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Based on Oscillation Energy Analysis Design of TCSC Damping Controller

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ABSTRACT

In this paper of TCSC damping controller, we are going to provide an idea on oscillation energy analysis of inter-area type oscillation for the study of inter area power oscillations and their effective destruction. The advanced oscillation energy role in this paper can interpret inter-area mode oscillations as a continuous process of conversion between oscillation kinetic energy and potential energy. A scheme of consuming oscillation energy has been developed to design the TCSC damping controller to minimize inter-area mode oscillations. For implementation of the control scheme, only active power flow along the tie line where the TCSC is installed is taken as feedback signal of the TCSC damping controller. It is presented in the paper that in order to develop the performance of the damping controller, the control gain is adjusted practically according to the magnitude of system oscillations. We have presented this paper to show the effectiveness and robustness of TCSC damping controller in a large inter connected power system.

Keywords: adaptive control, TCSC, immune feedback,inter-area mode oscillation, power system dynamic stability.

I. INTRODUCTION

Power System Stabilizer (PSS) is being widely used todampen power system oscillations and increase systemstability since it is economical and effective. With thequick development of Flexible AC Transmission System(FACTS), FACTS-based stabilizers offer an alternative wayin damping oscillations.The primary purpose of application of a thyristorcontrolled series compensator (TCSC) is to control powerflow along transmission line and to increase transmissioncapacity. In addition, it can suppress power systemoscillations if a damping control function is added, especiallyfor loosely connected power systems. The controlstrategy of TCSC to suppress oscillations has been studied and researched in the recent years [1]-[3]. Some arebased on linear model of power systems and damping torqueanalysis [1] [2]. These control schemes require detailedinformation about data and configuration of systems for thedesign of TCSC damping controllers including control schemeusing fixed control parameters [3]. However, the nature ofhigh nonlinearity of power systems and irregular changes inoperating conditions might bring in certain difficulties forthe designed TCSC damping controllers to providesatisfactory damping performance. The primary objective is toensure robustness of the damping controller to variableoperating conditions and non-linearity of power systems.

Concept of oscillation energy has been proposed in [4] forthe design of a TCSC damping controller that proves to beeffective in suppressing power system oscillations in spite of details of power system data and configuration beingunknown. This paper further explores the ideas proposed in [4], starting with the field of inter-area mode oscillation energyanalysis. A scheme of energyconsuming is proposed todesign a TCSC controller to damp inter-area modeoscillations. Oscillation suppression is implemented bycontinuously reducing the oscillation energy. The immunefeedback mechanism is applied to tune the gain of thecontroller adaptively.Case studies in a large interconnected system are presentedin the paper to show the advantages of the adjusted-gainadaptivecontroller in damping power oscillations. Thesatisfactory performance of the

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TCSC controllerdemonstrates that the proposed control scheme based onoscillation energy consuming is effective in designs ofFACTS based damping controllers.

II. OSCILLATION ENERGY ANALYSIS

In this section, we use oscillation energy analysis toexplain why and how an inter-area oscillation can be dampedby a TCSC damping controller installed in a power system.Following a short fault in the power system, the excess ofkinetic energy and potential energy as well as their sum(excess system transient energy) increases from zero until the fault has been cleared. The system excess transient energy indicatesthe extent of the oscillation in the power system. After the fault removal, it is a process of non-stop exchanges ofenergy between kinetic energy and potential energy. Withoutdamping, the total transient energy will remain constant andthe system will oscillate. During one cycle of oscillation,kinetic energy and potential energy are converted into eachother. Therefore, the oscillation is a process of periodicalconversion between kinetic energy and potential energy. Inorder to consume the overall excess of oscillation energy, it isan effective way to minimize the energy exchange rate duringoscillation. That is, to maximize the energy decreased inkinetic energy while the excess potential energy increases,and to minimize the energy increased in excess kinetic energywhile the excess potential energy decreases.

Considering the above, a method to enhance power systemdamping by the TCSC can be developed. With the operationof TCSC, the equivalent system network capacitance ischanged, and the excess oscillation energy is consumedcontinuously. The idea is to minimize the energy transfer rateso that the total oscillation energy is reduced and theoscillation is suppressed.

III. CONTROL STRATEGY

In this section, we take a two-area system as an example toexplain inter-area oscillation energy and TCSC controlstrategy to damp the inter-area oscillation.

(A) Inter-area mode oscillation energy

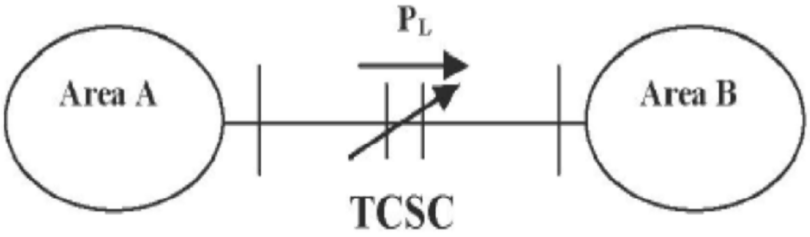


Figure 1: Two-area power system with TCSC

A two-area power system with a TCSC installed in middle of the tie line is shown in Fig. 1. The relative dynamic motion between the centres of inertia (COIs) of area A and B can be described by the following equations:

$$\omega_{AB} = (1/M_A)\,(P_A - P_L) - (1/M_B)\,(P_B + P_L)t\ P \tag{1}$$

$$\ddot{Y}_{AB} = \omega_{AB} \tag{2}$$

P_A and P_B denotes the total power generation and consumption in two areas.P_L the power flow along the transmission line. M_A and $M_B$represent the inertial constants of two COIs.

Wedefine V_{KE} as the excess kinetic energy, and V_{PE} as the excesspotential energy stored in the machines and the network:

For one swing cycle, we mark the start moment as t_1 and theend time t_2. Without damping, the total oscillation energy atboth moments is equal, that is:

$$V_{KE}(t_1) + V_{PE}(t_1) = V_{KE}(t_2) + V_{PE}(t_2) = \text{constant}$$

By modulating TCSC, the equivalent reactance of tie linecan be changed.

B. Control strategy ofTCSC

By ignoring the loss of the tie line, we have:

$$P_L= U_A U_B \sin Ÿ_{AB}/x+Äx \tag{5}$$

U_A and U_B are the terminal voltage of two areasrespectively, X is the original reactance of the tie line, and “X denotes reactance increment due to TCSC dampingcontrol function, from (5) we can see that P_L will increasewhen”X is less than zero or decrease when “X is greater than zero.

IV. DESIGN OF TCSC DAMPING CONTROLLER BASED ON IMMUNE FEEDBACK

(A) Control scheme

During the first swing cycle, the capacitance of TCSC isset to just about its maximum when relative speed is negative, and set to its minimum when it is positive.It makes more full use of the available capability of seriescompensator to avoid first swing instability.

To meet the various requirements that occur duringdifferent phases of power oscillations and achieve a quickdamping of inter-area mode oscillation, the magnitude of X+”X can be modulated by the immune feedback mechanism. After the first swing cycle, the gain of TCSC dampingcontroller is adjusted adaptively online. That is, the controlgain can either increase or decrease according to currentdamping effect of the controller. This overcomes thedrawback of conventional fixed-gain control schemes that thedamping effect becomes less effective due to excessive orunnecessary control actions[10]. Since the proposed methodguarantees the continuous descent of oscillation energy, theTCSC damping controller is robust to the variations ofoperating conditions.

(B) Immune feedback mechanism

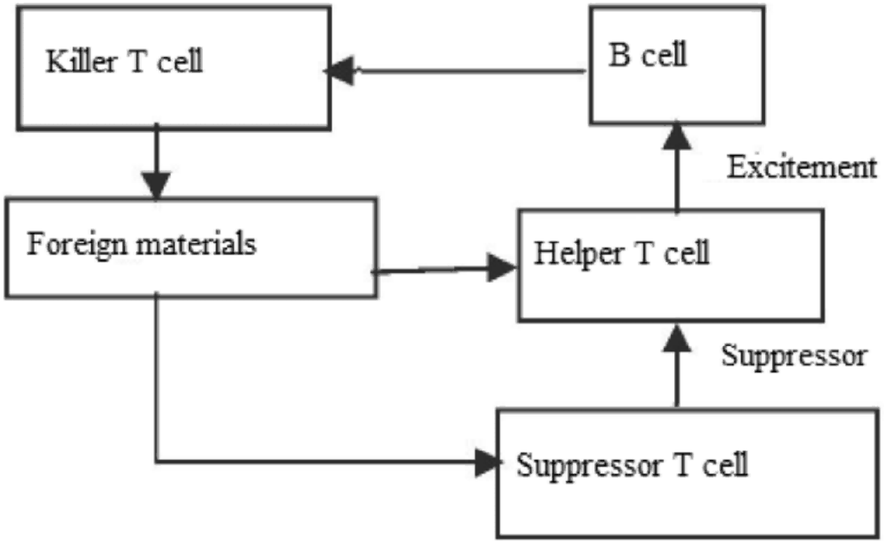


Figure 2: Immune feedback mechanism

Biologically motivated information processing systemsinclude neural network, evolutionary algorithms, andartificial immune systems [7]. The natural immune systemis a very complex system fordefence against pathogenicorganisms. From an information processing perspective, theimmune system is a remarkable parallel and distributedadaptive system. It also has learning, memory, and patternrecognition abilities.

An immune feedback mechanism simultaneously performstwo tasks: it rapidly responds to foreign materials and stabilizes the immune system. After the foreignmaterials (antigens, germ cells, or cells infected, by viruses)are digested by antigen presenting cells (APCs), the APCstransfer information about the antigen to helper T cells,activating the helper T cells, the killer T cells, and thesuppressor T cells. This regulation by activated, B cells andkiller T cells is considered to be the main feedbackmechanism of the immune system. The suppressor T cells arean inhibitive mechanism. The helper T cells and the foreignmaterials activate the suppressor T cells, and the suppressor Tcells inhibit the activities of all other cells, i.e., the helper Tcells, the B cells, and the killer T cells. This is anotherfeedback mechanism in theimmune system. This cooperationbetween the inhibitive mechanism and, the main feedbackmechanism enables the immune feedback mechanism torapidly respond to foreign materials and to quickly stabilizethe immune system.

We define the amount of foreign materials at the kthgeneration as u(k). The output from the helper T cellsstimulated by the foreign materials is defined as

$$T_h(k) = k_1\, u(k) \tag{6}$$

K_1 is a positive stimulation factor. The effect of thesuppress T cells on the Bcells is given by

$$T_s(k) = k_2 f\{u(k)/u(k-1)\}u(k) \tag{7}$$

k_2 is a positive suppression factor. f is a nonlinear functionintroduced to take account of the effect of the reactionbetween the killer T cells and the foreign materials.

$$f(x) = \exp(-x^2) \tag{8}$$

The output of function f is limited within the interval [O, 1].

The total stimulation received by the B cells is

$$\begin{aligned} y(k) &= T_h(k) - T_s(k) \\ &=[k_1 - k_2 f\{u(k)/u(k-1)\}]u(k) = g\,u(k) \end{aligned} \tag{9}$$

Formula (6) denotes the main feedback mechanism of theimmune system, and, (7) stands for the inhibitive feedbackmechanism. Parameter k controls the response speed.Parameter k_2 and function f control the stabilization effect.From (9), the total gain factor is tuned at any momentaccording to immune effect.

(C) Design of TCSC controller

Measurement of the active power flow along the tie linewhere TCSC is installed is used as feedback signal. Itsintegral denotes the speed difference. We treat the difference of the maximum and the minimum of P_L between two sample times as foreign materials u (k), and TCSC control output asthe amount of killer cells y(k).

V. SIMULATION RESULTS

The control strategy, as described above, is tested in an example power system shown by Fig.3.

As is shown in Fig. 3, 4-machine 2-area system is connected with infinite bus through tie line. The two-area system can be assumed as a subsystem of a large interconnected power system. TCSC is installed at the centre of the subsystem tie line.

With the help of time-domain simulations, the discussed approach is applied in the multi-machine power system to amplify the damping of inter-area oscillation mode. The tie line between infinite system

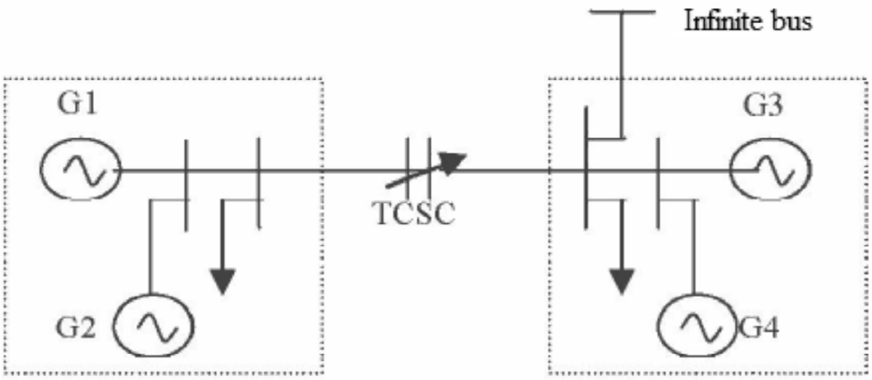


Figure 3: Test system

and subsystem is opened, at 1st to simulate disaggregation of the system under some emergency conditions. As the configuration of the power system has suddenly changed, there is a large disturbance in the subsystem.

To test the effect of the adaptive immune TCSC damping controller, three cases are used to compare the effect of the controllers: 1) without TCSC damping control, only PSS are included in the system; 2) with a fixed-gain phase compensation TCSC damping controller; and 3) with the proposed adaptive immune TCSC damping controller.Machine rotor angle difference and active power flow along the tie line of subsystem are shown as given below respectively.

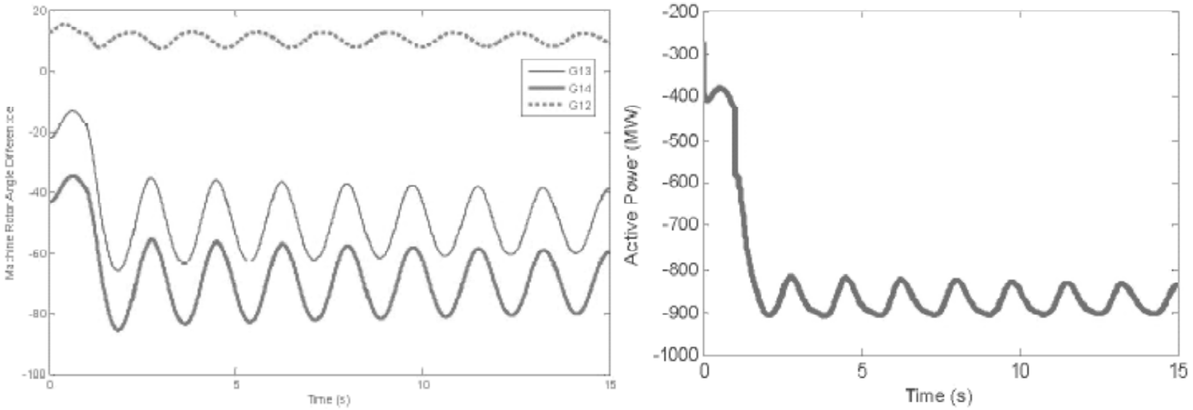


Figure 4: Simulation result of case 1

As is shown in Fig. 4, PSS is designed considering the topology structure before disaggregating. We can see that it is unable to reduce oscillation under such a highly stressed, condition.

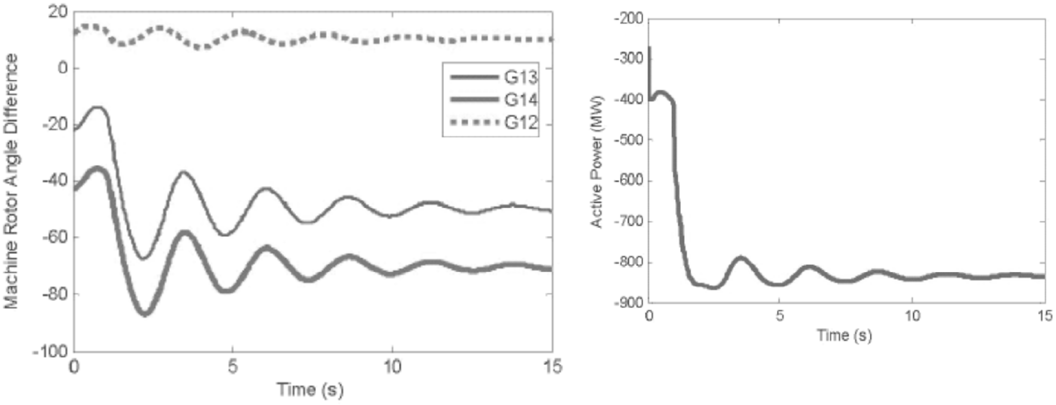
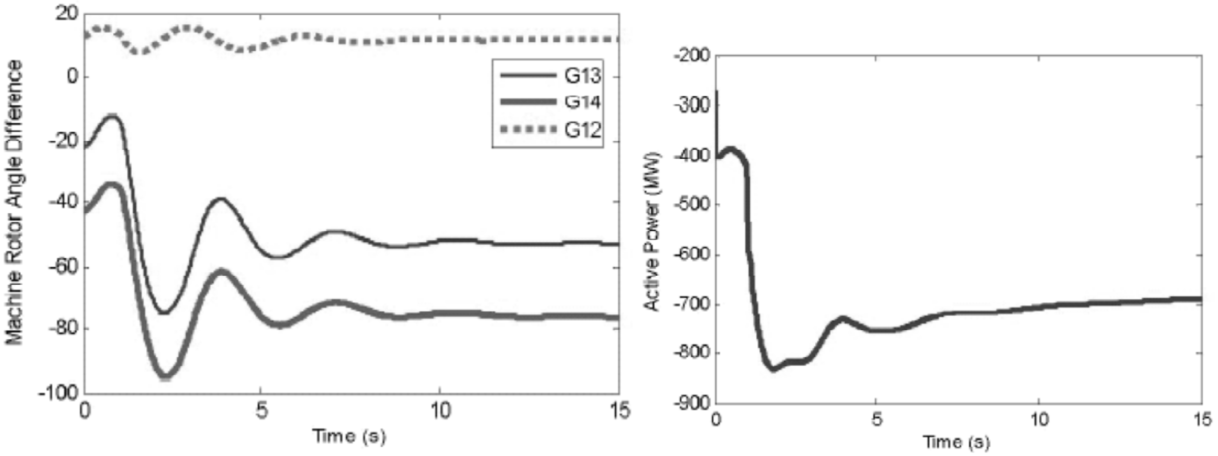


Figure 5: Simulation result of case 2

From Fig. 5, we can see that the fixed-parameter phasecompensation TCSC can provide damping for inter-areaoscillation. But as it is based on exact linear model and withfixed control parameters, it has its limitation in dealing withthe change of system configuration and operating conditions. Therefore it reduces the oscillation slowly. Now the signals are damped.



In Fig. 6, when a TCSC with the proposed controlapproach is placed, it improves the damping effectively andthe oscillation is suppressed quickly

VI. CONCLUSIONS

This paper presents a new scheme of designing anadaptive immune. TCSC damping controller to reduce interareamode oscillation based on oscillation energy analysis.The regulation of TCSC is calculated by the power deviationon the tie line where it is installed. The control gain isadaptively tuned on line by immune feedback mechanism. The advantage of this presented control scheme is that nodetailed information about data and configuration of powersystems is required in the design of the TCSC dampingcontroller. To implement the control strategy, only thetransmission power of tie line where TCSC is installed isrequired.

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