Transient behaviour of VSC-HVDC in an AC-DC interconnected system

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***Abstract*—In this paper, transient analysis of a VSC-HVDC based AC-DC interconnected system is carried out. In the proposed system power is evacuated from an Independent Power Producer (IPP) through a VSC-HVDC link. The system also has a provision for open access power transmission. For the system under study, control schemes are developed to reduce the power and current oscillations in the DC link during short duration faults and also to reduce the transient current in the converter valve. Modified controllers have been proposed to improve the transient performance of the VSC-HVDC system. The validity of the proposed control schemes are tested through faults in the inverter bus.**

Keywords—Transient analysis; Power oscillations; modified Dynamic power controller; Current limitation techniques.

I. INTRODUCTION

VSC-HVDC transmission systems are emerging as a robust and economically feasible solution for power transmission. These systems exhibit substantial technical and economical advantages over the conventional HVDC systems, owing to the rapid advancements in the field of high power electronic devices. It has been applied for back-to-back, point-to-point or multiterminal systems and for independent control of active and reactive power [1]. However, the HVDC systems integrated with renewable energy sources from IPPs have their own dynamic characteristics that impact transient stability of the entire power system. In such integrated power systems, the transient stability of the overall system should be carefully investigated to guarantee power system security.

The application of VSC-HVDC for enhancing reliability and efficiency of power transmission systems has been the area of interest in the recent past [2-5]. There have been earlier attempts to address issues related to the transient stability problems in a VSC-HVDC system [6-11]. Most of these papers propose methods to improve the transient stability of a radial system, in which, VSC-HVDC system is connected between two power system networks or between a windfarm and a transmission system. Also, the impact of the transient fault on the converter valves has not been addressed adequately.

In this paper,transient analysis of a VSC-HVDC based AC-DC interconnected system is carried out. In the proposed system shown in Fig 1(a) and 1(b), power is evacuated from an Independent Power Producer (IPP) through a VSC-HVDC link.

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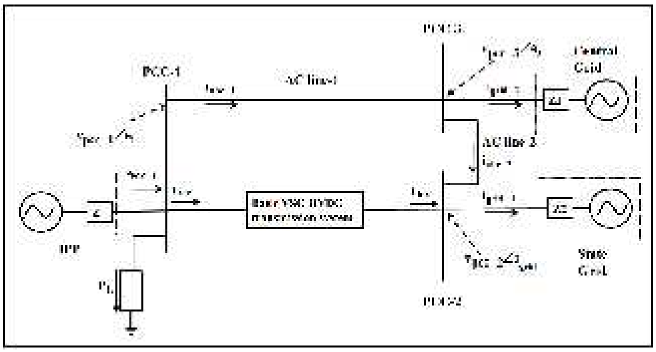


Fig. 1(a).Overall system configuration

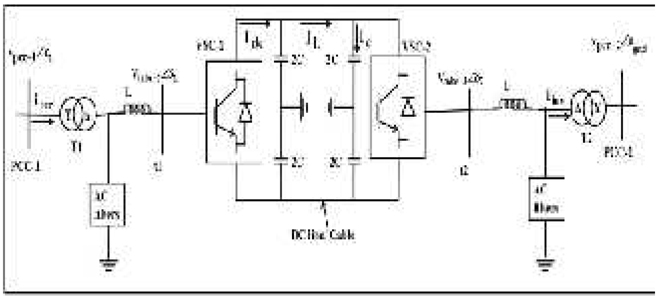


Fig. 1(b). Basic VSC-HVDC transmission system

The system also has a provision for open access power transmission, wherein, a pre defined amount of power in the DC link is to be transferred depending on the installation capacity of the IPP. For the system under study, control schemes are developed to reduce the power and current oscillations in the DC link during short duration faults and also to reduce the transient current in the converter valve.

Initially, the analysis has been carried out by applying the basic controllers in the VSC-HVDC system. Based on the results obtained with these basic controllers, modified controllers have been proposed to improve the transient behaviour of the system.The validity of the proposed control schemes are tested through various types of faults at the Point of Common Coupling (PCC) on inverter side of the VSC-HVDC system.

II. TRANSIENT BEHAVIOUR OF SYSTEM USING BASIC CONTROLLERS

The control structure of a basic VSC-HVDC system is as shown in Fig. 2. The main controllers present in this system

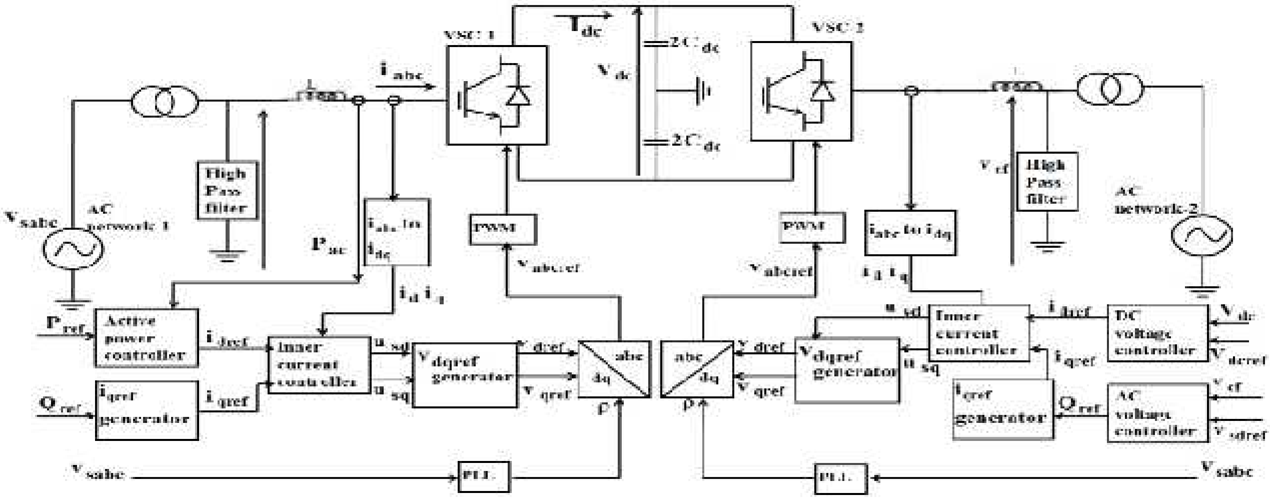


Fig. 2. Block diagram of control strategies for VSC_HVDC

are: (i) Active power controller, (ii) Inner current controller, (iii) DC voltage controller, and (iv) AC voltage controller. For the system under study, the controller parameters are obtained using the design procedure and the tuning techniques presented in [12-14], and are referred to as basic controllers. In designing the PI controllers, the switching frequency is chosen to be 1350 Hz. The values obtained for different controllers have been presented in Table 1.

In this section, the transient behaviour of the system shown in Fig. 1(a) has been analyzed for the following types of faults at PCC-2:

1. Single line to ground fault (L-G)
2. Double line to ground fault (L-L-G)
3. Three phase to ground fault (L-L-L-G)

However, waveforms for DC link voltage (V_{DC}), DC link current (I_{DC}), DC link power (P_{DC}) and the instantaneous current through the valve in VSC-2 are presented only for L-L-L-G fault in Fig. 3. A comparison of V_{DC} and current through the valve for all three types of faults is provided in Table 2. It is also found from the simulation results that, there is considerable increase in DC link power oscillations and overshoot in the valve current as the severity of the fault increases. In order to reduce the power oscillations and

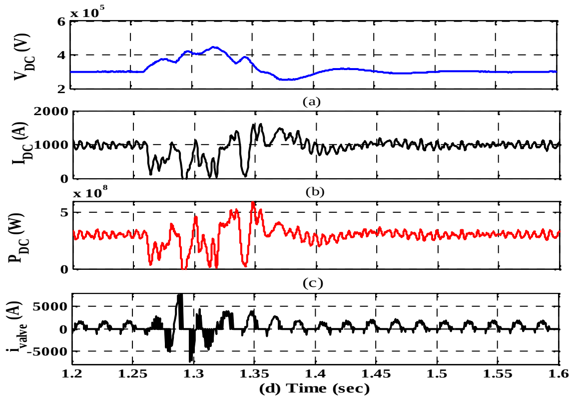


Fig. 3. DC link voltage, current, power and device current for L-L-L-G fault condition

TABLE 1. PI CONTROLLER PARAMETERS FOR VSC-1 AND VSC-2

Station	Controller	$K_p$pu	$K_i$pu
VSC-1	Inner Current controller: Active current controller	2.94	7.29
	Reactive current controller	1.94	7.29
	Active power controller	-0.84	35
VSC-2	Inner Current controller: Active current controller	0.6118	1.755
	Reactive current controller	1.9428	7.29
	DC voltage controller	-0.262	209.40
	AC voltage controller	-0.99	2.228

TABLE 2. VOLTAGE, CURRENT AND POWER VARIATION DURING VARIOUS FAULTS

Type of fault	Parameters	
	V_{DC} (pu)	I_{valve} (A)
L-G	1 to 1.1	2500A
L-L-G	1.17	5000A
L-L-L-G	1.4	8000A

over shoot of device current, a modified Dynamic power controller and current limitation techniques are proposed as described in the next section.

III. MODIFIED CONTROL SCHEMES

In this section, a modified Dynamic active power controller and current limitation techniqueare proposed for VSC-1 to reduce the power oscillations in the DC link. Also, in order to limit the valve current within the permissible limit during fault, a current limitation technique for the current controller in VSC-2 is proposed. The details of the proposed techniques are presented in the ensuing sections.

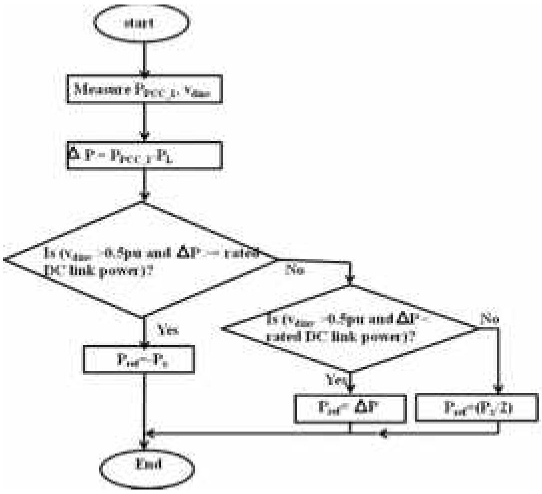
A. Modified Dynamic Power Controller

The modified control scheme that has been developed for the system, is aimed at maintaining the active power in the DC link at a value that is less than or equal to its rating, by dynamically setting P_{ref} in the active power controller. In addition, the proposed method also aims to reduce power oscillations during the transient fault.The logic for the proposed controller is illustrated in Fig. 4.

B. Current limitation Techniques

a) For VSC-1 current controller

This technique is aimed at reducing the oscillations in the DC link current and also to limit the current during the fault. The technique is developed by using the current i_{dref}, which is the output of the active power controller.The logic for the proposed current limitation technique is shown in Fig. 5, where, all the parameters in the figure refer to the rectifier station (VSC-1).



(Note: P_x=Rated DC link power+DC line loss)

Fig. 4. Logic for setting P_{ref}

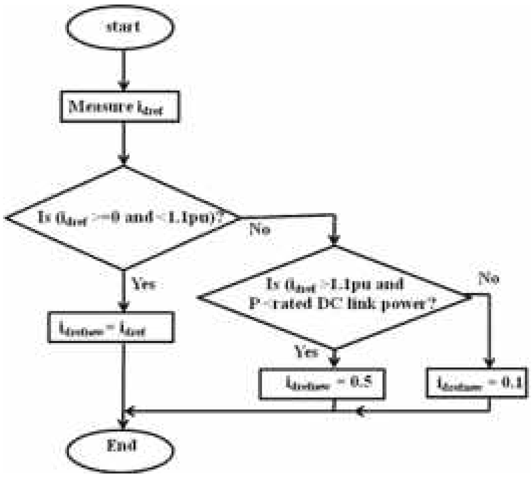


Fig. 5. Logic for setting i_{dref} in VSC-1 current controller

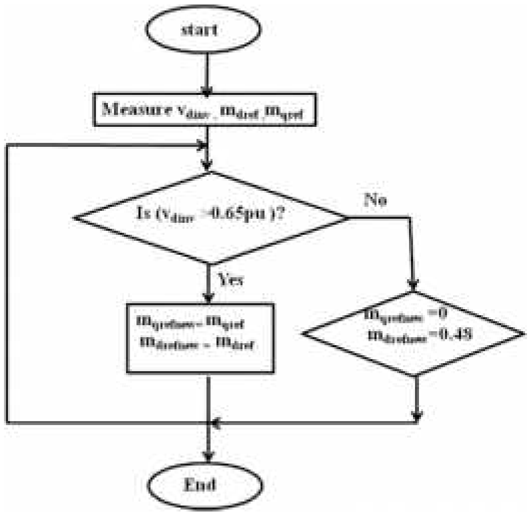


Fig. 6. Current limiting technique for VSC-2 current controller

B. For VSC-2 current controller

Under severe fault conditions, the VSC-2 valve current is observed to be extremely large (almost 4 times the pre fault current) as seen from Fig.3(d). The technique developed here is aimed at reducing the fault current in the valve to a permissible value.The logic of the proposed technique is represented in the flowchart shown in Fig. 6.

The validity of the proposed control schemes explained in Section 3 are tested for single line to ground fault, double line to ground fault and three phase to ground fault. The detailed analysis is presented in the following section.

IV. SYSTEM PERFORMANCE WITH MODIFIED CONTROLLERS

The study is carried out based on the performance of the controllers and power flow in the DC and AC lines during the transient fault. The validity of the modified power controller for all three types of fault is carried out in the following section.

A. Three phase to ground fault (L-L-L-G)

The system response for L-L-L-G fault is shown Fig. 7.One important observation from Fig. 7is that, the device current has reduced to slightly less than 5000A with the proposed current limitationtechnique, as against to 8000A with basic controllers.

B. Two phase to ground fault (L-L-G)

As seen from Fig. 8, the modified active power controller is effective in reducing the oscillations in the DC link power for L-L-G fault when compared to results with basic power controller. Also, the peak current is limited to around 2500A as against to current of around 5000A with the basic current controller during the transient fault.

C. Single line to ground fault (L-G)

It is observed that, the power oscillations in the DC link are reduced to a larger extent with the modified active power controller and the valve current is limited to a permissible limit of around 4000A (twice the prefault DC link current).

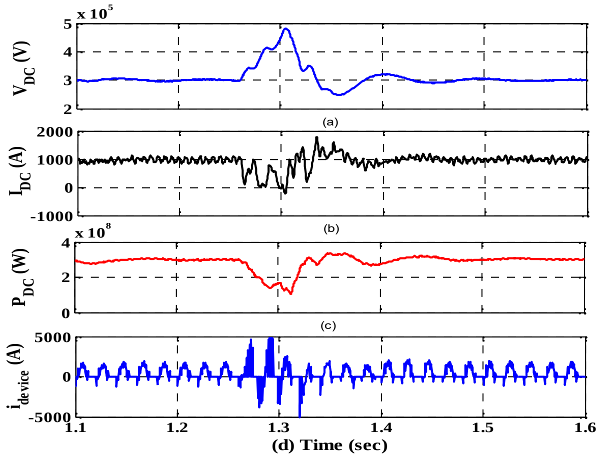


Fig. 7. Improved DC link voltage, current, power and device current for L-L-L-G fault condition

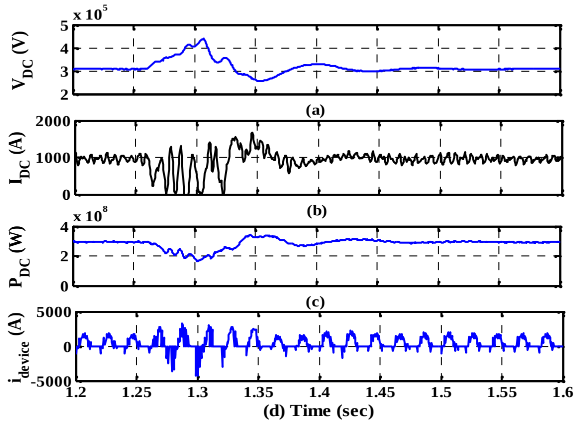


Fig. 8. Improved DC link voltage, current, power and device current for L-L-G fault condition

V. CONCLUSION

In this paper, the transient performance of VSC-HVDC system in an AC-DC interconnected transmission system that has provision for open access power transmission is analyzed. From the results presented for L-L-L-G fault, L-L-G fault and L-G fault, it has been found that, the proposed active power controller and the current limitation techniques are very effective in reducing the DC link power oscillations, in addition to controlling the current through the converter valves.

System Data

IPP	Equivalent AC source representing IPP with a capacity of 550MW and SC level of 2000MVA L-L voltage : 220kV, 50Hz
P_L	Local load: 10% of power generated, 220kV, 0.85 lag
State Grid	Equivalent AC source representing state grid substation with a SC level of 10000MVA L-L voltage : $220kV \angle -20^0$, 50Hz
Central Grid	Equivalent AC source representing central grid substation with a SC level of 12000MVA L-L voltage : $220kV \angle -10^0$, 50Hz
Converter transformer	315MVA,50Hz Winding 1 : Y connected, 220kV(L-L rms), Resistance:0.002pu, Leakage reactance:0.08pu Winding 2 : Δ connected, 150kV(L-L rms), Resistance:0.002pu, Leakage reactance:0.08pu
DC line	R=0.04242 Ω/km (ACSR Bersimis conductor of diameter 35mm) length=100 km
DC link and Reactor	DC voltage:±150kV, Rated Power:300MW, DC capacitor: 70μF, Reactor inductance (L)=0.034 H, Reactor resistance (R) =0.10Ω
AC Transmission line	Zebra conductors with positive and zero sequence resistance of 0.0746 Ω/km and 0.219 Ω/km respectively, positive and zero sequence inductance of 0.0012 H/km and 0.0004 H/km respectively, positive and zero sequence capacitances of 9.34e-009 F/km and 5.86e-009 F/km respectively, Line length=100km
Filter parameters	1. Double tuned filter for 5th and 7th harmonics: 15MVAR 2.Single tuned for 27th harmonic: 18MVAR 3. Single tuned for 54th harmonic: 22MVAR

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