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AN ADAPTIVE DEADBEAT STABILIZER FOR POWER SYSTEM DYNAMIC STABILITY

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ABSTRACT: This paper discusses an adaptive deadbeat stabilizer to improve power system damping. The method involves normalized recursive least squares estimation to yield a reduced order state space model of the power system. This reduced order model is used to design the required deadbeat stabilizer recursively, along with an adaptive observer to estimate the unknown states.

INTRODUCTION

Dynamic stability has been a major problem in power systems following the introduction of thyristor excitation systems and long tie lines. High gain and low time constant automatic voltage regulators (AVR) improve transient stability and help to maintain the terminal voltage within a close tolerance. Dynamic stability is however impaired in the process. This leads to poorly damped rotor and power oscillations following minor disturbances. The need to damp power system oscillations to enhance power transfer capability from generating units had led to extensive research into power system stabilizers (PSS) [1]. Often, difficulties have been experienced in the tuning of these PSS, to give good performance over a wide range of operating conditions, leading to recent interest in adaptive control techniques [2]. The adaptive control methods are typically done on input-output models obtained from identification, and require the inversion of high order matrices in real-time [2]. Considerable advantages exist in designing the adaptive stabilizer using state space techniques. A number of researchers have investigated the state space self tuning controllers [3]. In the present work, normalized recursive least squares estimation is used to generate a reduced order state space model of the power system. Incorporating a deadbeat state observer and controller, the adaptive stabilizer is seen to be effective in providing good damping. Normalization has been used to enhance the robustness of adaptive control to unmodelled error. The present treatment of normalization in the perspective of weighted least squares is believed to be novel.

THE PLANT MODEL

Fig. 1 shows the block diagram of a simplified linear power system connected to an infinite bus. The system equations can be put in the form,

$$\dot{X} = A X + B u \tag{1}$$

The coefficients K_1 to K_6 are functions of the plant loading and impedances and are computed as indicated in Ref. [1].

SYSTEM IDENTIFICATION AND STATE SPACE MODELLING

A dynamical system with sampled input signals $\{u(t)\}$ and output signals $\{y(t)\}$ can be modelled as a linear difference equation and represented as:

$$y(t) = \psi(t)\ \theta(t) + v(t) \tag{2}$$

where $v(t)$ represents the measurement noise at each observation time, parameter vector

$\theta(t) = [a_1\ a_2\ \dots\ a_N\ b_1\ b_2\ \dots\ b_N]^T$, and measurement vector

$\psi(t) = [-y_1(t-1)\ \dots\ -y_N(t-N)\ u_1(t-1)\ \dots\ u_N(t-N)]$

The normalized recursive least squares estimation now allows us to estimate θ from a knowledge of the normalized measurements y and ψ:

$$\theta(t+1) = \theta(t) + L(t)\ [y(t+1) - \psi(t)\ \theta(t)]$$

$$L(t+1) = \frac{w\ P(t)\ \psi(t+1)}{1 + w\ \psi^T(t+1)\ P(t)\ \psi(t+1)}$$

$$P(t+1) = P(t) - \frac{wP(t)\ \psi(t+1)\ \psi^T(t+1)\ P(t)}{1 + w\ \psi^T(t+1)\ P(t)\ \psi(t+1)} \tag{3}$$

Here, 'w' is a factor which accounts for the measurement normalization. Eqn. (3) can then be viewed as the recursive weighted least squares algorithm.

The selection of a proper model order is often a trade-off between robustness and computing speed. Model orders greater than two or three are rarely used for most engineering applications. In these cases, however, the adaptive scheme should be robust with reference to the unmodelled dynamics. Robustness issues of adaptive controllers is still open to discussion, and a number of researchers are engaged in such studies [4].

The model yielded by the system identifier is a discrete time structure and can be put in state space observer form, which can be written as:

$$\begin{aligned} X(nT+T) &= \phi X(nT) + \Gamma u(nT) \\ y(nT) &= HX(nT) \end{aligned} \tag{4}$$

To judge the validity of this model, the seventh order power system model was excited by a PRBS input to the AVR. Monitoring the change in real power (ΔP), the system was identified as a second order model and put into the state space form Eqn. (4). The eigenvalues of Eqn. (4) were obtained and compared with the plant dominant eigenvalues (Table 1). The dominant eigenvalues are recovered with good accuracy for a large number of operating conditions. The results indicate that the model in Eqn. (4) can be treated as a reduced order equivalent of Eqn. (1), and contains the dominant modes for the purpose of controller design.

STATE CONTROLLER AND OBSERVER

Deadbeat control seeks to shift the closed loop poles of the system in Eqn. (4) to the origin of the unit circle in at most N steps, where N is the order of the system.

Let the controller be chosen of the form:

$$u(nT) = -K\ X(nT) \tag{5}$$

Using the controller Eqn. (5) in Eqn. (4), the resulting closed loop characteristic equation can be forced to behave deadbeat, upon which we get a matrix equation to be solved for K. The solution may be obtained by a matrix inversion of order N.

The controller can now be implemented if the states X(nT) are available. This can be obtained from a state observer. The observer can be described by

$$\hat{X}(nT+T) = \Phi\hat{X}(nT) + \Gamma u(nT) + L\, v(nT) \tag{6}$$

$$\hat{y}(nT) = H\hat{X}(nT)$$

where $v(nT) = y(nT) - \hat{y}(nT)$ (7)

The dynamics of the observer error depends on the characteristic equation:

$$\det(qI - \Phi + LH) = 0 \tag{8}$$

By choosing the coefficients of L appropriately, the error transients can be made to subside soon. Owing to the structure of Eqn. (4), the choice of $\{l_i\} = -\{a_i\}$ corresponds to a deadbeat observer. This scheme works as long as the plant output does not contain higher order modes, else, higher frequencies will be forced into the controller through Eqn. (6) which will ultimately lead to adaptive control failure. Many studies have been reported to avoid this generic adaptive control problem [4]. In this work, a proper choice of the normalization factor 'w' in Eqn. (3) can give good performance.

SIMULATION RESULTS

The seventh order linear power system model presented earlier was tested with and without the adaptive stabilizer at two representative operating points. A sampling time of 0.05 seconds and a second order model structure was chosen. The change in real power (ΔP, computed from the states $\Delta\delta$ and $\Delta E'_q$), is used in this work as the output signal. The disturbance speeds up the rotor by 10% at time t = 0. The initial conditions chosen for the identifier in both cases are as follows: $\theta(0)=0$, except for $b(1) = 1$, $P(0) = 10I$. The measurement ΔP is normalized before using it in the identifier.

Figs. 2 and 3 show the rotor angle time response following the disturbance with and without the adaptive stabilizer, at the operating points P+jQ = 0.7 + j0.2, and 1.0 - j0.4 respectively. The adaptive stabilizer is seen to improve the system damping from the second half cycle, and within 1.5 seconds, the system oscillations have nearly ceased. Even when the uncompensated plant is unstable (Fig. 3), the adaptive stabilizer is seen to quickly damp the swings.

Figs. 4 and 5 show the convergence of the adaptive gains k_1 and k_2 at the two operating points respectively. Both gains starting with zero values at time t = 0 are seen to quickly build up and converge within 1.0 second. Such convergence is desirable in

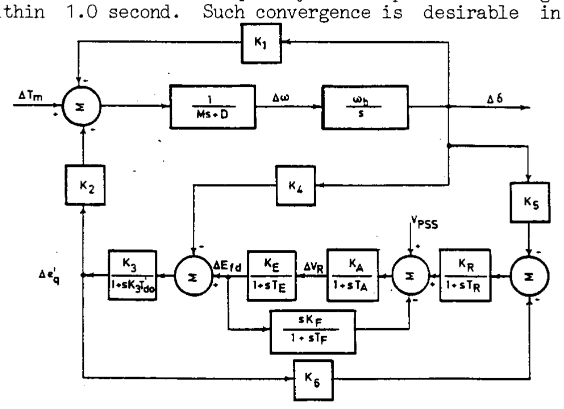

Fig. 1: Linearized Model of Power System

the adaptive control of LTI systems as it implies stable closed loop identification and controller design.

CONCLUSIONS

This paper has presented an adaptive deadbeat stabilizer based on state space techniques for improving power system dynamic stability. Simulation studies carried out on a linear power system model indicate that a second order model used in conjunction with the ΔP signal can represent sufficiently well, the dominant modes of the power system. The adaptive stabilizer is seen to stabilize the power system and damp the oscillations very effectively. The adaptive gains are shown to converge in the cases investigated.

The adaptive stabilizer presented in this paper has also been evaluated on a laboratory model power system with a PDP LSI 11/23 computer. Preliminary experimental investigations [5] have shown the adaptive stabilizer capable of improving power system damping in a real-time environment.

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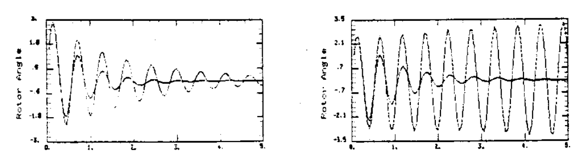
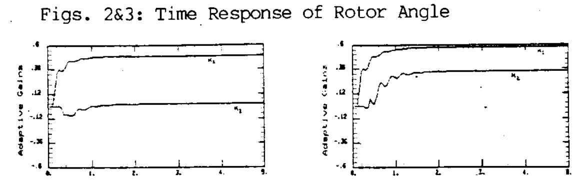
Table 1
Recovery of dominant eigenvalues (s-plane) of the system from the identified model after 300 iterations

Plant loading	Actual rotor modes	Identified rotor modes
0.7 - j0.4	-0.2600±j12.5150	-0.2645±j12.5258
0.7 + j0.2	-0.5162±j11.0568	-0.5285±j11.0938
0.8 - j0.4	-0.1603±j12.3448	-0.1538±j12.3471
0.8 + j0.2	-0.4642±j11.3424	-0.4619±j11.3724
0.9 - j0.4	-0.0597±j12.1222	-0.0655±j12.1431
1.0 - j0.4	0.0449±j11.8744	0.0429±j11.8685
1.0 + j0.2	-0.3257±j11.6964	-0.3286±j11.6222



Figs. 2&3: Time Response of Rotor Angle



Figs. 4&5: Convergence of Adaptive Gains