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Impact of PLL and VSC control parameters on the AC/MTDC systems stability

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ABSTRACT

The impact of PLL and VSC control parameters on the dynamic interactions between the AC and MTDC systems are discussed. A modularized method to incorporate the VSC-MTDC into transient stability programs (TSPs) is given. The proposed programs are validated via PSCAD simulation. Three results are obtained: (1) PLL has an insignificant effect on system stability. (2) The damping of MTDC grids is greatly affected by VSC control parameters. The inappropriate parameters would cause adverse effect on the damping performance of MTDC grids, resulting in large oscillation among DC voltages. However, these parameters have a negligible effect on small signal stability of AC systems. (3) Two forms of instability phenomena are found. One is caused by insufficient synchronizing torque; the other is caused by poorly damp of MTDC grids. As for the latter, it is the adverse interactions among the VSC controllers that cause the MTDC grids instability, thereby making the overall system easier to collapse.

1. Introduction

Over the last decades, the Voltage Source Converter based High Voltage Direct Current (VSC-HVDC) has developed rapidly around the world. Since the full-controlled devices are used in converters, the VSC-HVDC has many attractive technical advantages compared to current source converters, which allows it easy to be extended to Multi-Terminal high voltage Direct Current (MTDC) grids. It has been reported that, in the future, the MTDC grids are seen as a preferable solution in integrating large amounts of renewable energy sources in the European power system [1].

However, with the large number of VSC installation, the power system dominated by synchronous generators will experience a change in dynamic and operational characteristics. The topology of MTDC grids, operating conditions, control strategies and control parameters will impact on the transient process of the system after being subjected to a disturbance. As a result, this will cause a lot of favorable or unfavorable effects on the AC system. Especially, in some cases the adverse interactions among the converter controllers may lead to the overall system instability. Significant researches on the stability problem have been undertaken, but most of them are focused either on the AC network or the DC network, with consequent simplification of the other side. For example, in Refs. [4–7] the impact of VSC-HVDC on AC system stability has been discussed. In Ref. [8] the effect of VSC control strategies on the dynamic behavior of AC systems is investigated, and some valuable results are obtained. But they deal with the AC system only with a point-to-point VSC-HVDC system. In Refs. [9–11], the converters' interactions and instability phenomenon have been discussed, but they assume the converters are connected to a strong AC system, modeled by infinite nodes. The impacts of VSC control parameters and Phase-Locked-Loop (PLL) on VSC-HVDC system stability are studied in Refs. [12–15], but their analysis does not take into account any generators. Dynamic interactions between AC and MTDC system are addressed in Refs. [16] using Power Systems Computer-Aided Design (PSCAD), yet the impact of poorly designed controllers is not investigated. Reference [17] showed that the instability phenomenon of AC/MTDC systems could be only caused by DC-side variables, but it is limited on a small two-area system and the impact of the interactions among the converter controllers is not covered. What's more, to the best of the authors' knowledge no work has been presented to discuss the impact of PLL and VSC control parameters on the interconnected AC/MTDC system stability.

Therefore, a systematic approach needs to be taken. This paper aims to study the effects of MTDC grids on the interconnected AC system by using the conventional transient stability programs (TSPs) including full detailed models of VSC-MTDC systems. Note

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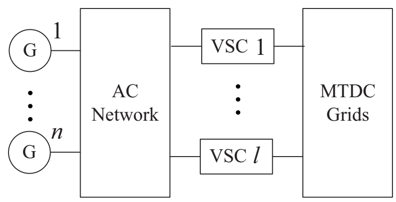

Fig. 1. AC/MTDC system structure.

that most of the commercial power system simulation software (e.g. Power System Simulator/Engineering) is not available for VSC-MTDC [17–19]. The basic dynamic modeling of VSC-MTDC in power system stability programs is derived in Refs. [19–22], yet the AC/DC interface is unrealistic, hence it cannot precisely reflect the dynamic interactions between AC and DC systems. In Ref. [17], an asymmetric bipolar model of MTDC that compatible with multi-machine AC system is presented using MATLAB Simulink, but it is only suitable to study a fixed topology MTDC grids and the nonlinear behavior of converter controllers, e.g., controller limiting, is not considered.

In this paper, full dynamic models of VSC-MTDC (including PLL, converters, control system, MTDC grids and AC/DC interface) are developed. Unlike previous works, the converter limiters are considered in system modeling and a modularized method to incorporate VSC-MTDC system into TSPs is given in details. Most of all, both the model analysis and nonlinear simulation are carried out to study the effect of PLL and control parameters on the interconnected AC/MTDC system stability.

The rest of this paper is organized as follows: Section 2 gives an overview of the program structure. The way to incorporate VSC-MTDC systems into TSPs has been given in Section 3. The algorithm of AC/MTDC TSPs is presented in Section 4. Section 5 gives the validation of the proposed programs. Section 6 studies the stability of AC/MTDC system.

2. AC/MTDC system structure

In Fig. 1, the AC/MTDC systems include generators, loads, AC network and VSC-MTDC systems. As the electromagnetic transient of AC network attenuates quickly during disturbances, a static model of AC network is considered adequate for transient stability analysis [2]. It is assumed that the generator is represented by classical model or 4th order model, and its mechanical system is represented by an equivalent single mass. All loads are represented as constant impedance throughout this paper. Details of the generator models and network information are given in Ref. [27]. In order to capture the fast and nonlinear dynamics associated with the MTDC grids, a detail model of VSC-MTDC systems is necessary, which will be presented in Section 3.

Based on the above assumptions, the holistic detailed mathematic model of the AC/MTDC systems can be written in a general form as differential algebraic equations.

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

where $\boldsymbol{x} \in \boldsymbol{R}^{n_x}$ are the state variables describing the dynamic characteristics of systems, $\boldsymbol{y} \in \boldsymbol{R}^{n_y}$ are the algebraic variables referring to the operating condition. $\boldsymbol{x} = \left[\delta, \omega, E'_q, E'_d, i_s^d, i_s^q, M_P, M_Q, M_d, M_q, M_{\mathrm{PLL}}, \theta_{\mathrm{PLL}}, U_{\mathrm{dc}}, I_{\mathrm{line}}\right]^{\mathrm{T}}$, where δ, ω, E'_q, E'_d are the state variables of generators whereas the rests are the state variables of VSC-MTDC systems. $\boldsymbol{y} = [V_x, V_y]^{\mathrm{T}}$, where V_x and V_y are the x and y-component of AC voltage. Assuming that the number of generators, converters, AC network nodes and DC lines is n_g, v, N and n_{dcline}, respectively. In this case, $n_x = 4n_g + 9v + n_{\mathrm{dcline}}$, $n_y = 2N$.

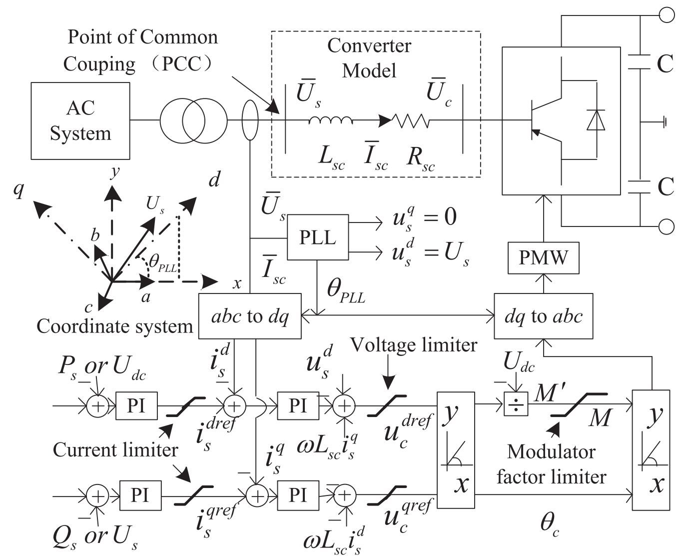

Fig. 2. A single-line diagram of a converter and its control systems.

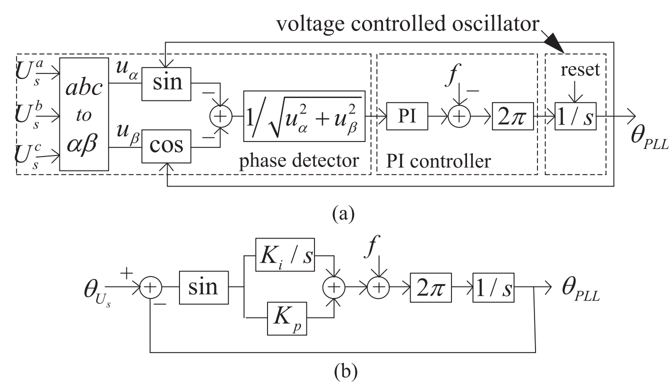

Fig. 3. Control block diagram of the PLL. (a) Detail PLL topology for EMTPs (b) simplified PLL topology for TSPs.

3. VSC-MTDC system

This paper studies the transient behavior of VSC-MTDC systems based on the conventional phasor model that is widely used in existing technical literature. The single-line diagram of the VSC-MTDC systems connected to AC systems and its control system are shown in Fig. 2. It includes PLL, converters, *dq*-decoupled control system, MTDC grids and AC/DC interface.

3.1. Phase-Locked-Loop

The PLL is a real-time phase tracking control system. In the VSC-MTDC, PLL is to make sure the AC voltage $\bar{U}_s$ at Point of Common Coupling (PCC) is locked with the d-axis, resulting in $u_s^d = U_s, u_s^q = 0$. The latest type of PLL as presented in Ref. [24] is considered in this paper. It consists of three basic components: a phase detector, a Proportional Integral (PI) controller and a voltage controlled oscillator, as shown in Fig. 3(a). If the d-axis leads q-axis 90°, the q-axis component of AC voltage can be expressed as,

$$u_s^q = u_\alpha \sin\theta_{\mathrm{PLL}} + u_\beta \cos\theta_{\mathrm{PLL}} \tag{2}$$

As the TSPs are based on fundamental frequency modeling techniques, a compatible representation of PLL for TSPs is needed.