Global Parameter Settings of FACTS-Controllers for Improving Power System Stability

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Abstract:

This paper presents a global procedure for parameter settings of FACTS controllers. With the help of the optimization mode in the simulation program system, parameters of controllers associated with the FACTS devices and PSSs in the system are globally determined relying only on local measured information which are available at the FACTS devices themselves. By the minimization of the power oscillations, all possible operation constraints such as voltages profiles at each node concerned are considered taking into account the whole non-linear system. The FACTS devices considered are a SVC and a TCSC. Results obtained from a 3 area power system by events of both large disturbance and small disturbance validated the improvement of the dynamic stability of the power system tested.

Keywords:

FACTS, PSS, SVC, TCSC, damping of power oscillation, power system dynamic stability, control, optimization.

1. Introduction

One of the most important stability problems arising in large interconnected power systems is the poorly or negatively damped electromechanical oscillations which might limit transmission capability. These electromechanical oscillations with low inherent damping have been observed in power systems where a generator or group of generators are weakly connected to the other part of the system or in systems with a long transmission distance. Once these oscillations started, they would continue for a while and then disappear, or continue to grow, causing system instability, especially in the case after critical faults.

Damping of power system oscillations plays an important role not only in increasing the transmission capability but also for stabilization of power systems after critical faults. The Power System Stabilizers (PSSs) has proved to be an efficient means for improving power system dynamic stability by the damping of mechanical mode for a synchronous generator. However, exciter mode with poor damping could also lead to power oscillations which PSS might not be able to effectively suppress [1]. In this case, additional damping devices might be needed.

Since Kimbark employed a switched series capacitors to improve the dynamic stability in 1966 [1], progress in the field of high power electronics has led to the development of new types of power electronic equipment for transmission systems, called Flexible AC Transmission Systems (FACTS). FACTS devices, such as Static Var Compensator (SVC), Thyristor Controlled Series Compensation (TCSC) and Thyristor Controlled Phase Angle Regulator (TCPAR) as well as Unified Power Flow Controller (UPFC) etc., offer the accuracy, continuity and fast response of control action and can be used to improve the dynamic performance, not only by small disturbance but also by transient stability, and to increase the stability margin.

SVC as a relevant FACTS device is already widely in operation. The main feature of SVC is the voltage control by means of the reactive power compensation, for which the most of the devices are installed. In the last few years, the SVC with proper control signals have been also used to damp out electromechanical oscillations [2]. TCSC is also an important FACTS device. An important feature of this device is a "self-controlled" compensation by means of thyristor controlling the line reactance. It allows an effective increase in power transmission at any given phase-angle displacement across the line [3]. Nowadays TCSC with supplementary controller signals is also recognized as an important damping source. Fig. 1 illustrates main technical features of some important FACTS devices.

	load control	voltage control	transient stability	oscillation damping
HVDC	❑❑❑	❑❑	❑❑	❑❑❑
SVC	❑	❑❑❑	❑	❑❑
TCSC	❑❑	❑	❑❑❑	❑❑
TCPAR	❑❑❑	❑❑	❑	❑❑
UPFC	❑❑❑	❑❑❑	❑❑❑	❑❑❑

Fig. 1 Main technical features of some FACTS devices

By some large interconnected power systems, different FACTS devices might be simultaneously installed for effectively improving dynamic stability. Due to the complexity of the control scheme involving PSSs, SVCs and TCSCs etc. with their supplementary controllers, the coordination of all local controllers can become a serious problem. In facts, the interaction of installed devices could negatively influence damping effects. In some critical cases, it could even amplify oscillations or increase voltage deviations due to the increase of reactive power oscillations [4].

Therefore, a challenging task faced in the use of FACTS devices is how to coordinate of various local controllers with proper parameter settings in order to successfully cope with global dynamic stability. In many publications, approaches for parameter settings of FACTS controllers in multimachines systems are mostly sequential, in sense that each controller is separately adjusted at a time. Even though such methods called "local mode" frequently show satisfactory results, they lack a more precise representation of inter-machine and inter-area dynamic interactions. This may result in a less optimum damping of power oscillations.

On the other hand, many controller design methods are based on small disturbance analysis and linearization of the system involved. However, power system instability phenomena are often non-linear problems. Especially by critical faults (large disturbances), such problems pose difficulties to linear methods.

In this paper, a global procedure for parameter settings of FACTS controllers is presented, which considers also large disturbance. With the help of the optimization mode in the simulation program system NETOMAC (Network Torsion Machine Control) [5], parameters of controllers associated with FACTS devices in the system will be simultaneously determined. By this procedure, all possible operation constraints such as voltages profiles at each node concerned are considered taking into account the whole non-linear system. Due to the fast time response of FACTS devices, it is desirable that they operate using only locally measurable information for modes of operation which require fast response. In this work, all FACTS controllers installed work only on local information. The setting procedure ensures also that the controls will not interact in a negative fashion, even though they are rely only on local measurements. An application to a 3 area power system as a example is presented. The devices considered include PSSs and a SVC as well as a TCSC with their supplementary damping controllers.

2. Power System and FACTS Controllers

The 400 kV system configuration [6] investigated is shown in Fig. 1. It consists of three subsystems interconnected by transmission lines. The subsystems are represented by equivalent generators and corresponding loads which were determined from a more complex configuration consisting of a number of generators. The generation is composed of typical units of nuclear power stations (1100 MW) and thermal power stations (300 and 600 MW respectively) as well as hydro power stations. In the system it is assumed that all equivalent generators are equipped with PSS. Besides that, the voltage, frequency and power control are also included in the model. All data used in the test system are given in Table 1, where all loads are assumed as linear.

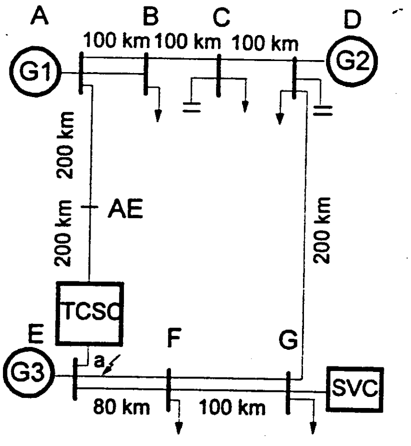

Fig. 1 Test system

Table 1. Data of the test system

X=0.25 Ω/km for all line, P in MW and Q in MVar

Bus	$P_{generation}$	P_{load}	Q_{load}	$Q_{compensator}$
A	1500	0	0	0
B	0	285	94	0
C	0	190	62	60
D	950	1900	624	400
E	1080	0	0	2 x 50 (TCSC)
F	0	190	62	0
G	0	950	312	± 300 (SVC)

The excitation system for the generators used is selected as the IEEE type 1 excitation system, neglecting saturation of the exciter. A conventional PSS comprising a pair of the lead lag networks with active power oscillation as input signal is assumed, and whose transfer function is given in (1).

The SVC is installed with a range of ± 300 MVar at the location G, almost the center of the transmission line between subsystem E and D, where the voltage is controlled and maintained as constant without time delay. The SVC is equipped with a supplementary controller modulating the SVC action, whose input signal is the active power oscillation ΔP at the location of SVC. The damping improvement is obtained due to the direct voltage influence between subsystem E and D and the indirect voltage influence through the loads.

The firing angles of the thyristors are adjusted using a PI controller by the variations of the voltage at the node G and the modulated signal from the supplementary controller for power oscillation damping. The susceptance of the SVC is then regulated in a way as shown in Fig. 3 which depicts the SVC mode used in this paper, where V_{act} is the SVC bas voltage, V_{ref} is a reference voltage, respectively.

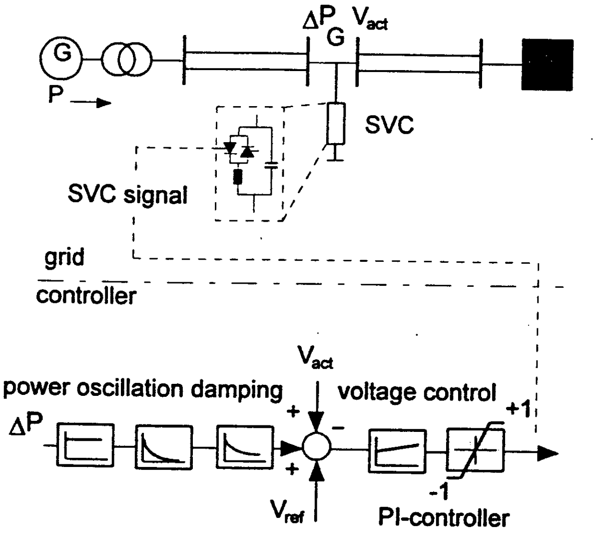

Fig. 3 SVC controller with supplementary signal ΔP

The TCSC with the range from 25% to 50% of the line impedance of the 400 km line between A and E is equipped at the location E. The reduced line impedance increases both the effective short-circuit capacity at E and the synchronizing torque between subsystem E and A to stabilize the system.

The action of the TCSC controller shown in Fig. 4 amounts to incrementally changing the series susceptance between buses E and A. The firing angles of the thyristors are adjusted using a PI controller by the variations between the set point power flow P_{ref} and the active power flow P_{EA} from bus E to A through the TCSC, and the modulated signal from the supplementary controller for power oscillation damping.

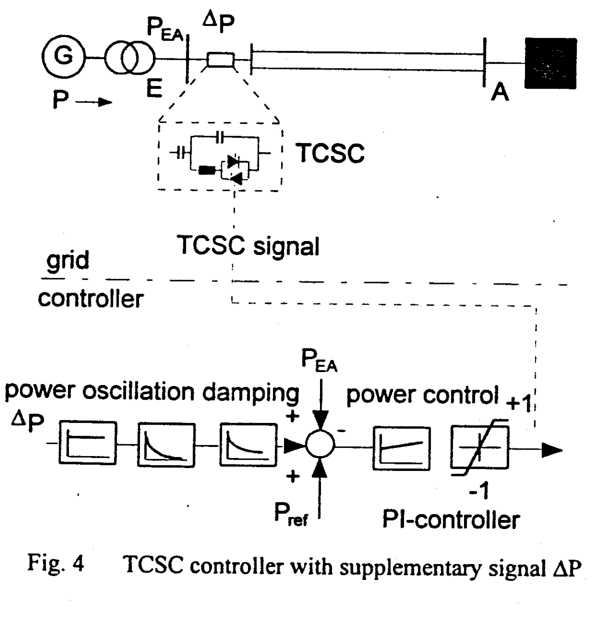

Fig. 4 TCSC controller with supplementary signal ΔP

The input signal of power oscillation damping controllers for SVC and TCSC can be usually either locally measured frequency or active power oscillation. The use of a frequency is suitable only when the power system oscillation frequency can be clearly filtered. In the case of loosely coupled power system this requirement is not always satisfied [4]. In this paper active power oscillations are adopted as control signal for supplementary controllers and also for PSSs equipped at generators in the system.

The power oscillation damping controller transfer function are assumed in the form of

$$F(s)=\frac{K(1+sT_1)(1+sT_3)}{(1+sT_2)(1+sT_4)} \qquad (1)$$

where time constants T_2 and T_4 are assumed as known and the parameters K, T_1 and T_3 are determined by the setting procedure to be described in the section 3.

3. Optimization Procedure

Maximal damping of system swings taking into account the whole non-linear system can be achieved if parameters of the FACTS controllers installed are simultaneously determined through a global setting procedure. In this section such a setting procedure based on non-linear optimization techniques for optimal design of FACTS controllers with the help of the simulation program system NETOMAC is presented.

As a special mode, optimization algorithms have been implemented in NETOMAC, which allows users flexibly to solve various optimization problems under consideration of all possible operation and security constraints. Using block-oriented simulation language (Fortran-like), almost all kinds of elements contained in a power system including FACTS devices and power control systems can be simulated and then optimized. The optimization mode enables a free representation of optimization problems including possible constraints. With this mode, all aspects of the representation, solution and initialization of the optimization problem considered are also under users control [7]. Users only need to model the corresponding simulation system and describe the objective function as well as define the state variables to be optimized in a input file. Any modification to the source program is not needed. After starting the program, all data are systematically interchanged in the optimization routine and the corresponding simulation model system. Once a new operating point is found by the optimization process, the simulation of the system is performed again based on this new operating point. The optimization will continue until one or all of the stopping criteria are satisfied. Fig. 5 illustrates briefly the optimization mode in NETOMAC.

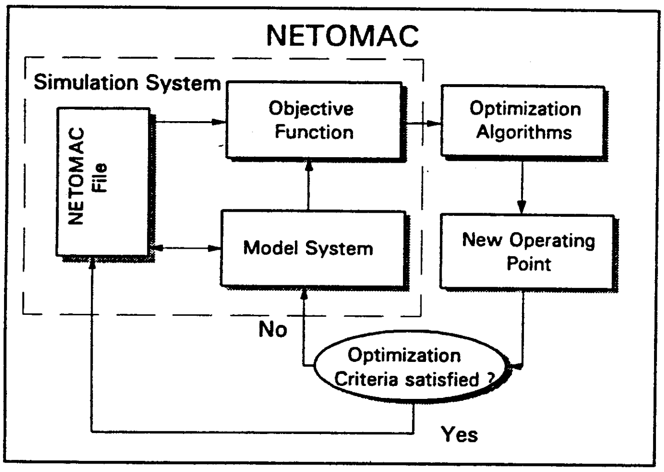

Fig. 5 Optimization in the program system

The target of oscillation damping with the help of FACTS devices is the minimization of power swings in the overall system, so that for setting of FACTS controller parameters the objective function could be defined as a minimization of active power oscillations at the locations considered. Assuming **n** FACTS devices being installed in the system, with the ISE (integral of squared error) techniques the objective function could be given in the form of

$$\min f = \int_0^\infty \left[\Delta P^T A \Delta P\right] dt, \qquad (2)$$

where ΔP^T is a **n** variables vector of locally measured active power oscillations at **n** locations of the FACTS devices and A is a identity matrix.

However, it is sometimes to observe that damping of active power oscillations with a large TCSC or SVC rating could lead to increasing reactive power oscillations and voltage deviations. In this paper, by the design of FACTS controllers the balance between active power oscillations and reactive power oscillations have been considered in the minimization of the following objective function

$$\min f = \int_0^\infty \left[\Delta P^T A \Delta P + K_Q \Delta Q^T A \Delta Q\right] dt \quad , \qquad (3)$$

$$\text{subject to} \quad U_{low} \le U \le U_{upp}$$

where

$\Delta P = [\Delta P_1,\dots,\Delta P_n]^T$	active power flow oscillations,
$\Delta Q = [\Delta Q_1,\dots,\Delta Q_n]^T$	reactive power flow oscillations,
$U = [u_1, ,\dots, u_m]^T$	m considered bus voltages in steady state,
U_{low}, U_{opp}	low, upper bound constraints of bus voltages respectively.

Besides, K_Q is a weight factor for damping of reactive power oscillations. A low value for K_Q means preference for damping effect and high value preference for the limitation of reactive power oscillations. It might be worthwhile to note that the optimal design problem defined in (3) is a non-linear constrained problem. To solve this problem using the optimization mode of NETOMAC, it is unnecessary to linearize it, so that the system performance with the parameter settings determined by directly solving the non-linear problem (3) might be insensible to either small or large disturbances. This means a robust performance of the controllers optimized could be achieved: they improve the damping of power oscillations and enhance the stability margin both by large and small disturbances.

Since the optimization procedure takes simultaneously the whole system dynamics including interactions of inter-machine and inter-area dynamic into account by minimizing the objective function (3), the parameters to be optimized in FACTS controllers are globally determined. On the other hand, the setting procedure considers overall power oscillations, especially that at the locations of FACTS devices installed, so that a negative interaction between FACTS devices could be eliminated.

In the setting procedure all together 7 parameters are to be optimized. They are: the gains K_{TCSC}, K_{SVC}, the time constants $T_{1(TCSC)}$, $T_{1(SVC)}$ and $T_{3(TCSC)}$, $T_{3(SVC)}$ in the transfer function (1) of power damping controllers for TCSC and SVC respectively, as well as the gain K_{PSS} of the PSSs.

4. Simulations

To verify the effectiveness of the proposed procedure, simulations are performed by both of small disturbance and large disturbance using the system shown in Fig. 2. As large disturbance a three-phase fault at location "a" in line EF was taken which, as a critical fault, might lead to system unstable in case of the FACTS controllers without optimization. As small disturbance three-phase faults with 100 ms and 200 ms were taken at the same location "a", respectively.

In case of transient stability problems a much large control area is often needed, so that the optimization procedure should be performed in such a way that the obtained parameter settings of FACTS controllers could also benefit transient stability following a critical fault. Therefore, it might be reasonable to take a large disturbance for performance of optimally designing FACTS controllers. In simulations it was observed that the system by absence of FACTS devices became unstable by three-phase faults with duration t ≥ 265 ms, so that setting procedure was performed by a three-phase fault with t = 265 ms.

In setting procedure the power flow oscillations ΔP_{AE}, ΔP_G at the location AE and G were simultaneously minimized which are control signals for supplementary damping controllers of TCSC and SVC respectively, while the reactive power oscillation ΔQ_G at the location G was also taken into account by applying the weight factor K_G. Because, as a main target, the setting procedure attempts to achieve a maximal damping effect, the weight factor K_G was set with a low value, e.g. $K_G = 0.2$. In addition, during this procedure the bus voltage deviations in steady state were also limited by setting their low and upper bound with value of 0.9 and 1.1 p.u., respectively.

Table 2 gives the parameter settings optimized for TCSC and SVC as well as PSSs through the setting method proposed in this paper, while the times constants $T_2 = T_4$ are known as 0.05 s for TCSC and SVC, $T_1 = T_3$ are 0.15 s and $T_2 = T_4$ are 0.28 s for PSSs. Note that in this paper the parameter settings are assumed as the same for each PSS installed in the system.

Table 2. Parameter settings optimized

	TCSC	SVC	PSSs
K	0.937	3.319	0.048
T_1	0.028 s	0.026 s	
T_3	0.063 s	0.058 s	

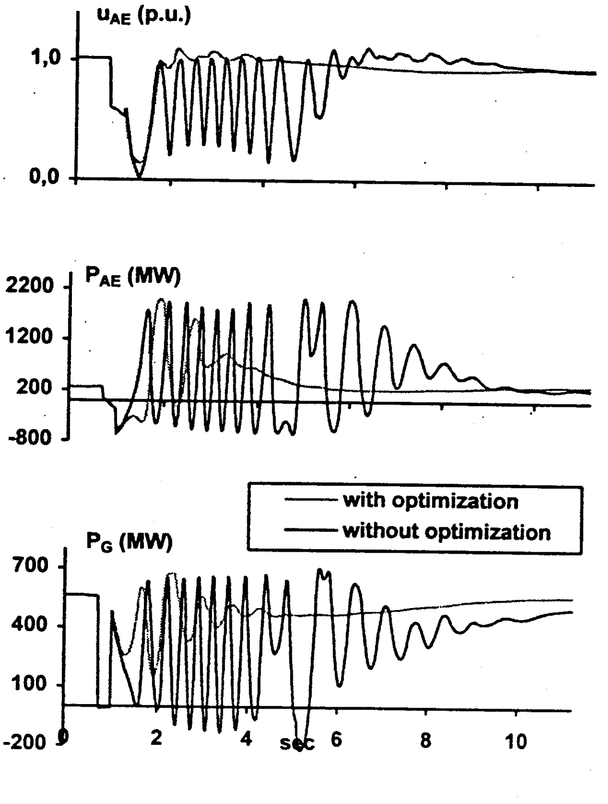

Fig. 6 simulation results with and without optimization by three-phase fault (t = 265 ms)

For comparison, Fig. 6 illustrates the simulation results at the stability limit of the system with initial and optimized parameter settings of damping controllers for TCSC and SVC respectively. From this figure, it is clearly to see that the performance of the system has been improved significantly with the help of the global setting procedures. By the initial parameter settings of damping controllers the system swung following the critical fault almost undamped with a large amplitude in the first 6 second, which, in real situations, could lead to a system separation. In the same case the optimized controllers stabilized the system quickly.

Although the damping controllers optimized well performed following a large disturbance, the question, whether the controllers optimized by small disturbances are also robust, is not cleared yet. Below, there are two figures (Fig. 7 and Fig. 8) which demonstrate the robustness of the controllers optimized. In theses figures system responses following small disturbances with a 100 ms and a 200 three-phase fault are given respectively, in which the controller parameter settings are already obtained through the optimization procedure by the large disturbance described above. From theses figures we can find out that by both small disturbances the controllers optimized improved the system performance as well.

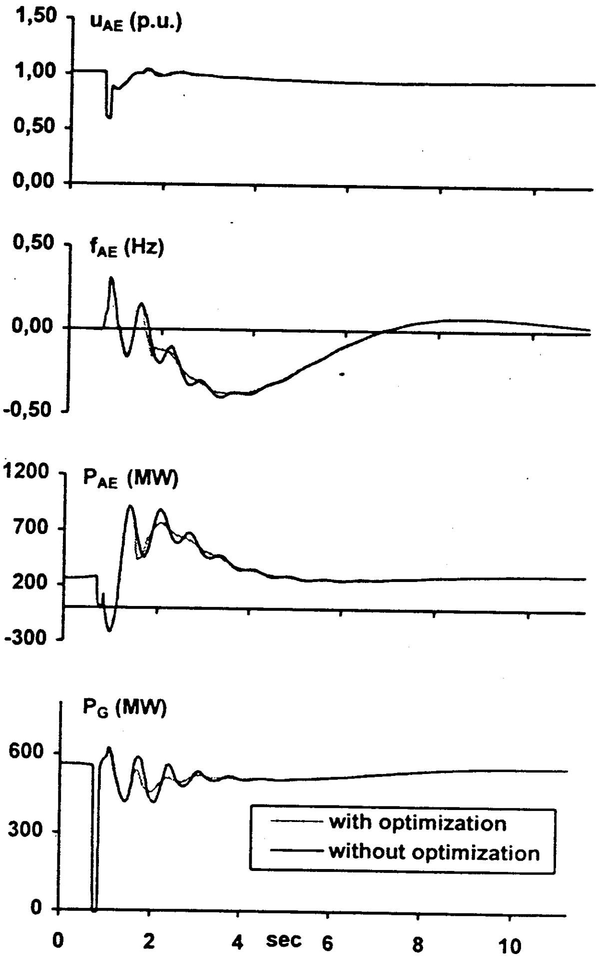

Fig. 7 simulation results with and without optimization by three-phase fault (t = 100 ms)

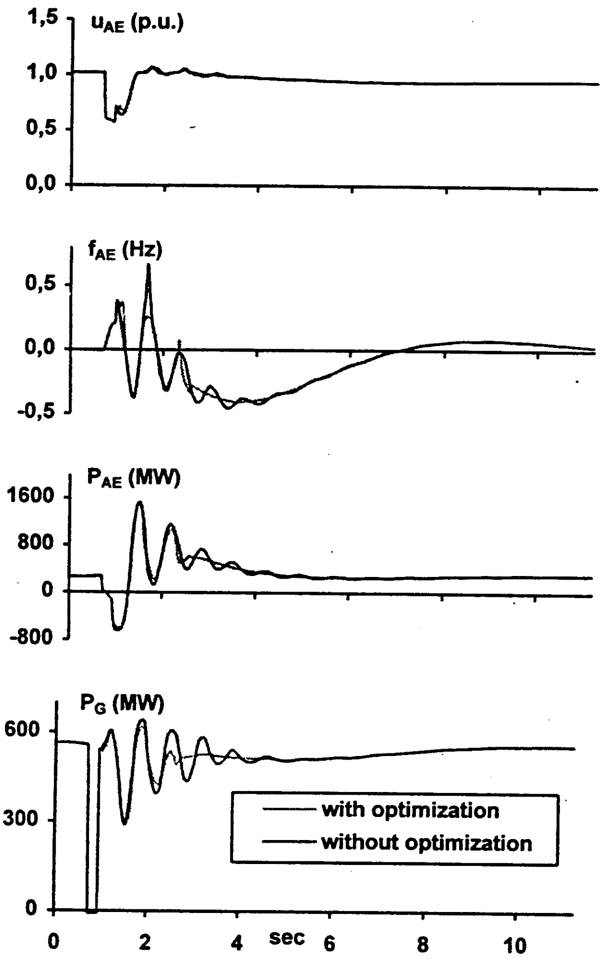

Fig. 8 simulation results with and without optimization by three-phase fault (t = 200 ms)

5. Conclusions

The paper presented a global parameter setting method for power damping control of FACTS devices. With the help of the optimization mode in NETOMAC, the parameter settings procedures take the whole non-linear system into account and determine globally the parameter settings of damping controllers associated with the FACTS devices and PSSs using only local measured information. Results obtained from the test system demonstrated the robustness of system performances with the damping controllers optimized not only by small disturbances but also by large disturbances and validated the effectiveness of the setting method proposed in this paper.

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Biographies:

Xianzhang Lei was born in China. He received the B.S. degree from Zhejiang University, China, the M.S. degree and the Ph.D. degree in electrical engineering from the Technical University Berlin, Germany, in 1982, 1987, and 1992, respectively. From 1987 to 1993, he taught and researched in the Dept. of Electrical Engineering at the Technical University Berlin, Germany. Currently, he is working in the department of power transmission and distribution at Siemens, Germany. His areas of interest are power system stability, optimization and control of power systems as well as system planning.

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