Designing an adaptive stabilizer for UPFC

[a]Mehdi Nikzad, [b]Shoorangiz Shams Shamsabad Farahani, [c]Habib Daryabad, [d]Hamed Sarbazi

[a, b] Department of Electrical Engineering, Islamshahr Branch, Islamic Azad University, Tehran, Iran
[c, d] Sama Technical and Vocational Training College, Islamic Azad University, Islamshahr Branch, Islamic Azad University, Tehran, Iran

Abstract: In this paper an adaptive method is used to design UPFC supplementary stabilizer for damping low frequency oscillations in a multi machine power system. The proposed method is evaluated against a classical stabilizer tuned by using genetic algorithms (GA). Nonlinear simulation results demonstrate the effectiveness of the proposed adaptive method to deal with uncertainties in power system.

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1. Introduction

Low frequency oscillations in the range of 0.1 Hz to 3.0 Hz are frequently encountered in an interconnected power system and usually occur during and after a small or large disturbance. These oscillations either decay gradually, or continue to grow causing system separation [1]. Low frequency oscillations are due to lack of damping of the electromechanical mode of the interconnected power system. Secure operation of the system thus requires application of damping controllers to control such oscillations. Such unstable oscillations of the rotor can be suppressed by controlling excitation system using auxiliary stabilizing signal. Power system stabilizers (PSSs) have been widely used in practice to enhance the damping of such oscillations [2-11]. However, this device e may not produce adequate damping during some operating conditions.

Now-a-days, flexible AC transmission system (FACTS) devices have been proved to be one of the most effective ways to improve power system operation controllability and power transfer limits. With the application of FACTS technology, power flow along transmission lines can be more flexible controlled. UPFC can provide simultaneous & independent control of important power system parameters: line active power flow, line reactive power flow, impedance and voltage. A UPFC performs this through the control of the in-phase voltage, quadratic voltage, and shunt compensation. Several attempts have been reported in the literature regarding the application of a UPFC for effective damping of power system low frequency oscillations [12-19]

In order to obtaining a good performance, it is necessary to design a appropriate controller for UPFC. Conventional controllers do not guarantee good performance over entire range of operating conditions. Thus, application of adaptive method to overcome the system uncertainties may be more suitable. Adaptive control techniques guarantee robust performance and robust stability, in the presence of uncertainties.

In this paper a stabilizer is designed based on UPFC. The proposed stabilizer is design by using model reference adaptive system method. The proposed adaptive stabilizer systematically deals with system uncertainties. The proposed method is evaluated against a classical stabilizer tuned by GA in a multi machine power system as case study. The nonlinear time domain simulation results show the ability of the proposed adaptive stabilizer in damping oscillations.

2. Model Reference Adaptive System

The general idea behind Model Reference Adaptive Control (MRAC) or Model Reference Adaptive System (MRAS) is to create a closed loop controller with parameters that can be updated to change the response of the system. The output of the system is compared to a desired response from a reference model. The control parameters are update based on this error. The goal is for the parameters to converge to ideal values that cause the plant response to match the response of the reference model. Figure 1 shows the general diagram of MRAS [20].

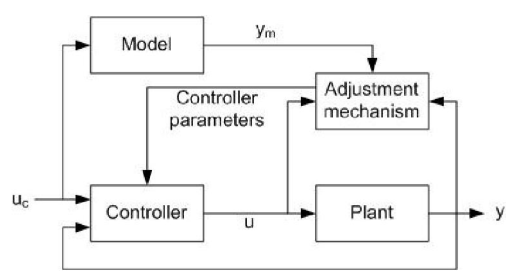

Figure 1: General diagram of MRAS

The idea behind MRAS is to create a closed loop controller with parameters that can be updated to change the response of the system to match a desired model. There are many different methods for designing such a controller. This tutorial will cover design using the MIT rule in continuous time. When designing an MRAS using the MIT rule, the designer chooses: the reference model, the controller structure and the tuning gains for the adjustment mechanism. MRAS begins by defining the tracking error, *e*. This is simply the difference between the plant output and the reference model output [20]:

$$e = y_{plant} - y_{model} \tag{1}$$

From this error a cost function of *theta* (*J(Θ)*) can be formed. *J* is given as a function of theta, with theta being the parameter that will be adapted inside the controller. The choice of this cost function will later determine how the parameters are updated. Below, a typical cost function is displayed.

$$J(\theta) = \frac{1}{2} e^2(\theta) \tag{2}$$

To find out how to update the parameter *theta*, an equation needs to be formed for the change in *theta*. If the goal is to minimize this cost related to the error, it is sensible to move in the direction of the negative gradient of *J*. This change in *J* is assumed to be proportional to the change in *theta*. Thus, the derivative of *theta* is equal to the negative change in *J*. The result for the cost function chosen above is:

$$\frac{d\theta}{dt} = -\gamma \frac{\delta J}{\delta \theta} = -\gamma e \frac{\delta e}{\delta \theta} \tag{3}$$

This relationship between the change in theta and the cost function is known as the MIT rule. The MIT rule is central to adaptive nature of the controller. Note the term pointed out in the equation above labeled "sensitivity derivative". This term is the partial derivative of the error with respect to *theta*. This determines how the parameter *theta* will be updated. A controller may contain several different parameters that require updating. Some may be acting n the input. Others may be acting on the output. The sensitivity derivative would need to be calculated for each of these parameters. The choice above leads to all of the sensitivity derivatives being multiplied by the error. Another example is shown below to contrast the effect of the choice of cost function:

$$J(\theta) = |e(\theta)|$$

$$\frac{d\theta}{dt} = -\gamma \frac{\delta e}{\delta \theta_c} sign(e)$$

$$where \tag{4}$$

$$sign(e) = \begin{cases} 1, & e > 0 \\ 0 & e = 0 \\ -1 & e < 0 \end{cases}$$

To see how the MIT rule can be used to form an adaptive controller, consider a system with an adaptive feed word gain. The block diagram is given as Figure 2. The plant model can be given as (5).

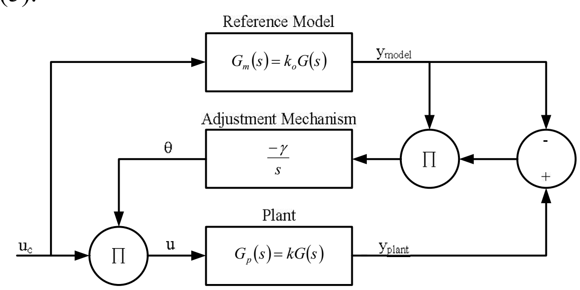

Figure 2: Adaptive feed forward gain

$$\frac{Y(s)}{U(s)} = kG(s) \tag{5}$$

The constant *k* for this plant is unknown. However, a reference model can be formed with a desired value of *k*, and through adaptation of a feed forward gain, the response of the plant can be made to match this model. The reference model is therefore chosen as the plant multiplied by a desired constant *ko*:

$$\frac{Y(s)}{U_c(s)} = k_o G(s) \tag{6}$$

The same cost function as above is chosen and the derivative is shown:

$$J(\theta) = \frac{1}{2} e^2(\theta) \rightarrow \frac{d\theta}{dt} = -\gamma e \frac{\delta e}{\delta \theta} \tag{7}$$

The error is then restated in terms of the transfer functions multiplied by their inputs.

$$e = y - y_m = kGU - G_m U_c = kG\theta U_c - k_o G U_c \tag{8}$$

As can be seen, this expression for the error contains the parameter *theta* which is to be updated. To determine the update rule, the sensitivity derivative is calculated and restated in terms of the model output:

$$\frac{\delta e}{\delta\theta} = kGU_c = \frac{k}{k_o} y_m \quad (9)$$

Finally, the MIT rule is applied to give an expression for updating *theta*. The constants *k* and *ko* are combined into *gamma*.

$$\frac{d\theta}{dt} = \gamma' \frac{k}{k_o} y_m e = -\gamma y_m e \quad (10)$$

The block diagram for this system is the same as the diagram given in Figure 2. To tune this system, the values of *ko* and *gamma* can be varied [20].

3. Designing UPFC stabilizer

3.1. Test system

Figure 3 shows a multi machine power system installed with UPFC. The system data can be found in [1]. The UPFC is assumed to be based on Pulse Width Modulation (PWM) converters. To assess the effectiveness and robustness of the proposed method over a wide range of loading conditions, three different loading conditions are considered and listed in Table 1.

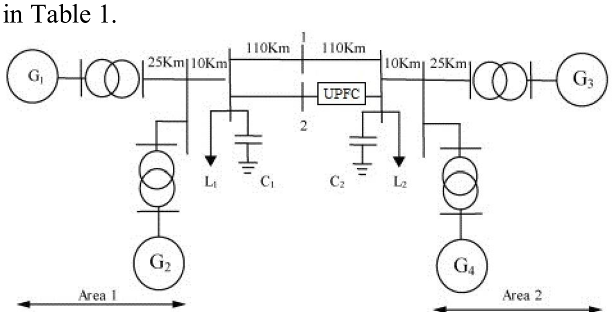

Figure 3: Four-machine eleven-bus power system

Table 1 - System loading conditions

Load	P	Q
	Light	
A	17.6258	-2.1000
B	9.64580	-0.8400
	Nominal	
A	18.5535	-2.625
B	10.1535	-1.050
	Heavy	
A	20.4089	-2.630
B	11.1689	-1.055

3.2. Adaptive stabilizer design

To get a suitable performance and tracking characteristics, a reference model should be defined for MRAS system. In this paper, since the UPFC supplementary stabilizer is a regulatory controller, thus, the reference model should have a regulatory nature. In this regard, the reference model is defined as below;

$$y = \frac{0.01s(s+1)}{s^2 + 3s + 1} u \quad (11)$$

3.3. classic stabilizer design

In order to comparison, a conventional stabilizer is designed based on UPFC. The transfer function model of a conventional stabilizer is as (12). This model contains two lead–lag compensators with time constants, T_1–T_4 and an additional gain K_{DC}. The parameters of the proposed stabilizer are tuned by using GA. The detailed procedure of stabilizer design based on UPFC by using optimization methods can be found in [17]. The proposed stabilizer is obtained as shown in table 2.

$$U_{out} = K_{DC} \frac{ST_W}{1+ST_W} \frac{1+ST_1}{1+ST_2} \frac{1+ST_3}{1+ST_4} \Delta\omega \quad (12)$$

Table 2: Optimal parameters of conventional stabilizer

Parameter	K_{DC}	T_1	T_2	T_3	T_4
Optimal value	1.55	0.17	0.01	0.88	0.01

4. Results and discussions

The simulations are carried out on the proposed test system. To evaluate the system performance under large disturbances, a three phase short circuit is assumed at bus 6 with 10-cycles duration. An index is defined to assess the performance of the proposed methods. This index is the Integral of the Time multiplied Absolute value of the Error (*ITAE*).

$$ITAE = \int_0^t t|\Delta\omega_1|dt + \int_0^t t|\Delta\omega_2|dt + \int_0^t t|\Delta\omega_3|dt + \int_0^t t|\Delta\omega_4|dt \quad (13)$$

The ITAE is calculated in all operating for both the proposed stabilizers and results are listed in Table 3. It is seen that the adaptive stabilizer performs better than conventional stabilizer at all operating conditions.

Table 3: The ITAE index

	MRAS	GA
Nominal operating condition	0.1413	0.2072
Heavy operating condition	0.1458	0.2099
Light operating condition	0.1451	0.2090

The simulation results following defined disturbance are also presented in Figures 4-7. The simulation results show that applying the supplementary stabilizer signal greatly enhances the damping of the generator angle oscillations. The results clearly show that in large electric power systems, UPFC supplementary stabilize can successfully increase damping of power system oscillations. The adaptive stabilizer has better performance than conventional stabilizer and the results clearly validate the adaptive method.

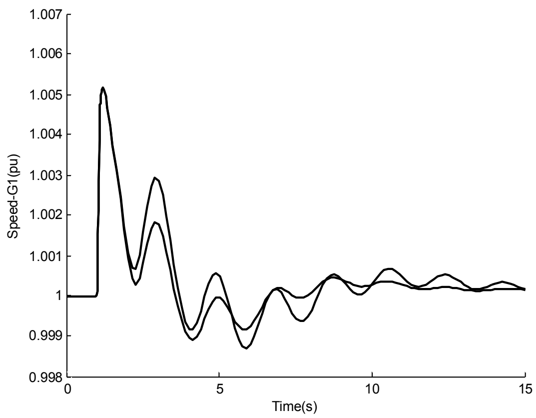

Figure 4: Speed G_1 in the nominal operating condition (Solid: MRAS, Dashed: GA)

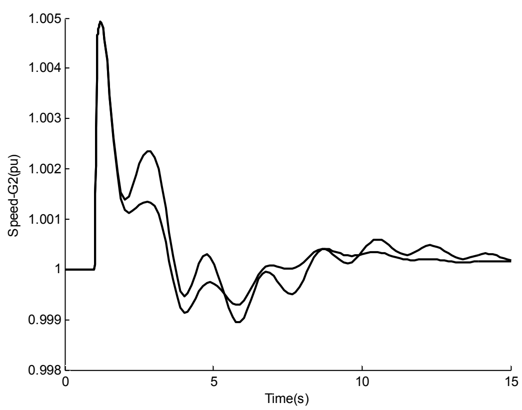

Figure 5: Speed G_2 in the nominal operating condition (Solid: MRAS, Dashed: GA)

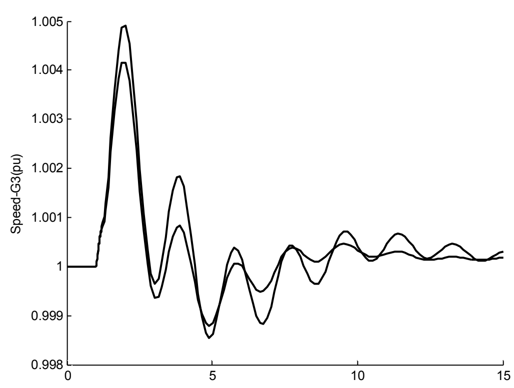

Figure 6: Speed G_3 in the nominal operating condition (Solid: MRAS, Dashed: GA)

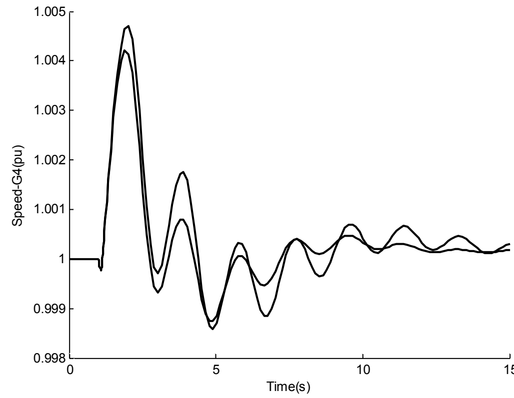

Figure 7: Speed G_4 in the nominal operating condition (Solid: MRAS, Dashed: GA)

5. Conclusions

In this paper dynamic stability of a multi machine electric power system has been successfully improved by using UPFC supplementary stabilizer. The proposed UPFC supplementary stabilizer is designed based on an adaptive method. The proposed method was compared with a conventional stabilizer and showed a better performance. The simulation results on a multi machine electric power system demonstrated that UPFC supplementary stabilizer can greatly enhance damping of power system oscillations in large electric power systems.

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