

Decentralized Control Model Research for Power System Low Frequency Oscillation

Xuncheng Huang^{1,a}, Huan Qi^{2,b}, Xiaopan Zhang^{3,c}, Lifang Lu^{2,d}, Yangyu Hu^{1,e}

1. Henan Electric Power Company, Zhengzhou, 450052, China;

2. Huazhong University of Science and Technology, Wuhan, 430074, China

3. Wuhan University of Technology, Wuhan, 430070, China

^ahxunc@126.com, ^bqihuanster@foxmail.com, ^czxp.whut@163.com,

^dlulifang186@126.com, ^e48342757@qq.com

Abstract—This paper considers the problem of decentralized control of interconnected power systems under the larger failure in real and reactive loads in the system model. A new decentralized control model has been presented. The model was designed based on the optimal damping ratio. Use the left-half plane pole configuration to achieve a grid isolated decentralized control. Simulation results show that the decentralized control model can suppress power oscillations effectively.

Keyword—decentralized control, optimal damping ratio, pole configuration, low-frequency oscillation

I. INTRODUCTION

Power system vulnerability is the power network security issue related to the grid structure and all kinds of outside interference. Power system became more complex in structure and more powerful energy transmission, while its network structure vulnerability also would increase. Theory and practice shown the low-frequency oscillation often appeared in long, heavy-duty transmission lines, especially in the modern power systems in which the high-top value multiple fast excitors have been adopted. LFO has bad influence on the power delivery, when the system was weak linking, it may cause the unit out of step, even system splitting.

Power system stabilizer (PSS) is the accepted power system damping device, which can increase the system damping. While multi-machine power system is a typical nonlinear dynamic system. There is interaction and influence between many sets of PSS. In the multi-machine power system, the input signal of PSS is usually the state value or output signal of local generator unit, and the output signal of the PSS acted on the local generator unit. Thus the multi-machine power system with the PSS is similar to the distributed control system with dynamic compensator in structure. Therefore, the decentralized control of power system is completely feasible and has greater technical and economic advantages.

Many kinds of decentralized controller has been proposed in the past few decades. Such as J.W. Chapman studied a controller for the generator excitation system which was described that uses a combination of feedback linearization and the observation decoupled state space. The controller used only local measurements, and its performance was consistent with respect to changes in network configuration, loading and power transfer conditions[1].

Yi Guo designed a nonlinear decentralized robust controller for the multi-machine power systems. The controller can maintain a transiently stable closed-loop system at the present of uncertain network parameters. The effect of persistent disturbance whose bound was not known as a priori was effectively attenuated[2]. Tomonobu Senjyu designed a H_∞ controller to achieve simultaneous control of the damping of power system oscillations and terminal voltage of multi-machine power system. It uses the normalized coprime factorization approach to improve terminal voltage control performance and increase the damping of the power system oscillations. Use of normalized coprime factorization approach made simplify in the selection of weighting function in the H_∞ controller[3]. Valery A. Ugrinovskii designed a decentralized controller to deal with the small disturbance perturbations in the system model. Using an Integral Quadratic Constraints description for system interconnections and disturbances, they obtained necessary and sufficient conditions for the existence of a decentralized controller which stabilized the overall system and guaranteed its optimal robust performance[4]. Ali Karimi proposed a backstepping controller with additive nonlinear damping term for stability enhancement of multi-machine power systems through excitation control. The decentralized control scheme is practical in systems especially when couplings are handled appropriately. Results on 50 machines 145 buses show that extended-backstepping controllers effectively stabilize the system for severe contingencies in comparison with conventional power system stabilizer[5]. H.F. Wang studied the multi-machine power system low frequency oscillation decentralized stabilization, and pointed out the electromechanical oscillations was not caused by the fixed mold of the decentralized closed-loop system. Thus proving the low frequency oscillation can be controlled by the decentralized controller[6].

In this paper, we discuss the decentralized coordinated control based on dynamic compensators for power system.

II. DECENTRALIZED DYNAMIC OUTPUT FEEDBACK CONTROL MODEL

Decentralized dynamic output feedback control is the overall dynamic control for large-scale system, by using one dynamic compensator or more, shown in

Figure 1. The dynamic compensator only observe the subsystem output, and only control the subsystem input.

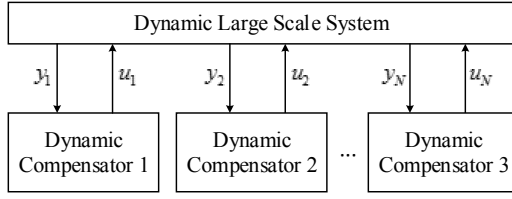


FIGURE 1. DECENTRALIZED DYNAMIC OUTPUT FEEDBACK CONTROL SYSTEMS

Dynamic equations of the system is

$$\begin{cases} \dot{x} = Ax + \sum_{i=1}^N B_i u_i \\ y_i = C_i x, i = 1, 2, \dots, N \end{cases} \quad (1)$$

where, x is the state vector, y_i and u_i represent the input vector and output vector of the i th dynamic compensator respectively, A, B_i, C_i are the real constant matrix of the corresponding dimension.

The output feedback control laws for the i th dynamic compensator is:

$$\begin{cases} \dot{z}_i = F_i z_i + G_i y_i \\ u_i = H_i z_i + M_i y_i \end{cases} \quad (2)$$

z_i is the state vector, F_i, G_i, H_i, M_i are matrix waiting for solving of the corresponding dimension. The state equation of the decentralized control closed-loop system is:

$$\begin{bmatrix} \dot{x} \\ \dot{z} \end{bmatrix} = \begin{bmatrix} A + BMC & BH \\ GC & F \end{bmatrix} \begin{bmatrix} x \\ z \end{bmatrix}, \quad (3)$$

where F, G, H and M are the block diagonal matrix constituted by F_i, G_i, H_i, M_i , B and C are block vector constituted by B_i, C_i .

The object of the dynamic large-scale systems' decentralized stabilization is determining the decentralized dynamic output feedback control law of the type (2). Then the augmented system is asymptotically stable shown in type (3).

The system is always decentralized stabilization when the decentralized fixed modes is not existing in distributed control system or although exist but they are located in the left half complex plane. Either with one or more units with dynamic dispersion compensation controller, if the sum of their order is not more than N , the closed loop system's observability mode can be optionally configured. Where

$$N = \min \{P_c - 1, P_0 - 1\}, \quad (4)$$

P_c is controllability index, P_0 is observability index.

Our concern of the low frequency oscillation mode in power system low frequency oscillation problem is just a small part in the controllable observable mode. In addition, practical as long as guarantee the stability of power system, and there is no need to configure mode oscillations discretionarily. Therefore, adopting the

decentralized dynamic output feedback to control the power system low frequency oscillation, not only has strict theoretical basis, but also relatively easy to implement.

III. DECENTRALIZED STABILIZATION OF MULTI-MACHINE POWER SYSTEM LOW FREQUENCY OSCILLATION

Direct Digital Controllers (DDC) are installed in the M-machines power system to suppress low frequency oscillation and improve the system damping, where $1 \leq N \leq M$. The structure diagram is shown in figure 2.

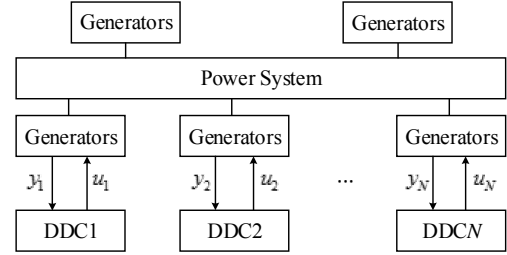


FIGURE 2. MULTI-MACHINE POWER SYSTEM WITH DDC

The order number and weight of y_i and u_i can be selected flexibly. y_i can be chose as the easily obtained local signals. u_i can be chose as the signals of single output and add on the reference voltage phase and adding of excitation system. Then DDC is of the auxiliary regulator of the excitation controller.

The differential-algebraic equation which describe the dynamic behavior of multi-machine power system is linearized in the vicinity of its steady-state operating point. The linearized equation like type (1) is obtained. At the same time, the DDC equations of DDC is written in the form of type (2). The state equation of decentralized closed-loop control system shown in figure 2 can be written in the form of (3).

The problem of multi-machine power system low-frequency oscillation suppression based on the principle of decentralized dynamic output feedback control is to determine the appropriate F, G, H and M as shown in (3).

IV. THE OPTIMAL ALLOCATION OF DDC

DDC is not necessary the more the better, but for its location, right action in a timely manner. Its installation position better, or its parameters more reasonable, its observation ability on the system is stronger, its control effect will be more in time. Therefore, there is special need to research the optimal allocation of DDC.

For conjugate eigenvalues of A_{sys} $\lambda = \sigma \pm j\omega$, the damping ratio is defined as:

In order to make the system meet the certain stability and transient response indicators, Usually require all eigenvalue real part of A_{sys} is smaller than a negative and the minimum damping ratio of low frequency oscillation modal is greater than a certain positive number.

In principle, the optimal allocation of DDC is regarded as a nonsmooth optimization problems with inequality constraints:

$$\begin{cases} \max \xi_{\min} \\ s.t. \sigma_{\max} < \sigma_0 \end{cases} \quad (6)$$

where ξ_{\min} is minimum damping ratio of all the low frequency oscillation modes, σ_{\max} is the maximum real part of all the characteristic values, σ_0 is the threshold value of all the characteristic values.

The problem of optimal damping ratio can be solved using optimization algorithm, such as evolutionary algorithms.

V. SIMULATION

The power plants of 220kv level and 500kv level in Nanyang region include Yahekou, Huilong and Zhiyuan. Yahekou power plant including 220kv level of generators and 500kv level generator. The generators in Huilong and zhiyuan plant are 220kv. The speed control system in Huilong power plant is water turbine, the others are steam turbine power plants. Simulation model of Nanyang region electric power network is set up in MATLAB, as shown in figure 3.

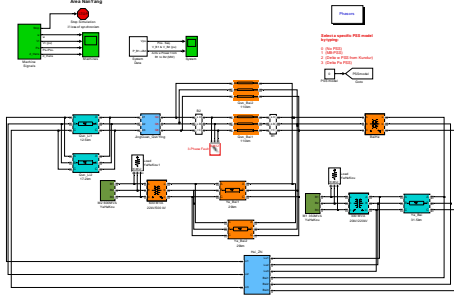


FIGURE 3. SIMULATION MODEL OF NANYANG REGION

Operation model of power flow calculation, can get the waveform parameters as shown in figure 4.

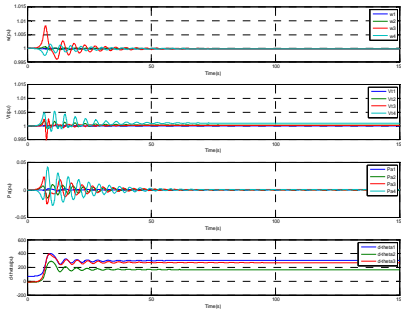


FIGURE 4. THE SIMULATION WAVEFORM NANYANG REGION

In line fault cases, join the decentralized control strategy based on optimal damping ratio to Yahekou1, Yahekou2, Huilong and Zhiyuan power plants, the response is shown in figure 5:

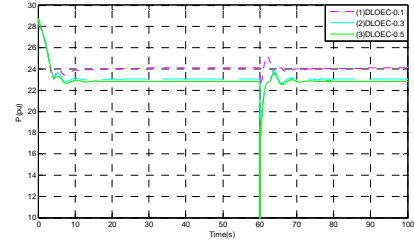


FIGURE 5. THE TIME DOMAIN RESPONSE OF THE ACTIVE POWER IN FAULT LINE

As shown in figure 5, the decentralized control strategy is effective in suppressing low frequency oscillation

VI. CONCLUSION

Low frequency oscillation is often happened in the operation of power grid, and has great harm to the stable operation of the power grid. In this paper, we researched the decentralized control strategy based on optimal damping ratio. The simulation shown the satisfactory performance of the strategy. More studies have shown that increasing the damping ratio has much help in restrain low frequency oscillation.

ACKNOWLEDGEMENTS

This work was financially supported by the National Natural Science Fund(60904073) and The Hubei Natural Science Fund(2012FFB05111)

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