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Control of Multi-Terminal DC Transmission Supported Voltage Source Converters

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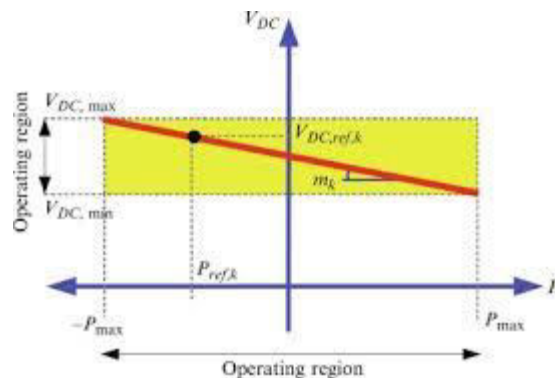
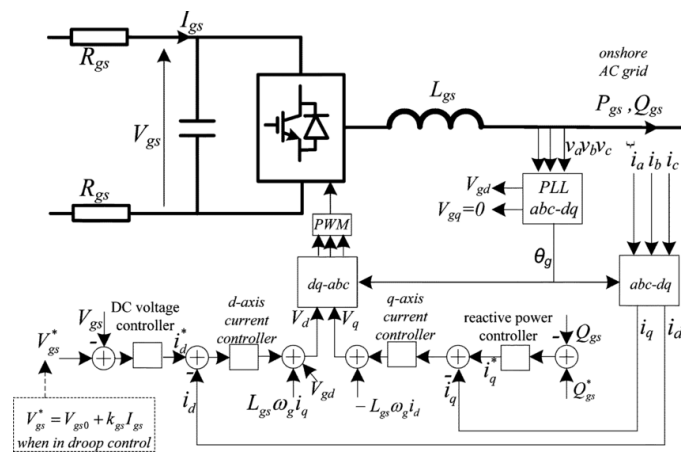
ABSTRACT: This paper discusses control strategies that enhance active These paper discusses the control strategies which will improve power control in multi-terminal dc transmission systems the control of the facility flow and power dispatch in voltage supported the voltage source converter so as to reply to source converter based multi-terminal dc transmission any power demand irrespective of the designated control systems. This is achieved by allowing the converter mode at the terminals. This is achieved by including the controlling the dc line voltages to participate in active power active power - dc voltage droop characteristic within the control control using active power – dc voltage droop characteristics. system of the terminals that are designated for dc voltage The paper also presents a recovery strategy that allows regulation. The paper also demonstrates the recovery strategy voltage source converter based multi-terminal dc that permits a multi-terminal dc transmission to recover transmissions to get over ac faults with minimum voltage from ac faults without significant rise of the dc link voltage and current stresses on the converter switches. This is (This means minimal voltage stresses on the converter achieved by matching the power command to the actual semiconductors). This feature is achieved by adjusting the power which will be transferred, because the voltage on the ac side active power commands given to the converters controlling collapses due to the fault or any major disturbance. The the active power so on eliminate the trapped energy within the validity of those strategies are confirmed by simulation.

KEYWORDS: Current source converter, high-voltage dc transmission system and reactive power support

I. INTRODUCTION

Converter to deliver active power reduces as the voltage magnitudes at the purpose of common coupling (PCC) collapses. High-voltage dc transmission can be implemented using Therefore any plan to eliminate the trapped energy within the current source converters with thyristors because the main switches dc side during the ac fault must take under consideration the voltage or voltage source converters with IGBTs as the main magnitude in the least PCCs. This necessitates modification of the switches. The thyristor based HVDC system can use line or active power loop to be sensitive to any variation in voltage capacitor commutated converters. These HVDC transmission magnitude at the points of common coupling. systems are limited by thyristor switching characteristics, resulting in high reactive power consumption and harmonic 2. Test system current, an outsized footprint, and restricted control. so as to demonstrate the validity of the proposed strategies, HVDC systems using voltage source converters with carrier the four-terminal system in Fig. 1 is simulated in Matlab-s based or optimal pulse width modulation (PWM) provide Simulink. Converters VSC1 and VSC2 control active power additional features, compared to the present source converter and VSC3 and VSC4 regulate the dc link voltage at 275kV dc. based HVDC systems. a number of these features are [1]-[8][5]: Converter VSC4 incorporates dc voltage droop control to

1) Independent control of active and reactive power. enable active power sharing between VSC3 and VSC4 at any
2) Reactive power capability at no additional cost. ratio. All the converters are modelled as 300MVA two-level
3) Black start capability. converters using sinusoidal pulse width modulation (SPWM) 4) Bi-directional power flow with uni-polar dc link voltage. with a carrier frequency of 2.1kHz. G1 through to G4
represent four ac networks, their ratings shown in Fig. 1. The These features make VSC-HVDC transmission attractive for power flow directions indicated in Fig. 1 are assumed as the implementation of multi-terminal HVDC systems. positive. so as to utilize the complete benefits of multi-terminal HVDC systems



VSC2. These control schemes use a standard decoupled is shown in Fig. 2c. ΔP is the active power that can be strategy to control active and reactive power with feed- exchanged between converters VSC3 and VSC4. The forward terms to improve system disturbance rejection relationship between ΔP and the reference dc voltage of immunity. A rate limiter in Fig. 2 is used to control the converter VSC4, when the dc link of the converter VSC3 is power slope during active power ramping. Modified active held at V_{dc} , is:

power control allows the converters **to regulate** the active power 1 1 2

$$V = V + V - \Delta R P (1)$$

dc4 2 dc 4 dc

command in proportion to the average reduction in the voltage magnitudes at buses B3 and B4. Adjustment of the where R is the effective resistance of the line connecting converter power commands can minimize the amount of converters VSC3 and VSC4.

active power which **can't be** transferred to G3 and G4. This Therefore inclusion of the active-power-dc voltage droop will act to minimise the energy which must be temporarily characteristic in Fig. 2c, **within the system** of the converter absorbed by the dc link capacitors, reducing the dc link VSC4 will allow converters VSC3

III. PERFORMANCE EVALUATION

order **to extend** the share of the active power **that has got to** be delivered through converter VSC4 while the dc link voltage of This section evaluates the proposed power management converter VSC3 remains at 275kV (see Figs. 3e and 3f). At scheme of the four-terminal dc **transmission** in Fig. 1. $t=1.1s$ another power command to converter VSC4 increases A. Power management scheme the share of the power must be delivered through the **so as to** ~~guage~~ the performance of the proposed power converter VSC3 by 100MW. The dc link voltage of converter management scheme, the system in Fig. 1 is configured such VSC4 is raised by 0.2kV and the power flow in the link **that every** converter (VSC1 and VSC2) injects 140MW into the connecting converters VSC3 and VSC4 is reversed. **the facility** system. At time $t=1.8s$ the active power injected by VSC2 is flow in the link between the converters VSC1 and VSC2 is increased to 240MW while that injected by VSC1 remains at similar. When the power injected by converter VSC2 is 140MW. Initially converters VSC3 and VSC4 act **to manage** increased to 240MW, the active powers that must be the terminal dc link voltages at 275kV. In this case, delivered through converters VSC3 and VSC4, have increased. converters VSC3 and VSC4 equally share the exported active The results shown in Fig. 3 demonstrate the effectiveness of power from the ac systems G1 and G2, and also, there **are not any** active power-dc voltage droop control in allowing the power flows between converters VSC1 and VSC2, and VSC3 converters controlling the dc link voltage to participate in and VSC4 (see Figs. 3a, and 3d). At $t=0.5s$ the active power- power flow control in multi-terminal dc transmission systems. dc voltage droop control of converter VSC4 is activated to **an equivalent** concept **are often** extended to a dc system with any increase the active power delivered by converter VSC4 by number of terminals. 100MW. During this period, it is observed that the dc link voltage of the converter VSC4 is reduced by about 0.3kV in

(a) Active and reactive power at busses B1 and B2 (b) Active and reactive power at busses B3 and B4

(c) Power flow **within the** dc lines (P13 and P24) (d) Power flow **within the** dc lines (P12 and P34)

(e) DC link voltage of converters VSC1 and VSC2 (f) DC link voltage of converters VSC3 and VSC4

Fig. 3: Waveforms demonstrating the control flexibility **within the** four-terminal system in Fig. 1, using active power-dc voltage droop characteristic

B. Response to Network alterations voltage stresses **thanks to** a sudden rise of the dc link voltage.

This section investigates the response of the multi-terminal Figs. 5c and 5d show transient power flow in the dc side dc **transmission** in Fig. 1 to a sudden load change at when converter VSC2 increases its active power **and through** a bus B4 and a solid three-phase fault at point F. The system is three-phase fault. Adjustment of **the facility** commands to the started with both converters VSC1 and VSC2 exporting converters controlling the active power, successfully limits 140MW, and at $t=0.5s$ the exported power from converter the rise of the dc link voltage at the terminal of converter VSC2 is increased to 240MW. At $t=0.9s$ a load of $(80+j60)$ VSC3 to the acceptable level. Figs. 5g and 5h show the MVA is connected to bus B4 and at $t=1.4s$ the system is zoomed in version of **the present** injected into buses B3 and subjected to a three-phase fault at point F with duration of B4 during the fault period. 200ms. The system response **to those** events is plotted in Fig.



IV. CONCLUSION

The system is able to respond to these events without imposing any risk to overall system stability. The system 5. treats the introduction of (80+j60) MVA load at bus B4 as This paper has investigated **an influence** management scheme for local event, and its impact **is restricted** to the ac network G4. As a voltage source converter based multi-terminal dc a result, converter VSC4 increases its reactive power output transmission system. The scheme improves the control **so as** to support the voltage at bus B4 (see Fig. 5b). The flexibility over power flow on the dc side in order to impact of the three-phase fault at point F is universal, minimize power losses and allows the converters controlling because of two reasons. The first reason is that during the the dc voltage to respond to any power demand, hence fault period the active power transferability of converter improving system power dispatch flexibility. The paper also VSC3 is significantly reduced **because the** voltage magnitude at bus presented a strategy for recovery from ac faults for multi- B3 collapses to 20% of the nominal value (Fig. 5b). This terminal dc transmission systems. The strategy minimizes causes the dc link voltage of converter VSC3 to rise (Fig. 5f) the converter over-voltage on the dc side, by matching power transferring the active power **that can't** be delivered through commands to the converters controlling active power **and therefore the** converter VSC3, to converter VSC4. As a result the power actual amount of power **which will** be transfer during the fault.

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