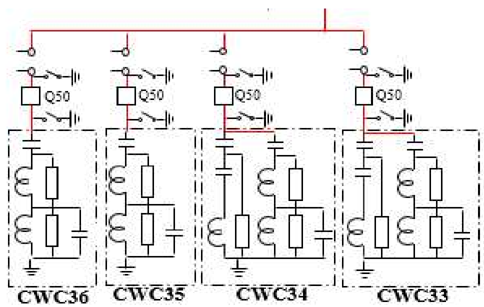
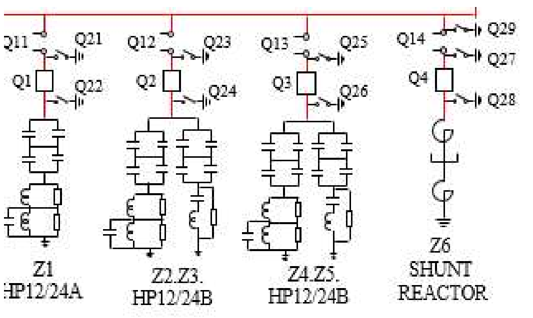
FILTER PROTECTION COMPARISON

Pole	Pole-1(ALSTOM)
No of Filters	7
East	CWC23,**(Double Tuned)** CWC24,**(Double Tuned)** CWC25**(Single Tuned)**
South	CWC33,**(Double Tuned)** CWC34,**(Double Tuned)** CWC35,**(Single Tuned)** CWC36,**(Single Tuned)**
SLD	
Protections	Resistor Overload(SAW)
	Resistor Open Circuit Alarm(MCGG22)
	IDMT Over Current Relay(SPAG160C)
	Instantaneous Over Current(MCAG39)
	Earth fault Relay(MCGG22)
	Breaker fail(MCT139)
	Capacitor Unbalance Stage-1(FOOC)
	Capacitor Unbalance Stage-2(FOOC)
	Capacitor Unbalance Stage-3(FOOC)
	NA
	NA
	NA

Pole-2(ABB)
8
WA2-Z1**(HP12/24A)** Z2Z3**,(HP12/24B)& 3** Z4Z5,**(HP12/24B)& 3** Z6**(SHUNT REACTOR)**
WA1-Z1,**(HP12/24A)** Z2Z3,**(HP12/24B)& 3** Z4Z5,**(HP12/24B)& 3** Z6**(SHUNT REACTOR)**

Reactor/resistor thermal overload prot.
NA
NA
NA
AC filter Earth fault Protection
Breaker fail
Capacitor unbalance prot.
NA
NA
Ferro Resonance Detection
Low Voltage capacitor protection
AC filter Detuning Supervision

GEC ALSTHOM T&D POWER ELECTRONIC SYSTEMS LIMITED				Specification No. CF0136/0012/FUNC	
				Sheet 1 of 102	
Title:	Functional Specification for Reactive Power Control			Ref. 730/CF0136/T06/ DRM001C.SPC	
				Original A	12.5.97
		Customer	POWERGRID	Approved	BAR
Situation	Visakhapatnam				
Issue	B 8.5.98	C 14.4.99	D	E	F	G
Approved	BTB	N.MK				

CONTENTS

RELATED DOCUMENTS

[1] POWERGRID specification for Visakhapatnam 500MW HVDC Back-to-Back Station
[2] Functional Test Specification for Reactive Power Control Equipment CF0136/0012/FTS
[3] Pole Control Functional Specification CF0136/0049/FUNC
[4] Visakhapatnam 500MW Back-to-Back Station Reactive Power Control S/TaDPoEl b1037
[5] Tender Addenda 1 to 6 for Visakhapatnam 500MW HVDC Back-to-Back Station
[6] Hardware Design Description for Reactive Power Control Cubicle CF0136/0053/EQUIP
[7] Series IV Hardware IO Description for Reactive Power Control CF0136/0053/DESC

KEY WORDS

Reactive Power, RPC, Visakhapatnam, POWERGRID, Back-to-Back, Filter, Reactor

RELATED SCHEDULE ITEM NUMBERS

Equipment : SI 3.3.2 Spares : SI 3.3.2

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SCHEDULE OF REVISIONS

Issue A written by D R Monkhouse
Original Issue

Issue B written by D R Monkhouse

Glossary Updated

Clause 7.1.4 text added
Clause 7.2.2 'current' replaced with 'frequency'
Clause 7.2.3 margin added to equations 3 and 4
Clause 7.5.5 time delay added
Clause 7.5.11 functionality included
Clause 7.7.1.5 'var clearance'/minimise losses function added
Clause 7.7.2.1 'var clearance' replaced with 'excess var'
Clause 7.7.2.4 'var clearance' replaced with 'excess var'
Clause 7.7.2.5 'var clearance'/minimise losses function added
Clause 7.8.1 functionality modified
Clause 7.8.1 reference to Clause 7.12.1 omitted
Clause 7.8.2 reference to Clause 7.12.1 changed to Clause 7.5.1
Clauses 7.9.3 changed to align with Chandrapur
Clause 7.9.4 functionality modified
Clause 7.9.5 functionality modified
Clause 7.10.2 equation numbers corrected
Clause 7.10.2 equations 19 & 20 modified to allow de-energisation down to one filter
Clause 7.13.4 open loop equations modified to incorporate IVA term
Clause 7.14.1 Clause (f) added
Clause 7.14.3 Clause added for reactor tripping
Clause 7.15.2 functionality modified
Clause 7.16.3 reference to Related Document [3] added and functionality modified
Clauses 7.18.2 and 7.18.3 exchanged
Clause 7.18.2 Clause re-written
Clause 7.18.3 manual filter control altered
Clause 7.20.3.1 TFVA equation corrected to use reactor Mvar
Clause 8.1.1 reactor breakers added
Clause 8.1.2 CWE02 disconnectors added
Clause 8.1.3 'composite' removed from South CT reference
Clause 8.3.3 outputs removed
Clause 8.3.4 'Block Pole' input removed

1 Glossary

$ACDO_{e/s}$	Accepted offset to Convertor Deficit (East/South) (Mvar).
$ACSO_{e/s}$	Accepted offset to Convertor Surplus (East/South) (Mvar).
ACVCM	AC Voltage Control Mode.
Automatic Control	RPC decides what switchgear action is required and performs it without operator intervention.
Convertor $Deficit_{e/s}$	The lower limit of reactive power export to the ac system (+ve represents net generation to the ac system, -ve represents net absorption from the ac system) (Mvar).
$CDO_{e/s}$	Convertor Deficit Offset (East/South) (Mvar).
Convertor $Surplus_{e/s}$	The upper limit of reactive power export to the ac system (+ve represents net generation to the ac system, -ve represents net absorption from the ac system) (Mvar).
$CSO_{e/s}$	Convertor Surplus Offset (East/South) (Mvar).
$CTO_{e/s}$	Convertor Target Offset. To centre the open loop var control within the deadband = (default surplus limit+default deficit limit)/2 (Mvar).
C-type filter	Filter tuned to 3rd harmonic.
Combined filter	A C and D type filter combined as one 106Mvar unit.
C_{var}	Convertor Reactive Power Absorption factor. The ratio of convertor reactive power absorption to real power transfer in Vdo mode.
D_{eff}	Total effective distortion.
D_n	Individual harmonic distortion.
D-type filter	Double damped filter tuned to the 12th and 24th harmonics.
E_n	Rms value of the n^{th} harmonic voltage (phase to ground).

E_{ph}	Rms value of the fundamental voltage (phase to ground).
EVA	Excess Var Available (+ve represents reactive power generation, -ve represents reactive power absorption) (Mvar).
E_{vw}	Valve-winding fundamental emf (Volts).
F_n	Weighting factor for the TIF calculation.
HVDC	High Voltage Direct Current.
ICA	Increase in Convertor Absorption (scalar value)(Mvar).
I_d	Direct current (Amp).
IDMT	Inverse Definite Minimum Time.
inv	Inverter.
IVA	Increase in Var Absorption (Mvar).
K	Constant used to determine the amount of var relaxation when V_{ac} exceeds 427kV, and depends on V_{ac} (see Figure 6).
LVCC	Low Voltage Current Clamp. Used to limit the direct current flowing through the inverter valves when they are not commutating, i.e. in TCR mode. It acts by imposing a pre-determined Current Order whenever the direct voltage falls below a threshold (presently 0.08pu).
LW	Line-winding of the convertor transformer (connected to the ac system).
$MACC_{e/s}$	Maximum Absorption Capability of the Convertors, East/South (+ve represents var generation, -ve represents var absorption) (Mvar).
Manual Control	RPC indicates to the operator which filter/reactor to switch in order for the operator to carry it out via the main station mimic.
Max.	Maximum.
Min	Minimum.

n	Harmonic order.
NEF	Number of energised filters.
N_{harm}	Number of filters required for harmonic performance (see table 2).
Nom	Nominal.
PCCS	Pole Control Command System.
$PCDO_{e/s}$	Present Convertor Deficit Offsets at the time when ACVCM demand is executed, East/South (Mvar).
$PCSO_{e/s}$	Present Convertor Surplus Offsets at the time when ACVCM demand is executed, East/South (Mvar).
P_{demand}	A target value for power transfer set by the operator (or by Load Frequency Control via Telecom). It is a dc value, and changes only when operator "executes" another set value (MW).
P_o	The input power order to a closed-loop controller, which may contain frequency dependent components etc. (It is a value to be targeted and processed. It is an input to PCCS) (MW).
$P_{o\text{-filtered}}$	Input signal from Master Control. It is a component of P_o which excludes power modulation components, and is used for tapchanger control and reactive power control (MW).
$PVL_{e/s}$	Present Voltage Level at the time when ACVCM demand is executed, East/South (line-line kVrms)
Q_{filter}	Filter Mvar at the time of switching (scalăr value) (Mvar).
$Q_{reactor}$	Reactor Mvar at the time of switching (scalar value) (Mvar).
Q_{rel}	Relative error in var export (used in IDMT relay)
rect	Rectifier.
RPC	Reactive Power Control.

RPEM	Reactive Power Exchange Mode.
RPM	Reactive Power Mode (operation with reduced direct voltage/valve winding voltage).
SER	Sequence of Events Recorder.
$SCL_{e/s}$	Short Circuit Level, East/South (MVA).
SPM	Switch Position Monitor.
TCR	Thyristor Controlled Reactor. (This mode of operation is encountered when the ac system voltage collapses, the thyristor valves of the convertor at the faulty side cease to commutate, while the valves at the healthy side operate at a firing angle near $\alpha = 90°$. This circulates current through the HVDC convertors at near zero direct voltage, transferring little real power, but with increased convertor absorption)
$TFVA_{e/s}$	Total Filter Var Available East/South (Mvar).
TIF	Telephone Influence Factor.
T_j and T_j'	Signals from the Thermal Analogue which represent the thyristor valve junction temperature.
TOV	Temporary Overvoltage.
$TVL_{e/s}$	Target Voltage Level selected by operator, East/South (line-line kVrms)
t_x	Time delay for switching, in seconds, for a relative var error Q_{rel} of X%, used in IDMT relay.
V_{ac}	AC system voltage (line-to-line kV rms).
var	Reactive power (Mvar).
V_d	Direct voltage of the HVDC link (Kv).
$V_{depress}$	The amount by which V_d is depressed to adjust reactive power absorption compared with the 'Maximum Direct Voltage Limit' (V_{dmax}).

	V_{dip}	The amount of temporary voltage depression used to change convertor var absorption to partially offset the step change of reactive power when a filter is switched.
	V_{dmax}	The maximum Direct Voltage that may be used at a particular power level. (It is a function of Power transfer and is slew rate limited)
C	$V_{dmax}VA$	Var absorpion of the convertors with respect to dc power transfer at the Maximum Direct Voltage limit (Mvar)
	V_{ll}	Valve-winding Voltage (line-to-line kV_{pk}).
	V_o	Actual Voltage Order prior to switching a filter, i.e. it is the instantaneous Voltage Order used for controlling var export. (RPC will need this value to calculate whether the convertor is using too much var control. This value does not include the amount of voltage depression necessary for providing var compensation on filter switching) (kV).
C	V_oVA	Var absorption of the convertors with respect to dc power transfer at the actual voltage order (Mvar)
	VW	Valve-winding of the convertor transformer (connected to the thyristor valves).
	$\Delta Q_{e/s}$	Change in Reactive power to meet the target voltage level. East/South (Mvar).
	$\Delta VL_{e/s}$	Change in Voltage Level requested by operator. East/South (pu).

2 GENERAL

This specification defines the performance required from Reactive Power Control (RPC) for the Visakhapatnam 500MW HVDC Back-to-Back Link. The reactive power control strategy described in this functional specification is to be applied to each "side" of the convertor station, ie. eastern region and southern region, unless otherwise specified. A simplified single line diagram of the HVDC system is shown in Figure 1, illustrating the reactive components. RPC must comply with the POWERGRID specification.

Reactive Power Control determines the steady state reactive power exported from the HVDC scheme to the ac systems. Usually, the reactive export will be kept within the limits stipulated in the POWERGRID specification, but Reactive Power Control is also used to restrain the voltage changes caused by load rejections or filter switching. Its behaviour may be modified to keep the harmonic voltage distortion within the performance limits as far as possible with the filter components available.

Signals exchanged between Reactive Power Control and other equipments are listed in section 8 and are discussed in the related document, "Hardware Description of Reactive Power Control [6]". The arrangements for exchanging signals between Reactive Power Control and Pole Control are defined in the related document, "Pole Control Functional Specification" [3].

In this document, "Reactive Power Control" is abbreviated to "RPC". Any clauses/statements which are for commentary are contained in brackets. It is intended that the software will be based on that used for the Chandrapur 2x500MW Back to Back Reactive Power Control with relevant changes made where necessary.

3 STANDARDS

The equipment will be designed, manufactured and tested generally in accordance with IEC and GEC ALSTHOM T&D Power Electronic Systems Limited standards.

4 QUANTITY

There is one RPC for the scheme.

5 QUALITY ASSURANCE

Refer to Appendix 1 for the Quality Assurance specification for this equipment.

6 DESIGN PROCEDURE

The equipment shall be designed for ease of maintenance and comprehension. At each key stage of the design, details shall be provided to HVDC Systems Department for review. (This is to enable the concepts of the design to be examined to ensure there are no misunderstandings in the interpretation of the performance specification and that any unforeseen consequences of the implementation are detected as early as possible.) The documentation provided is to be in a form which can be simply comprehended by engineers who are not software specialists, and shall show the partitioning of the function into separate tasks, the interaction of the tasks and the relative timing of the execution of the tasks, and shall identify the hardware which will support each task. The partitioning of functions and the documentation shall be such that corrections/changes can be accommodated without excessive re-design effort, ie. the software/hardware shall be divided into many sub-units so that a slight change in the specification does not affect the whole piece of software/hardware.

7 PERFORMANCE

Principal Functions

The following is a list of the principal functions of Reactive Power Control. Some of them are extracted from the POWERGRID specification [1].

All the time settings/control limits will be capable of adjustment by technician level staff under the authority of the Engineer unless otherwise specified.

7.1 General

7.1.1 Reactive Power Control is achieved by a combination of open-loop (coarse control) and closed-loop techniques. In open-loop control, filters and reactors are switched according to the Power Order while the closed loop control is based on measured var and harmonic performance. Open-loop control is always active while closed-loop control may be disabled under extreme conditions or during non-steady state conditions.

7.1.2 AC system voltage and frequency measurements shall each be subjected to slew rate limiting of $4kV_{rms}$/sec. and 0.05Hz/sec. respectively. This slew rate shall apply for all measurements unless otherwise stated.

7.1.3 Clause not used.

7.1.4 During steady state operation the reactive power exported to the ac system on each side of the link (E and S) is to remain within the reactive power limits stipulated in the POWERGRID specification [1], while the ac system voltage and frequency remain within the normal performance ranges of 380kV to 420kV and 47.5Hz to 51.5Hz respectively. Figures 2 and 3 illustrate the normal limits specified for the eastern and southern ac systems respectively. The limits are shown as a function of the filtered Power Order ($P_{o\text{-filtered}}$). Table 1 lists the numerical values of the var export limits of the eastern and southern region measured from figures 2.3.3.1 and 2.3.3.2 of the POWERGRID technical specification.

Although the reactive power limits continue up to 140% power, the reactive compensation equipment is only rated to meet these limits up to 110% power. Reactive Power Control will still target the reactive power limits up to 140% power however under certain ac operating conditions they may not be met.

RPC is also required to operate in "Reactive Power Exchange Mode" (RPEM) or "AC Voltage Control Mode" (ACVCM), during which reactive power or ac system voltage targets can be adjusted by POWERGRID's operator (see also Additional Functions 7.20.1). The details of these control actions are not design-determining conditions for the main circuit components, eg. filters, convertor transformers, valves, etc..

7.1.5 The reactive power exported from the convertor station to the ac system of the southern region is to be measured at the connection of convertor station ac busbar to the existing substation. The reactive power exported from the convertor station to the ac system of the eastern region is to be measured on the 400kV ac lines on the line side of the POWERGRID shunt reactors. These measurement points are indicated as (1) and (2) in Figure 1.

7.2 Size of AC Harmonic Filters and Shunt Reactors

7.2.1 Reactive power exported to the ac systems can be adjusted in discrete steps by switching ac filters and shunt reactors. The filters are nominally 106Mvar each at 400kV and the reactors 80Mvar each at 420kV (72.56Mvar at 400kV). Nominal conditions are: nominal frequency, nominal ac system voltage, nominal temperature and 0% capacitor and reactor manufacturing tolerance. The var absorption of the convertors shall be increased when necessary to ensure that the var exported to the ac system does not exceed the "Convertor Surplus" limit (see clause 7.5.3).

7.2.2 The Mvar rating of a filter at a particular operating condition can be calculated from Equation 1:

$$Q_{Filter} = 106 \times \left(\frac{\text{AC System Voltage}}{400}\right)^2 \times \frac{\text{AC System Frequency}}{50}$$

where AC System Voltage is expressed in line-to-line kV_{rms}

AC System Frequency is expressed in Hz

Equation 1

The Mvar rating of a reactor at a particular operating condition can be calculated from Equation 2:

$$Q_{reactor} = 80 \times \left(\frac{\text{AC System Voltage}}{420}\right)^2 \times \frac{50}{\text{AC System Frequency}}$$

where AC System Voltage is expressed in line-to-line kV_{rms}

AC System Frequency is expressed in Hz

Equation 2

The ac system voltage and frequency measurements shall be subject to slew rate limiting as per clause 7.1.2.

7.2.3 Since the reactive power "deadband" (i.e. the permitted range of reactive power export) on both the eastern and the southern network is narrow (i.e. less than 130Mvar), switching a filter on either region (or a reactor on the Eastern side) may cause the convertor to change its var absorption. For example, if the var exported to the southern ac system before de-energising a filter on the eastern region is close to the "Convertor Surplus" limit, then the southern region may dictate the extent to which the convertors are required to use RPM after the switching event, and may force the var exported to the eastern ac system to fall below the "Convertor Deficit" limit. Consequently, the filter on the eastern region could then be required to re-switch even though the power transfer had not altered. RPC shall ensure that the interaction imposed on either network will not cause a filter or reactor to be re-switched. If the output of Equation 3 or Equation 4 are true, then a filter may be de-energised on the eastern or southern side respectively without risk of it being required to be re-switched. Even when the conditions as per clause 7.4.3 and 7.7 are fulfilled, a filter on either network shall only be disconnected if the conditions stated below for its particular network are also met.

On the eastern network:

$$(Q_{Filter-East} + Margin) < \text{var export}_{East} - \text{"Convertor Deficit" limit}_{East} - \text{var export before switching}_{South} + \text{"Convertor Surplus" limit}_{South}$$

Equation 3

where: $Q_{Filter-East}$ = Eastern side filter Mvar at the time of switching, see clause 7.2.2

Margin = 20 Mvar

On the southern ac network:

$$(Q_{Filter-South} + Margin) < \text{var export}_{South} - \text{"Convertor Deficit" limit}_{South} - \text{var export before switching}_{East} + \text{"Convertor Surplus" limit}_{East}$$

Equation 4

where: $Q_{Filter\text{-}South}$ = Southern side filter Mvar at the time of switching, see clause 7.2.2

Margin = 20 Mvar

7.2.4 If both sides of the convertor station (East and South) require a filter to be de-energised but the conditions of Equations 3 and 4 are false then a filter shall be de-energised on both sides of the convertor station regardless of the condition of Equations 3 and 4.

7.3 Quantity of AC Harmonic Filters and Shunt Reactors

7.3.1 The number of filters and reactors on each side of the convertor station are as follows, as shown in Figure 1:

Eastern
Two (2) Combined filters
One (1) D-type filter
Two (2) Line charging reactors

Southern
Two (2) Combined filters
Two (2) D-type filters

RPC shall ensure that a Combined filter is always energised during normal steady state operating conditions (see clause 7.8.1). Further D-type filters are energised according to the measured harmonic performance and the reactive power exported to the ac system. The second Combined filter is provided as a spare and serves mainly for reactive power performance at high power transfers (see clause 7.13.3).

7.4 Harmonic Performance Considerations

7.4.1 During steady state operation the harmonic performance measured at the 400kV ac busbar on each side of the link (E and S) is to remain within the limits stipulated in clause 7.4.5, while the ac system voltage and frequency are within the normal performance ranges of 380kV to 420kV and 48.5Hz to 50.5Hz, and the filtered Power Order ($P_{o\text{-filtered}}$) does not exceed 550MW.
Under normal operation the harmonic performance monitor shall remain active in the range 50 - 400MW. In RPEM or ACVCM the harmonic performance monitor shall remain active over the entire power range (see clause 7.20.2).

7.4.2 During normal operation (i.e. not RPEM/ACVCM), **IF** any of the harmonic calculations of clause 7.4.5 are exceeded, **AND** the power transfer is in the range 50-400MW

THEN :

- **IF** the number of filters energised is less than the number pre-determined from worst case calculation results (see table 2),

THEN :

- energise a D-type filter, or if a D-type is not available then energise a Combined filter.

ELSE :

- give a minor alarm to the SER (harmonic voltage limit exceeded).

For power transfers greater than 400MW the number of filters energised shall be at least as many as given in Table 2 (more if required for var reasons).

IF any of the harmonic calculations of clause 7.4.5 is exceeded, **AND** the power transfer is greater than 400MW

THEN :

- give a minor alarm to the SER (harmonic voltage limit exceeded).

7.4.3 During normal operation (i.e. not RPEM/ACVCM), if the number of filters equals the number pre-determined from worst case calculation results (see table 2) and if all four harmonic calculations of clause 7.4.5 give results which are less than half (0.5) of the maximum permitted limits, then a D-type filter can be de-energised if requested by the closed var loop control (see clause 7.7). This threshold shall be adjustable between 0.1 and 0.8. This is only applicable for power transfers in the range 50 - 400MW. For power transfers above 400MW, RPC shall ensure that at least as many filters as shown in Table 2 are always energised (see clause 7.4.2).
Alternatively; if the number of ac harmonic filters energised exceeds the number pre-determined from worst case calculation results (see table 2), then an ac harmonic (Combined or D-type, see clause 7.13.3) filter can be de-energised if

requested by the closed loop var control (see also clause 7.7) irrespective of the harmonic calculations of clause 7.4.5.
During RPEM/ACVCM operation, refer to clause 7.20.6.

7.4.4 The harmonic performance is to be measured by using the voltage derived from the AC Voltage Capacitive Divider (CVD) provided on the PLC filter capacitor.

7.4.5 Harmonic performance is assessed from the measured harmonic voltage averaged over a default period of thirty (30) seconds. The averaging period shall be adjustable between twenty (20) seconds and sixty (60) seconds. The order of harmonics to be considered shall be from 11^{th} to 50^{th}. The harmonic frequencies are defined as multiples of the power frequency of the ac system at the time of measurement. Four criteria are to be satisfied, see Equation 5.

$$D_n = \frac{E_n}{E_{ph}} \times 100\% \leq 1.0\%$$

$$D = \sum_{n=11}^{50} \frac{E_n}{E_{ph}} \times 100\% \leq 4.0\%$$

$$TIF = \sqrt{\sum_{n=11}^{50} \left(\frac{E_n \times F_n}{E_{ph}}\right)^2} \leq 30.0$$

$$D_{eff} = \sqrt{\sum_{n=11}^{50} \left(\frac{E_n}{E_{ph}} \times 100\right)^2} \leq 3.0\%$$

Equation 5

where : F_n = weighting factor (see Appendix 2)
n = harmonic order between eleven (11) and fifty (50).

(Harmonics below the 11th order are not considered for harmonic performance calculations. The double damped filter (D-type) is tuned to the 12th and 24th harmonics and is therefore relatively ineffective below about the 10th harmonic. RPC is prevented from switching filters as a result of harmonics below the 11th, since the filters will have no influence.)

7.5 Filter/Reactor Switching

7.5.1 Since the filter Mvar rating is so large that switching a filter during low ac system fault level would otherwise cause a voltage change greater than 7.5%, convertor operating conditions are to be varied to reduce the net change in reactive power when a filter is switched. Except where otherwise stated, this strategy will be applied at all ac system fault levels and at all ac system voltage levels, ie. even below 360kV or above 440kV. This action takes place whether filter switching is under Manual or Automatic control. The convertor control angles are to be increased progressively (by reducing the direct voltage order) before a filter is disconnected. They are to be allowed to revert to normal as the disconnection takes place (by restoring direct voltage order). Similarly, the convertor control angles are increased immediately (by reducing the direct voltage order suddenly) at the time when a filter is energised. The effects of voltage change on switching are illustrated in Figure 8 (see also clause 7.5.6). The amount of direct voltage depression (depressing the voltage order to the pole by an amount, V_{dip}) required to provide the compensation is shown below in Equation 6:

$$V_{dip} = \frac{35 \times Q_{Filter}}{8 \times P_{o\text{-filtered}}} \times f$$

Equation 6

where

f = correction factor for pre-existing level of RPM

$$= 1 - \sqrt{\frac{V_{dmax} - V_o}{V_{dmax}}}$$

Equation 7

$P_{o\text{-filtered}}$ = filtered power order in % of 500MW

V_o = voltage order in % of 205kV prior to switching

V_{dmax} = maximum direct voltage limit prior to switching (depends on V_{LL} and $P_{o\text{-filtered}}$)

V_{dip} = required temporary voltage depression

Q_{filter} = filter Mvar at the time of switching, see clause 7.2.2

No pre/post-conditioning will be necessary for reactor switching.

7.5.2 When the valve-winding voltage falls outside the normal tapchanger control deadband, filter/reactor switching is permitted according to the open-loop determined rules of clause 7.13.4. Switching a filter/reactor according to the var/harmonic performance under this condition may require that the filter or reactor is re-switched after the tapchanger has corrected the valve-winding voltage and is therefore restricted. To avoid "hunting", a filter or reactor shall not be switched according to clauses 7.4.2, 7.4.3 and 7.16.1 until the valve-winding voltage is restored to within ±1.25% of the target value. However, if the ac system voltage lies outside the normal performance range of 380kV to 420kV the tapchanger may be incapable of meeting the target position, therefore RPC shall perform the necessary filter/reactor switching according to clauses 7.4.2, 7.4.3 and 7.16.1 after the tapchanger has settled (indicated by "Tapchanger Reached End Tap" from PCCS). This limits the var exported to the ac system (see clauses 7.9.2, 7.9.3 and 7.9.4 for var control during abnormal ac system voltage condition). No alarm shall be given if var/harmonic performance limits are exceeded while the ac system voltage lies outside the normal performance range (380kV to 420kV).

7.5.3 The convertors default to operate with the direct voltage equal to the "Maximum Direct Voltage Limit" (see Figure 4) at which no var control is exerted by the convertors. However, if control of reactive power by filter or reactor switching is too coarse (which would otherwise result in exceeding the reactive power surplus limit), the convertors are to be operated in Reactive Power Mode (RPM). This mode of operation involves reducing the direct voltage and increasing the direct current, which **increases** the var absorption of both convertors whilst maintaining ordered power transfer. This will also affect the var export on the other side of the HVDC scheme, and may initiate switching there. (See clauses 7.6.2 and 7.5.4 for the actions to be taken when var export falls below the "Convertor Surplus" limit). The process of increasing the var absorption of the convertor, by reducing the direct voltage, to conform with the stipulated var export limit after a switching event shall be performed progressively in two (2) seconds (adjustable between half (0.5) a second and five (5) seconds, see clause 7.5.6) to minimise the disturbance to the ac system.

7.5.4 When the var exported to the ac system falls below the "Convertor Deficit" limit and:

either i) the direct voltage has reached the "Maximum Direct Voltage Limit", i.e not in Reactive Power Mode.

or ii) the var export from the other side of the scheme is at or above the "Convertor Surplus" limit, resulting in it requesting Reactive Power Mode,

then on the Southern Side:

a filter shall be energised, provided that the condition of clause 7.16.1 is also fulfilled. (See clause 7.5.3 for the actions to be taken when var export exceeds the "Convertor Surplus" limit).

and on the Eastern Side:

a filter shall be energised, providing that the conditions of clause 7.16.1 is also fulfilled. (See clause 7.5.3 for the actions to be taken when var export exceeds the "Convertor Surplus" limit). When all the filters have been energised, reactors will be permitted to be de-energised.

7.5.5 When a "Tapchanger Failed" signal from PCCS is received continuously for 10 seconds (adjustable between one (1) and ten (10) seconds), RPC shall release RPM, i.e. RPC shall cease using the convertors for reactive power control. However, RPC shall take appropriate action to prevent "Excessive var" export to the ac systems by switching filters and reactors. "Excessive var" means that the var exported to the ac system exceeds the "Convertor Surplus" limit by more than 125Mvar (adjustable between 50Mvar and 200Mvar). In this case the de-energisation of filters/energisation of reactors by IDMT as per clause 7.7 shall be inhibited. Under this condition, the var exported to the ac system may temporarily exceed the stipulated limits (see also CF0136/0049/FUNC [3]). When the "Tapchanger Failed" signal is rescinded, RPC shall resume RPM.

7.5.6 Since filter and reactor switching invokes convertor control action, both the var export and the harmonic performance at both sides diverge temporarily from their steady state values when switching takes place. Except in an emergency, eg. load rejection and/or runback, RPC shall not initiate any further action while switching is in progress. (The time to complete an energisation operation is two (2) seconds [adjustable between one second and five seconds] after the end of the post-conditioning process, or two (2) seconds [adjustable between one second and five seconds] before the beginning of a de-energisation process [delay the switching for the pre-conditioning process], see Figure 8).

7.5.7 When an emergency switching demand (eg. caused by a load rejection etc.) arises during the time when a filter or reactor is being switched, RPC shall ensure that the total number of filters/reactors to be switched in responding to the emergency demand takes into account the number of filters/reactors already being switched.

7.5.8 The effect of voltage changes arising from filter/reactor switching sequences is to cause temporary variation in var exported to the ac systems to which the HVDC scheme is connected. In principle this could cause a spurious switching signal to be generated at either or both ac busbars. RPC shall be designed to inhibit switching under such temporary conditions, so that "hunting" is avoided.

7.5.9 Once an appropriate filter or reactor switching has taken place, it is not permissible to switch any further filters or reactors until the power transmission has changed by at least five percent of rated capacity in either direction.

(Note that this is interpreted as applying only during constant ac system operating conditions, i.e. voltage and frequency. While the ac system operating conditions remain constant, the reactive power controller shall not initiate any further switching until the power transfer has changed by at least five percent (5%) in either direction. However, if the ac system operating conditions do change in any way which affects the supply of reactive power, the 5% hysteresis may be modified. Thus a change of 2.5% in ac system voltage could reduce the hysteresis to zero. [This 5% hysteresis and it's variation are embedded in RPC])

7.5.10 The sequence of filter/reactor switching is to be arranged to spread the number of circuit breaker operations approximately equally between the breakers wherever possible.

7.5.11 Once a filter is de-energised it shall not be re-energised for five (5) minutes (adjustable to a maximum of ten (10) minutes), regardless of whether filter switching is in Automatic Control or Manual Control. This is to permit stored charge to be dissipated. However, in the event of assisting fault recovery (see the list below), filters shall be permitted to be re-energised after a time delay of two minutes (adjustable between one and four minutes). The condition for which this exception applies is:

After a filter is tripped then a filter which was de-energised for at least two minutes shall now be permitted to be re-energised.

(NOTE: Administrative or other procedures must be implemented to ensure that human access to the filter equipment is denied for at least five minutes after de-energisation. Two minutes only allows the stored charge to dissipate to the extent necessary to safeguard the capacitor units against excessive inrush. More time is needed to render them harmless to personnel.)

There shall be no lockout time after reactor de-energisation.

7.5.12 When a filter is de-energised and the status of the filter isolator or breaker is open, RPC will send a "inhibit filter unbalance protection" signal. This signal will be rescinded when the filter is energised.

7.5.13 On the Eastern side, the rules to determine whether to switch a filter or reactor are:

For increasing power transfer; all available filters will be energised before allowing reactors to be de-energised.

For decreasing power transfer; all available reactors will be energised before allowing filters to be de-energised.

At constant power transfer the rules for filter/reactor switching are:

If the var exported to the ac system is on or above the Convertor Surplus limit priority shall be to energise an available reactor rather than de-energise a filter.

If the var exported to the ac system is below the Convertor Deficit Limit priority shall be to energise an available filter rather than de-energise a reactor.

7.6 Reactive Power Mode (RPM) - Closed Loop Var Control

Also see section 7.7

7.6.1 The Long term "Maximum Direct Voltage Limit" is a function of $P_{o\text{-filtered}}$ only (see Figure 4).

7.6.2 Whenever the var exported to the ac system falls below the "Convertor Surplus" limit (see Figure 2 and Figure 3), RPC shall allow the direct voltage to rise until either:

a) the direct voltage reaches the limit governed by the "Maximum Direct Voltage Limit", ie. operation in V_{do} Mode, or

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Approved	BTB	MK					

b) the var exported to the ac system by the other side of the scheme reaches its "Convertor Surplus" limit, so that the convertors use RPM to control the var export on that side.

7.7 Convertor Var Surplus IDMT Characteristic

C RPM is used to control the var exported to the ac system in conformity with the "Convertor Surplus" limit (see Figure 2 and Figure 3). The additional var absorption by the convertors when operating in RPM is achieved by depressing the direct voltage, by an amount which may be determined from Equation 8.

$$\text{Increase in var absorption (IVA)} = V_o VA - V_{dmax} VA$$

Equation 8

where

$V_o VA$ = var absorption of the convertor at maximum direct voltage limit (obtained from lookup table, see Attachment 1)

$V_{dmax} VA$ = var absorption of the convertor at the actual voltage order (obtained from lookup table, see Attachment 1)

7.7.1 This clause is only applicable to the eastern region during operation in RPM (the criterion for deciding on the disconnection of a filter on the southern region is stated in clause 7.7.2).

7.7.1.1 Provided that the conditions of clauses 7.4.3 and 7.2.3 are fulfilled, and that the var exported to the ac system is on or above the "Convertor Surplus" limit, a filter/reactor shall be switched if the "Excess var" calculated as below exceeds a certain level for a certain period.

For reactor energisation,

$$\text{Excess var} = \text{Increase in var absorption} + (\text{var export} - \text{"Convertor Deficit limit"}) - 5\%\ \text{Hysteresis} - Q_{Reactor}$$

Equation 9

For filter de-energisation,

Excess var = Increase in var absorption + (var export − "Convertor Deficit limit") − 5% Hysteresis − Q_{Filter}

Equation 10

where

$Q_{Filter/Reactor}$ = filter/reactor Mvar at the time of switching, see clause 7.2.2.

C 5% Hysteresis = is 25 Mvar

All available reactors must be energised before de-energising any filters.

The time-error relationship for the above is based on an Inverse Definite Minimum Time (IDMT) characteristic defined below and shown in Figure 9. The data used to derive the IDMT characteristic is also shown below. Timing shall start only when the valve-winding voltage is within ±1.25% of the target value and shall be reset if the valve-winding voltage moves outside the target deadband (ie. "Evw Outside Deadband" from PCCS becomes true) for more than two (2) seconds. (See clause 7.16.1 for filter energisation).

$$t_x = \frac{K}{Q_{rel\ x} + Q_{offset}} - t_{offset}$$

t_x = time delay for de-energisation, in seconds, for Q_{rel} = x %

$$Q_{rel} = \frac{\text{Excess var}}{10 \times \text{Threshold}} \times 100\%$$

Threshold = 50 Mvar

$$t_0 = 50, \quad t_1 = 10, \quad t_2 = 2.5$$

$$Q_{rel\ 0} = 2, \quad Q_{rel\ 1} = 25, \quad Q_{rel\ 2} = 100$$

Equation 11

$$Q_{offset} = \frac{Q_{rel\,0}\,Q_{rel\,1}\,(t_1 - t_o) + Q_{rel\,2}\,Q_{rel\,1}\,(t_2 - t_1) + Q_{rel\,0}\,Q_{rel\,2}\,(t_0 - t_2)}{t_0\,(Q_{rel\,1} - Q_{rel\,2}) + t_2\,(Q_{rel\,0} - Q_{rel\,1}) + t_1\,(Q_{rel\,2} - Q_{rel\,0})}$$

$$= 3.979$$

$$t_{offset} = \frac{t_0\,Q_{rel\,0} - t_1\,Q_{rel\,1} + Q_{offset}\,(t_o - t_1)}{Q_{rel\,1} - Q_{rel\,0}} = 0.3979$$

$$K = (t_o + t_{offset})\,(Q_{rel\,o} + Q_{offset}) = 301.32$$

Equation 12

Therefore,

-a filter/reactor may be switched if "Excess var" of at least 10 times the threshold (500Mvar) is calculated for two point five (2.5) seconds.

- a filter/reactor may be switched if "Excess var" of at least 2.5 times the threshold (125Mvar) is calculated for ten (10) seconds.

- a filter/reactor may be switched if "Excess var" of at least 0.2 times the threshold (10Mvar) is calculated for fifty (50) seconds.

7.7.1.2 Clause not used.

7.7.1.3 The "Threshold" (presently defined as 50Mvar) shall be adjustable between 10Mvar and 100Mvar, and the time settings (t_0, t_1 and t_2) shall be adjustable between 100ms and fifty (50) seconds.

7.7.1.4 The output of the IDMT relay shall be permitted to decay at a rate equal to the integration rate. Therefore,

- the output of the IDMT relay shall decay from its operate threshold to zero if **negative** "Excess var" of at least 10 times the threshold (-500Mvar) is calculated for two point five (2.5) seconds.

- the output of the IDMT relay shall decay from its operate threshold to zero if **negative** "Excess var" of at least 2.5 times the threshold (-125Mvar) is calculated for ten (10) seconds.

- the output of the IDMT relay shall decay from its operate threshold to zero if **negative** "Excess var" of at least 0.2 times the threshold (-10Mvar) is calculated for fifty (50) seconds.

The output of the IDMT relay shall not be permitted to change if the calculated "Excess var" is zero, nor shall it be permitted to assume any value less than zero.

7.7.1.5 When the var export limits are modified such that the deadband is larger than 180 Mvars, then the 'excess var' calculation in the IDMT characteristic of clauses 7.7.1.1 and 7.7.1.4 shall be replaced by 'var clearance' as defined below:

Var clearance = (var export − "Convertor Deficit" limit) − (Q-Filter + 25)

Q-Filter = Filter Mvar at the time of switching

Equation 13

This allows a filter to be de-energised to minimise losses subject to the harmonic criteria of clause 7.4.3 being met.

7.7.2 This clause is only applicable to the Southern region during operation in RPM.

7.7.2.1 Provided that the conditions of clauses 7.4.3 and 7.2.3 are fulfilled, and that the var exported to the ac system is on or above the "Convertor Surplus" limit, a filter shall be de-energised if the "Excess var" calculated as below exceeds a certain level for a certain period.

$$\text{Excess var} = \text{Increase in var absorption} + (\text{var export} - \text{"Convertor Deficit limit"}) - 5\%\ \text{Hysteresis} - Q_{Filter}$$

Equation 14

where

C Q_{Filter} = filter Mvar at the time of switching, see clause 7.2.2.
5% Hysteresis = is 25 Mvar

Filter de-energisation shall be based on an (IDMT) characteristic defined below. Timing is to take place only when the valve-winding voltage is within ±1.25% of the target value and shall be reset if the valve-winding voltage moves outside the target deadband (ie. "Evw Outside Deadband" from PCCS becomes true) for more than two (2) seconds.

$$t_x = \frac{K}{Q_{rel\ x} + Q_{offset}} - t_{offset}$$

t_x = time delay for de-energisation, in seconds, for Q_{rel} = x %

$$Q_{rel} = \frac{\text{excess var}}{10 \times \text{Threshold}} \times 100\%$$

Threshold = 50 Mvar

$t_0 = 50$, $t_1 = 10$, $t_2 = 2.5$

$Q_{rel\ 0} = 2$, $Q_{rel\ 1} = 25$, $Q_{rel\ 2} = 100$

$Q_{offset} = 3.979$

$t_{offset} = 0.3979$

$K = 301.32$

Equation 15

Therefore,

- a filter may be de-energised if "excess var" of at least 10 times the threshold (500Mvar) is calculated for two point five (2.5) seconds.

- a filter may be de-energised if "excess var" of at least 2.5 times the threshold (125Mvar) for ten (10) seconds.

- a filter may be de-energised if "excess var" of at least 0.2 times the threshold (10Mvar) is calculated for fifty (50) seconds.

7.7.2.2 Clause not used.

7.7.2.3 The "Threshold" (presently defined as 50Mvar) shall be adjustable between 10Mvar and 100Mvar, and the time settings (t_0, t_1 and t_2) shall be adjustable between 100ms and fifty (50) seconds.

7.7.2.4 The output of the IDMT relay shall be permitted to decay at a rate same as the integration rate. Therefore,

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					Original A	12.5.97
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Approved	BTB	[signature]				

- the output of the IDMT relay shall decay to zero if **negative** "excess var" of at least 10 times the threshold (-500Mvar) is calculated for two point five (2.5) seconds.

- the output of the IDMT relay shall decay to zero if **negative** "excess var" of at least 2.5 times the threshold (-125Mvar) is calculated for ten (10) seconds.

- the output of the IDMT relay shall decay to zero if **negative** "excess var" of at least 0.2 times the threshold (-10Mvar) is calculated for fifty (50) seconds.

The output of the IDMT relay shall not be permitted to change if the calculated var clearance is zero, nor shall it be permitted to assume any value less than zero.

7.7.2.5 When the var export limits are modified such that the deadband is larger than 180 Mvars, then the 'excess var' calculation in the IDMT characteristic of clauses 7.7.2.1 and 7.7.2.4 shall be replaced by 'var clearance' as defined below:

Var clearance = (var export − "Convertor Deficit" limit) − (Q-Filter + 25)

Q-Filter = Filter Mvar at the time of switching

Equation 16

This allows a filter to be de-energised to minimise losses subject to the harmonic criteria of clause 7.4.3 being met.

7.8 Energisation and De-energisation of Filters at Minimum Power Transfer

7.8.1 Once the "Go to Service" signal is received from PCCS, RPC shall ensure that at least 1 Combined filter is available on both sides. If this condition is not satisfied, then RPC shall instruct PCCS to return to standby. All available shunt reactors on the eastern side shall then be energised, if not already, subject to a one second delay (adjustable between 0.5 seconds and 5 seconds) between subsequent switchings. The time delay shall start from the instant the closed status is confirmed. One second after the second reactor breaker closes a Combined filter on each side of the scheme shall be energised. Both reactor and Combined filter switching shall take place regardless of the voltage change and pre/post-conditioning requirements for filter switching stated in clause 7.5.1. If both Combined filters energise, a signal shall be sent to Pole Control 100ms later to indicate the conditions are acceptable to de-block. If, for some reason, a Combined filter fails to energise, then RPC will instruct PCCS to return to standby.

Once power transfer is in progress, subsequent filter/reactor switching shall be used to maintain compliance with the steady state var and harmonic performance requirements.

If the power transfer remains unchanged after the pole is deblocked, or if the change in power transfer after deblock is small, so that there is no need for additional var (see clause 7.13.4), a delay of thirty (30) seconds (time required to update the averaged harmonic performance after a switching event, which is adjustable between 20 seconds and 60 seconds, see clause 7.4.5) shall be allowed between switching events to permit reliable harmonic measurements to be taken. This means that the ac harmonic performance limits may be exceeded temporarily after power transfer commences or during small changes in power transfer after deblock. An alarm shall not be generated if the harmonic performance is exceeded during this period.

7.8.2 The last Combined filter shall be de-energised immediately after the pole is blocked (see Figure 22), regardless of the voltage change requirement stated in clause 7.5.1. RPC shall ensure that on blocking all available reactors are left energised.

7.9 Operation with Extreme AC Network Voltage

7.9.1 RPC shall not respond to measurement of var (i.e. closed loop control) when the ac system voltage is below a threshold level of 85% of 400kV (adjustable between 90% and 70%). Response shall not be reinstated until the ac system voltage remains above the threshold by at least five percent (5%) for at least two (2) seconds (adjustable between zero (0) and ten (10) seconds). RPC shall also be prevented from exerting control and/or switching filters/reactors based on var measurement when the ac system voltage unbalance exceeds 5% (adjustable to a maximum of ten percent (10%)). This inhibit shall be rescinded when unbalance < two percent (2%) for at least two (2) seconds (adjustable between zero (0) and ten (10) seconds.

7.9.2 When the ac system voltage falls below 380kV (minimum for specified performance) and approaches 360kV (lowest for continuous operation), RPC shall still seek to control the var export to both ac systems in accordance with the specified limits. If the ac system voltage on one side falls still further, ie. below 360kV, no filter on that side shall be permitted to de-energise (or reactor energise) based on var measurement, except when a load rejection occurs (see clause 7.10.3) or for a PDO (see clause 7.13.5). However, RPC shall energise filters (de-energise reactors) if the var exported to the ac system falls below the "Convertor

Deficit" limit, subject to the conditions of 7.5.4, 7.13.4 and 7.16.1 being fulfilled. If the tapchanger is incapable of meeting the target valve-winding voltage under this condition (indicated by "Tapchanger Reached End Tap" from PCCS), then RPC shall allow the time counting for filter energisation (as per clause 7.16.1) to be started when it receives the "Tapchanger Reached End Tap" from PCCS.

7.9.3 As the ac system voltage on one side (eastern or southern region) exceeds the performance maximum of 420kV and approaches 427kV, the tapchanger will be incapable of meeting 0.83pu valve winding voltage. When the signals "Tapchanger Reached End Tap" and "Evw Outside Deadband" from PCCS are both true, the reactive power surplus limits (on both eastern and southern regions) shall be relaxed progressively after fifteen (15) seconds (adjustable between 0 and 60 seconds), subject to slew rate limiting of 10Mvar/sec (adjustable between 5Mvar/sec and 50Mvar/sec). The surplus limit is relaxed when the ac voltage exceeds 427kV and is fully relaxed at 437kV. It is progressively restored when the voltage falls from 430kV to 420kV. This is shown in Figure 6.

It is only necessary to relax the surplus limits when the power transfer is less than 100MW (20%). The amount of var relaxation to the surplus limit is given by Equation 17:

$$\text{var relaxation} = \frac{K \times (20 - P_{o\text{-filtered}})}{2}\ \text{Mvar}$$

where $P_{o\text{-filtered}}$ = filtered power order in % of rated value

K = depends on V_{ac}, see figure 6

$\therefore$ var export limit = originally allowed + var relaxation

Equation 17

7.9.4 If one or both of the line charging reactors are not available to RPC where available is defined as:

either a) its reactor breaker Q50 is available, its associated disconnector is closed, and is connected to at least one energised busbar.

or b) its reactor breaker Q50 is available and closed, its associated disconnector is closed, is not connected to an energised busbar but is connected to an energised line.

then the "Convertor Surplus" limit on the eastern ac system shall be relaxed further by an amount related to the ac system voltage at all power transfers. This "further var relaxation" is given in Equation 18.

$$\text{Further var Relaxation} = \text{No. of Reactors Unavailable} \times 80 \times \left(\frac{V_{ac}}{420}\right)^2 \times \left(\frac{50}{f_{ac}}\right)$$

where V_{ac} = eastern ac system voltage, phase to phase, in kV_{rms}

$\therefore$ var export limit = originally allowed + var relaxation

+ further var relaxation

Equation 18

7.9.5 When the ac system voltage on one side (eastern or southern region) exceeds the maximum of 440kV, the convertors shall no longer be used to control the reactive power exported to either ac system, ie. RPM shall become disabled. The process of disabling RPM shall only be undertaken when full relaxation of the surplus limit has occurred (see Clause 7.9.3). When operating above 100MW (in which case there will be no surplus relaxation), there shall be a fifteen (15) second delay (adjustable between 0 and 60 seconds) after the signals "Tapchanger Reached End Tap" and "Evw Outside Deadband" from PCCS become true before RPM is disabled. Under this condition, filters/reactors may be energised/de-energised when required on the side whose ac system voltage is below 440kV, whereas no additional filter/reactor shall be permitted to energise/de-energise on the ac system whose voltage exceeds 440kV, until the voltage falls below 430kV, except to restore filters/reactors due to disconnection not initiated by RPC or due to a PDO. When RPM is disabled, RPC shall de-energise any unwanted filters and energise reactors when necessary to prevent "excessive var" exported to the ac systems. "Excessive var" means that the var exported to the ac system exceeds the "Convertor Surplus" limit by more than 125Mvar (adjustable between 50Mvar and 200Mvar). No alarm shall be given if the var/harmonic performance is exceeded under this condition.

When the ac system voltage falls below 430kV, RPC shall progressively restore RPM capability in ten (10) seconds (adjustable between one (1) second and thirty

(30) seconds).

7.10 TOV Control

7.10.1 If the ac system voltage exceeds the threshold of the "AC Voltage Limit" (which is for ac system overvoltage control and is a feature of Phase Control residing in Pole Control), Pole Control will increase the var absorption of the convertors by depressing the direct voltage until the overvoltage is limited to a level determined by the setting in Phase Control, regardless of the var exported to the ac system or of the harmonic performance (see clause 7.4.5 and Figure 14). No alarm shall be given if the var/harmonic performance limits are exceeded during this condition. Further discussion of TOV control requirements is contained in the related document CF0136/0049/FUNC [3].

7.10.2 RPC shall reinforce TOV control by disconnecting filter(s) and energising reactors. If the ac system voltage exceeds 1.2pu of 400kV (adjustable to a maximum of 1.4pu) for longer then 1.1 second* (adjustable between 0.5 second and 2 seconds), RPC shall energise all available reactors and disconnect filter(s) (one or two at a time) at intervals of 0.1 second (adjustable between 0.05 second and 0.2 second) without invoking the pre/post-conditioning technique for filter switching described in clause 7.5.1. RPC shall cease to initiate further filter/reactor switching action for TOV control after 1.5 seconds (adjustable to a maximum of two (2) seconds) or when no more than one filter remains energised (see Figure 14). No alarm shall be given if the var/harmonic performance limits are exceeded for approximately ten (10) minutes after this action. The ac system voltage used for TOV assessment **shall not** be subjected to the low-pass filtering as per clause 7.1.2.

On the Southern Side:

IF (NEF > 2) THEN (disconnect 2 filters at a time)

ELSE IF (3 > NEF > 1) THEN (disconnect 1 filter)

ELSE (do nothing)

where NEF = Number of Energised Filters

Equation 19

On the Eastern Side:

Energise all available reactors

IF reactors energised = 2

THEN

IF NEF > 1 THEN disconnect 1 filter

ELSE do nothing

ELSE

IF NEF > 2 THEN disconnect 2 filters at a time

ELSE IF 3 > NEF > 1 THEN disconnect 1 filter at a time

ELSE do nothing

Equation 20

* 1.1 seconds is not less than the maximum time between ac network fault detection and circuit breaker lock-out, see Figure 7.

7.10.3 In the event of a pole trip, all filters shall be de-energised and all reactors on the eastern side energised within 3 cycles.

7.11 AC System Voltage Collapse - TCR Mode

7.11.1 The convertor is to use TCR mode to limit the TOV on the "healthy" ac system if the direct voltage collapses. During this condition, the normal var/harmonic performance requirements do not apply. When direct voltage is less than the threshold below which LVCC assumes control of direct current, the convertor is said to be operating in TCR mode. The need for TCR mode to limit the TOV is stated in CF0136/0049/FUNC [3]. When the convertors are operating in TCR mode (this is indicated to RPC by a "Commutation Failure" signal from PCCS), RPC shall not generate any alarm if var/harmonic performance is/are exceeded. See also 7.15.1

7.12 Clause Not Used

7.13 Open Loop Reactive Power Control

This clause describes the switching of filters and reactors based on power transfer to provide coarse control (open loop) of reactive power exchange. This feature is always active in order to maintain control during rapidly changing conditions.

7.13.1 Filter/reactor switching shall not respond to the power modulation component of power order. However, RPC shall continue to provide var support (see clause 7.13.4) based on the unchanging/slowly changing part of the power transfer. (Power Modulation is defined by POWERGRID as a modulation signal with frequency between 0.1Hz and 10Hz). The output of the IDMT relay (in the closed-loop part of RPC) shall also be disabled when appreciable power modulation is present. This is illustrated in Figure 25.

7.13.2 Clause not used.

7.13.3 During normal operation, one Combined filter must always be energised. Priority shall then be given to energising D-type filters (before energising the second Combined filter) whereas priority shall be given to de-energising the second Combined filter (before de-energising D-type filters). The last filter to be disconnected when shutting down shall be a Combined filter.

7.13.4 When RPC receives a ramp in power order, filters and reactors shall be switched according to open-loop determined rules to provide coarse control of reactive power support, even if the feature described in clause 7.5.2 is inactive, eg. if V_{LL} is not within ±1.25% of the target value. The rules to be observed are as follows:

C On the Southern side during an increase in power transfer, only filter energisation is allowed (see Equation 21):

$$\text{Total Filters Required}_{South} = \text{Rounded Down}\left[\frac{ACDO_s + (0.95 \times V_{dmax} VA) + CTO_s}{Q_{Filter}}\right]$$

Equation 21 (South)

On the Southern side during a decrease in power transfer, only filter de-energisation is allowed (see Equation 22):

Filters to remain = if $(N_{var} > N_{harm})$; then (N_{var}); else (N_{harm})

C

$$N_{var_{South}} = \text{Rounded Up}\left[\frac{ACSO_s + V_o VA + CTO_s}{Q_{Filter}}\right]$$

Equation 22 (South)

C On the Eastern side during an increase in power transfer, filter energisation will first be allowed up to the maximum available (see Equation 23), no reactor de-energisation will be permitted until all available filters are energised:

$$Filters_{East} = \text{Rounded Down}\left[\frac{ACDO_e + (0.95 \times V_{dmax} VA) + (N_r \times Q_{reactor}) + CTO_e}{Q_{Filter}}\right]$$

Equation 23 (East)

C When the maximum number of available filters are energised, then reactors will be permitted to be de-energised during an increase in power transfer (see Equation 24)

$$Reactors_{East} = \text{Rounded Up}\left[\frac{-ACDO_e - (0.95 \times V_{dmax} VA) + (N_f \times Q_{filter}) - CTO_e}{Q_{reactor}}\right]$$

Equation 24 (East)

C On the Eastern side during a decrease in power transfer, reactor energisation is allowed up to the maximum available (see Equation 25), no filter de-energisation will be initially allowed until all available reactors are energised:

$$Reactors_{East} = \text{Rounded Down}\left[\frac{-ACSO_e - V_o VA + (N_f \times Q_{filter}) - CTO_e}{Q_{reactor}}\right]$$

Equation 25 (East)

C When the maximum number of available reactors are energised, then filters will be permitted to be de-energised during a decrease in power transfer (see Equation 26). Filters to remain = if ($N_{var} > N_{harm}$); then (N_{var}); else (N_{harm})

$$N_{var_{East}} = \text{Rounded Up}\left[\frac{ACSO_e + V_o VA + (N_r \times Q_{reactor}) + CTO_e}{Q_{Filter}}\right]$$

Equation 26 (East)

where

$CTO_{e/s}$ = (Default surplus Limit + Default deficit limit)/2

	=	Convertor Target Offset (east/south)
$ACSO_{e/s}$	=	Accepted offset to Convertor Surplus (east/south)
$ACDO_{e/s}$	=	Accepted offset to Convertor Deficit (east/south)
C V_oVA	=	Var absorption of the convertors at actual voltage order
C $V_{dmax}VA$	=	Var absorption of the convertors at the maximum direct voltage limit
$Q_{reactor}$	=	Single Reactor Mvar at time of switching. The ac system voltage used to calculate the filter Mvar **should not** be subject to low pass filtering as per clause 7.1.2.
Q_{Filter}	=	Single Filter Mvar at the time of switching. The ac system voltage used to calculate the filter Mvar **should not** be subject to low pass filtering as per clause 7.1.2.
N_f	=	No. of energised filters on eastern side
N_r	=	No. of energised reactors on eastern side
N_{harm}	=	number of filters required for harmonic performance (see table 2)

The coarse control action shall respond to rapid changes in $P_{o\text{-filtered}}$.

For a fixed power transfer, immediate filter/reactor switching may also be necessary, to avoid a large discrepancy in reactive power performance, as a result of a large rapid change in ac system voltage. Therefore, RPC shall also initiate a minimum number of switching actions, even if the feature described in clause 7.5.2 is inactive, so that the number of energised filters/reactors remains within the value(s) determined by the open-loop determined rules stated above. The coarse control action shall respond to rapid changes in ac system voltage and shall be subject to slew rate limiting of 40kV/second.

The switching action caused by a rapid change in ac system voltage shall only be permitted when the discrepancy lasts for two (2) seconds (adjustable between 1 second and 5 seconds).

The values of C_{var} are calculated using the as-built commutating reactance for the Chandrapur and Visakhapatnam converter transformers.

7.13.5 When executing a step change in power order, an appropriate number of filters/reactors, determined by the rules stated below, shall be switched immediately without taking time to observe either the voltage change requirement defined in clause 7.12.1 or the pre/post-conditioning requirement defined in clause 7.5.1. However, at least one Combined filter must be left energised.

C On the Southern side during an increase in power transfer, only filter energisation is allowed (see Equation 27):

$$\text{Total Filters Required}_{South} = \text{Rounded Down}\left[\frac{ACDO_s + (0.95 \times V_{dmax}VA) + CTO_s}{Q_{Filter}}\right]$$

Equation 27 (South)

On the Southern side during a decrease in power transfer, only filter de-energisation is allowed (see Equation 28):

C Filters to remain = if ($N_{var} > 1$); then (N_{var}); else ($N = 1$)

$$N_{var_{South}} = \text{Rounded Up}\left[\frac{ACSO_s + V_oVA + CTO_s}{Q_{Filter}}\right]$$

Equation 28 (South)

C On the Eastern side during an increase in power transfer, filter energisation will first be allowed up to the maximum available (see Equation 29), no reactor de energisation will be permitted until all available filters are energised:

$$\text{Filters}_{East} = \text{Rounded Down}\left[\frac{ACDO_e + (0.95 \times V_{dmax}VA) + (N_r \times Q_{reactor}) + CTO_e}{Q_{Filter}}\right]$$

Equation 29 (East)

C When the maximum number of available filters are energised, then reactors will be permitted to be de-energised during an increase in power transfer (see Equation 30)

$$\text{Reactors}_{East} = \text{Rounded Up}\left[\frac{-ACDO_e - (0.95 \times V_{dmax}VA) + (N_f \times Q_{filter}) - CTO_e}{Q_{reactor}}\right]$$

Equation 30 (East)

C On the Eastern side during a decrease in power transfer, reactor energisation is allowed up to the maximum available (see Equation 31), no filter de-energisation will be initially allowed until all available reactors are energised:

$$Reactors_{East} = \text{Rounded Down}\left[\frac{-ACSO_e - V_o VA + (N_f \times Q_{filter}) - CTO_e}{Q_{reactor}}\right]$$

Equation 31 (East)

When the maximum number of available reactors are energised, then filters will be permitted to be de-energised during a decrease in power transfer (see Equation 32)

C Filters to remain = if ($N_{var} > 1$); then (N_{var}); else ($N = 1$)

$$N_{var_{East}} = \text{Rounded Up}\left[\frac{ACSO_e + V_o VA + Q_{reactor} + CTO_e}{Q_{Filter}}\right]$$

Equation 32 (East)

where

	$CTO_{e/s}$	=	(Default surplus Limit + Default deficit limit)/2
		=	Convertor Target Offest (east/south)
	$ACSO_{e/s}$	=	Accepted offset to Convertor Surplus (east/south)
	$ACDO_{e/s}$	=	Accepted offset to Convertor Deficit (east/south)
C	$V_o VA$	=	Var absorption of the convertor at the actual voltage order
C	$V_{dmax} VA$	=	Var absorption of the convertor at the maximum direct voltage limit
	$Q_{reactor}$	=	Single Reactor Mvar at time of switching. The ac system voltage used to calculate the filter Mvar **should not** be subject to low pass filtering as per clause 7.1.2.
	Q_{Filter}	=	Single Filter Mvar at the time of switching. The ac system voltage used to calculate the filter Mvar **should not** be subject to low pass filtering as per clause 7.1.2.
	N_f	=	No. of energised filters on eastern side
	N_r	=	No. of energised reactors on eastern side
	N_{harm}	=	number of filters required for harmonic performance (see table 2)

7.13.6 A ramp function is defined as a change in power order ($P_{o\text{-filtered}}$) less than or equal to 1400MW/min (adjustable between 1000MW/min and 2000MW/min). A change in power order greater than the limit set for a ramp will be considered as a step change.

7.14 Filter Tripping

7.14.1 When a filter trips, the control system shall ensure that power transfer is maintained at the pre-fault value as nearly as is possible. This is to be achieved by energising available filters as required. If insufficient filters are available and the performance criteria are exceeded, appropriate alarms are to be raised as usual.

The number of filters to be energised following filter trips shall be governed by the following rules:

a) a D-type filter may be replaced by a Combined filter, or vice versa, if an equivalent is not available.

b) if x filters are tripped, then energise another x filters.

c) if x filters are tripped and only x-1 filters are available, then energise all available filters (ie. x-1).

d) if x filters are tripped and less than x-1 filters are available, then all available filters are energised. Under this condition, RPC shall allow the direct voltage order to increase to a value dictated by the "Maximum Direct Voltage Limit", see Figure 4. This shall be executed as a step increase in dc voltage. The direct voltage shall not be permitted to depress for var control until the valve-winding voltage is corrected to within ±1.25% of the tapchanger control deadband (when "E_{vw} Outside Deadband" is false) or until "Tapchanger Reached End Tap" is received.

e) If the total reduction in the ac system voltage in 0.5 second (adjustable between 0.2 second to 1.0 second) after the tripping event exceeds 10% of 400kV (adjustable between 5% and 20%), then RPC shall send a "Rapid Power Reduction" signal to PCCS.

f) If a Combined filter trips and the other Combined filter is not available to replace it then it shall be replaced by a D-type filter as in part a) above. However, if a Combined filter subsequently becomes available it shall

7.13.6 A ramp function is defined as a change in power order ($P_{o\text{-filtered}}$) less than or equal to 1400MW/min (adjustable between 1000MW/min and 2000MW/min). A change in power order greater than the limit set for a ramp will be considered as a step change.

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f) If a Combined filter trips and the other Combined filter is not available to replace it then it shall be replaced by a D-type filter as in part a) above. However, if a Combined filter subsequently becomes available it shall

On the Eastern side during a decrease in power transfer, reactor energisation is allowed up to the maximum available (see Equation 31), no filter de-energisation
C will be initially allowed until all available reactors are energised:

$$\text{Reactors}_{East} = \text{Rounded Down}\left[\frac{-ACSO_e - V_oVA + (N_f \times Q_{filter}) - CTO_e}{Q_{reactor}}\right]$$

Equation 31 (East)

When the maximum number of available reactors are energised, then filters will be permitted to be de-energised during a decrease in power transfer (see Equation 32)

C Filters to remain $= \text{if } (N_{var} > 1)\text{; then } (N_{var})\text{; else } (N = 1)$

$$N_{var_{East}} = \text{Rounded Up}\left[\frac{ACSO_e + V_oVA + Q_{reactor} + CTO_e}{Q_{Filter}}\right]$$

Equation 32 (East)

where

$CTO_{e/s}$	=	(Default surplus Limit + Default deficit limit)/2
	=	Convertor Target Offest (east/south)
$ACSO_{e/s}$	=	Accepted offset to Convertor Surplus (east/south)
$ACDO_{e/s}$	=	Accepted offset to Convertor Deficit (east/south)
C V_oVA	=	Var absorption of the convertor at the actual voltage order
C $V_{dmax}VA$	=	Var absorption of the convertor at the maximum direct voltage limit
$Q_{reactor}$	=	Single Reactor Mvar at time of switching. The ac system voltage used to calculate the filter Mvar **should not** be subject to low pass filtering as per clause 7.1.2.
Q_{Filter}	=	Single Filter Mvar at the time of switching. The ac system voltage used to calculate the filter Mvar **should not** be subject to low pass filtering as per clause 7.1.2.
N_f	=	No. of energised filters on eastern side
N_r	=	No. of energised reactors on eastern side
N_{harm}	=	number of filters required for harmonic performance (see table 2)

replace the D-type immediately i.e. not replace the D-type as part of a routine filter switch for var/harmonic reasons. The same shall apply if a D-type filter trips and is replaced with a Combined filter.

7.14.2 If equipment is unavailable (eg. if it is under maintenance), the normal performance limits may be exceeded in order to maintain the required power transfer. However, the operating conditions will continue to be constrained within the physical capabilities of the plant, eg. by current limits, and the usual alarms will continue to be raised when performance criteria are not met.

7.14.3 If one of the shunt reactors trips and the other shunt reactor is available to be energised, then this shall be energised immediately. If the other shunt reactor is already energised or is unavailable, then no further switching shall take place and surplus relaxation shall occur as specified by clause 7.9.4.

7.14.4 Clause not used.

7.14.5 If a filter suffers a trip caused by Filter Protection, then an equivalent element (if one is available, see clause 7.5.11) shall be energised within seven (7) cycles* (from the time when the faulty filter is tripped, indicated by the signal circuit breaker auxiliary contacts), regardless of the pre/post-conditioning requirement for filter switching stated in clause 7.5.1, to minimise the disturbance to the ac system. Alternatively; a different type of filter may be energised within seven (7) cycles* (from the time when the fault is detected), if no similar filters are available (see part (a)).

If neither type of filter is available, then RPC shall allow the direct voltage to fall by an amount dictated by the equations stated in clause 7.5.1 within two (2) seconds (this time period is to be co-ordinated with the time delay in Filter Protection) after receiving the signal "Imminent Trip" from Filter Protection. The direct voltage order shall be restored immediately to the pre-disturbed value upon receiving the signal generated by the circuit breaker auxiliary contacts.

If the pre-fault power transfer exceeds 110% and no spare filter is available, then RPC shall also generate a signal; "Reduce Power Now" to PCCS upon receiving confirmation from the circuit breaker auxiliary contacts.

* The maximum permissible connection time is seven (7) cycles at 51.5Hz, ie. 136ms. This includes the operation times (closing) of filter circuit breaker (≅ 100 ~ 120ms) and interposing relay (≅ 5ms), see Figure 10.

7.15 Thermal Constraints

7.15.1 When the convertors are required to operate in TCR mode (see clause 7.11) and a "Commutation Failure" signal (from PCCS) is asserted for two (2) seconds or more (adjustable between 200ms and two (2) seconds), RPC shall have the facility to utilise the Tj and Tj' inputs from the thyristor valves which are bypassed (i.e. the valves on the side where the ac voltage has collapsed). This is to determine whether filter(s) must be de-energised/reactors energised on the healthy ac system to prevent the thyristor valves overheating as defined below:

For the Southern side:

IF Tj > (Tj' × a) + b
THEN switch out x filters

where: x = 1
a = 0.576
b = 39.0

For the Eastern side:

IF Tj > (Tj' x a) + b
THEN IF (No. of available reactors = 2)
THEN energise both reactors

ELSE energise any available reactors
AND switch out x filters

where: x = 1
a = 0.576
b = 39.0

7.15.2 Surge Arrester or Damping Resistor Adverse Firing Angle (AFA) capability ON/OFF signals are sent from Pole Control to indicate the thermal capability of the thyristor valve surge arresters and damping resistors (these elements may become overheated if the control angles demanded by RPC for var control are too large for too long). When the signal is ON, RPC shall select RPEM on both sides (see 7.20) and ramp up both "Convertor Surplus" limits at a rate of 50Mvar/sec (adjustable between 10Mvar/sec to 100Mvar/sec) and an alarm "AFA capability limit" shall be given. This is shown in Figure 15. The "Convertor Surplus" limit shall not be permitted to be restored by the operator, nor shall the operator be permitted to change the demanded offsets to the var export limits (see clause 7.20) until the signal changes to OFF. When the signal changes to OFF, the operator shall be prevented from changing the offsets for a further 5 minutes. The alarm for "var/harmonic limit exceeded" shall not be required when the signal "Surge Arrester or Damping resistor AFA capability" is ON. The strategy is shown in Figure 15.

7.16 Valve-Winding Voltage Characteristics

7.16.1 While the valve-winding voltage is within ±1.25% of the target value (ie. when "E_{vw} Outside Deadband" from PCCS is false), RPC shall energise a filter if the reactive power exported to the ac system falls below the "Convertor Deficit" limit (see also clause 7.5.4) according to an Inverse Definite Minimum Time (IDMT) characteristic as defined in clause 7.7.1.2 and 7.7.2.2. Figure 9 illustrates the proposed characteristic. Timing shall take place only while the valve-winding voltage is within ±1.25% of the target value and shall be reset if the valve-winding voltage falls outside the target deadband (ie. "Evw Outside Deadband" from PCCS becomes true). (See clause 7.7 for filter disconnection).

7.16.2 Since the target valve-winding voltage is limited whenever the power transfer is lower than about 65%, the maximum direct voltage attainable will also be limited. To avoid creating demands for smaller than normal control angles during steady state operating conditions or when tapchanger is moving, which might lead to increased risk of commutation failure, RPC shall not demand a direct voltage in excess of the "Maximum Direct Voltage Limit" as shown in Figure 4 (see also clause 7.6.1).

7.16.3 At high power transfers, if the reactive power falls below the "Convertor Deficit" limit and all filters have been energised (and all reactors de-energised on eastern side), RPC shall send a signal to Pole Control to reduce the valve-winding voltage thus restricting the firing angle to within a pre-determined deadband. Refer to Related Document [3]. This control function is only required for power transfer from the East to the South. The logic to determine this is:

For the Southern Inverter:
IF the following conditions are true for 10 seconds (adjustable between 10 and 60 seconds)

Qdeficit is +ve (outside var deadband)

All 4 filters energised
$90\% < P_{o\text{-filtered}} > 110\%$
$380kV < V_{ac} < 400kV$
$47.5Hz < f_{ac} < 51.5Hz$
Not operating in RPEM/ACVCM mode
Not operating in RPM mode
Southern side is inverter

THEN Send signal to activate tap-changer control of gamma function
De-activate closed loop var control

To de-activate the function:

If any of the following conditions are true for 10 seconds (adjustable between 10 and 60 seconds)

IF Qdeficit < -50Mvars
OR Not all 4 filters energised
OR $88\% > P_{o\text{-filtered}} > 112\%$
OR NOT ($375kV < V_{ac} < 405kV$)
OR NOT ($46.5Hz < f_{ac} < 52.5Hz$)
OR In RPM
OR In RPEM/ACVCM
OR South side is rectifier

THEN Send signal to Pole Control to revert to normal open-loop valve-winding voltage control.
Enable closed loop control.

7.17 Switch Position Monitor

7.17.1 RPC shall be provided with signals via the SCADA Bay Interface Outstation to indicate whether any filter/reactor on either side of the scheme is unavailable. Control signals must not be sent to these elements. If an "unavailable" signal is received from an energised filter, then a disconnection signal shall be sent to this filter and an energisation signal shall be sent to another filter simultaneously, regardless of the voltage change requirement stated in clause 7.12.1 and of the pre/post-conditioning requirement for filter switching stated in clause 7.5.1.

7.17.2 RPC shall provide a switch position monitor (SPM) which indicates whether certain nodes are connected to each of the busbars. These nodes will include the filter breakers at the point where they join their corresponding disconnector and convertor terminals. Logical operations may then be applied to this information to ascertain whether a filter breaker can be connected to a busbar which is connected to the pole.

7.17.3 If during normal operation it is detected that a convertor is deblocked when no filters have been connected to it for more than 2 seconds (adjustable between 1 and 5 seconds) than a signal shall be sent to Pole Control to carry out a normal "Go To Standby" sequence.

7.18 Manual Control of Filter and Shunt Reactor Circuit Breakers

7.18.1 Control of filter and reactor switching is to be selectable to either **Auto** or **Manual**. In **Auto** RPC will carry out all actions to regulate both the convertor reactive power absorption and opening/closing of filter/reactor circuit breakers in support of the reactive power and harmonic performance. In **Manual** control, RPC will still carry out the required actions to control var and harmonic performance, except that the switching of filter/reactor circuit breakers will not be executed directly by RPC. In the event that RPC requires a filter/reactor to be switched, it will indicate to the operator which specific circuit breaker to switch. It is then the responsibility of the operator to carry out the required action.

7.18.2 If the operator has not performed the required switching action within 30 seconds of the command being given, then RPC shall override the **Manual Control** action. An alarm shall be given to the Alarm Monitoring and Reporting System showing that pre-emptive control action has been taken. However, if the ac system voltage exceeds 440kV when a filter is required to be de-energised (reactor energised), the operator shall be overridden after 10 seconds. Similarly, if the ac voltage falls below 360kV when a filter is required to be energised (reactor de-energised), the operator shall also be overbidden after 10 seconds.

7.18.3 When the convertor station is in the standby state or one of the Jeypore lines and it's charging reactor are not connected to the convertor station busbars, e.g. when both the bay **and** tie breaker associated with the line are open, control of the shunt reactor breaker will be allowed to be from the mimic without the request of RPC i.e. full manual control. In this case, a permanent indication shall be given to the operator as to which reactor breaker is in manual control. This facility is required for line energisation.

7.18.4 The **Manual Control** action shall be overridden immediately by **Auto** if the switching action is to assist fault recovery, ie.

- switching off filters (and energising reactors) for TOV control caused by e.g. load rejections (see clauses 7.10.2 and 7.10.3),
- switching on a filter when another filter is tripped (see clause 7.14.5),
- switching off filter(s) if required when operating in "TCR mode" (see clause 7.15.1).
- Power Demand Overrides (PDO's)

7.18.5 The information given to the operator will be as follows:

a) the var exported to the ac system at the point of connection.

b) an indication as to which filter/reactor to switch and an alarm if the var/harmonic performance is exceeded. The alarm shall be given with a time delay of 30 seconds (adjustable between 10 seconds and 60 seconds).

7.18.6 Transition between Automatic Control and Manual Control shall take place without disturbance to power transfer. All relevant control history must be maintained. If all control history is lost, RPC shall prevent filters from energising for at least two (2) minutes.

7.19 Alarms

7.19.1 During normal operation, if a filter or reactor circuit breaker fails to respond to instruction then an alarm "Not Responding" shall be issued and then the actions described by table 3 carried out (see also Figure 11).

7.19.2 If all the available filters are energised (and all reactors on the Eastern side de-energised) and the var exported to the ac system falls below the "Convertor Deficit" limit, an alarm shall be given after a time delay of sixty (60) seconds (adjustable between 30 seconds and 120 seconds).

7.20 Additional Functions

The following clauses detail the control actions required under special operating conditions.

7.20.1 Control Modes

As stipulated in Clause 4.7.1.2(iii) of POWERGRID's specification, it shall be possible to select Reactive Power Exchange Mode or AC Voltage Control Mode by means of a switch on the Mimic. The transfer from one operating mode (ie. normal, RPEM or ACVCM) to any other mode shall be transient-free.

7.20.1.1 Reactive Power Exchange Mode (RPEM)

In this mode it shall be possible to adjust the upper and lower reactive power export limits. This facility shall be available on each side of the scheme, and shall offer on-line selection of the "Convertor Surplus" limit and the "Convertor Deficit" limit which are allowed to persist before corrective action is taken. The width of the deadband, ie. difference between "Convertor Surplus" and "Convertor Deficit" limits, is permitted to increase beyond the default size or to be restored to the default size, but is not permitted to decrease to less than the default size. This feature shall not determine the rating of equipment.

7.20.1.2 AC Voltage Control Mode (ACVCM)

In this mode, it shall be possible to set a target for ac system voltage which replaces the normal (measured var) target for control of var exported to the ac system. This shall be achieved by applying an offset to both the "Convertor Surplus" limit and the "Convertor Deficit" limit according to the difference between the selected target ac system voltage and the reference voltage. Thus, a target ac system voltage less than the ac system voltage, i.e. the ac system voltage at the time when ACVCM demand is executed, shall generate a negative offset (ie. to absorb var from the ac system), while a target ac system voltage greater than the ac system voltage shall generate a positive offset (ie. to export var to the ac system). However, the size of the var export deadband shall not be affected. This feature shall not determine the rating of equipment.

7.20.1.3 Limits

POWERGRID has suggested the following ranges and targets for RPEM and ACVCM.

RPC should be capable of operating in RPEM or ACVCM. During RPEM, the operator should be able to bias the "Convertor Surplus" and "Convertor Deficit" limits separately for reactive power exported to the ac system by up to ± 300 Mvar. The default value is zero when RPEM and ACVCM are not selected, see Figure 2 and Figure 3. RPC shall ensure that the width of the var export deadband is at least as large as the default size. If the operator asks for offsets which reduce the width of the var export deadband below that of the default, RPC shall ignore the latest offsets.

During ACVCM, the operator shall be able to select a target 400kV$_{rms}$ voltage level within a range of 0.95pu to 1.05pu. A target voltage higher than the initial ac system voltage, ie. the ac system voltage when ACVCM demand is executed, will result in a positive offset (ie. to export var to the ac system) applied to both the "Convertor Deficit" and "Convertor Surplus" limits, whereas a target voltage lower than the ac system voltage will result in a negative offset (ie. to absorb var from the ac system) applied to both the "Convertor Deficit" and "Convertor Surplus" limits. The total offset to be applied shall not exceed ±300Mvar.

These operation modes and the limits/target value shall be selectable regardless of the ac system operating condition, ie. voltage and frequency, and the power transfer. This implies that changing the limits/target value may involve filter switching even when the ac system conditions, ie. voltage and frequency, and the power transfer are fixed (see clause 7.5.9). (Although a mode change can only be initiated "bumplessly", ie. without change of variable.)

The facilities described above shall utilise the inherent capability of the HVDC equipment, and shall not influence equipment ratings. However, the operational requirements of the RPC stated in this specification still apply.

7.20.2 The following is a list of supplementary requirements for implementing ACVCM and RPEM proposed by GEC ALSTHOM.

a) When operating in RPEM, RPC shall receive up to four different offsets to the "Surplus Limit" and "Deficit Limit" for the two sides (Convertor Surplus$_{c/s}$/Deficit$_{c/s}$, ie CSO_c, CSO_s, CDO_c and CDO_s) from the Mimic. RPC shall ensure that the width of the revised var exchange deadband is not less than the default and shall reject offsets which violate this. In ACVCM, RPC shall receive a voltage demand from the Mimic and shall ensure that the accepted convertor offsets give a deadband which is equal to the default.

b) It shall not be possible to de-select from RPEM until RPC receives zero demand offsets from the Mimic.

c) When ACVCM is selected, an offset calculated from the difference between the target V_{ac} (defined by the operator) and the V_{ac} at the time ACVCM