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Coordinated control of pulse width modulation based AC link series compensator and power system stabilizers

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ABSTRACT

This study suggests a novel and mathematical dynamic index for greatest coordinated control of Pulse Width Modulation based AC link Series Compensator (PWMSC) and Power System Stabilizers (PSS) in multi-machine networks. The planned new dynamic index is developed as a fitness function to reinforce the oscillations damping under totally different loading conditions. A nonlinear constrained optimization programming is applied for reducing the dynamic index based mostly from critical eigenvalues of the systems. The robustness of the coordinated control is reached directly through extending numerous loading conditions from that of the nominal case. The best proficiency of the proposed control is showed through simulations on a four-machine and sixteen-machine power networks for various conditions. Linear and nonlinear analysis presents the high priority of the suggested dynamic index in tuning of the parameters controller.

Introduction

Modern electrical networks become additional heavily loaded under economic and environmental pressures and damping of electromechanical oscillations tends to decline. Hereon, electromechanical oscillations are cleared in these networks world-wide, where groups of synchronous machines are connected over long distance transmission lines in areas. Then, these transmission lines are weak and should suffer high levels of the active power flow during throughout traditional loading. As a result, the inter-area and local oscillation modes can most likely show the poor damping or undamped in the absence of an appropriate damping stabilizer. If damping signal failed to offer, size of those oscillations might keep rising till network is unstable.

Usually, power system stabilizers (PSSs) are installed to insert additional control action across the excitation system of synchronous machines [1]. In some situations, the PSSs do not provide adequate damping action for the inter-area oscillation modes in a large scale network. Flexible AC Transmission System (FACTS) technologies have been growing to improve steady-state and dynamic performance and became a wishing alternative in cost compared to the new transmission system expansion [2]. Because of fast control act, the FACTS based damping controller and the PSSs are capable to add a high level stability to the networks, they have the more potential for deleterious interaction with one another and sublation of expected performance [3]. Associated with deregulating today electric networks, the operational restrictions such as environment, financial and market require the application of modern control techniques to purvey utilizable reliability and financial profitableness. Uncoordinated style of the PSSs and the FACTS additional stabilizer might cause dynamic interactions between them. But, a coordination control may be needed to prevent such possible interactions between these controllers. In fashionable electric networks, the coordination controllers could also be rather complex because of system dimensions [4–6].

There have been growing studies that report the coordination control of the PSSs and the FACTS based stabilizers for damping of the oscillations [7,8]. Mathematical programming [9–12], fuzzy modeling approach [13], eigenvalue distance minimization technique [14] artificial neural networks [15], artificial intelligence Based techniques [16–19] and robust performance criterion [20] based coordinated control are reported in the publications.

Nowadays, PWM based AC link series compensation (PWMSC) as new FACTS technology is presented to control the transmission line impedance and supply additional damping signal to system critical modes. The PWMSC technology offers an approach of

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controllable series compensation [21–23]. Besides controlling transferred active power, it can improve stability of networks. The main contribution of this work can be summarized as follows:

- A novel dynamic index for greatest coordinated control of a damping stabilizer for the PWMSC and the PSSs to moderate low frequency oscillations is presented.
- The gain and time constants of the phase lead/lag stabilizers are calculated by using of the nonlinear constrained optimization programming.
- The best proficiency of the proposed control is simulated on a 4-machine and 16-machine networks.

In this paper, two different interaction phenomena between PWMSC controller and PSSs are distinguished by their specific frequency characteristics: low and high frequency modals interaction. Caused by the discrepancy of the interaction phenomenon, a novel and mathematical dynamic index is planned to eliminate these deleterious interactions. The dominant target of the methodology in this article is to study the circumstantialities of the coordinated control approach of a damping stabilizer for the PWMSC employed and the PSSs to moderate low frequency oscillations in such way interactions are reduced. For this reason, a nonlinear constrained optimization programming is carried out to coordinate among several damping controllers at the same time. This method is taken into account for simultaneous parameter design of the PWMSC-damping controller and the PSSs to improve the stability of test cases. By optimizing the proposed dynamic index in which the impressions of PSSs and PWMSC damping controller are supposed, interactions among these stabilizers are reduced.

Interaction analysis and control objectives

Interaction analysis

Interactions among the PWMSC controller and the PSSs are recognized to result oscillating stability drawback as illustrated in Ref. [1]. In recently studies, damping controller interactions are categorized into two types by frequency ranges in [6]: low and high frequency modal interactions. Without taking account of the interactive dynamics between the damping stabilizers, unwanted high frequency modal interactions can befall while the controllers are in joint operation. Straightly following a fault, the synchronous generators might begin to oscillate relative to each other, causing variations in network variables as example frequency, the load flows on the lines and so on. The PWMSC based damping controller contributes to in retaining stability under large faults. But, in some cases, interactions between the PSSs and PWMSC controller may destabilize the electrical network, if two PWMSC devices are placed in the same area or the locations of the PWMSC controllers result portion of the system to island after the removal of the large disturbance.

The contribution of the PSSs and the PWMSC damping controller to the natural modes could be positive or negative. So, after the damping controllers are embedded into the network, old natural oscillation modes may be excited caused by the interactions between the PSSs and the PWMSC controller, which is a factor that limits the damping ability of the controllers. All the PSSs and the PWMSC controller ought to be coordinated and controlled to reduce the deleterious effect on other natural modes so that these modes have enough stability margin for different loading conditions in the multi-machine environment.

Control objectives

When a perturbation befalls in the network, the duration of some oscillation modes in the time domain is specified by various critical eigenvalues at the utmost right sides on the complex plane. Eigenvalue based control functions are modeled often by the damping factor and the damping ratio on the design of the controller parameters and reported in several studies [8,10,12]. The suggested control functions may get higher frequency or low frequency poorly damped modes. Based on the above interaction analysis, the new dynamic index, ψ, is presented to overcome the disadvantage and to meet the design control objectives for coordinating the PSSs and PWMSC damping controller. The dynamic index is defined as:

$$\psi = \frac{-(\sigma - \sigma_0)}{\sqrt{(\sigma - \sigma_0)^2 + \omega^2}} \times 100\% \tag{1}$$

where σ is the real part of the eigenvalue. In this paper, the dynamic index (DI) may be formulated as a control function:

$$\mathrm{DI} = \sum_{j=1}^{\mathrm{NP}} \sum_{\psi_i \leqslant \psi_0} (\psi_0 - \psi_i)^2 \tag{2}$$

where ψ_{ij} is the dynamic index of the ith eigenvalue. The ψ_0 is a fixed value of the interested damping. A conic sector with the top at σ_0 is created by Eq. (2)in which all damping indices is no less than ψ, also the slope of the direct line is showed as Eqs. (3) and (4). Fig. 1 declares that DI does not have these difficulties modes with higher or low frequency weakly damped modes.

$$\begin{aligned} &\psi^2((\sigma - \sigma_0)^2 + \omega^2) = (\sigma - \sigma_0)^2 \\ &\omega = \pm(\sigma - \sigma_0)\sqrt{\tfrac{1}{\psi^2} - 1} \end{aligned} \tag{3}$$

$$\mathrm{Slope}_{\psi_0} = \pm\sqrt{\left(\frac{1}{\psi_0^2} - 1\right)} \tag{4}$$

The new dynamic index can transfer all oscillation modes to the left aspect of the complicated plane.

Constraints

In the coordination control of the PSSs and PWMSC damping controller a stable system with satisfactory damping in the low and high frequency modes is desired and the realizable parameters is also entirely required. The subsequent constraints therefore are formulated as:

$$\begin{aligned} &K_i^{\min} \leqslant K_i \leqslant K_i^{\max}; \quad T_{1i}^{\min} \leqslant T_{1i} \leqslant T_{1i}^{\max} \\ &T_{2i}^{\min} \leqslant T_{2i} \leqslant T_{2i}^{\max}; \quad T_{3i}^{\min} \leqslant T_{3i} \leqslant T_{3i}^{\max} \\ &T_{4i}^{\min} \leqslant T_{4i} \leqslant T_{4i}^{\max}; \quad i = 1, 2, \ldots, N_s \end{aligned} \tag{5}$$

where N_s is the number of damping controllers.

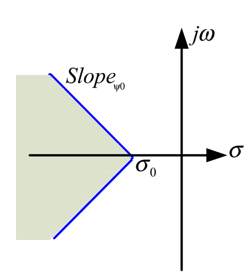

Fig. 1. Conic region with tip at σ_0 and dynamic index ψ_0.