

Study on Voltage Quality of VSC-HVDC Supplying Passive Networks

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Abstract—The voltage source converter based high voltage direct current transmission (VSC-HVDC) supplying passive networks is subject to voltage quality problem. In this paper, based on analyzing the influence of time delay introduced by PWM inverter and computation, a delay compensation method for vector control method is proposed to improve the control dynamic and therefore enhance the voltage quality. Simulation results are obtained from PSCAD/EMTDC under different operation conditions. The comparison of the behavior between the proposed control method and the conventional method clearly shows the proposed control method can improve the voltage quality during the load changing and AC grid fault.

Keywords—VSC-HVDC; voltage sag; power quality; tracking-differentiator(TD) ; proposed model

I. INTRODUCTION

After the world's first HVDC light transmission, there has been a growing interest in the research on high-voltage direct current (HVDC) transmission technology with voltage source converter (VSC) (VSC-HVDC). The VSC-HVDC uses full controlled power electronic devices and pulse width modulation(PWM)technology, which takes a number of potential advantages. For example, the VSC-HVDC can feed into passive networks with no local power generation, and enables the operation of power in four quadrants so as to allow the reversal of direct current without the need of changing the polarity of dc voltage. With such very favorable advantages, VSC-HVDC will likely be part of future transmission and distribution system which supply industrial systems with a high load density, high reliability and quality requirement [1-3].

As advantages mentioned above, a lot of research have been implemented in this area. The control method supplying passive networks is given out by analyzing the mathematics model of VSC-HVDC in d-q coordinate [2-3]. In [4], the steady-state model of fixed voltage control method has been proposed, and the feedback linearization method is successfully introduced into rectifier station. A detailed study of control strategies supplying passive networks is discussed in [5-6]. Simulation results show the advantages of VSC-HVDC system supplying passive networks. Many publications have investigated control algorithms of supplying passive networks. However, hardly any work has

to be performed on investigating the impact on the voltage quality caused by the changing of loads or a three-phase fault at AC grid.

In this paper, based on the steady-state model supplying passive networks, a new fixed ac voltage controller is designed with sampling delay and nonlinear elements considered. This strategy gives a high priority to the ac voltage control since the new TD link is sensitive to the current rate of change. Impact of load changing under traditional control model and the new proposed control model are simulated in PSCAD/EMTDC to test the designed control system. The simulation results verify the effectiveness of the controller for VSC-HVDC under transient model.

II. SYSTEM STRUCTURE AND MATHEMATICAL MODEL OF VSC-HVDC

A single line diagram of the simulation system is shown in Fig.1, which includes a VSC-HVDC system and a passive simulation system. The passive networks are connected to the VSC-HVDC system at a point of common coupling(PCC). The rectifier side is directly linked with AC grid. Induction motor IM is considered as the dominant load of the passive system. The detailed parameters of the VSC-HVDC system and the passive networks are shown in table I and II.

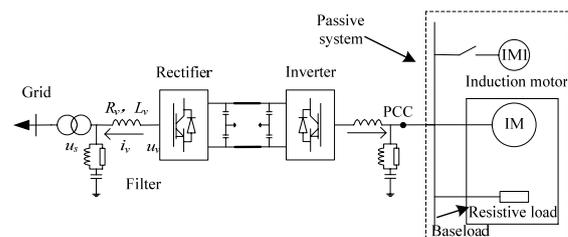


Fig.1 Single line diagram of a simplified equivalent VSC-HVDC system

III. CONTROLLER DESIGNING

A. Rectifier controller designing

The control system of VSC-HVDC is based on a fast inner current control loop controlling the ac current. As shown in Fig.2, the ac current reference is supplied by the outer controllers. In this paper, dc voltage controller and reactive power controller are used on rectifier side.

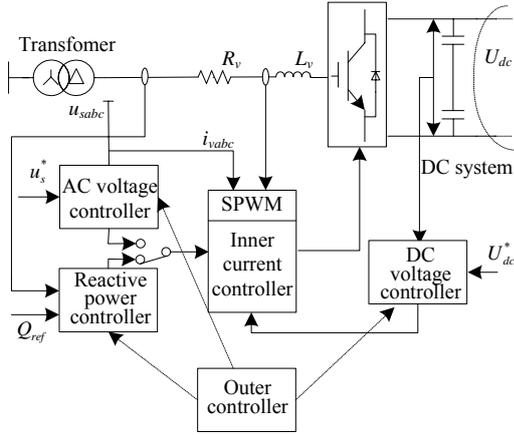


Fig.2 The diagram of rectifier inverter

B. Inverter controller designing

In general, ac voltage controller is adopted in inverter station so as to get an uninterrupted ac voltage and balanced ac voltage of sinusoidal waveform. Under balanced network conditions, the response characteristics of ac voltage controller have no significant effect on VSC-HVDC system. According to Fig.1, the dynamic characteristic is expressed as

$$\begin{cases} u_{vd} = R_v i_{vd} + \omega L_v i_{vq} + u_{sd} \\ u_{vq} = R_v i_{vq} - \omega L_v i_{vd} + u_{sq} \end{cases} \quad (1)$$

When the loads (Nonlinear load's inputting such as induction motor) of passive networks changes or a three-phase fault occurs at AC grid, the instantaneous current and current rate of change will increase sharply so that the fixed ac voltage controller under traditional vector control model will be difficult to meet the control requirements. Moreover, the relationship between the model of fixed ac voltage controller and the object model of VSC has been changed due to delay caused by sampling and the inverter itself. Therefore, the relationship between voltage reference and outputting voltage of the inverter is described as

$$u_v = U_v^* e^{-\tau s} \quad (2)$$

Where τ is the delay time. The normalized delay time $\tau = 1.5\omega / (2f_s)$, where $2f_s$ is the sampling frequency and f_s is the switching frequency [7]. The graph of the element is shown in d-q frame and three-phase static coordinate as part of Fig.3.

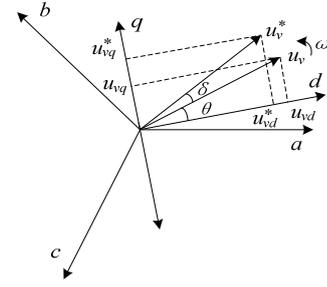


Fig.3 The diagram of output voltage and reference voltage in d-q synchronous coordinate system

In Fig.3, θ is the angle between d-axis and u_v , δ is the delay angle, and ω is the angular mechanical velocity of the d-q frame and the reference voltage vector. The values of u_v^* and

$$\begin{aligned} u_{vd} &= U_v^* \cos(\theta + \delta), u_{vq} = U_v^* \sin(\theta + \delta) \\ u_{vd} &= U_v^* \cos \omega, u_{vq} = U_v^* \sin \omega \end{aligned} \quad (3)$$

The voltage deviation after delay is then proposed as

$$\begin{cases} \Delta u_{vd} = u_{vd}^* - u_{vd} \\ \Delta u_{vq} = u_{vq}^* - u_{vq} \end{cases} \quad (4)$$

Where the delay angle $\delta \ll \theta$. The cosine and sine functions are linearized as

$$\begin{aligned} \sin(\theta + \delta) &\approx \sin \theta + \delta \cos \theta \\ \cos(\theta + \delta) &\approx \cos \theta - \delta \sin \theta \end{aligned} \quad (5)$$

By submitting (3) into (4), the linearized equation (10) between the deviation voltage and the delay angle is obtained as

$$\begin{cases} \Delta u_{vd} = -\delta u_{vd} \\ \Delta u_{vq} = \delta u_{vq} \end{cases} \quad (6)$$

According to the equation (1) and (6), a new proposed model is shown in Fig.4.

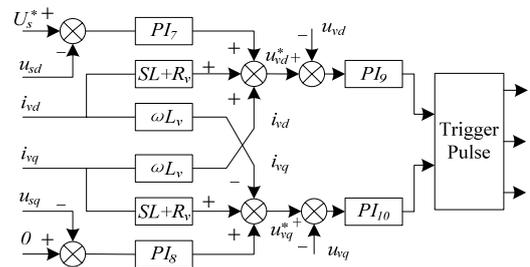


Fig.4 Fixed ac voltage controller in transient model

A PI controller introduced behind the error of the feedback signal and the output reference voltage is used to decrease the influence resulted from sampling delay. The introduction of differential current aspect improves the dynamic response speed, and also more accurately to describe the dynamic response of the system.

IV. SIMULATION STUDY

To verify the control design and the analytical model, a VSC-HVDC supplying passive networks is built in the simulation software PSCAD/EMTDC. The specific parameters [8] and VSC-HVDC system has been given out in Fig.1. In order to avoid overcurrent through the IGBTs, a current limit is implemented in the control system. The maximum of reference current is set as 1.2 times of the load current.

A. Motor Starting

Simulation results are shown in Fig.5 and Fig.6. As shown in the figures, the waveforms respectively represent the operation situation of the system using different control methods. The induction motor IM1 starts at 1.5 second.

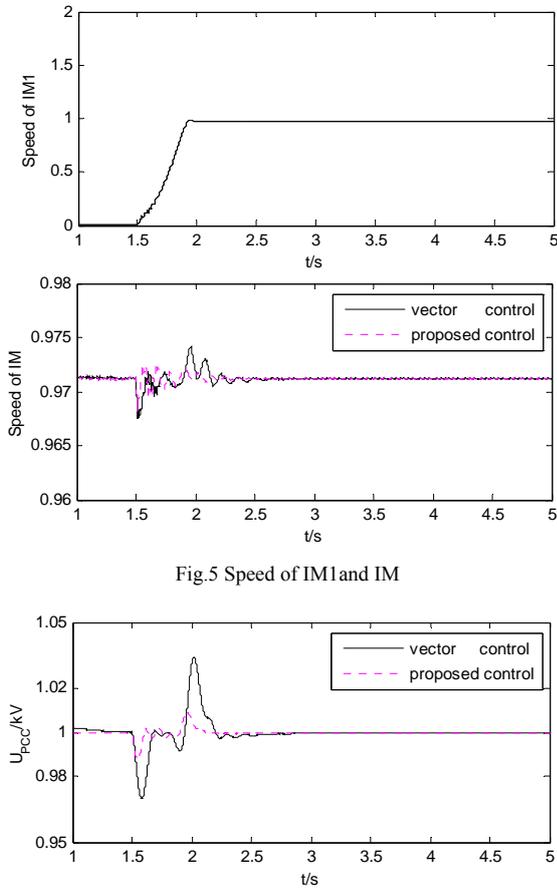


Fig.5 Speed of IM1 and IM

Fig.6 AC voltage amplitude, current amplitude, direct voltage, active and reactive power at PCC point during IM1 starting

From Fig.5 and Fig.6, It can be seen that:

- (1) With the starting of IM1 at 1.5 seconds, the voltage at PCC drops. The current amplitude and current ratio increase sharply due to the load changing. The modified controller can be used to decrease the degree of voltage dips.
- (2) As shown in figures, during a motor start, the reactive power can be several times as large as the normal values. The fluctuation of speed, reactive and reactive power illustrate that the load changing bring a certain influence on

the operation of IM. With the proposed control method used in the controller, the voltage quality will be improved.

B. Three-Phase Fault at the Sending Side

A voltage dip with a retained voltage of 0.8 p.u. is simulated at the sending side of the VSC-HVDC. The dynamics of the link during and after the dip depend on the remaining control margin, i.e. on the between the steady-state model and the transient model. The results are shown in Fig.7 and Fig.8. The fault is applied at 1.5s and is cleared 5 cycles later.

From the simulation result it is derived that different fixed ac voltage control can significantly affects the dynamics of the system during and after a fault at the grid side. For the proposed control model is able to maintain the dc voltage and ac voltage at the PCC at the desirable values. In that case the loads are hardly experiencing any disturbance.

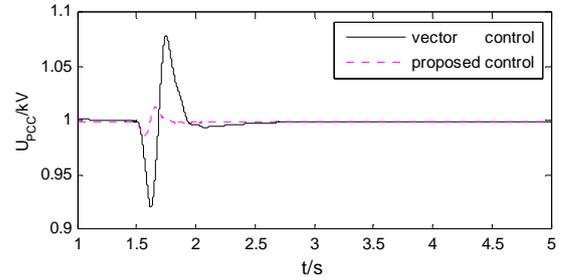


Fig.7 AC voltage amplitude, DC voltage and active power at rectifier during a three-phase fault.

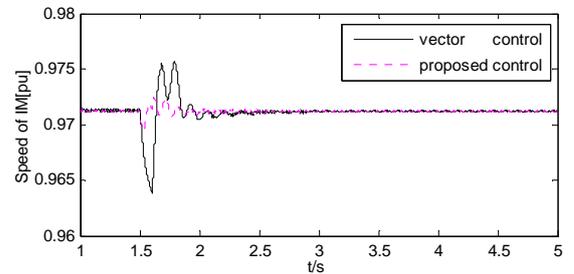


Fig.8 Speed, active and reactive power of IM during a three-phase fault.

V. CONCLUSIONS

The paper has designed controllers of rectifier and inverter converters supplying passive networks and presented a new fixed voltage controller. Based on the simulation, comparisons have been presented. It can be concluded that:

- (1) The simulation system established in this paper and its control method can simulate the situation supplying passive networks well.
- (2) The controllers of rectifier can achieve the current decoupling control and the regulating of active and reactive power.
- (3) A new fixed ac voltage controller can decrease the influence led by load fluctuation or a three-phase fault and tracks the reference values well. The use of the VSC-HVDC

significantly enhances the quality of power supply to industrial plants.

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