# COORDINATION OF PSS AND FACTS DAMPING CONTROLLERS IN LARGE POWER SYSTEMS FOR DYNAMIC STABILITY IMPROVEMENT

**KAZEMI A., NAJAFI M.**

*Center of Excellence for Power System Automation and Operation*
*Iran University of Science and Technology,*
*Tehran, Iran*
***Email**: kazemi@iust.ac.ir*

## Abstract

Damping of power system oscillations between interconnected areas is very important for the system secure operation. Power system stabilizer (PSS) and fexible AC transmission systems (FACTS) devices are used to enhance system stability. In large systems multi-machine, using only conventional PSS may not provide sufficient damping for inter-area oscillations. In these cases, FACTS power oscillation damping controllers are effective solutions. But uncoordinated local control of FACTS devices and PSS's may cause destabilizing interactions. In this paper, using objective function which maximizes the function, the total damping ratios of the system are optimized and dynamic stability of the system will be improved. In this method all the operation conditions are considered. Simulation results for a large system and different operation conditions of the system shows that this method has a good efficiency and can be effective solution for this problem in a large system. This method can be effective for the coordinating of multi-controllers in large power systems.

## 1 Introduction

Present day interconnected power systems are typical examples of large-scale, complex multi-variable systems[1]. Due to the increase in size and the tendency to operate systems near their stability limits, emphasis has been placed on the design of additional control schemes to maintain the dynamic performance of the system at acceptable levels.

Damping of power system oscillations between interconnected areas is very important for the system secure operation. Besides power system stabilizers (PSS), and flexible ac transmission systems (FACTS) devices are also applied to enhance system stability [2],[3]. In large multi-machine systems, for damping inter-area oscillations conventional PSS can not be effective solution. In this case the use of FACTS devices are effective solution. Combination of these two technologies (PSS and FACTS) can provide sufficient damping for inter-area oscillations. However uncoordinated local control of FACTS devices and PSS's may cause destabilizing interactions. To improve overall system performance, many researches were made on the coordination between PSS's and FACTS controllers [4]. Some of these researches are based on the complex nonlinear simulation, while the others are based on the linearized power system model [4].

In this paper, an optimization algorithm for optimizing the total system performance is described. By maximizing the objective function is used the influences of both PSS's and FACTS controllers are improved. Therefore the overall system performance is optimized.

In this paper, following the introduction, the PSS's and FACTS controllers are described in section II. In section III, coordination and tuning method is discussed in detail. Then in section IV, the test system comprising a static VAR compensation (SVC) and 8 generators is shown. The simulation results are given in section V.

## 2 PSS and FACTS Controllers

### 2.1 PSS

The disturbances occurring in a power system induce electromechanical oscillations of the electrical generators. These oscillations, also called power swing, must be effectively damped to maintain the system stability. Electromechanical oscillations can be classified into four main categories:

- Local oscillations (frequency between 0.8-4.0 Hz)
- Interplant oscillations (frequency between 1-2 Hz)
- Inter-area oscillations(frequency between 0.2-0.8 Hz)
- Global oscillations (Frequency <0.2 Hz)

The PSS is modelled by the nonlinear system shown in Figure 1.

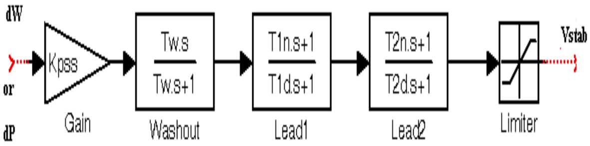



Figure 1. PSS model

The model consists of a low pass filter, a general gain, a washout high pass filter, a phase compensation system and an output limiter. The general gain $K$ determines the amount of damping produced by the stabilizer. The washout high pass filter eliminates low frequencies that are present in the $d_w$ signal and allows the PSS to respond only to speed changes. The phase compensation is represented by a cascade of two-first order lead transfer functions used to compensate the phase lag between the excitation voltage and the electrical torque of the synchronous machine.

### 2.2 SVC

Static VAR compensator (SVC), with the high speed in voltage and reactive power control, is an effective solution for damping power system oscillations by employing SVC's three independent dimensions of control, namely, in phase voltage control, quadrature voltage control and shunt compensation. In general, voltage regulation is the first mode in control and improves voltage stability and transient stability. However, the effect of SVC in damping of power system oscillations that is only received by voltage regulation is small. In this case, a complementary control must be used. The effect of SVC in small signal stability improvement depends on the following cases:

- The location of SVC
- The SVC input signals
- Design controller

In this paper, the SVC consists of a constant capacitor (CP) and a thyristor controlled reactor (TCR), and is used for improvement of damping inter-area oscillations.

The structure of SVC and the complementary controller is shown in Figure 2 [5].

The input signal used for complementary control and SVC, must be sensitive to the oscillation modes. The amplitude of current line can be a good selection for input signal. This parameter has much influence on the frequency of inter-area mode [5].

## 3 Coordination and Tuning Method

Many researches have been made on the parameter coordination. Some of these methods use a nonlinear optimization that is introduced for minimizing the interactions between FACTS and PSS controllers.

In this section, an optimization-based method for coordination of the FACTS and PSS controllers is proposed.

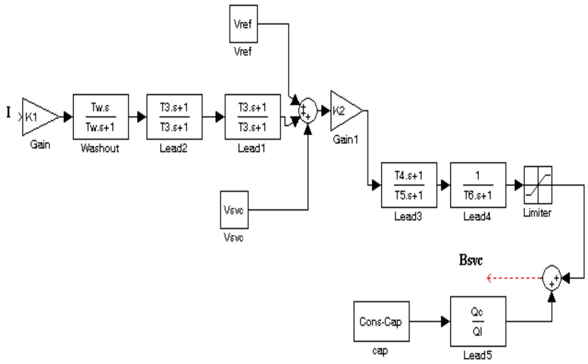



Figure 2. SVC and complementary controller model

The global optimization of the overall system damping performance is the objective of coordination. This requires the optimization and coordination of the parameter setting of the FACTS and PSS controllers to maximize the damping of all modes of oscillations: for instance, local, inter-area, exciter modes and other controller modes. For design of controllers, first system linearization and allocation of controllers must be do, then selection of parameters of controllers for optimize the global system behaviour, is done.

Using the modified ARNOLDI method, can linearize the system mentioned in step 1.

To choose the location of FACTS devices, many researches with different goals, are made. In step 2 the modal analysis is used to find which controller (i.e. governer, exciter, etc.) has the largest influence on these modes. Then the correspondent countermeasure on the controller settings should be applied. This paper focuses on the step 3 concerning the optimization-based parameter coordination. For covering the nonlinear nature of the power system, particular range of system operating conditions (faults, etc.) will also be studied to verify the performance of the optimized controller setting.

### 3.1 Linearized System Model

Once the optimal locations of the damping controllers are chosen, the total linearized system model extended by PSS and FACTS devices can be drived and represented by the following equation:

$$\Delta \dot{X} = A\Delta X + B\Delta u \qquad (1)$$
$$\Delta Y = C\Delta X + D\Delta U$$

From this equation, the eigenvalues $\lambda_i = \sigma_i \pm j\omega_i$ of the total system can be evaluated. The proposed method is to search the best parameter sets of the controllers, and the best operation condition so that a comprehensive damping index (CDI) can be maximized:

$$CDI = \sum_{i=1}^{n_z}\sum_{j=1}^{n_c}\left|\xi_{ij}\right| \qquad (2)$$

where $\xi_{ij} = \frac{-\sigma_{ij}}{\sqrt{\sigma_{ij}^2 + \omega_{ij}^2}}$ is the damping ratio ($\sigma_{ij}$ is the real part of the $i$th eigenvalue at the $j$th operating condition), and $n_z$ is the total number of the dominant eigenvalues which include the inter-area modes, local modes, exciter modes, and controller modes. This index includes the influences of both FACTS and PSS controllers.
In order to ensure the robustness of the control parameters, a set of operating conditions, $n_c$, is properly selected and taken into consideration simultaneously in the optimization problem(Eq.2).

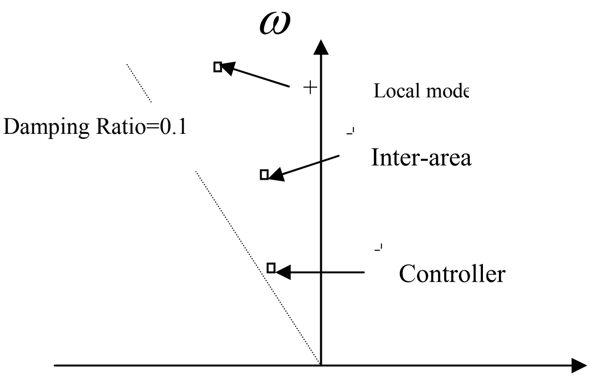



Figure 3. Objective of the optimization-based tuning: +:eigenvalues before the optimization , □: eigenvalues after the optimization

Among the dominant eigenvalues, only those which have a damping ratio less than 0.1 are considered in the optimization.

Hence, it can be seen that the optimal solution, CDI maximizes the total damping ratio of the system for the eigenvalues its damping ratio is the largest one among all $n_c \times n_z$ eigenvaues. In other words, the objective of the optimization is to move the total considered eigenvalues to the negative region, and thus to maximize the damping ratio as much as possible (Figure 3).

## 3.2 Non-linear Optimization Technique

The objective of the parameter optimization can be formulated as a nonlinear programming problem expressed as follows:

$$\begin{aligned} \max . f(Z) = CDI &= \sum_{i=1}^{n_z}\sum_{j=1}^{n_c}\left|\xi_{ij}\right| \\ s.t. \quad E(Z) &= 0 \\ F(Z) &\geq 0 \end{aligned} \qquad (3)$$

where $f(Z)$ is the objective function defined as (2), $Z$ is a vector which consists of the parameters of the PSS's and FACTS controllers that have to be tuned and coordinated. $Z$ can contain the gains of the FACTS controller ($K_{FACTS}$) and those of all PSS controllers ($K_{PSS}$). $E(Z)$ shows the equality constrains and $F(Z)$ shows the inequality constrains. For the proposed method, only the parameter constrains of $Z$, which prevent optimized parameter from reaching unacceptable values, are necessary. The flow chart of the optimization- based simultaneous coordinated tuning algorithm is shown in Figure 4.

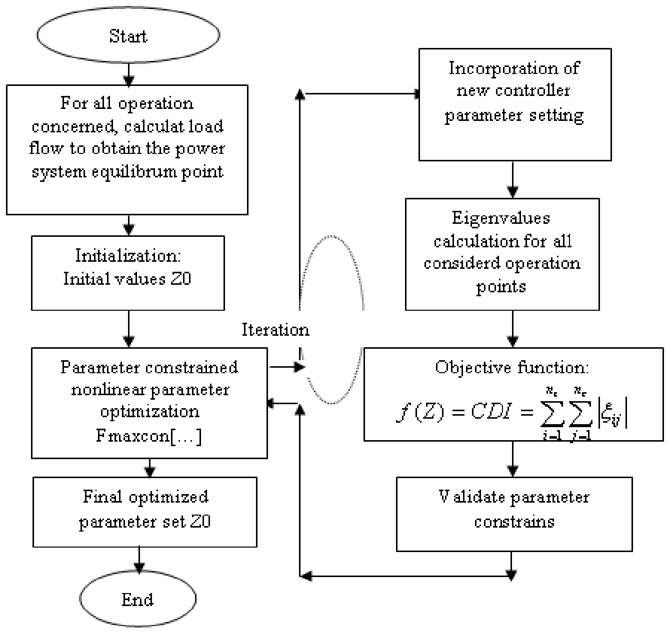



Figure 4. Flowchart of optimization-based coordinated tuning

The optimization starts with the selected one of operating conditions, and initial values of the controllers $Z_0$ is selected. Then the nonlinear algorithm is employed to adjust the parameter iteratively, until the objective function (2) is maximized. The proposed method allows considering several operating conditions of the system.
Therefore the CDI can be calculated for each operating condition successively and gives the best response.
This nonlinear optimization algorithm will converge to an incorrect local optimum if the initial values of the controller parameters are not properly selected. In order to obtain the optimal damping and accomplish

convergence, the initial values $Z_0$ are selected using the conventional sequential tuning method.

# 4 Multimachine Test System

The 8-machine power system with a shunt FACTS device, as shown in Figure 5 , is simulated in this study.
Each generator is described by a six-order model and the shunt FACTS device is simulated using a power-injection model.

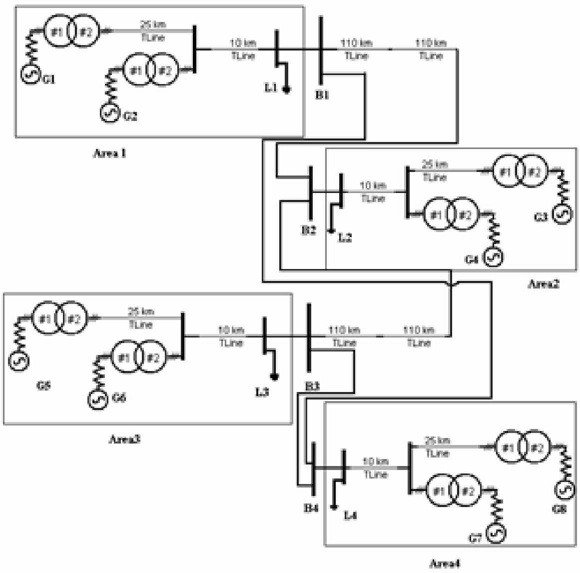



Figure 5. Multi-machine system for test and simulation

By means of the modal analysis, the test system can be divided into four areas.
Shunt FACTS devices are the key devices of the FACTS family. In this research a shunt FACTS device, the static var compensator (SVC) is employed for damping inter-area oscillations. The SVC is located between buses B1 and B2 (on the line between areas 1 and 2).

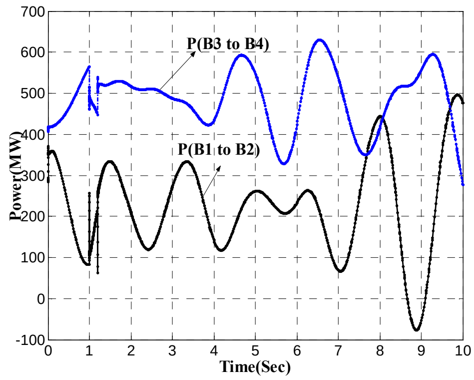
# 5 Simulation Results

To verify the performance of the proposed coordinated tuning method, the algorithm is tested in the multi-machine system shown in Fig7. In this system, all machines are equipped with static exciters and PSS's.
In Practice, in order to achieve the robustness of the coordinated tuning, the controller setting needs to be optimized under different possible operation conditions.
In this study, the test system is simulated: for two disturbances, First, for a disconnection on one of the lines between area1 and area2, then for a large disturbance, a three-phase short circuit of 0.2 s duration at the middle of line1 between area1 and area2.

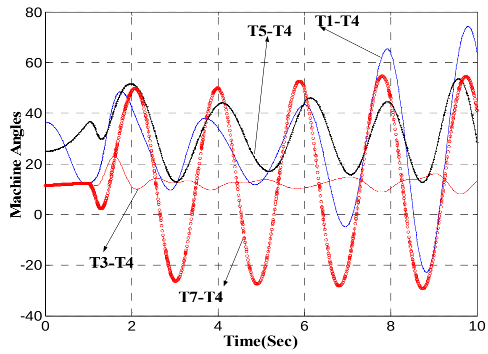
Simulation has done for varies conditions.

## 5.1 The power system without FACTS and PSS controllers

First, the power system is evaluated without FACTS and PSS controllers. As shown in Figure 6, the examined system is unstable.




a) Transfer power between buses




b) Angle of generators

Figure 6. Response of the system without SVC & PSS

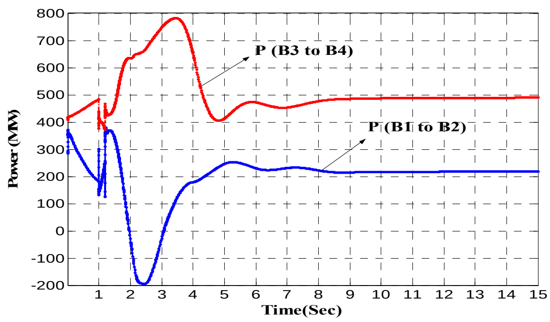
## 5.2 The power system with FACTS and PSS controllers, but by conventional sequential design

After the conventional sequential design of the damping controllers, i.e. without coordinated tuning, the power system becomes stable. This results is shown in Figure 7. However, the damping ratios of some local modes (1.087, 1.117Hz) and some inter-area modes (0.545Hz) are not satisfactory.

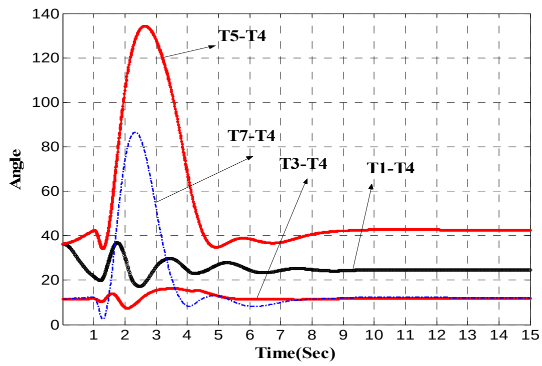
## 5.3 The power system after the coordinated tuning

By applying the coordinated tuning proposed method, as shown in Figure 9, all of the modes (local, inter-area and exciter modes of oscillations) are now well damped. All the damping ratios of dominant modes are more than 5%. The details of controller parameters are given in Appendix A (see table 1 and 2) and the final dominant modes, damping ratios and frequencies are given in Appendix B (see table3).

The nonlinear simulation results validate the proposed coordination method under large disturbance, as shown in Figure 10. It can be seen that in comparison with the conventional sequential tuning, the damping behavior is improved significantly.




a) Transfer power between buses




b) Angle of generators

Figure 7. Response of the system with SVC & PSS, but by conventional tuning

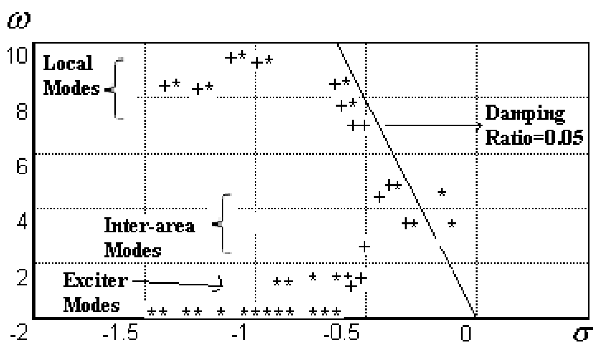
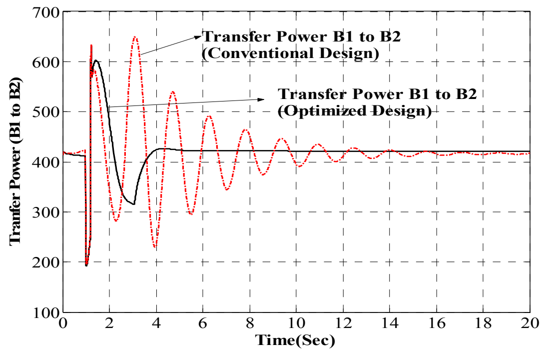
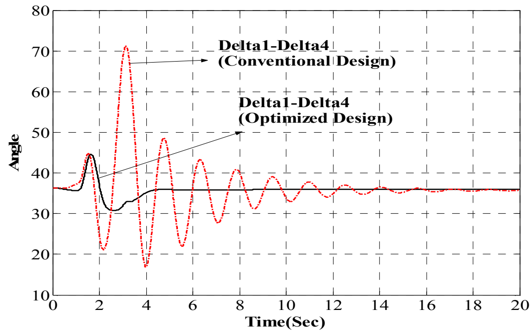



Figure 8. Location change of eigenvalues : * eigenvalues before optimization , + eigenvalues after optimization




a) Transfer power between bus1 & bus2




b) Angle of G1

Figure 9. Nonlinear simulation results (conventional design & optimized design)

## 5 Conclusions

Power system stabilizer (PSS) and flexible ac transmission systems (FACTS) devices are applied to enhance system stability. In multi-machine systems, using only conventional PSS may not provide sufficient damping for inter-area oscillations. In these cases, FACTS power oscillation damping controllers are effective solutions. But uncoordinated local control of FACTS devices and PSS's may cause destabilizing interactions.

In this paper, an optimization algorithm is proposed to optimize the total system performance. By maximizing the objective function the influences of both PSS's and FACTS controllers are improved. Therefore the overall system performance is optimized.

## Reference

[1] M. A. Al-Biati and M. A. El-Kady, "Dynamic Stability Improvement via Coordination of Static Var Compensator and Power System stabilizer Control actions", Elsevier, 2001.

[2] Y. H. Song and A. T. Johns, *Flexible AC Transmission Systems (FACTS)*. London, U.K.: IEE Press, 1999.

[3] N. G. Hingorani and L. Gyugyi, *Understanding FACTS—Concepts and Technology of Flexible AC Transmission Systems*. New York: IEEE Press, 2000.

[4] L. J. Cai and I. Erlich, “Fuzzy coordination of FACTS controllers for damping power system oscillations,” in *Proc. Int. Symp. Modern Electric Power Systems*, Wroclaw, Poland, Sep. 2002, pp. 251–256.
[5] P.Kundur, "Power System Stability and Control", New york 1994.

## APPENDIX A

Table I: Initial and Optimized Parameter of PSS Controllers

| Gen. Num. | Initial Gain | Optimized Gain | *Tw* | *T1n* | *T1d* | *T2n* | *T2d* |
|---|---|---|---|---|---|---|---|
| G1 | 30 | 42 | 10 | 0.08 | 0.01 | 0.08 | 0.01 |
| G2 | 30 | 42 | 10 | 0.08 | 0.01 | 0.08 | 0.01 |
| G3 | 30 | 45 | 10 | 0.06 | 0.02 | 0.06 | 0.02 |
| G4 | 30 | 45 | 10 | 0.06 | 0.02 | 0.06 | 0.02 |
| G5 | 30 | 38 | 10 | 0.05 | 0.02 | 0.05 | 0.02 |
| G6 | 30 | 38 | 10 | 0.05 | 0.02 | 0.05 | 0.02 |
| G7 | 30 | 40 | 10 | 0.03 | 0.01 | 0.03 | 0.01 |
| G8 | 30 | 40 | 10 | 0.03 | 0.01 | 0.03 | 0.01 |

Table II: Optimized Parameter of SVC Controller

| No. | Type | *K1* | *K2* | *Tw* | *T3* | *T4* | *T5* | *T6* |
|---|---|---|---|---|---|---|---|---|
| 1 | SVC | 0.3 | 15 | 10 | 0.54 | 0.76 | 0.35 | 0.03 |

## APPENDIX B

Table III: Some of Dominant oscilation modes

| Type | Eigenvalues With Optimization Design | Freq. | Damping Ratio | |
|---|---|---|---|---|
| | | | Conven. | Optim. |
| Exciter | $-39.89 \pm 0.142i$ | 0.026 | 0.8 | 0.999 |
| | $-40.89 \pm 0.048i$ | 0.0076 | 0.75 | 0.999 |
| Inter-area | $-0.411 \pm 3.43i$ | 0.545 | 0.032 | 0.189 |
| | $-0.315 \pm 3.13i$ | 0.498 | 0.08 | 0.10 |
| | $-0.611 \pm 2.43i$ | 0.387 | 0.123 | 0.275 |
| Local | $0.352 \pm 5.86i$ | 0.933 | 0.063 | 0.0599 |
| | $0.503 \pm 7.06i$ | 1.12 | 0.065 | 0.072 |
| | $0.152 \pm 4.5i$ | 0.716 | 0.056 | 0.053 |
| | $0.452 \pm 4.86i$ | 0.773 | 0.11 | 0.093 |

## ENERJİSİSTEMLƏRİNİN STABİLİZATOR-LARININ DEMPFER NƏZARƏTÇİLƏRİNİN KOORDİNASİYASI VƏ DİNAMİK STABİLLİYİ TƏMİN ETMƏK ÜÇÜN BÖYÜK ENERJİ SİSTEMLƏRDƏ DƏYİŞƏN CƏRƏYANIN ÖTÜRÜLMƏSİNİN ÇEVİK SİSTEMİ

**QAZƏMI A., NƏCƏFI M.**

Enerji sistemlərinin qarşılıqlı əlaqəli sahələrinin rəqslərinin dempfer edilməsi sistemin etibarlı idarə olunması üçün vacib şərtdir. Stabilliyi təmin etmək üçün stabilizatordan və çevik dəyişən cərəyan ötürücü sistemdən istifadə olunmuşdur. Qeyd olunan qurğuların koordinasiyası təmin olunmadıqda rəqsləri kifayət qədər dempferləşdirmək mümkün olur. Məqalədə sistemin dempfer prosesinin optimallaşdırma alqoritmi şərh olunmuşdur. Göstərilmişdir ki, bu üsul böyük enerji sistemlərində multinəzarətçilərin koordinasiya olunmasına effektiv üsul ola bilər.

## КООРДИНАЦИЯ ДЕМПФИРУЮЩИХ КОНТ-РОЛЛЕРОВ СТАБИЛИЗАТОРА ЭНЕРГОСИС-ТЕМЫ И ГИБКОЙ СИСТЕМЫ ПЕРЕДАЧИ ПЕРЕМЕННОГО ТОКА В БОЛЬШИХ ЭНЕР-ГЕТИЧЕСКИХ СИСТЕМАХ ДЛЯ УЛУЧШЕ-НИЯ ДИНАМИЧЕСКОЙ СТАБИЛЬНОСТИ

**КАЗЕМИ А., НАДЖАФИ М.**

Демпфирование колебаний энергетической системы между взаимосвязанными областями необходимо для надежного управления системой. Для увеличения стабильности системы используются стабилизатор системы и гибкая система передачи переменного тока. Но при не координированном использовании указанных устройств не обеспечивается достаточное демпфирование колебаний. В статье описан алгоритм оптимизации процесса демпфирования системы. Показано, что метод может быть эффективным для координирования мультиконт-роллеров в больших энергетических системах.