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Improvement of power system stability by using a VSC-HVdc ☆

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ABSTRACT

The capabilities of a VSC-HVdc to improve the stability in power systems are analyzed in this paper. The analysis considers a power system which has the need for increasing the transmission capacity. Two options are analyzed: connection of a new ac transmission line or connection of a VSC-HVdc link. Different disturbances are applied in the system in order to analyze the dynamic response of the system. Supplementary control is included in the control of the VSC-HVdc. The control strategies in the supplementary control are based on nonlinear and linear theory. Furthermore, remote and local information are used as input signals in the control strategies. Simulation results clearly showed the benefits of VSC-HVdc in the improvement of power system stability.

1. Introduction

Steady state stability, lack of reactive power supply, voltage stability, electromechanical oscillations and transient stability are common problems that can occur in networks that transmit large amount of power over long distance transmission corridors. If these long corridors are used in the interconnection of power systems, poor damping of low frequency interarea oscillations and load flow problems are also very likely to happen.

The increase of both transmission capability and flexibility in these type of grids with conventional ac options is a challenge [1]. Voltage or transient stability, increase of short circuit levels and unaccepted network loop flows often limits the expansion with ac transmission lines [2].

Thanks to the capacity of independent control of active and reactive power, the use of VSC-HVdc systems in ac networks have shown to be an advantageous solution in these cases. By having embedded VSC-HVdcs in ac grids it is possible to enhance the stability in power systems and have a higher control of power flow [3,4].

The objective of this paper is to analyze the impact of connecting either a new ac line or a new VSC-HVdc link on the stability in a power system. The analysis is done by comparing the dynamic response of a test power system under different fault cases. The control of the VSC-HVdc includes a supplementary control to enhance the stability of the system by modulating the active power. Two control strategies based on different theory frame are also compared. Moreover local and remote information in the input of the control strategies are also analyzed.

1.1. VSC-HVdc

VSCs are based on valves that can be switched on and off by a control signal. By choice of the switching instant it is possible to generate any desired wave shape. With higher switching frequency components it is possible to use Pulse Width Modulation (PWM) technology to re-create the ac voltage with any phase angle or voltage amplitude (within certain limit). Thus, PWM offers the possibility to control both active and reactive power independently. The control of the voltage magnitude and the phase angle of the converters makes the use of separate control for active and reactive power possible. The active power loop can be set to control either the active power or the dc-side voltage. In a dc link, one station will then be selected to control the active power while the other must be set to control the dc-side voltage. The reactive power control loop can be set to control either the reactive power or the ac-side voltage. Either of these two modes can be selected independently at either end of the dc link [5].

In the research, the open model of the trademark HVDC-Light available in the software of simulation [6,7] is used. Fig. 1 shows a block diagram of the control of the VSC.

In the figure, the inputs ΔP_c, ΔQ_c and ΔU_{ac-c} are intended for supplementary control. In this paper only the input ΔP_c is used to improve damping and stability.

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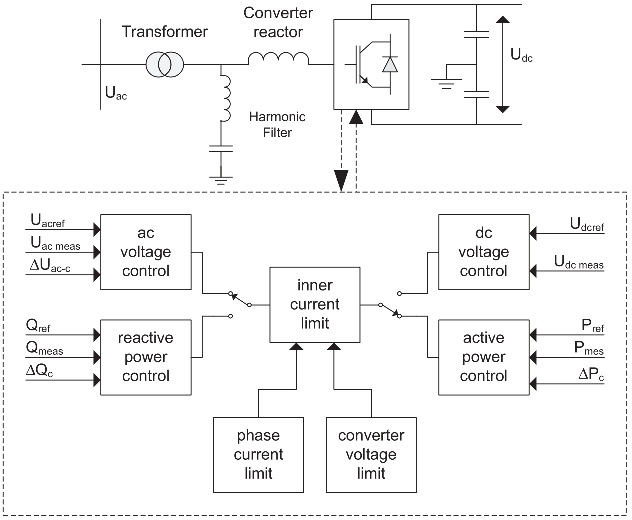

Fig. 1. Control VSC-HVdc.

2. Control strategies

In general, multi-machine power systems are described by a set of differential equations and a set of algebraic equations of the form:

$$\begin{aligned} \dot{x} &= f(x,y,u) \\ 0 &= g(x,y,u) \end{aligned} \tag{1}$$

In this model x is a vector of state variables associated with the dynamic of generator, loads and other system controllers. y is a vector of algebraic variables associated with magnitudes and angles of voltage phasors. u is a vector of input parameters.

2.1. Rotor angle stability

2.1.1. Nonlinear analysis-based control strategy

This control strategy is based on theory of Control Lyapunov Function (CLF). Lyapunov theory has been applied to FACTS devices [8,9], HVdc systems [10] and also in power flow control [11].

In the derivation of the control strategy, the VSC-HVdc is represented by a couple of loads at the buses of connection of the VSCs. This representation is referred to as Injection Model.

From the buses of connection, the converters in a VSC-HVdc can be seen as synchronous machines without inertia connected to the grid with a series reactance which represents the power transformer. Fig. 2 shows this modeling.

The controllable voltage sources, $\bar{E}_i$ and $\bar{E}_j$ are defined as

$$\bar{E}_i = E_i e^{j\gamma_i} \quad \bar{E}_j = E_j e^{j\gamma_j} \tag{2}$$

where E_i, E_j, γ_i and γ_j are the controllable variables (magnitude and phase angle, respectively) of the voltage sources. x_{ti} and x_{tj} are the reactances of the power transformers.

If harmonics are ignored the injection of power into the HVdc is defined by:

$$\begin{aligned} P_{si} &= \frac{U_i E_i \sin(\theta_i - \gamma_i)}{x_{ti}} \\ Q_{si} &= \frac{U_i[U_i - E_i \cos(\theta_i - \gamma_i)]}{x_{ti}} \\ P_{sj} &= \frac{U_j E_j \sin(\theta_j - \gamma_j)}{x_{tj}} \\ Q_{sj} &= \frac{U_j[U_j - E_j \cos(\theta_j - \gamma_j)]}{x_{tj}} \end{aligned} \tag{3}$$

From (3) can be concluded that P_{si}, Q_{si} can independently be controlled by γ_i and E_i. Likewise P_{sj}, Q_{sj} controlled by γ_j and E_j.

For derivation purposes, the losses of the converters and dc cables are neglected. The relation between bus i and bus j is given by the active power: $P_{sj} = -P_{si}$; the reactive power is independent at each bus. Fig. 3 shows the injection model.

where P_{si}, Q_{si}, P_{sj} and Q_{sj} are included in $g(x,y,u)$.

By using the injection model, an energy function for a VSC-HVdc and the Control Lyapunov Function (CLF) can be derived [10]. The CLF control strategy is expressed by.

$$\Delta P_c = \Delta P_{CLF} = K_f(f_i - f_j) \tag{4}$$

where i, j are the buses of connection of the VSC-HVdc, K_f a positive gain, f_i the frequency measured at bus i and f_j is the frequency measured at bus j.

Although the control strategy is derived by using the injection model, the control strategy is used in the model of VSC-HVdc described in Section 1.1.

Alternatively, remote information from generators can be applied to the control strategy (4) by using, for instance, the SIngle Machine Equivalent (SIME) method [12]. The SIME method transforms the trajectories of a multimachine power system into the trajectory of a single machine equivalent system. The machines in a power system are classified in two groups, namely critical machines and noncritical machines, which are replaced by a single machine equivalent system. The identification of the machines is done by studying post-fault conditions when the power system is subjected to a disturbance that presumably drives it to instability. The critical machines are responsible of the loss of synchronism.

Let

$$M_C = \sum_{i \in C} M_i \tag{5}$$

$$M_{NC} = \sum_{i \in NC} M_j \tag{6}$$

The angle and the speed of SIME are expressed by:

$$\omega_{SIME} = \omega_C - \omega_{NC} \tag{7}$$

$$\delta_{SIME} = \delta_C - \delta_{NC} \tag{8}$$

with

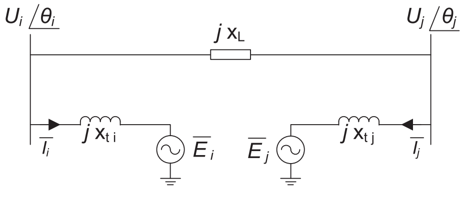

Fig. 2. Modeling of VSC-HVdc.

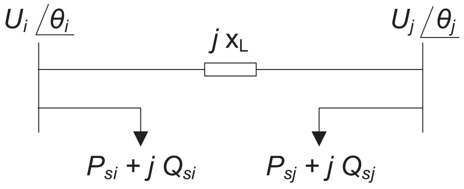

Fig. 3. Injection model of a VSC-HVdc.