SELF-TUNING STABILIZERS BASED ON POLE ASSIGNMENT FOR MULTIMACHINE POWER SYSTEMS

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ABSTRACT – The application of Self-Tuning controllers as Power System Stabilizers in multimachine power systems is considered. The choices of the control and identification strategies are based on the analysis of the properties of multimachine power systems. Such analysis points to the use of the Extended Least-Squares algorithm for the identification and a partial Pole Assignment control strategy. The resulting adaptive control algorithm is applied to the New England test system. The simulation results show the good performance achieved with the proposed control scheme and its tracking capability.

1 INTRODUCTION

Power System Stabilizers (PSS's) are the most usual way to enhance the dynamic stability of Power Systems (PS's). A PSS design is usually carried out by means of classical control methods such as frequency response and root-locus techniques applied to a linearized model of the system around some selected operating point. However, the system may be demanded to operate under conditions very dissimilar to those the PSS was designed for, thus degrading its performance. Although PSS's designed in this fashion have been successfully applied by the electrical industry since the early 1970's, the increasingly stressed conditions in which current PS's are required to operate demand increasing performance from PS's controllers. The application of methods to guarantee PSS's performance in a wider variety of conditions, thus enlarging the PS stability margins, is therefore much in order. The ability of an adaptive controller to automatically and continuously tune itself makes it attractive for application to PSS's units. On the other hand, the recent application of digital PSS's has opened new avenues for applying innovative control strategies for PSS's design(Bollinger *et alii* 1993).

The application of the adaptive control theory to PSS's design has been given a great deal of attention in the literature since the late 70's(Irving *et alii* 1979, Pierre 1987). Most publications explore the use of explicit *Self-Tuning* (ST) regulators in PSS applications(Barreiros 1989, Chandra *et alii* 1988, Chen *et alii* 1993, Fan *et alii* 1990, Bazanella e Silva 1995, Bazanella e Silva 1995a). A Self-Tuning PSS (STPSS) tunes its parameters in real-time as the system operating condition drifts with daily load variations, generating rescheduling and topological changes due to contingencies. Such explicit ST controllers are the combination of a recursive identification method and the online tuning of the controller parameters according to some control strategy(Aström and Wittenmark. 1989). The least-squares estimator has been used as the identification algorithm in most applications, due to its simplicity and fast convergence. As for the control strategy, a variety of methods has been proposed, including Linear Quadratic Regulators, Generalized Minimum Variance Control and *Pole Assignment*. Simulation results provided in the aformentioned papers show the effectiveness of the STPSS's in a variety of conditions, in contrast to the conventional PSS design whose performance is degraded by changes in the PS operating condition. Numerous results for single machine against infinite busbar systems have been presented. A few multimachine systems applications have been provided as well, although the problems raised by the multimachine condition have not always been taken into account in a systematic fashion. Later publications describe the implementation of STPSS's in real systems(Norum and Bollinger 1993, Malik and Mao. 1993).

In this paper the use of Pole Assignment in STPSS's is discussed first on an analytical ground and then based on a case study. A new Self-Tuning Pole Assignment PSS is presented. The proposed controller presents novel ideas both in the control and the identification methods. These novelties are motivated by specific multimachine considerations. Besides that, the interaction between identification and control in the Self-Tuning algorithm is explicitly taken into account in the design and discussed on an analytical ground, which is an issue that does not seem to appear in previous papers.

The paper is organized as follows. In Section 2, the identification method is described and discussed. The use of the Extended Least Squares method is proposed to improve the identification in multimachine systems. The Pole Assignment control method is presented in Section 3. A particular policy for choosing the closed-loop poles in the Pole Assignment design is proposed in Section 4. This policy aims at obtaining a good trade-off between regulation performance on one side and tracking capability and control effort on the other, which is done by exploring the peculiarities of power systems dynamic behavior. Simulation results of a benchmark multimachine Power System with

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the application of the proposed Self-Tuning, Pole Assignment based PSS are presented in Section 5. These results show the good performance of the control scheme and support the claims of the preceding sections. Finally, in Section 6, the conclusions are given.

2 IDENTIFICATION

2.1 System model

The system is modeled by a stochastic sampled-data model whose exogenous input is the supplementary signal to the Automatic Voltage Regulator. The output is the signal to be fed back by the PSS, which can be the shaft speed or the accelerating power, for instance. Let T be the sampling period, $y(n)$ and $u(n)$ be respectively the values of the output and the input at time $t = nT$. The model can be written as

$$A'(q^{-1})y(n) = q^{-1}B'(q^{-1})u(n) + C(q^{-1})e(n) \qquad (1)$$

where q^{-1} is the backward difference operator defined by $q^{-1}y(n) = y(n-1)$,

$$\begin{aligned} A'(q^{-1}) &= 1 + a_1 q^{-1} + \ldots a_{n_a} q^{-n_a} \\ B'(q^{-1}) &= b_0 + b_1 q^{-1} + \ldots + b_{n_b} q^{-n_b} \\ C(q^{-1}) &= 1 + c_1 q^{-1} + \ldots + c_{n_c} q^{-n_c} \end{aligned}$$

and $e(n)$ is a zero mean uncorrelated random sequence.

2.2 Extended recursive least-squares

Let the process be described by (1). Then the output at $t = nT$ is given by

$$\begin{aligned} y(n) = & -a_1 y(n-1) - \ldots - a_{n_a} y(n-n_a) + \\ & b_0 u(n-1) + \ldots + b_{n_b} u(n-1-n_b) + \\ & e(n) + \ldots + c_{n_c} e(n-n_c) \end{aligned} \qquad (2)$$

The model (2) can be approximated by a pseudo linear regressor model

$$y(n) = \theta' \varphi(n)$$

where the parameter vector θ and the regressor vector φ are defined as

$$\theta \triangleq [\ a_1 \quad \ldots \quad a_n \quad b_0 \quad \ldots \quad b_{n_b} \quad c_0 \quad \ldots \quad c_{n_c}\ ]'$$

$$\begin{aligned} \varphi(n) &\triangleq [\ \varphi_1'(n) \quad \varphi_2'(n) \quad \varphi_3'(n)\ ]' \\ \varphi_1(n) &\triangleq [\ -y(n-1) \quad \ldots \quad -y(n-n_a)\ ]' \\ \varphi_2(n) &\triangleq [\ u(n-1) \quad \ldots \quad u(n-n_b-1)\ ]' \\ \varphi_3(n) &\triangleq [\ \hat{e}(n) \quad \ldots \quad \hat{e}(n-n_c)\ ]' \end{aligned}$$

with

$$\hat{e}(n) \triangleq y(n) - \hat{\theta}'(n)\varphi(n)$$

where $\hat{\theta}(n)$ is the estimate of the parameter vector θ at time $t = nT$. These estimates are obtained recursively from

$$\begin{aligned} \hat{\theta}(n) &= \hat{\theta}(n-1) + K(n)(y(n) - \varphi'(n)\hat{\theta}(n-1)) \\ P(n) &= (I - K(n)\varphi(n))\frac{P(n-1)}{\lambda} \end{aligned}$$

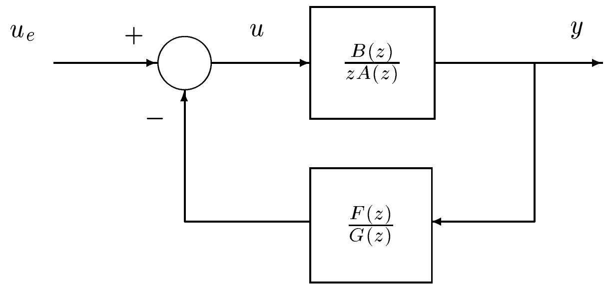

Figure 1: Block diagram of the control structure

where I is the identity matrix, λ is a real number belonging to the interval $[0,1]$ and the following definitions have been used:

$$\begin{aligned} \Phi(n) &\triangleq \begin{bmatrix} \varphi'(0) \\ \vdots \\ \varphi'(n) \end{bmatrix} \\ P(n) &\triangleq \Phi'(n)\Phi(n) \\ K(n) &\triangleq P(n-1)\varphi'(n) \end{aligned}$$

By setting $n_c = 0$ in the identification model (1) the ordinary Least-Squares (OLS) method is obtained. It is known that the estimates obtained with the ordinary Least-Squares method are biased when the noise $e(n)$ entering the system is not white. Although this method has been used in most PSS applications with good results, this biasing is expected to be larger in multimachine systems. Indeed, the effect of the noise should be more significant in a multimachine system than in single-machine, since there are more sources of noise. Moreover, there is the "under-modeling noise", which is not a major concern in sigle machine systems because in this case the order of the actual system is close to that of the model. Indeed, the use of Extended Least-Squares (ELS) instead of OLS has provided better identification for the A and B polynomials in (1) for the application presented in this paper. Since in practice the noise is a much bigger concern than it is in simulation experiments, this effect is expected to be even stronger in practice.

3 SELF-TUNING POLE ASSIGNMENT

3.1 Self-Tuning Control

A Self-Tuning controller identifies a stochastic model like (1) and uses the deterministic part of the identified model for the purpose of design.

The design model can therefore be written as a sampled transfer function model:

$$y(z) = \frac{B(z)}{zA(z)}\, u(z) \qquad (3)$$

where:

$$\begin{aligned} A(z) &= z^{n_a}\, A'(z^{-1}) \\ B(z) &= z^{n_b}\, B'(z^{-1}) \end{aligned}$$

The controller is given by

$$u(z) = \frac{-F(z)}{G(z)}\, y(z) + u_e(z) \qquad (4)$$

where

$$\begin{aligned} F(z) &= f_0 z^{n_f} + f_1 z^{n_f-1} + \dots f_{n_f} \\ G(z) &= z^{n_g} + g_1 z^{n_g-1} + \dots + g_{n_g} \end{aligned}$$

and u_e is an external signal. The control scheme is shown in Figure 1

Self-tuning controllers rely on the *certainty equivalence principle*, according to which the estimates are used as if they were the true parameters for the purpose of design. A wide spectrum of algorithms can be conceived, depending on which parameter estimation scheme is chosen and which control law is used. Some combinations will work better than others and some will not work at all. This fact reveals the interaction between the processes of identification and control in self-tuning regulators, which is not taken into account when using the certainty equivalence principle.

Because of the inevitable undermodeling of the system, the identified parameters depend on the spectrum of the input signal u to the plant. It is known that the ideal situation from the point of view of identification is to have an input signal with a spectrum which is flat in the modeled band and zero in the remaining frequency range(Bitmead *et alii* 1990). To guarantee persistency of excitation while maintaining the best possible identification conditions a Pseudo Random Binary Signal (PRBS) is usually added to the system input. The amplitude of this PRBS must be small enough not to disturb the system output but large enough to guarantee an adequate level of excitation(Barreiros 1989).

3.2 Pole Assignment

Pole Assignment (PA) is a well established and widely applied control strategy. It consists in choosing the controller parameters such that the closed-loop poles lie in pre-specified positions in the z-plane. The mathematical formulation is presented in the following lines. In this presentation some of the specified positions for the closed-loop poles coincide with the open-loop poles, that is, some of the open-loop poles (say r of them) are moved by the controller and the remaining are not. This is referred to as Partial Pole Assignment. In the usual Pole Assignment all the open-loop poles are moved from their positions. This is referred to as Full Pole Assignment and can be seen as a particular case of Partial Pole Assignment, namely when $r = n_a$.

Let the polynomials in the model (3) be decomposed as

$$A = A_s A_u \quad (5)$$

$$B = B_s B_u \quad (6)$$

where the z argument has been omitted in the interest of clarity. In (5) A_s and A_u are monic polynomials, where the roots of A_u are the open-loop poles to be moved (denominated *unstable poles*, even when they may be stable) and the roots of A_s the remaining open-loop poles (denominated *stable poles*). In (6) B_s is a monic polynomial whose roots are those zeros that can be canceled by the compensator (denominated *stable zeros*) and B_u is a polynomial whose roots are the open-loop zeros that can not be canceled by the compensator (denominated *unstable zeros*). Note that this decomposition is determined both by the system's nature and by a designer's choice.

Let $deg(\cdot)$ represent the degree of a polynomial, $r \triangleq deg(A_u)$ and $q \triangleq deg(B_u)$. In order to maintain the location of the $n_a - r$ stable poles and move the remaining r, the following controller can be used:

$$\frac{F}{G} = \frac{A_s}{B_s}\frac{F_1}{G_1} \quad (7)$$

where F_1 and G_1 are the polynomials to be designed. By applying this controller the closed-loop transfer function R below is obtained:

$$R \triangleq \frac{y}{u_e} = \frac{BG_1}{A_s[A_u G_1 + B_u F_1]} \quad (8)$$

and R indeed has the roots of A_s as its poles. The polynomials F_1 and G_1 are obtained by solving a diophantine equation(Bazanella e Silva 1995a)

$$A_u G_1 + B_u F_1 = A_d A_o \quad (9)$$

where A_d is the monic polynomial whose roots are the specified positions in the complex plane for the closed-loop poles and A_o is the observer polynomial(Aström and Wittenmark. 1989).

In order to obtain a causal controller, the orders of the polynomials must satisfy

$$n_a - r + deg(F_1) \le n_b - q + deg(G_1) \quad (10)$$

Minimizing the order of the compensator under (9) and the above causality constraint (10) yields

$$\begin{aligned} deg(F_1) &= r - 1 \\ deg(G_1) &= n_a - n_b + q - 1 \end{aligned}$$

Solving the diophantine equation (9) requires the solution of the following linear system, whose order equals $n_a - n_b + r + q - 1$(Aström and Wittenmark. 1989).

$$Mx = p \quad (11)$$

where:

$$x \triangleq \left[\begin{array}{cccccc} f_{n_f} & \dots & f_0 & g_{n_g} & \dots & g_1 \end{array}\right]^T$$

$$p \triangleq \left[\begin{array}{cccccc} p_{n_p} & \dots & p_1 & 0 & \dots & 0 \end{array}\right]^T$$

$$M = \left[\begin{array}{cccccc} b_q^u & 0 & \dots & a_r^u & 0 & \dots \\ b_{q-1}^u & b_q & \dots & a_{r-1}^u & a_r^u & \dots \\ \vdots & \vdots & & \vdots & \vdots & \\ b_0^u & b_1^u & \dots & a_{r-q}^u & a_{r-q+1}^u & \dots \\ \vdots & \vdots & & \vdots & \vdots & \\ 0 & 0 & \dots & 0 & \dots & a_{r-q}^u \end{array}\right]$$

The a_i^u's and b_i^u's are respectively the coefficients of the polynomials A_u and B_u, the $p_i's$ are the coefficients of the closed-loop characteristic polynomial $A_d A_o$, and $n_p = deg(A_u) + deg(G_1)$ is the order of this polynomial. Note that $deg(A_o) = q$.

Several publications have provided applications of PA in Self-Tuning PSS's (Malik and Mao. 1993, Barreiros 1989), always using Full Pole Assignment, that is, $r = n_a$. The best choice for the positions of the closed-loop poles in the z-plane is usually not obvious and strongly depends on the particular application. In Self-Tuning PSS applications a pole shifting is usually carried out, that is, the open-loop poles are shifted towards the origin of the z-plane, reducing their modules by a factor $\alpha < 1$ to determine the positions of the closed-loop poles(Barreiros 1989).

4 CONTROL DESIGN

The conflict between the identification and control objectives is expected to be stronger in multimachine power systems than it is in single machine systems. We should explicitly take this conflict into account in our analysis in order to obtain design guidelines that will provide a good trade-off in multimachine systems. To this end we analyze the effect of the controller on the identification conditions from a frequency domain perspective.

In order to provide better identification conditions, noise is injected into the input u_e. From the identification point of view, we would like the input u to the system to have a flat spectrum in the low frequency range, with a bandwidth equal to that of the system. For that purpose, we inject a noise the spectrum of which has these characteristics. However, the control signal is added to this point, and the resulting system input will have its spectrum determined by the transfer function from the external input u_e to the plant input u, which is given by

$$T \triangleq \frac{u}{u_e} = \frac{1}{1+\frac{B}{A}\frac{A_s F_1}{B_s G_1}} = \frac{A_u G_1}{A_u G_1 + B_u F_1} = \frac{A_u G_1}{A_d A_0} \quad (12)$$

The zeros of T are those open-loop poles that are to be moved by the controller and its poles are the positions to where they will be moved. Hence, the input signal to the plant u can be seen as generated by the input signal u_e to the system when filtered so that the frequencies corresponding to the open-loop poles are supressed and those corresponding to the desired closed-loop poles are reinforced.

A third or fifth order model is usually adequate to describe Power Systems' behavior. Due to the oscillatory nature of power system's dynamics, the identified model will have a pair of complex poles in a third-order model, and usually two pairs in a fifth-order model. The PSS is aimed at the damping of these complex poles, and it is not necessary to move also the real pole, which is not responsible for the poor dynamic performance of the system. Moreover, many times in a fifth-order model only one of the two pairs of complex poles is poorly damped and therefore responsible for the poor dynamic behavior of the system. In this case, it is only necessary to move the troublesome pair, leaving the three remaining poles in their original places. Moreover, we claim that the smaller the dislocation of the poles the better will be the identification.

This claim is based on the analysis of the transfer function T in (12). Consider a situation typical for PSS applications: let in (12) $deg(A_u) = 2$, $q = 0$, and suppose that a pole shifting is performed by the controller. Then the transfer function (12) becomes

$$T(z) = \frac{z^2 - 2\sigma z + (\sigma^2+\omega^2)}{z^2 - 2\alpha\sigma z + \alpha^2(\sigma^2+\omega^2)} \quad (13)$$

A Bode plot of the transfer function (13) for $\sigma = 1, \omega = 0.3$ and $\alpha = 0.7$ is shown in Figure 2. These values are also typical in STPSS applications. We note the following points:

- The gain is low exactly around those frequencies that correspond to the open-loop poles that have been moved, so that the identification of the system response in these frequencies will be poor.
- The high-frequency gain is larger than the low-frequency gain.

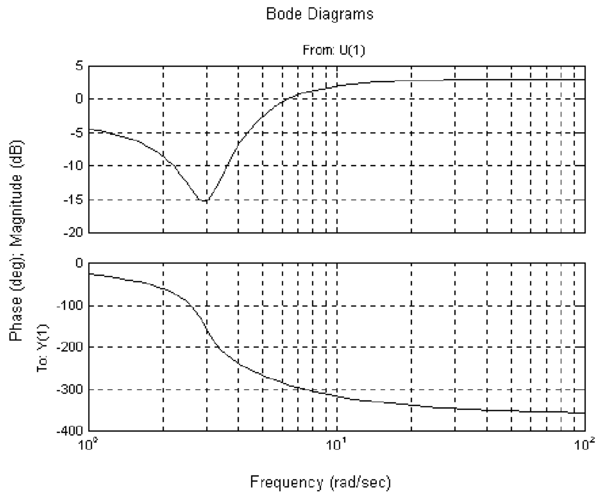

Figure 2: Bode plot of the transfer function (13)

- The smaller is α, the larger will be this high-frequency gain; hence, as the poles are moved farther away from their original positions, the input spectrum tends to be wider, thus worsening the identification.

The conflict between identification and control roles is thus seen in a frequency response plot. The transfer function (12) has $r/2$ "valleys" in its Bode plot, one for each pair of complex poles in A_u. Moreover, its high-frequency gain grows when the distance between the roots of A_u and A_d grows. Therefore, it is interesting from the point of view of the identification in a Self-Tuning PSS to move only the poles that are really troublesome, and not to move them too far away from their original positions. Hence, partial Pole Assignment, moving only those poles directly associated to poorly damped electromechanical oscillations, is expected to provide better identification conditions than full Pole Assignment. Furthermore, by moving these poles just inside a region of enough stability the high-frequency gain is kept close to the low-frequency gain, so that the high-frequency components of the signal u_e are not amplified and the spectrum of u is adequate for the identification. This approach is also expected to reduce the control effort.

The choice of the closed-loop positions for the poles (the roots of A_d) can be made in several ways. Radial pole shifting is the usual choice in previously proposed PASTPSS's. Another choice, which is adopted in this paper, is to make the closed-loop poles to have a predetermined damping factor, while maintaining the original open-loop natural oscillating frequency. The desired closed-loop polynomial is then given by

$$\begin{aligned} A_d(z) &= z^2 + a_1^d z + a_2^d \\ a_1^d &= -2e^{-\xi\omega_n T}\cos(\omega_n\sqrt{1-\xi^2 T}) \\ a_2^d &= e^{-2\xi\omega_n T} \end{aligned}$$

where T is the sampling period, ω_n is the natural undamped oscillating frequency of the pole (in the continuous time domain) and ξ is the desired damping in closed-loop.

Therefore the proposed algorithm consists of the the following steps at each sampling time:

1. sample the system to obtain $u(nT)$ and $y(nT)$;

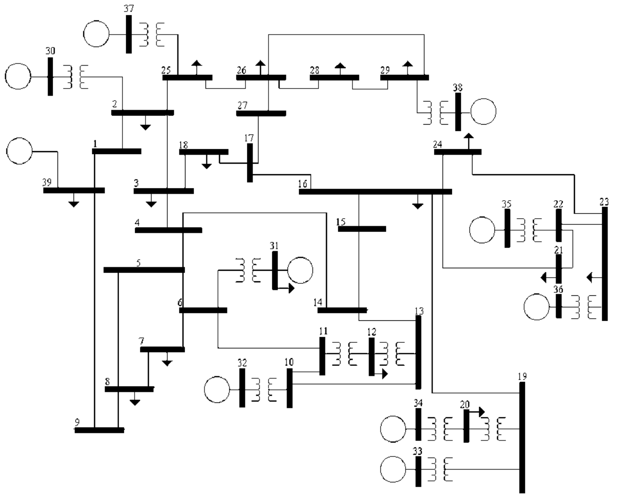

Figure 3: New England Test System

2. identify the parameters of the system model (1) by the ELS method;

3. calculate the singularities of the system identified in the previous step;

4. choose which pair(s) of complex poles to move according to some stability criterion and which zeros can be canceled;

5. determine the polynomials A_s, A_u, B_s and B_u from (5) based on the choice above;

6. obtain the polynomials F_1 and G_1 by solving equation (9);

7. obtain the controller transfer function using the polynomials A_s, B_s, F_1 and G_1 just obtained from (7);

8. calculate the control from the recursion equation associated with the transfer function just obtained and apply it to the system.

5 APPLICATION TO A BENCHMARK

5.1 The test system

The test system is the New England Power System. The one-line diagram is given in Figure 3.

The system consists of nine generators, an infinite busbar and thirty-nine buses. The modeling and load data are the same as in reference (Byerly *et alii*, R.T., D.E. Sherman, and R.J. Bennon. 1978), except for the AVR data, which have been modified: all the synchronous machines are supposed to be equipped with AVR described by a first-order transfer function:

$$AVR(s) = \frac{K}{1 + sT}$$

The AVR parameters are presented in Table 1

The system exhibits poor dynamic performance for typical operating conditions. For the operating condition considered, dynamic instability is observed. The eigenvalues associated to the unstable electromechanical modes of the system are presented in Table 2. The behavior of the load angles of the nine generators in response to a solid short-circuit at bus 22 is shown in Figure 4. It is shown in (Bazanella *et alii* 1995) that conventional PSS's designed for this operating condition are not able to provide enough damping for other operating conditions.

Table 1: AVR data

Gen. bus	K	T
30	5.0	0.06
31	6.2	0.05
32	5.0	0.06
33	5.0	0.06
34	40.0	0.02
35	5.0	0.02
36	40.0	0.02
37	5.0	0.02
38	40.0	0.02

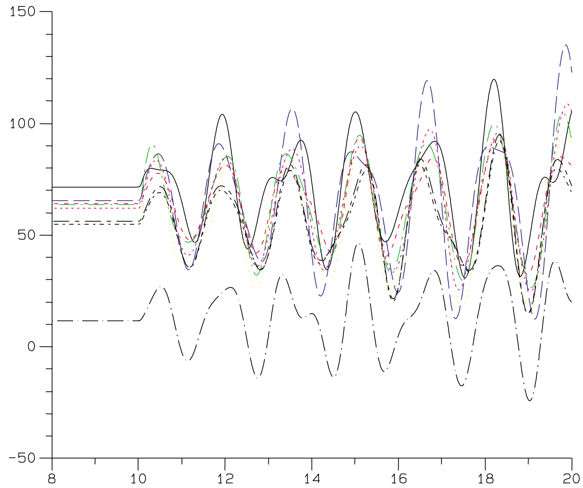

Figure 4: Open–loop generator angles

Table 2: Unstable electromechanical eigenvalues of the test system.

+0.0024 ± $\jmath$ 7.0606
+0.1261 ± $\jmath$ 6.0564
+0.0355 ± $\jmath$ 6.2696
+0.0683 ± $\jmath$ 4.0736

5.2 The controller design

Participation factors are used to determine which generator is more strongly associated to each unstable electromechanical mode. One PSS is attached to each one of these four generators. One more PSS is installed at a generator strongly associated to some of the electromechanical modes. Hence, five PSS's are used overall. All the PSS's use electric power as the feedback signal.

Several design choices must be made for the STPSS's. The sampling period (T) is chosen first, based on usual sampled data control systems considerations (Aström and Wittenmark. 1989). The parameters of the controller are not updated at each sample, but only at intervals of κ samples. The orders for the polynomials in the model (n_a, n_b and n_c) are selected based on the

Table 3. Main features of the STPSS's.

n_a	3
n_b	4
n_c	2
r	2
T	100 ms
ξ	0.7
κ	10
N_{frozen}	50

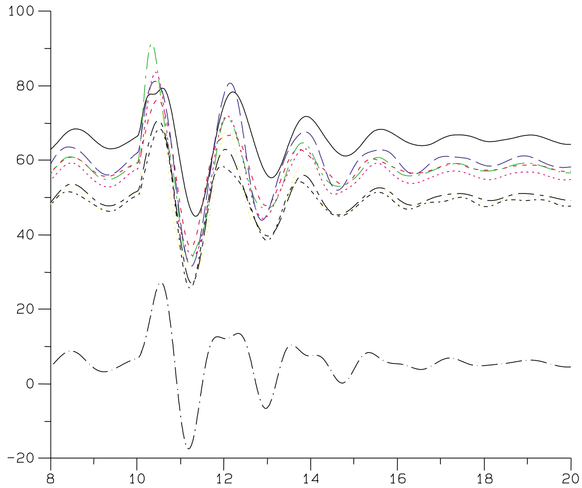

Figure 5: Generator angles with partial pole placement

previous knowledge of the system behavior and a trial and error procedure. They are such that the identification does not improve by making them bigger. The number of poles to be moved $r = 2$ is the one recommended by the previous discussion and is indeed the one that has yielded the best results. The pair of complex poles is moved so that its natural frequency is maintained while improving its damping factor up to a prespecified value ξ. Identification freezing imediately after a fault is also applied; N_{frozen} is the number of samples the identification is frozen after a fault. Table 3 presents the design choices made for the STPSS's in this paper.

5.3 Simulation results

The *Self-Tuning, Pole Assignment based, Power System Stabilizers* (STPAPSS's) described above were implemented using numerically robust routines and applied to the New England test system at the simulation level. The behavior of the load angles of the nine generators in response to a solid short-circuit at bus 22 is shown in Figure 5.

The simulation starts with all the parameters in the PSS's identification model set to zero, except b_0, which is set to one. The model parameters are identified within a few seconds, so that the PSS's tune themselves to the given operating condition to provide the system with good damping of the electromechanical oscillations. The parameter tracking of the PSS installed at generator 1 is presented in Figure 6.

Let us compare these results with those obtained with full Pole

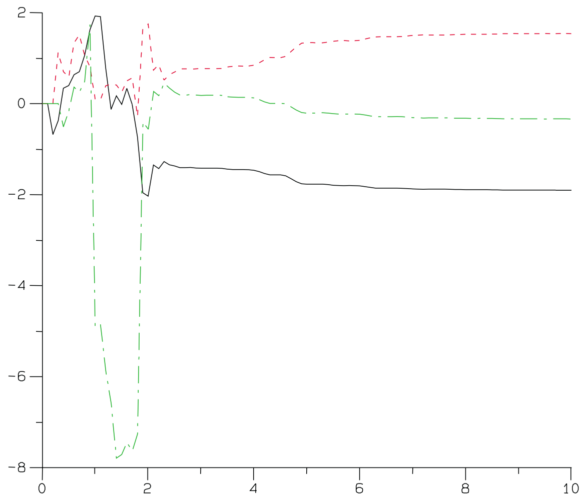

Figure 6: Identified parameters (partial pole placement)

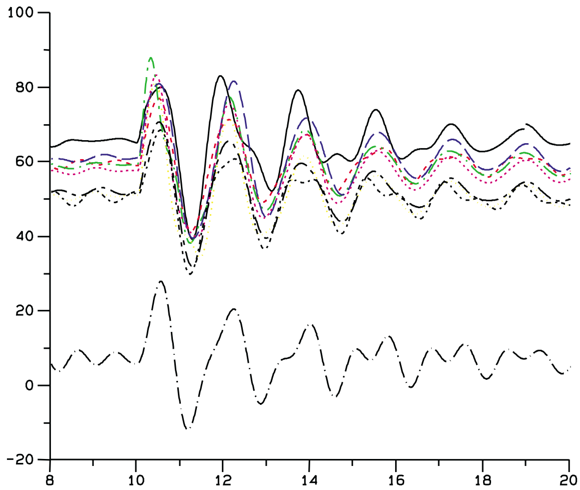

Figure 7: Generator angles with full pole placement

Assignment. To this end we change the control strategy of the five PSS's to full Pole Assignment with radial pole shifting, keeping the other control and identification parameters unaltered. The best results are obtained for $\alpha = 0.85$. The load angle of the generators in this case for the same fault as before are shown in Figure 7; the parameter tracking of the PSS installed at generator 1 is presented in Figure 9.

The PSS's outputs for the partial and full Pole Assignment are presented in Figures 8 and 10, respectively. It is seen that the partial Pole Assignment demands less control effort, although better damping has been obtained.

Finally, we compare the results obtained with the application of the partial Pole Assignment strategy along with ordinary Least-Squares identification. The load angles are given (again for the same fault) in Figure 11, where we notice that the performance is not as good as obtained using the extended Least-Squares.

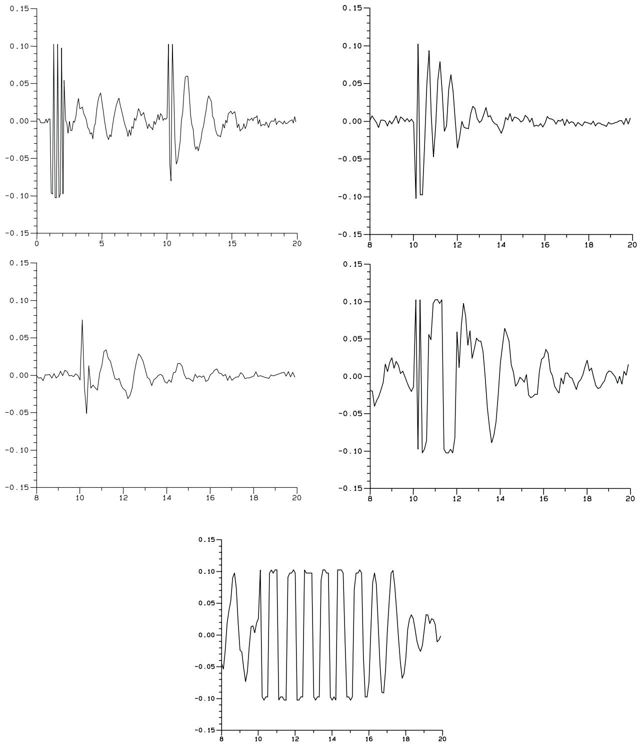

Figure 8: PSS outputs (partial pole placement)

Although the convergence of the parameters, shown in Figure 12, is very fast, the estimates obtained are biased, which deteriorates the system performance.

6 CONCLUSIONS

Self-Tuning control is a promising alternative to deal with operating point variations in power systems stabilizers and as such has been extensively explored in the literature. Yet, results for multimachine systems are scarce to date. The unpleasant effects of undermodeling, nonlinearities and noise on the performance of Self-Tuning controllers are more significant in the multimachine case. Hence, design choices which explicitly take into account the conflict between identification and control objectives are very important. In this paper we discussed this issue and proposed a new Self-Tuning PSS to deal with it. The performance of this controller has been assessed and compared to a well-established strategy in a benchmark.

The proposed controller applies a Partial Pole Assignment control strategy along with the Extended Least-Squares method for identification. The ELS is more suited to noisy applications and for this reason is expected to provide significant improvement in identification of multimachine systems when compared to the ordinary Least-Squares. Regarding the control strategy, it has been shown analytically that moving only those open-loop poles responsible for the system instability provides better identification conditions than Full Pole Assignment. It has also been argued that smaller control effort can be expected in this case. Both this expectation and the analytical results have been confirmed in a case study presented.

The simulation results obtained for the case study show the good performance of the proposed control algorithm for a multimachine benchmark. The controllers quickly identify the linear model for the system and tune themselves to the current operating condition. The dynamic performance obtained is quite satisfactory, achieving good damping for all the electromechanical modes. Significant performance improvement has been obtained when compared to full Pole Assignment: better damping is achieved with less control effort. Furthermore, the comparison between the two identification methods shows that the reduction of the bias in the parameter estimates achieved with the extended Least-Squares identification also improves the system performance.

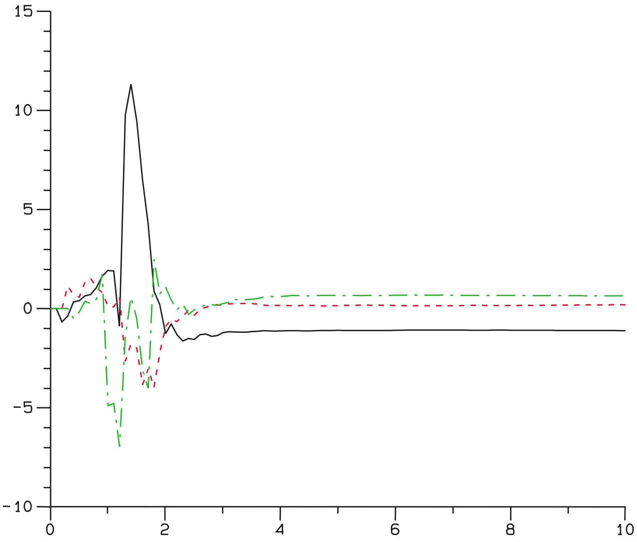

Figure 9: Identified model parameters (full pole placement)

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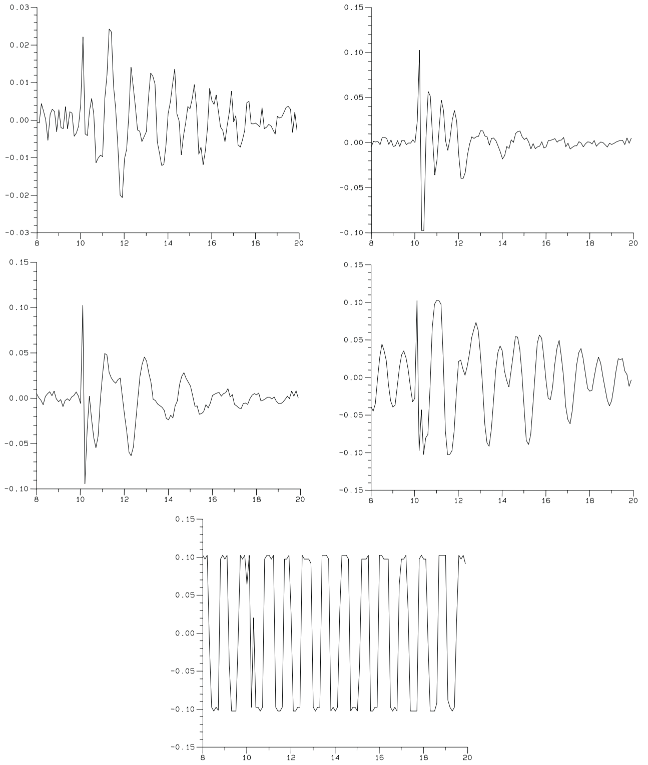

Figure 10: PSS outputs (full pole placement)

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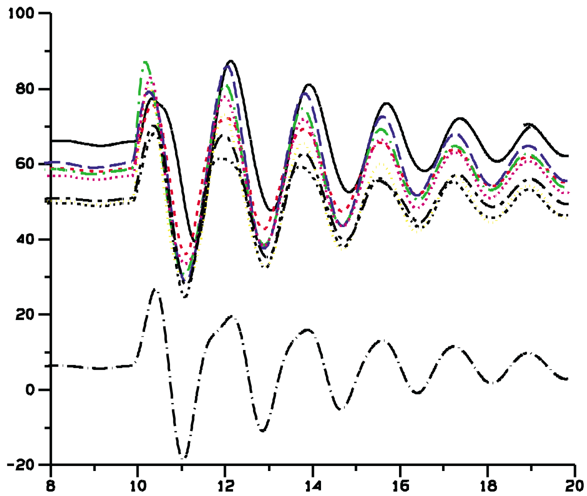

Figure 11: Generator angles with the ordinary least-squares

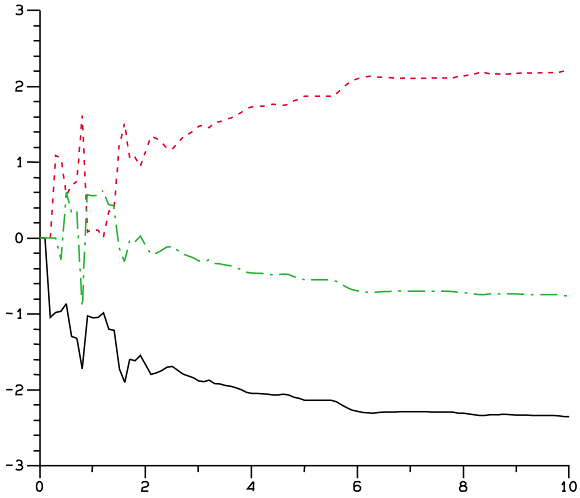

Figure 12: Identified parameters with the ordinary least-squares

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