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ScienceDirect
Electrical Power and Energy Systems 29 (2007) 565–570
ELECTRICAL POWER & ENERGY SYSTEMS
www.elsevier.com/locate/ijepes

A nonlinear control for enhancing HVDC light transmission system stability

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Received 22 March 2005; accepted 8 January 2007

Abstract

The purpose of this paper is to study the mathematical model and its control strategy of HVDC Light transmission system in order to enhance system stability. In this paper, the steady state mathematical model for the HVDC Light system is developed and the decoupled relationship between the controlling variables is proposed. An appropriate controller utilizing nonlinear control for HVDC Light system is proposed to maintain the dc link voltage and control the active and reactive power. The control is not complex. Basic functions of HVDC Light system can be realized. What is further, better performances are obtained when compared with a traditional control. The digital simulation results show that the proposed nonlinear control is effective to damp system oscillations and enhance system stability.

Keywords: HVDC light; Nonlinear control; Digital simulation; PWM

1. Introduction

The past five decades witnessed significant development in high voltage direct current (HVDC) electrical power transmission system, which is continuously innovated by utilizing state-of-the-art power electronic devices. Most of these transmission systems are based on current source converters (CSC) utilizing thyristor technology. The shortcoming of this transmission technology is that the valve, thyristor, cannot be turned off with gate signal directly. That limits the range of its application.

In the recent year, rapid advancement is achieved in the field of power electronic devices which can not only switch on but also switch off immediately, such as insulated gate bipolar transistor (IGBT). That opens the opportunities for the power industry via the utilization of HVDC light [1–5], which is based on voltage sourced converters (VSC) with IGBT technology. Owing to IGBT valves, this new innovative technology exhibits substantial technical and economical advantages over conventional CSC-based HVDC transmission system. The benefits include: (i) active and reactive power exchange can be controlled flexibly and independently; (ii) no commutation failure problem; (iii) No communication required between two stations, and etc. [4].

To ensure the stable operation of HVDC Light transmission system, many research works about its control strategy have been carried out. Sinusoidal phase width modulation (SPWM) technology is now widely employed. SPWM modulator is constructed by comparing a low frequency sinusoidal with a unity amplitude triangular carrier. The sine wave signal holds two degrees of freedom, i.e., phase and amplitude. On the basis of it, phase and amplitude control (PAC) technology is developed [6,7]. The problem for this technology is that it is not easy to realize the decoupled control of real and reactive power. To solve this problem, a decoupled PI control of real and reactive power for HVDC Light system has been proposed in [9].

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0142-0615/$ - see front matter © 2007 Elsevier Ltd. All rights reserved.
doi:10.1016/j.ijepes.2007.01.008

In this paper, a nonlinear feedback linearization control [8,10] is introduced into the HVDC Light transmission system. A steady-state model of HVDC Light system is firstly developed, and then it is transformed into d-axis and q-axis in rotating synchronous frame. According to this model, the corresponding relationship between the two control inputs and the two controlled variables of each station is determined. System stability is improved with the proposed control method. The validity of the steady-state model and the proposed control strategy is verified in EMTDC/PSCAD simulation environment.

The rest of the paper is organized as follows. In Section 2, the modeling of HVDC Light system is presented. In Section 3, the nonlinear PWM control is developed and discussed. Simulation results are presented and illustrated in Section 4. At last, Conclusions are drawn in Section 5.

2. Modeling of HVDC light system

There are two converter stations in the system. Each station shown in Fig. 1 is coupled with AC network via equivalent converter impedances R_1+jX_1 and R_2+jX_2. DC capacitors C_1 and C_2 ($C_1 = C_2 = C$) are used across DC side. It is assumed that AC networks at the terminal are very strong. Hence, they are modeled as the AC sources in the paper. It is possible because most of HVDC Light systems' capacities are relatively small when compared with that of power system [11]. What is more, three-phase line-to-line voltages are assumed to be well balanced.

Each VSC has 2 degrees of freedom. The reactive modulation of each VSC will use up one degrees. The other degree is used to control the real power or dc voltage. The real power modulation is applied in Inverter Station, while the dc voltage modulation is proposed in Rectifier Station to maintain power balance, as described in (7). In this paper, Station 1 is chosen as Rectifier station while Station 2 is designated as Inverter station.

The following equations indicate the relationships among different variables of the system [8].

Rectifier station:

$$\frac{di_{d1}}{dt} = -\frac{R}{L}i_{d1} + \omega i_{q1} + u_{d1} \tag{1}$$

$$\frac{di_{q1}}{dt} = -\omega i_{d1} - \frac{R}{L}i_{q1} + u_{q1} \tag{2}$$

$$\frac{dv_{dc1}}{dt} = \frac{3u_{sq1}i_{q1}}{2Cv_{dc1}} - \frac{i_L}{C} \tag{3}$$

where $u_{q1} = \frac{u_{sq1}-u_{rq1}}{L}$, $u_{d1} = \frac{u_{sd1}-u_{rd1}}{L}$

Inverter station:

$$\frac{di_{d2}}{dt} = -\frac{R}{L}i_{d2} + \omega i_{q2} + u_{d2} \tag{4}$$

$$\frac{di_{q2}}{dt} = -\omega i_{d2} - \frac{R}{L}i_{q2} + u_{q2} \tag{5}$$

$$\frac{dv_{dc2}}{dt} = \frac{3u_{sq2}i_{q2}}{2Cv_{dc2}} + \frac{i_L}{C} \tag{6}$$

where $u_{q2} = \frac{u_{sq2}-u_{rq2}}{L}$, $u_{d2} = \frac{u_{sd2}-u_{rd2}}{L}$

Interconnected relationship between Rectifier station and Inverter Station is:

$$v_{dc1}i_L = v_{dc2}i_L + 2R_0 i_L^2 \tag{7}$$

In the synchronous frame, u_{sd1}, u_{sd2}, u_{sq1} and u_{sq2} are the d, q axes components of the respective source voltages, i_{d1}, $i_{d2,}i_{q1}$ and i_{q2} are that of the line currents, u_{rd1}, $u_{rd2}u_{rq1}$ and u_{rq2} are that of the converter input voltages. P_1, P_2, Q_1 and Q_2 are real and reactive power transferred from the network to the station. v_{dc1} and v_{dc2} are the DC bus voltages. i_L is the load current.

At the side of Station 1, the q-axis is set to be in phase with the source voltage $U_{s1.}$ Correspondingly, the q-axis is set to be in phase of the source voltage U_{s2} at the side of Station 2. Therefore, u_{sd1} and u_{sd2} are equal to 0 while u_{sq1} and u_{sq2} are equal to the magnitude of u_{s1} and u_{s2}, which will simplify the following discussion.

Then the power flows from the sources can be given

$$P_1 = \frac{3}{2}(u_{sq1}i_{q1} + u_{sd1}i_{d1}) = \frac{3}{2}u_{sq1}i_{q1} \tag{8}$$

$$Q_1 = \frac{3}{2}(u_{sq1}i_{d1} - u_{sd1}i_{q1}) = \frac{3}{2}u_{sq1}i_{d1} \tag{9}$$

$$P_2 = \frac{3}{2}(u_{sq2}i_{q2} + u_{sd2}i_{d2}) = \frac{3}{2}u_{sq2}i_{q2} \tag{10}$$

$$Q_2 = \frac{3}{2}(u_{sq2}i_{d2} - u_{sd2}i_{q2}) = \frac{3}{2}u_{sq2}i_{d2} \tag{11}$$

The model of the HVDC Light system is based on (1)–(6) and a number of assumptions, from which the following discussions can proceed. To have the discussions validated, it will be necessary to build models of the converters for testing. Short of building real-life models, simulation studies are made through the PSCAD/EMTDC software package in the paper.

3. Nonlinear control design of HVDC light system

3.1. Rectifier control design

Without loss of generality, Station 1 is chosen as the rectifier and Station 2 the inverter. In Station 1, there are two

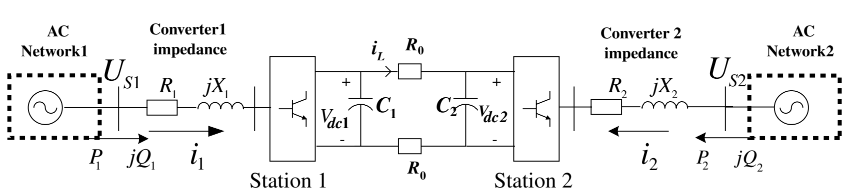

Fig. 1. Physical model of HVDC Light system.