A Novel Concept for Stabilization of AC/DC Network with UPFC

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Abstract: This paper presents a novel concept for stabilization of AC/DC network with Unified Power Flow Controller (UPFC). The system considered has the structure of two areas connected by HVDC link. The investigation for perturbation in ac bus voltages has been carried out and the effect on the stability deterioration has been analyzed. The new concept of control has been proposed by embedding UPFC and then generating the control decisions adequately which stabilizes the earlier one. The concept of including the Unified Power Flow Controller (UPFC) in AC/ DC network especially where a DC link is embedded to connect the two AC Systems is proposed. The proposed control design has been done utilizing a Novel Discrete –Time model of AC/DC system. The complete system stability has been studied in which the individual controller such as HVDC-SVC and HVDC-SVC-UPFC performance under varying perturbation of ac system voltage has been widely analyzed. The results show that in situations the HVDC-SVC alone is unable to reject the perturbation, the UPFC along with the HVDC – SVC damps the oscillations, thus matching the real and reactive power demands adequately. This novel combination can effectively be utilized in situations when the ac system bus voltage undergoes the fluctuations due to changing P and Q requirements.

Keywords: - HVDC, SVC, UPFC, Discrete-time, continuous time, multirate sampling

1. INTRODUCTION

The HVDC transmission technology is well established nowadays. So, many schemes all over the world are running well including back-to-back, point-to-point and multi-terminal. The basic operational requirement of the HVDC schemes is adequate control action, depending upon the power order for damping the power network oscillations. Sometimes, the inadequate control action such as, absence of adequate control of Static VAR Compensator (SVC) at the converter bus, might result in unstable system behaviour. So far, no remedy has been reported in literature, where there is a variation of the AC switchyard line-to-line voltage because of external reasons, which might ultimately affect the operation of converter. A new approach has been proposed for the network in which DC link is embedded. When AC bus voltages of converter station fluctuate, the SVC may not be in a position to help to damp this and so the converter may land to control instability. This is very detrimental for the system. To alleviate this novel concept of Unified Power Flow Controller (UPFC) in between the AC switchyard has been proposed which acts as a supplementary controller for the AC network and thus regulates the system dynamics adequately in situations of perturbations in AC switchyard voltages either side, which in turn improves the overall system stability as desired.

In the power system network, two regional grids can be interconnected by HVDC back-to-back. The two converter stations are connected through the DC link and the converters have their individual controls. In case of power oscillations, the converters will function by their firing angle controls. As the firing angle can vary within a certain limit as directed by the control, the Static VAR Compensator will also act accordingly. But, when the HVDC converter controls along with SVC are not sufficient enough to damp the oscillations, i.e., reactive power mismatch is not met, and then the AC system voltage will come down from normal 1 p.u. value. As this is noticed by the network, it will first land to converter control instability and associated afterwards failure and then may enter to AC/ DC system interaction.

Moreover, if the voltage in the AC side of the corridor becomes low, then DC link voltage, as well as the power transfer through the DC link will come down undesirably.

Now, providing an UPFC block, in between the AC switchyards, parallel to the AC tie line, and the DC link, the real and reactive power both can be modulated adequately, by their multifunctional and coordinated control. The capability of UPFC has been demonstrated (Hingorani Narain G, 1999; Wang H.F., 2000) in damping oscillations. In case, there is reactive power drop in the network, which cannot be met by SVS, etc. then, the UPFC will pump that power to the AC corridor, immediately, and thus stability of the power network can be maintained. Depending on the rating of UPFC and SVS, the real and reactive power can be modulated and the whole network can be made stable, up to a certain extent. Thus, chances of network tripping, due to large, sudden and sustained power mismatch can be minimized a lot and stability of the AC/DC system can adequately be enhanced.

From the results shown in this work, it can be said that this proposed HVDC-SVC-UPFC compact system (Fig.I) is far better to design the effective control strategy for HVDC link, suited to restore stability in a very short time, which is essential to ensure better stability for a dynamically varying power network. But, UPFC also cannot sustain a very large amount of power oscillations because its DC link capacitor has a maximum limit to support the required VAR. So, this proposed model may not guaranty power network stabilization for a very high amount of perturbation, but it can definitely give a higher level of confidence to the power system researchers. In earlier research studies, no such concept has been proposed yet, so this proposed concept will be interesting to power engineers and researchers worldwide.

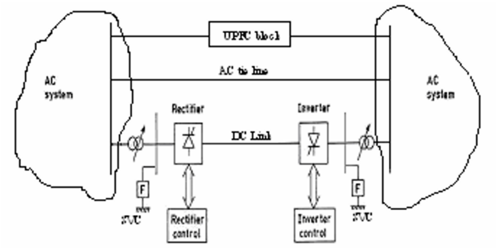

Fig.I HVDC-SVC-UPFC system representation

II DISCRETE-TIME MODEL OF HVDC-SVC-UPFC

In standard practice stability investigations are performed using linearized perturbation models in which the system is linearized around a nominal operating point. To achieve this objective, it is important that the behaviour of various components of the HVDC system be appropriately represented in a linear domain.

2.1 Discrete-time HVDC System Model

Continuous–time (Carrol and Krause, 1970) and discrete–time system representation have been described in the literatures (*Pandey, et al., 1990*). Discrete-time equations for converters in HVDC system (*Pandey, et al., 1990*) are given below:

Rectifier Side

$$\Delta V_{dr1}(kT) = A_1 \Delta\alpha_i (kT+T_1) + A_2 \Delta\alpha_r (kT) + A_3 [\Delta I_{dr}(kT+T_1) - \Delta I_{dr}(kT)]$$

$$\Delta V_{dr2}(kT+T_1) = A_4 \Delta\alpha_i (kT+T_1) + A_5 [\Delta\alpha_r (kT+T_1) + Ur] + A6 [I_{dr}(kT+T_2) - I_{dr}(kT+T_1)]$$

$$\Delta V_{dr3}(kT+T_2) = A_7 [\Delta\alpha_i (kT+T_2) + \Delta U_i] + A_8 [\Delta\alpha_r (kT+T_1) + \Delta U_r] + A_9 [\Delta I_{dr} (kT+T_3) - \Delta I_{dr}(kT+T_2)]$$

$$\Delta V_{dr4}(kT+T_3) = A_{10} [\Delta\alpha_i (kT+T_3) + \Delta U_i] + A_{11} \Delta\alpha_r (kT+T_3) + A_{12} [\Delta I_{dr} (k+1)T - \Delta I_{dr} (kT+T_3)] \quad (1)$$

Inverter Side

$$\Delta V_{di1}(kT) = B_1 \Delta\alpha_r (kT) + B_2 \Delta\alpha_i (kT+T_1) + B_3 [\Delta I_{di} (kT+T_1) - \Delta I_{dr} (kT)]$$

$$\Delta V_{di2}(kT+T_1) = B_4 [\Delta\alpha_r (kT+T_1) + \Delta U_r] + B_5 \Delta\alpha_i (kT+T_1) + B_6 [I_{di} (kT+T_2) - I_{di} (kT+T_1)]$$

$$\Delta V_{di3}(kT+T_2) = B_7 [\Delta\alpha_r (kT+T_2) + \Delta U_r] + B_8 [\Delta\alpha_i (kT+T_2) + \Delta Ui] B_9 [I_{di}(kT+T_3) - \Delta I_{di} (kT+T_2)]$$

$$\Delta V_{di4}(kT+T_3) = B_{10} \Delta\alpha_r (kT+T_3) + B_{11} [\Delta\alpha_I (kT+T_3) + \Delta U_i] + B_{12} [I_{di} (k+1)T - \Delta I_{di}(kT+T_3)] \quad (2)$$

where A_1 to A_{12} and B_1 to B_{12} are linearized scalar constants. The relation ship between the DC current Id and the overlap angle U are derived for both the cases of rectifier and inverter (*Pandey, et al.,1990*). The linearized values of the overlap angles U_r and U_i in terms of DC currents and firing angles are given as,

$$\Delta U_r = [\Delta I_{dr} (kT+T_2) + I_{dr} (kT) - d_1 \Delta\alpha_r (kT)] / d_2$$

$$\Delta U_i = [\Delta I_{di} (kT+T_1) + I_{di} (kT+T_3) - d_3 \Delta\alpha_I (kT+T_1)] / d_4$$

Combining the transmission line and current controller model, state space expression is obtained (Since it has been assumed that, the predictive type control at inverter end, the variable $\Delta\alpha_i$ has been represented in terms of the variable ΔI_{di})

$$\dot{\Delta \mathbf{x}} = \mathbf{A}\, \Delta \boldsymbol{x} + \boldsymbol{B}\, \Delta \boldsymbol{V_d}$$

where, $\Delta \boldsymbol{x} = [\Delta\alpha_r \quad \Delta I_{dr} \quad \Delta I_{di} \quad \Delta V_{cL}]^T$