs fitted		15.9.1

Setting	Range	Default	Section
Wdg 1 prep sw/out rst	1 – no. of inputs fitted		15.9.1
Wdg 2 prep sw/out set *	1 – no. of inputs fitted		15.9.1
Wdg 2 prep sw/out rst *	1 – no. of inputs fitted		15.9.1
Tap block	1 – no. of inputs fitted		15.3.4
Volt target offset A1	1 – no. of inputs fitted		15.8.1
Volt target offset A2	1 – no. of inputs fitted		15.8.1
Volt target offset A3	1 – no. of inputs fitted		15.8.1
Volt target offset A4	1 – no. of inputs fitted		15.8.1
Volt target offset B1 *	1 – no. of inputs fitted		15.8.2
Volt target offset B2 *	1 – no. of inputs fitted		15.8.2
Volt target offset B3 *	1 – no. of inputs fitted		15.8.2
Volt target offset B4 *	1 – no. of inputs fitted		15.8.2
Volt target offset B5 *	1 – no. of inputs fitted		15.8.2
Volt target offset B6 *	1 – no. of inputs fitted		15.8.2
Volt target offset B7 *	1 – no. of inputs fitted		15.8.2
Volt target offset B8 *	1 – no. of inputs fitted		15.8.2
Volt target increment	1 – no. of inputs fitted		15.8
Volt target decrement	1 – no. of inputs fitted		15.8
Target inc/dec reset	1 – no. of inputs fitted		15.8
Volt offset L1 enable *	1 – no. of inputs fitted		15.8.3
Volt offset F1 enable *	1 – no. of inputs fitted		15.8.4
Freq. trip enable *	1 – no. of inputs fitted		15.9.3
Freq. trip activate *	1 – no. of inputs fitted		15.9.3
Tap stagger S1 activate *	1 – no. of inputs fitted		15.9.2
Tap stagger S2 activate *	1 – no. of inputs fitted		15.9.2
Tap stagger S3 activate *	1 – no. of inputs fitted		15.9.2
Tap stagger S4 activate *	1 – no. of inputs fitted		15.9.2
Alt settings group 1	1 – no. of inputs fitted		6.2, 15.10.3
Alt settings group 2	1 – no. of inputs fitted		6.2, 15.10.3
Alt settings group 3	1 – no. of inputs fitted		6.2, 15.10.3
Alt settings group 4	1 – no. of inputs fitted		6.2, 15.10.3
Alt settings group 5	1 – no. of inputs fitted		6.2, 15.10.3
Alt settings group 6	1 – no. of inputs fitted		6.2, 15.10.3
Alt settings group 7	1 – no. of inputs fitted		6.2, 15.10.3
Alt settings group 8	1 – no. of inputs fitted		6.2, 15.10.3

Setting	Range	Default	Section
Increment setting grp	1 – no. of inputs fitted		
Decrement setting grp	1 – no. of inputs fitted		
T/C motor overload	1 – no. of inputs fitted		
Winding 1 CB closed	1 – no. of inputs fitted		
Winding 2 CB closed *	1 – no. of inputs fitted		
Busbar CB 1 closed *	1 – no. of inputs fitted		15.6
Busbar CB 2 closed *	1 – no. of inputs fitted		15.6
Busbar CB 3 closed *	1 – no. of inputs fitted		15.6
Busbar CB 4 closed *	1 – no. of inputs fitted		15.6
Busbar CB 5 closed *	1 – no. of inputs fitted		15.6
Busbar CB 6 closed *	1 – no. of inputs fitted		15.6
Busbar CB 7 closed *	1 – no. of inputs fitted		15.6
Busbar CB 8 closed *	1 – no. of inputs fitted		15.6
Block EVR CB trip *	1 – no. of inputs fitted		15.9.4
Block EVR CB reclose *	1 – no. of inputs fitted		15.9.4
Select master *	1 – no. of inputs fitted		15.1.3.3
Timer 1	1 – no. of inputs fitted		15.11.8
Timer 2	1 – no. of inputs fitted		15.11.8
Timer 3	1 – no. of inputs fitted		15.11.8
Cooling pumps running *	1 – no. of inputs fitted		15.10
Cooling fans running *	1 – no. of inputs fitted		15.10

* This setting will not always be visible, depending on relay configuration

Table 2-30 Binary outputs submenu

Setting	Range	Default	Section
Invert output	1 – no. of outputs fitted		
Relay healthy	1 – no. of outputs fitted		
Relay enabled	1 – no. of outputs fitted		15.2.1
Relay in SCADA	1 – no. of outputs fitted		15.2.2
Relay in auto	1 – no. of outputs fitted		15.2.2
VT fuse failure	1 – no. of outputs fitted		15.3.4
Ready for switch out	1 – no. of outputs fitted		15.9.1
Preparing for sw/out	1 – no. of outputs fitted		15.9.1
End of tap range	1 – no. of outputs fitted		15.3.4
Tap not achievable	1 – no. of outputs fitted		15.3.4

Setting	Range	Default	Section
TPI failure	1 – no. of outputs fitted		
T/C motor overload	1 – no. of outputs fitted		
CAN bus failure	1 – no. of outputs fitted		15.3.4
Data logging alarm	1 – no. of outputs fitted		
Comms card failure	1 – no. of outputs fitted		
Comms link lost alarm	1 – no. of outputs fitted		
Overload alarm	1 – no. of outputs fitted		15.3.4
Reverse current alarm	1 – no. of outputs fitted		
Voltage high alarm	1 – no. of outputs fitted		15.3.4
Voltage low alarm	1 – no. of outputs fitted		15.3.4
Phase reference alarm	1 – no. of outputs fitted		15.3.4
Volt out of band alarm	1 – no. of outputs fitted		15.3.4
Tap changer runaway	1 – no. of outputs fitted		15.3.4
Tap incomplete	1 – no. of outputs fitted		15.3.4
Invalid CB status signal *	1 – no. of outputs fitted		
Auto BB group warning	1 – no. of outputs fitted		15.6
Parallel operation	1 – no. of outputs fitted		
Volt target offset A1	1 – no. of outputs fitted		15.8.1
Volt target offset A2	1 – no. of outputs fitted		15.8.1
Volt target offset A3	1 – no. of outputs fitted		15.8.1
Volt target offset A4	1 – no. of outputs fitted		15.8.1
Volt target offset B1	1 – no. of outputs fitted		15.8.2
Volt target offset B2	1 – no. of outputs fitted		15.8.2
Volt target offset B3	1 – no. of outputs fitted		15.8.2
Volt target offset B4	1 – no. of outputs fitted		15.8.2
Volt target offset B5	1 – no. of outputs fitted		15.8.2
Volt target offset B6	1 – no. of outputs fitted		15.8.2
Volt target offset B7	1 – no. of outputs fitted		15.8.2
Volt target offset B8	1 – no. of outputs fitted		15.8.2
Load offset L1 active *	1 – no. of outputs fitted		
Volt offset F1 active *	1 – no. of outputs fitted		
Wdg 1 CB trip *	1 – no. of outputs fitted		15.9.3
Wdg 1 CB close *	1 – no. of outputs fitted		15.9.3
Wdg 2 CB trip *	1 – no. of outputs fitted		15.9.3
Wdg 2 CB close *	1 – no. of outputs fitted		15.9.3

Setting	Range	Default	Section
Master *	1 – no. of outputs fitted		15.1.3.3
Out of step alarm *	1 – no. of outputs fitted		15.1.3.3
Timer 1	1 – no. of outputs fitted		15.11.8
Timer 2	1 – no. of outputs fitted		15.11.8
Timer 3	1 – no. of outputs fitted		15.11.8
Cooling pumps *	1 – no. of outputs fitted		15.10
Cooling fans *	1 – no. of outputs fitted		15.10
Thermal alarm H1 *	1 – no. of outputs fitted		15.10
Thermal alarm H2 *	1 – no. of outputs fitted		15.10
mA/Pt100 faulty alarm *	1 – no. of outputs fitted		15.10
Cooling device fault *	1 – no. of outputs fitted		15.10

* This setting will not always be visible, depending on relay configuration

Table 2-31 Milliamp and Pt100 inputs submenu

Setting	Range	Default	Section
Ambient temperature	mA input 1, mA input 2, Pt100 1, Pt100 2, Pt100 3	Unused	15.11.5
Oil temperature	mA input 1, mA input 2, Pt100 1, Pt100 2, Pt100 3	Unused	15.11.5
Winding temperature	mA input 1, mA input 2, Pt100 1, Pt100 2, Pt100 3	Unused	15.11.5
Tapchanger temperature	mA input 1, mA input 2, Pt100 1, Pt100 2, Pt100 3	Unused	15.11.5

Table 2-32 Milliamp outputs submenu

Setting	Range	Default	Section
Output 1 function	Unused, Fixed output, Tap position, Effective target V, Measured voltage, Tx real power, Tx reactive power, Tx apparent power, mA input 1 - 2†, Pt100†, Basic target V, Wdg1 - 2 current	Tap position	15.10.6
Output 2 function *	Unused, Fixed output, Tap position, Effective target V, Measured voltage, Tx real power, Tx reactive power, Tx apparent	Unused	15.10.6

Setting	Range	Default	Section
	power, mA input 1 - 2†, Pt100†, Basic target V, Wdg1 - 2 current		
Output 3 function *	Unused, Fixed output, Tap position, Effective target V, Measured voltage, Tx real power, Tx reactive power, Tx apparent power, mA input 1 - 2†, Pt100†, Basic target V, Wdg1 - 2 current	Unused	15.10.6
Output 4 function *	Unused, Fixed output, Tap position, Effective target V, Measured voltage, Tx real power, Tx reactive power, Tx apparent power, mA input 1 - 2†, Pt100†, Basic target V, Wdg1 - 2 current	Unused	15.10.6
Fixed output ‡	0.0 – 24.0 mA	10.0 mA	15.10.6
Tap position val 1 ‡	Tap 0 - 39 : 0.0 - 24.0 mA	Tap 0 : 0.0 mA	15.10.6
Tap position val 2 ‡	Tap 0 - 39 : 0.0 - 24.0 mA	Tap 17 : 20.0mA	15.10.6
Effctiv target voltage val 1 ‡	0.0 - 140.0 % : 0.0 - 24.0 mA	80% : 0.0mA	15.10.6
Effctiv target voltage val 2 ‡	0.0 - 140.0 % : 0.0 - 24.0 mA	120% : 20.0mA	15.10.6
Meas voltage val 1 ‡	0.0 - 140.0 % : 0.0 - 24.0 mA	80% : 0.0mA	15.10.6
Meas voltage val 2 ‡	0.0 - 140.0 % : 0.0 - 24.0 mA	120% : 20.0mA	15.10.6
Tx real pwr val 1 ‡	-320.00 - +320.00 MW : 0.0 - 24.0 mA	-30.00 MW : 0.0 mA	15.10.6
Tx real pwr val 2 ‡	-320.00 - +320.00 MW : 0.0 - 24.0 mA	+30.00 MW : 20.0 mA	15.10.6
Tx rctv pwr val 1 ‡	-320.00 - +320.00 Mvar : 0.0 - 24.0 mA	-30.00 Mvar : 0.0 mA	15.10.6
Tx rctv pwr val 2 ‡	-320.00 - +320.00 Mvar : 0.0 - 24.0 mA	+30.00 Mvar : 20.0 mA	15.10.6

Setting	Range	Default	Section
Tx apnt pwr val 1 ‡	0.00 - 320.00 MVA : 0.0 - 24.0 mA	0.00 MVA : 0.0 mA	15.10.6
Tx apnt pwr val 2 ‡	0.00 - 320.00 MVA : 0.0 - 24.0 mA	30.00 MVA : 20.0 mA	15.10.6
mA Input 1 val 1 ‡	-25.0 - +25.0 mA : 0.0 - 24.0 mA	0.0 mA : 0.0 mA	
mA Input 1 val 2 ‡	-25.0 - +25.0 mA : 0.0 - 24.0 mA	+20.0 mA : 20.0 mA	
mA Input 2 val 1 ‡	-25.0 - +25.0 mA : 0.0 - 24.0 mA	0.0 mA : 0.0 mA	
mA Input 2 val 2 ‡	-25.0 - +25.0 mA : 0.0 - 24.0 mA	+20.0 mA : 20.0 mA	
Pt100 val 1 ‡	-50.0 - +200.0 °C : 0.0 - 24.0 mA	0.0 °C : 0.0 mA	
Pt100 val 2 ‡	-50.0 - +200.0 °C : 0.0 - 24.0 mA	+100.0 °C : 20.0 mA	
Wdg current val 1 ‡	0 - 6000 A : 0.0 - 24.0 mA	0 A : 0.0 mA	
Wdg current val 2 ‡	0 - 6000 A : 0.0 - 24.0 mA	1600 A : 20.0 mA	

* This setting or submenu will not always be visible, depending on relay configuration

‡ This setting is only visible if the relevant output function is selected

† These setting values will not always be visible, depending on relay configuration

Table 2-33 Timer delays submenu

This setting menu will not always be visible, depending on relay configuration

Setting	Range	Default	Section
Timer1 pickup delay	0 – 240 s	60 s	15.11.8
Timer1 dropoff delay	0 – 240 s	60 s	15.11.8
Timer2 pickup delay	0 – 240 s	60 s	15.11.8
Timer2 dropoff delay	0 – 240 s	60 s	15.11.8
Timer3 pickup delay	0 – 240 s	60 s	15.11.8
Timer3 dropoff delay	0 – 240 s	60 s	15.11.8

Table 2-34 Busbar grouping menu

Setting	Range	Default	Section
Busbar grouping ctrled by	Settings *, CB statuses †, Automatic ⌂	CB statuses	15.6
Bus section 1 is in busbar group *‡	A – O	A	15.6
Bus section 2 is in busbar group *‡	A – O	B	15.6
…			
Bus section 15 is in busbar group *‡	A – O	O	15.6
CB 1 connects bus sections †	1 and 1 – 15 and 15	1 and 1	15.6
CB 2 connects bus sections †	1 and 1 – 15 and 15	2 and 2	15.6
…			
CB 8 connects bus sections †	1 and 1 – 15 and 15	8 and 8	15.6

*,† The setting identified by the symbol is only visible if the setting value identified by the same symbol is selected

‡ This setting is only visible if a transformer winding or feeder measurement is allocated to the bus section

⌂ This setting value will not always be visible, depending on relay configuration

Table 2-35 Communications menu

This setting menu will not always be visible, depending on relay configuration

Setting	Range	Default	Section
Enabled protocol	IEC 61850, IEC 60870-5-103 [1], DNP3 [2]	DNP3	15.12.2
Station address [1,2]	0 - 65519	0	15.12.2
Destination address [2]	0 - 65519	1	15.12.2
Allow unsolicited msgs [2]	No, Yes	No	
Comms medium [2]	Serial †, Ethernet ‡	Ethernet	15.12.2
Baud rate †	2400, 4800, 9600, 19200, 38400, 57600, 115200	9600	15.12.2
Parity †	None, Even, Odd	None	15.12.2
PRP ‡	Disabled ⌂, Enabled	Disabled	15.12.2
Ethernet 0 IP address ‡	0.0.0.0 – 255.255.255.255	192.168.1.228	15.12.2
Ethernet 0 netmask ‡	0.0.0.0 – 255.255.255.255	255.255.255.0	15.12.2
Ethernet 0 gateway ‡	0.0.0.0 – 255.255.255.255	192.168.1.1	15.12.2
Ethernet 1 IP address ‡ ⌂	0.0.0.0 – 255.255.255.255	192.168.2.229	15.12.2

Ethernet 1 netmask [‡] [⌂]	0.0.0.0 – 255.255.255.255	255.255.255.0	15.12.2
Time source [‡]	Master, SNTP	Master	15.12.2
SNTP IP address [‡]	0.0.0.0 – 255.255.255.255	192.168.10.2	15.12.2
Time sync interval	Disabled, 60 - 7200 s	3600 s	15.12.2
Voltage dead band	0.1 – 2.0 %	0.5 %	
Current dead band	0.2 – 5.0 %	1.0 %	
Power dead band	0.2 – 5.0 %	1.0 %	
Frequency dead band	3 – 100 mHz	10 mHz	

[†], [‡], [⌂], [1], [2] The setting identified by the symbol is only visible if the setting value identified by the same symbol is selected

> Note. The settings in this table are not applied until 'APPLY' is selected from the bottom of the settings menu. At this point the settings will be applied and the communications card restarted.

Table 2-38 Communications link monitoring menu

This setting menu will not always be visible, depending on relay configuration

Setting	**Range**	**Default**	**Section**
Lost comms link timeout	15 – 3600 s	60 s	
Change to settings group	Disabled, 1 – 8	Disabled	
Reset setpoints	Disabled, Enabled	Disabled	
Deactivate A offsets	Disabled, Enabled	Disabled	
Deactivate B offsets *	Disabled, Enabled	Disabled	
Disable frequency offsets *	Disabled, Enabled	Disabled	
Disable frequency tripping *	Disabled, Enabled	Disabled	
Disable load based offsets *	Disabled, Enabled	Disabled	
Deactivate tap stagger *	Disabled, Enabled	Disabled	

* This setting will not always be visible, depending on relay configuration

Table 2-36 Relay configuration menu

Setting	Range	Default	Section
Enter password [†]	A-Z, a-z. 0-9, _		
Edit password [†]	A-Z, a-z. 0-9, _		
Log out [†]	No, Yes	No	
Reset password code [†]	00000000 – FFFFFFFF		
Relay name *	A-Z, a-z. 0-9, _	SuperTAPP	
Time			
Date			
Time zone offset from GMT [‡]	-15.00 – +15.00 hours	0.00 hours	
Data logging interval	1 s, 2 s, 5 s, 10 s, 15 s, 20 s, 30 s, 60 s	1 s	
Backlight timeout	5 – 60 min	10 min	
Advanced relay code	00000000 – FFFFFFFF	00000000	
Communications watchdog [‡]	Enabled, Disabled	Enabled	
Restart relay	No, Yes	No	n/a
Reset CAN data	No, Yes	No	n/a
Restore default settings	No, Yes	No	n/a
Reconfigure HW and reset settings	No, Yes	No	n/a
Upgrade software	No, Yes	No	n/a
Upgrade communications software [‡]	No, Yes	No	n/a

* Only if no SCADA communications fitted

[†] These settings are shown depending on whether a valid password has been set or entered.

[‡] Only if SCADA communications fitted

Table 2-37 Commissioning menu

Setting	Range	Default	Section
Active settings group	1 – 8	1	n/a
Wdg 1 start prepare for switchout	No, Yes	No	n/a
Wdg 1 cancel prepare for switchout	No, Yes	No	n/a
Wdg 2 start prepare for switchout *	No, Yes	No	n/a
Wdg 2 cancel prepare for switchout *	No, Yes	No	n/a
Reset inc/dec offset *	No, Yes	No	n/a
Volt target offset B1 *	Off, On	Off	n/a
Volt target offset B2 *	Off, On	Off	n/a
Volt target offset B3 *	Off, On	Off	n/a
Volt target offset B4 *	Off, On	Off	n/a
Volt target offset B5 *	Off, On	Off	n/a
Volt target offset B6 *	Off, On	Off	n/a
Volt target offset B7 *	Off, On	Off	n/a
Volt target offset B8 *	Off, On	Off	n/a

* This setting will not always be visible, depending on relay configuration

18 Specifications

18.1 General

18.1.1 Legal Requirements

European Union

Conformity	Reference
Low Voltage Directive	2014/35/EU
Electromagnetic Compatibility Directive	2014/30/EU
Batteries and Accumulators Directive	2013/56/EU
Restriction of Hazardous Substances Directive	2011/65/EU

SuperTAPP SG is CE marked.

18.1.2 Product Standards

Standard		Reference
Measuring relays and protection equipment	Electromagnetic compatibility requirements	BS EN 60255-26:2013 (IEC 60255-26:2013)
	Product safety requirements	BS EN 60255-27:2014 (IEC 60255-27:2013)

18.1.3 Industry Standards

Standard	Reference
ENA Environmental test requirements for protection and control equipment and systems	Technical Specification 48-5 (Issue 4 2015)
ENA Protection Assessment Functional Test Requirements – Voltage and Frequency Protection	Technical Specification 48-6-5 (Issue 1 2005) section 2.2

18.1.4 Reference Conditions

Specification	Levels
Ambient temperature	20 °C
Energising quantities	Nominal (unless specified)
Frequency	50 Hz

18.1.5 Operating Environment

Specification	Levels
Environmental level	Zone A, severe electrical environment
Overvoltage category	III
Pollution degree	2
Insulation class	1 (equipment must be earthed)

18.2 Functional Characteristics

18.2.1 Functional Accuracy

Characteristic	Accuracy
Timers	±250 ms
Frequency	±0.05 Hz
Frequency response	400 ms *

* hardware version 02 onwards

18.2.2 Communications

Characteristic	Specification
Physical layer options	RS485 over serial twisted pair, ethernet 100base-T, ethernet 100base-F
Data link layer options	RS485, TCP/IP
Application layer options	IEC 61850, DNP3, IEC 60870-5-103

18.3 Electrical Characteristics

18.3.1 Energising and Output Quantities

Port		Nominal[‡]	Operating Range	Withstand	Burden	Accuracy
Auxiliary supply	(type A)	Vx = 110/230 V ~	87.5-260 V ~ 47-63 Hz ~	300 V ≈	< 30/50 VA *	–
		Vx = 110 V ⎓	87.5-132 V ⎓		< 15/25 W *	
	(type B)	Vx = 24/48 V ⎓	18 V-72 V ⎓	75 V ≈	< 15/25 W *	
Tapchanger interface		110/230[†] V ≈	87.5-260[†] V ≈ 45-63 Hz ~	300[†] V ≈	–	–
Voltage inputs		Vn = 63.5/110 V ~	0-145 V ~ 45-65 Hz ~	264 V ~ cont. 300 V ~ 1 s	< 1 VA (across op. range)	±0.5% (80%-120% Vn)
Current inputs		5 mA ~	0-10 mA ~ 45-65 Hz ~	10 mA ~	≤ 30 mVA (across op. range)	±1% (20%-120% nom.)
with external CT type FP1030		In = 0.5/1/5 A ~	0-10 A ~ 45-65 Hz ~	40 A cont. 1000 A 1 s (1 turn)	≤ 30 mVA (across op. range)	±1% (20%-120% In)
Digital inputs		24/48/110/220 V ⎓ 110/230 V ~	19.2-260 V ⎓ 87.5-260 V ~ 45-63 Hz ~	300 V ≈	< 0.2 W ⎓ < 0.5 VA ~	–
mA inputs (passive)		0-10 / 0-20 / 4-20 mA ⎓	−25 - +25 mA ⎓	25 mA ⎓	100 Ω	±1% (20%-100% nom.)
RTD inputs (Pt100 temperature sensor resistor)		IEC 60751 100 Ω platinum resistor	−80 - +327 °C	0 - ∞ Ω	–	±0.5 °C
Analogue tap position input		–	chain resistance 50 Ω - 50 kΩ min. 5 Ω per res.	0 - ∞ Ω	–	±0.2 taps on 40 position tap changer
mA (passive)		0-10 / 0-20 / 4-20 mA ⎓	0 - +25 mA ⎓	50 mA ⎓	270 Ω	±1% (20%-100% nom.)
Digital tap position inputs		Dry / volt-free contacts	–	–	–	–
mA outputs (active)		0-10 / 0-20 / 4-20 mA ⎓	0 - 24 mA ⎓ loop res. < 1 kΩ	–	–	±1% (20%-100% nom.)

[†] Hardware version 04 has an upper operating limit of 132 V ≈ and withstand of 150 V ≈

[‡] Nominal AC frequency 50/60 Hz

* Quiescent / Maximum burden

18.3.2 Output Relays

Specification	Levels
No. of cycles	>100,000
Make and carry	10 A ≈
Break	10 A ~ 300 W ⎓

18.3.3 Electrical Withstand

Specification	Levels
Rated insulation voltage	300 V ≈
Dielectric test voltage	2.3 kV ~ for 1 min
Impulse test voltage	5 kV

18.4 Electromagnetic Characteristics

18.4.1 Radiated Emissions

Specification	Levels
CISPR 11 30 – 230 MHz	40 dB(μV/m) quasi peak at 10m 50 dB(μV/m) quasi peak at 3m
CISPR 11 230 – 1000 MHz	47 dB(μV/m) quasi peak at 10m 57 dB(μV/m) quasi peak at 3m
CISPR 22 1 – 3 GHz	56 dB(μV/m) average 76 dB(μV/m) peak at 3m
CISPR 22 3 – 6 GHz	60 dB(μV/m) average 80 dB(μV/m) peak at 3m

18.4.2 Conducted Emissions

Specification	Levels
CISPR 22 0.15 – 0.5 MHz	79 dB(μV) quasi peak 66 dB(μV) average
CISPR 22 0.5 – 30 MHz	73 dB(μV) quasi peak 60 dB(μV) average

18.4.3 Electromagnetic Immunity

Specification	Levels
IEC 61000-4-2 Electrostatic discharge	6 kV contact
IEC 61000-4-3 Radiated RFI	10 V/m rms
IEC 61000-4-4 Fast transient	4 kV (2kV comms)
IEC 61000-4-5 Surge	4 kV (2kV comms)
IEC 61000-4-6 Conducted radiofrequency interference	10 V rms sweep
	10 V rms spot 27, 68 MHz
IEC 61000-4-8 Power frequency magnetic field	30 A/m continuous
	300 A/m 1 s – 3 s
IEC 61000-4-16 Power frequency	Level 4, 300 V c.m.
IEC 61000-4-17 DC ripple	Level 4 ,15%
IEC 61000-4-18 Slow damped oscillatory wave	1 kV pk. diff. (not comms) 2.5 kV pk. c.m.
IEC 61000-4-29 Voltage dips, interruptions and variations	100% 1s, 100% 5s, 60s ramp

18.5 Mechanical and Atmospheric Characteristics

18.5.1 Fixings

Use	Requirement
Case fixings	6off M4 screws (not supplied)
Terminal fixings	M4 x 8mm bright zinc plated pan head pozidrive screws with captive spring washer (supplied)
Wire fixings	Right angle ring crimps max. 2 per terminal, max. 1 wire per crimp (not supplied)

18.5.2 Weight Unpackaged

Specification	Mass
Relay with no additional cards	7 kg
Relay with all additional cards	8 kg

18.5.3 Dimensions

See Figure 2-65.

18.5.4 Environmental Immunity

IP Rating

Specification	Levels
From front of panel when mounted in normal position of use	IP54

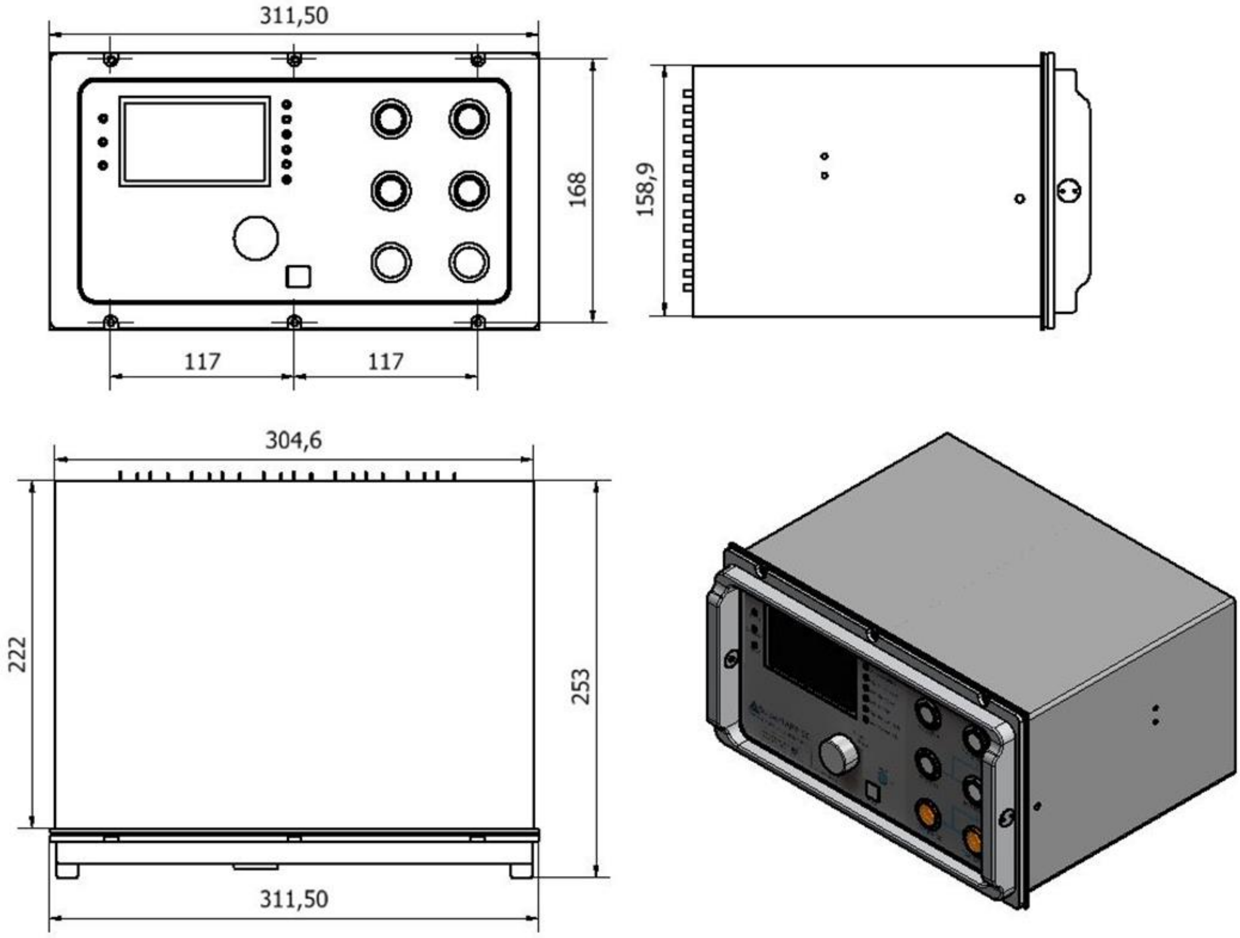
Temperature

Specification		Levels
IEC 60255-1 dry heat and cold	operational	0 – +55 °C
	storage	-20 – +55 °C
IEC 60255-1 damp heat	operational	+55 °C 95% r.h.

Mechanical

Specification	Levels
IEC 60255-21-1 vibration	Severity class 1
IEC 60255-21-2 shock	Severity class 1
IEC 60255-21-2 bump	Severity class 1
IEC 60255-21-3 seismic	Severity class 1

Figure 2-65 SuperTAPP SG dimensions



19 Connection Diagrams

The diagrams which follow show typical connection arrangements for the various modules which the SuperTAPP SG can contain.

The input and output numbering shown in the diagrams is typical, with the exact allocation being dependent on the number and location of other modules fitted. Please refer to the wiring drawing, provided with each SuperTAPP SG, to determine the exact configuration for your unit and **do not rely on the numbering in these diagrams**.

The user must refer to the relay code, printed on the front of the relay, to determine which module is in each location, and hence connected to which terminal block.

Figure 2-66 Typical connection diagram for AC input modules

Note. Numbering of current and voltage inputs is typical only. Refer to the correct SuperTAPP SG wiring diagram for complete allocation.

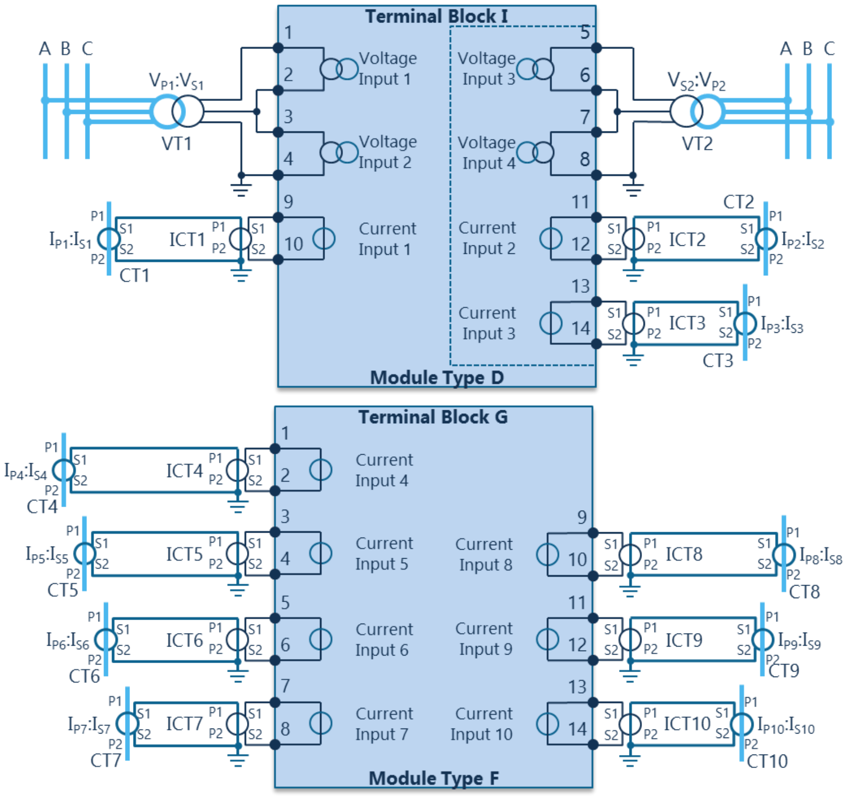


Figure 2-67 Typical connection diagram for power supply and scheme logic module

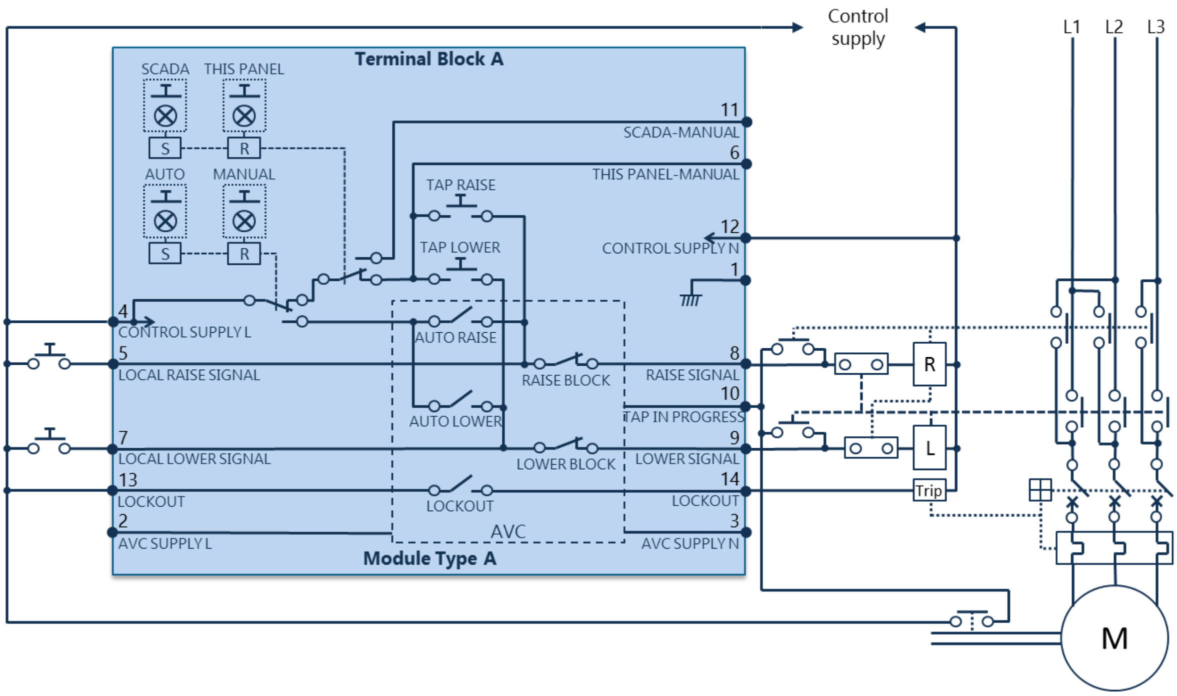


Figure 2-68 Connection diagram for tap position input module

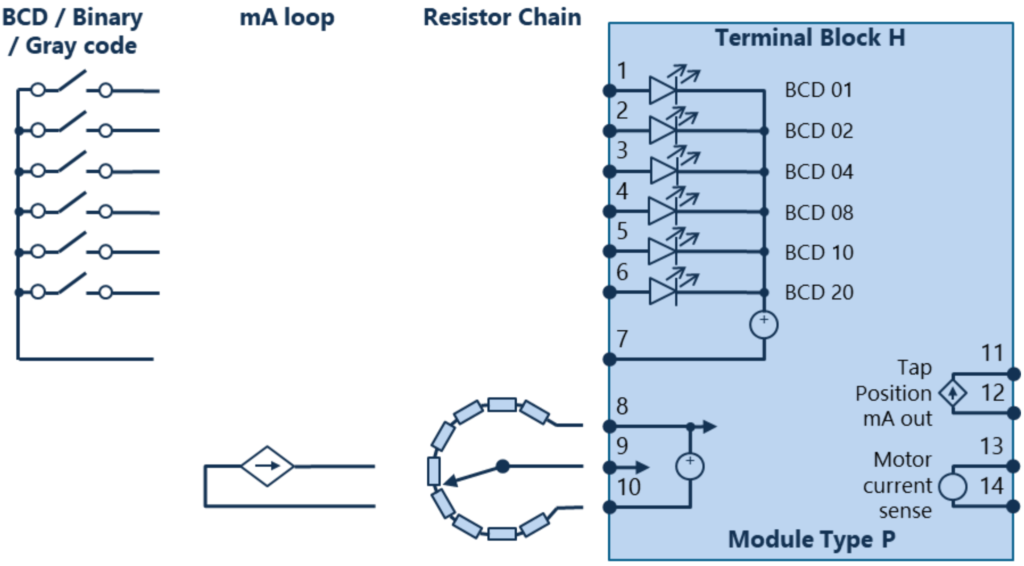


Figure 2-69 Connection diagram for inter-relay communications

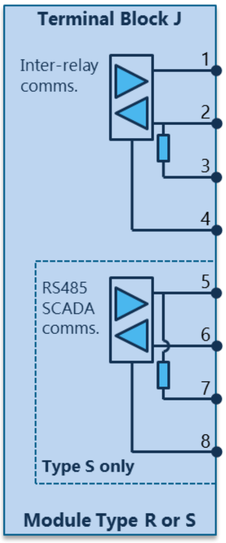


Figure 2-70 Connection diagrams for digital I/O modules

Note. Numbering of digital inputs and output relays is typical only. Refer to the correct SuperTAPP SG wiring diagram for complete allocation.

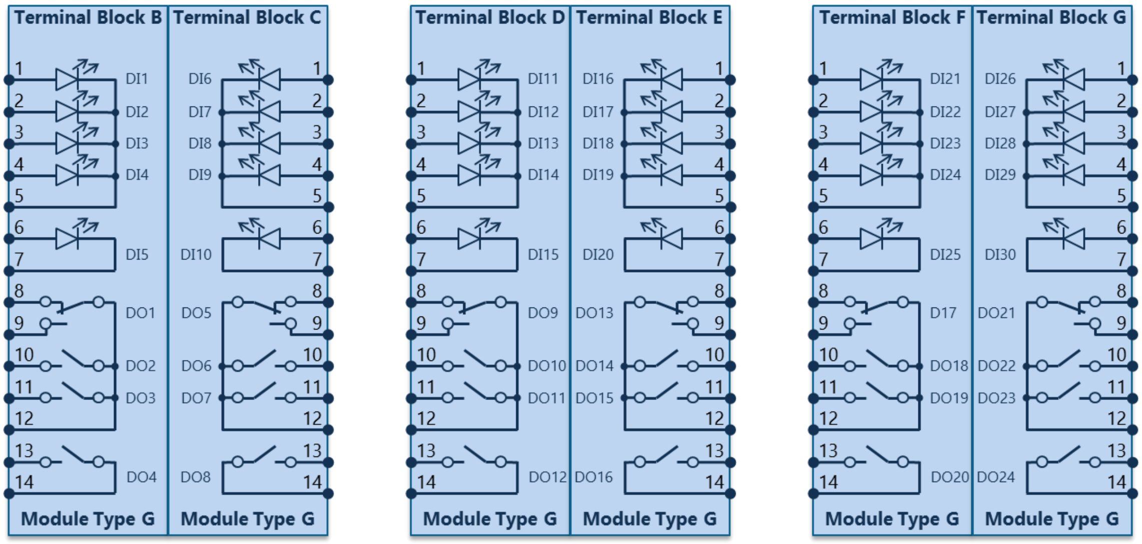
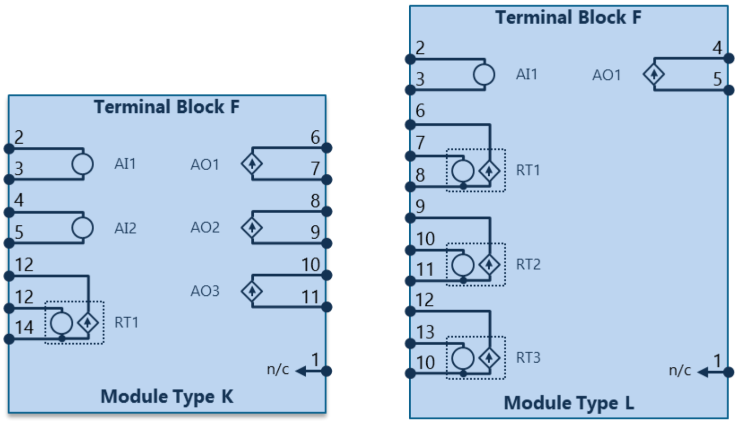


Figure 2-71 Connection diagrams for analogue DC modules



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