SELF-TUNING REGULATORS FOR A GROUP OF TURBOGENERATORS

By :

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Abstract

With the need to improve the transient stability of existing generating units, multivariable self-tuning regulators are proposed in this paper with particular emphasis on their application to large disturbances. This work involves the identification of a group of turbogenerator parameters and the determination of regulator parameters. By simulation and implementation, the use of certain recursive identification techniques shows better parameter tracking, under the transient as well as the dynamic conditions. The use of optimal control or pole-shifting strategy utilizing, respectively, suitable weighting matrices and shifting factor, increasing the flexibility when applied to varying operating conditions encountered in any power system. Comparative results of studies, based on alternate self-tuning regulator algorithm and conventional fixed parameter regulator, show some improvement in the response perform- ed by the adaptive algorithm.

Introduction

Additional feedback signals such as speed, power and frequency are widely used as stabilising signal to provide good damping during transient conditions. In these conditions, linear control design techniques are normally used for the control of synchronous machines in spite of their nonlinear characteristics. The change of the machine operating point should be followed by the one of the controller parameters.

Advantages of on-line changes of the controller parameters have been demonstrated for various processes (Ghosh, 1984). The applications of Adaptive Control to synchronous machines have been discussed in several papers over the past five years. After these controllers detect changes in system operating conditions, a new set of controller parameters are determined. Among the available adaptive control techniques, the most effective and simple approach to the control problems, as the self-tuning concepts are attractive. The self-tuning technique involves two aspects, firstly, identification of system parameters, and secondly, control calculation using preselected strategy.

Different identification techniques commonly used are : the recursive least-squares, unbiased least-squares, maximum likelihood, and instrumental variable methods. For the reason of bias, the recursive instrumental variable technique is used popularly in the power system modelling. This technique gives an excellent performance.

Control strategies based on adaptive control techniques are surveyed by Ghosh (1984). Minimum variance controllers can only be used for small disturbance cases, provided the system is minimum phase. Linear quadratic and pole shifting controllers can be beneficial when the system is not well known, but has stable open-loop poles. Pole assigned controllers can only be used in the cases where the system is well known, although it can damp out large disturbances efficiently.

Most papers are concerned to single input single output system. It leads to several drawbacks due to the difficulty in choosing the suitable input and output variables.

The aims of this paper is to present the multivariable adaptive controller improving the transient stability of a turbogenerator with particular emphasis on their application to large disturbances. The control scheme consist of a fixed parameter voltage

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regulator for limiting the first swing following a fault, and an adaptive stabiliser affecting the subsequent damping. On-line identification and control design are discussed, followed by simulation and experimental results.

Proposed Adaptive Control Scheme

The adaptive stabiliser design considered in this paper is based on an explicit identification of the transfer function between the system input u and output y as shown in Fig. 1. The recursive instrumental variable identification technique is used for the parameter estimation.

The system model is described by a difference equation at the k-th sampling instant :

$$Y_k = A\,Y_{k-1} + B\,u_{k-1} \qquad (1)$$

with Y_k is the (n,1) vector of noise contaminated measurements of state and u_k is the (m,1) vector of input signals.

Based on the estimation of the system parameters A and B, the stabiliser parameters are computed for each sampling period. Using some control strategies described later, the controlled u is then calculated.

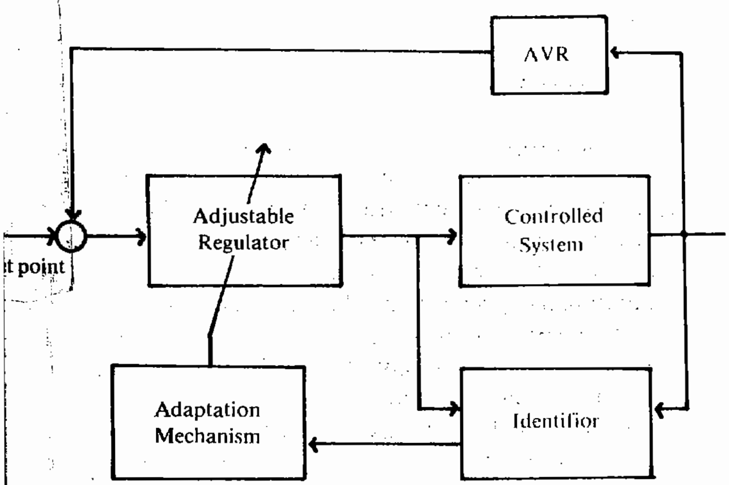

Fig. 1. **Proposed adaptive control scheme**

System Identification

The main objective of identification is to represent the system dynamics with a low-order linear model in recursive form.

To achieve an accurate identification process, a performance index is assumed as follow :

$$PI = (1/N) \sum_{k=1}^{n} e_k^{T} e_k \qquad (2)$$

which is to be minimized, where e_k is the error function defined as :

$$e_k = y_k - \hat{A}\,y_{k-1} - \hat{B}\,u_{k-1} \qquad (3)$$

$\hat{A}$, $\hat{B}$ are identified parameter matrices calculated with N sets of measurements.

Four methods of on-line identification for modelling and control of a nonlinear laboratory turbogenerator system are evaluated (Sharaf and Hogg, 1981). The recursive least squares algorithm is very reliable, rapid convergence, and sensitive to the noise. The unbiased recursive least squares is also reliable, but much less affected by noise. The method of stochastic approximation has excellent computational characteristics, but slow convergence and poor reliability. It is sugested to use the recursive instrumental variable approximation, which is fast and accurate. This method was found to be the most suitable identification technique for dynamic power system modelling. This technique is applied in this study.

The recursive equation at the chosen method is given :

$$W_k = W_{k-1} + [y_k - W_{k-1} Z_{k-1}]\, S_{k-1}^{T} P_k \qquad (4)$$

$$P_k = P_{k-1} - P_{k-1} Z_{k-1} [S_{k-1}^{T} P_{k-1} Z_{k-1} + 1]^{-1} S_{k-1}^{T} P_{k-1} \qquad (5)$$

where : Z is the (n + m,1) augmented state vector, and
W is the (n,m + n) parameter matrix.
P is the (n + m, n + m) covariance matrix, and
S is the (n + m, 1) augmented vector which equal to

$$S_k = [h_k^{T}\ u_k^{T}]^{T} \qquad (6)$$

where h is (n,1) vector representing the instrumental variables, chosen as :

$$h_k = W_k S_{k-1} \quad (7)$$

Regulator Design

Control laws using linear optimal and pole-shifting methods are derived in the following section.

a. Linear Optimal control

A performance index of quadratic form is chosen:

$$I = \sum_{k=1}^{N} y_{k+1}{}^{T} Q y_{k+1} + u_k{}^{T} R u_k \quad (8)$$

where Q is the weighting matrix of the output deviation and R is that of the control effort. The minimization of the performance index is derived by discretising α I :

$$I_k = y_{k+1}{}^{T} Q y_{k+1} + u_k{}^{T} R_k \quad (9)$$

and then by substituting for y_{k+1}, finally by differentiating of I_k with respect to u_k, the control effort is :

$$u_k = -(R + B^T Q B)^{-1} B^T Q A y_k \quad (10)$$

It is shown that the feedback control for satisfying the minimization of performance index I is very simple, obtained without using any algebraic solution of Riccati equation.

b. Pole Shifting Method

This method is a modification of the pole-assignment technique. In the pole-assignment design, the closed loop poles of the system are specified by user.

Based on the identified system model described in(1), the controller is proposed to be :

$$u_k = G(z^{-1})(I + F(z^{-1}))^{-1} y_k \quad (11)$$

where G and F are pole matrix given by :

$$G(z^{-1}) = G_0 + G_1 z^{-1} + \dots + G_{ng} z^{-ng} \quad (12)$$

$$F(z^{-1}) = F_1 + F_2 z^{-2} + \dots + F_{nf} z^{-nf} \quad (13)$$

G_i, i = 0, 1 ..., ng are $(r,n)^4$ matrices and Fl, i = 1, 2 ..., nf are (m,n) matrices.

If the closed-loop of the system are specified as the root of a polynomial :

$$T(z^{-1}) = I_n + z^{-1} T_1 + \dots + z^{-nt} T_{nt} \quad (14)$$

and if the choice of T could be considered as a shifting radially toward the origin of the open-loop poles, the system characteristic equation becomes :

$$T(z^{-1}) = A(\alpha z^{-1}) \quad (15)$$

where α is close to, but less then one. In this case, the closed-loop equation is :

$$I + Az^{-1} - z^{-1} B G_0 = T(z^{-1}) = I + A \alpha z^{-1} \quad (16)$$

By this identity, the control effort has a form of :

$$u_k = (1 - \alpha)(B^T B)^{-1} B^T A y_k \quad (17)$$

By choosing a value of α which is close to one, the control computation is stable.

Simulation Results

Simulation Studies

The proposed control scheme is initially evaluated by digital simulation of a power plant. The power plant relates to a structure of one machine infinite bus turbogenerator system. The synchronous machine is represented by a set of seven first order differential equations. Especially for the Governor/Turbine and the AVR/Exciter models are represented by two sets of two first order differential equations. The machine parameters and time constants are given (Ashon, Hogg and Pullman, 1979), the exciter voltage and governor valve position limits are included. The transmission lines is represented as a parallel distributed π of impedance (0.025 + j 0.35) pu. The infinite bus voltage is assumed to be 0.932 pu.

The load angle, the rotating speed, the valve position, the mechanical torque, and the exciter current are chosen as stabilising signals for the adaptive stabilise to provide the control signals, i.e : exciter voltage and governor.

The recursive instrumental variable algorithm is firstly applied for the initial value of the entired self-tuning algorithm, using 200 sets of samples every 20 microseconds. This method gives a satisfactory representation of the original system.

A step change of 10% of full load was made from the 80% of full load operating point. The optimal and pole shifting controllers performed creditably as opposed to a conventional stabiliser. Fig. 2. shows the comparison of the load-angle responses with the three controller. The next figure, relates to a step change in reference voltage. The latest, corresponding to the purpose of this study, a short circuit was applied at the midpoint of one circuit of the transmission line, with successful reclosure after 0.1 sec. For this case, the system performance is consistently improved with the proposed stabilisers.

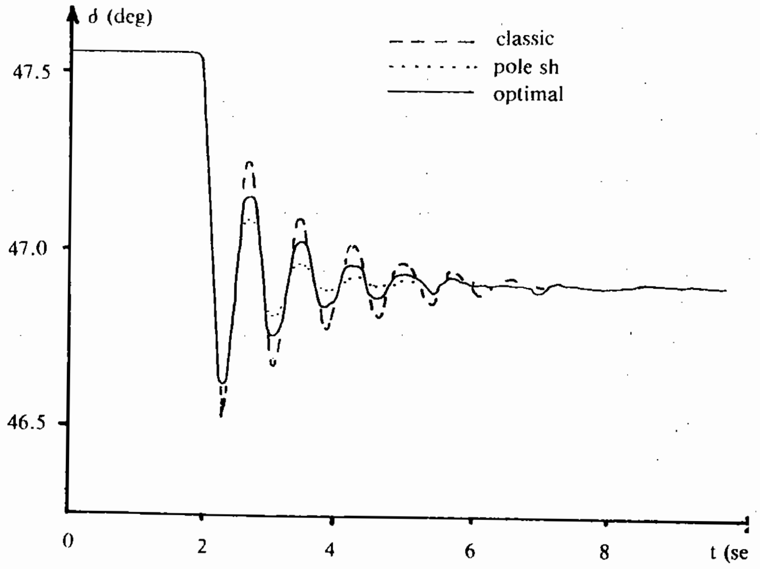

Fig. 3. System response to a 50% step in reference voltage

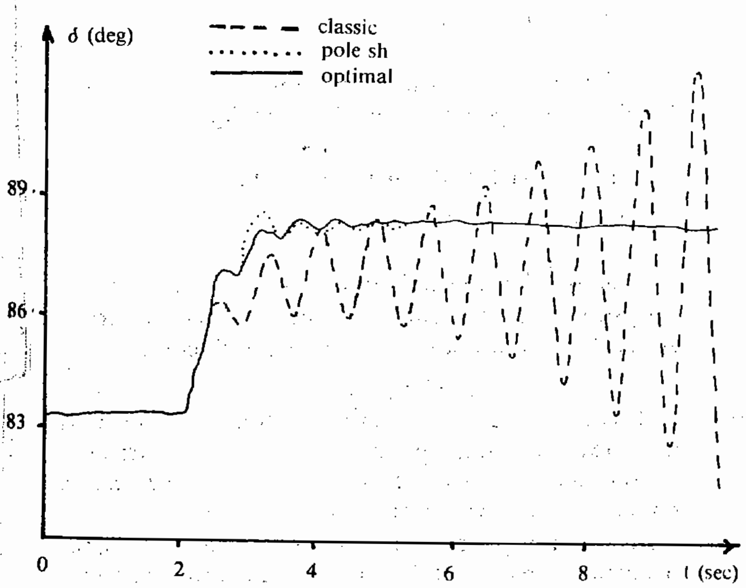

Fig. 2. System response to a 10% step in load

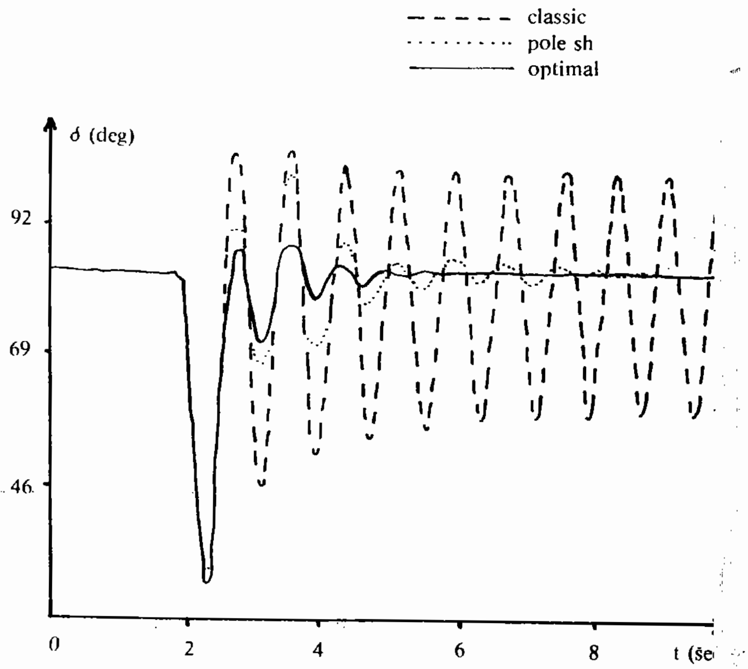

Fig. 4. Short circuit test, successful roolosure after 0.1 sec.

Parameter Variations

For precise identification, Goodwin (1977) indicated that there must exist an exciting disturbance in the system input which causes a sufficient variation in the output. The problem following the direct application of Adaptive techniques using explicit identification is the action of the identifier during a fault. The large change in output immediatly following a fault causes a large change in parameter estimates. At these periods, the control parameters are wildly in error. It is sugested to turn off the identification for a short period following the onset of the fault to avoid a condition where the estimates converge to the parameters of the faulted system.

Fig. 5 shows the parameters variations when the identification was turned off for 0.5 second. When the identifier was switch back, the parameters made a smooth transition to the new operating point. Fig. 6. presents the identification turn off effect.

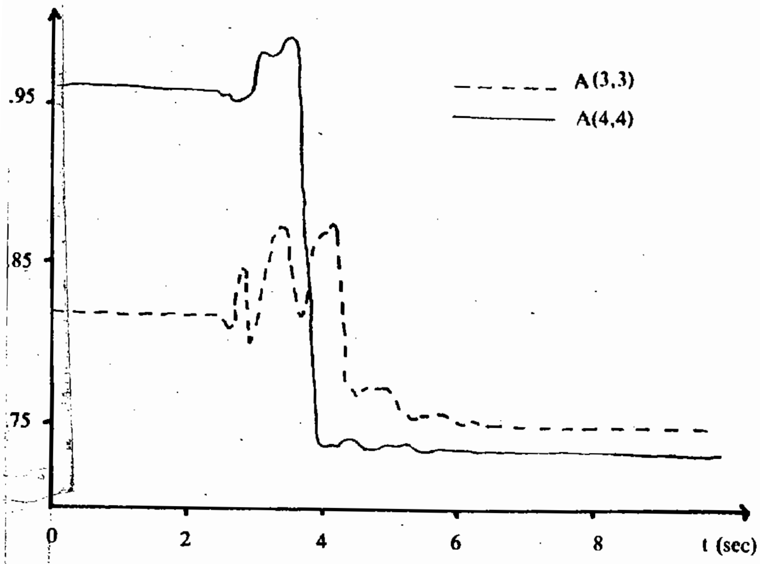

Fig. 5. Parameter variations with 0.5 sec of an identification turn off

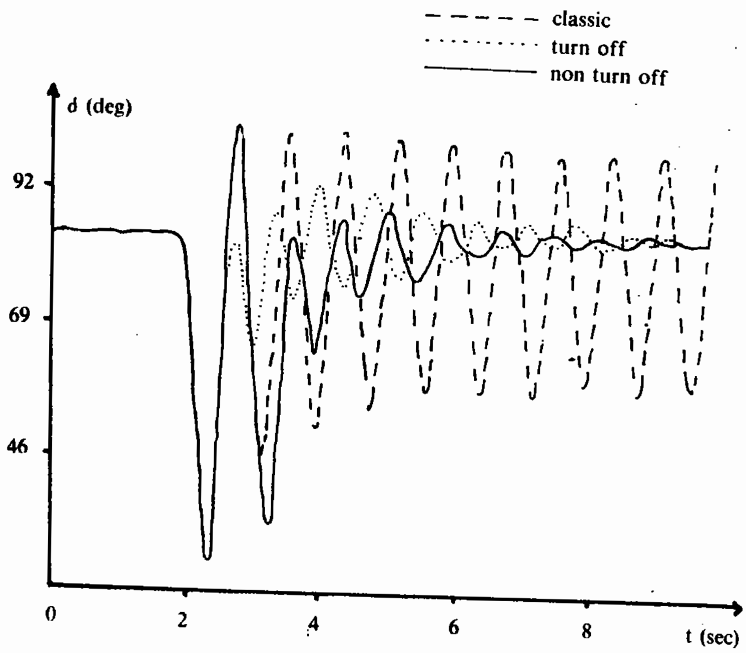

Fig. 6. Identification turn of effect of system response

Selection of Q and α

The control laws derived above for both the optimal (10) and pole-shifting (17) techniques are :

$$u_k = -(R + B^T QB)^{-1} B^T QAy_k$$

$$u_k = (1 - \alpha)(B^T B)^{-1} B^T A\, y_k$$

It is shown that the weighting matrices Q and R, the pole-shifting coefficient α and the parameter matrices A and B in instant k define the feedback control.

The selection of performance index weighting matrices method are surveyed by Johnson (1987). A more exact method for determining these matrices is introduced (Pramono, Moret and Talaat, 1987), based on eigenvalue loci, R is considered as a constant matrix. In this paper, the Q and R matrices are respectively taken to the stabilising signals mentioned above :

$$R = \text{diag}\,|\ 1 \quad 10\ |$$

$$Q = \text{diag}\,|\ 60 \quad 30 \quad 50 \quad 400 \quad 300\ |$$

Following Ghosh (1985), the value of α which is chosen close to one, derive both the polynomial F and the resultant control computation are stable. More over, the system linearity is satisfied. For the studies described in this paper, the best value of α is :

$$0.98 < \alpha < 1.00$$

Laboratory Implementation

As the result of the algorithm mentioned before, we would present the implementation in a micromachine power system model. Fig. 7. shows the scheme of turbogenerator and control laboratory system with interface to microcomputer board.

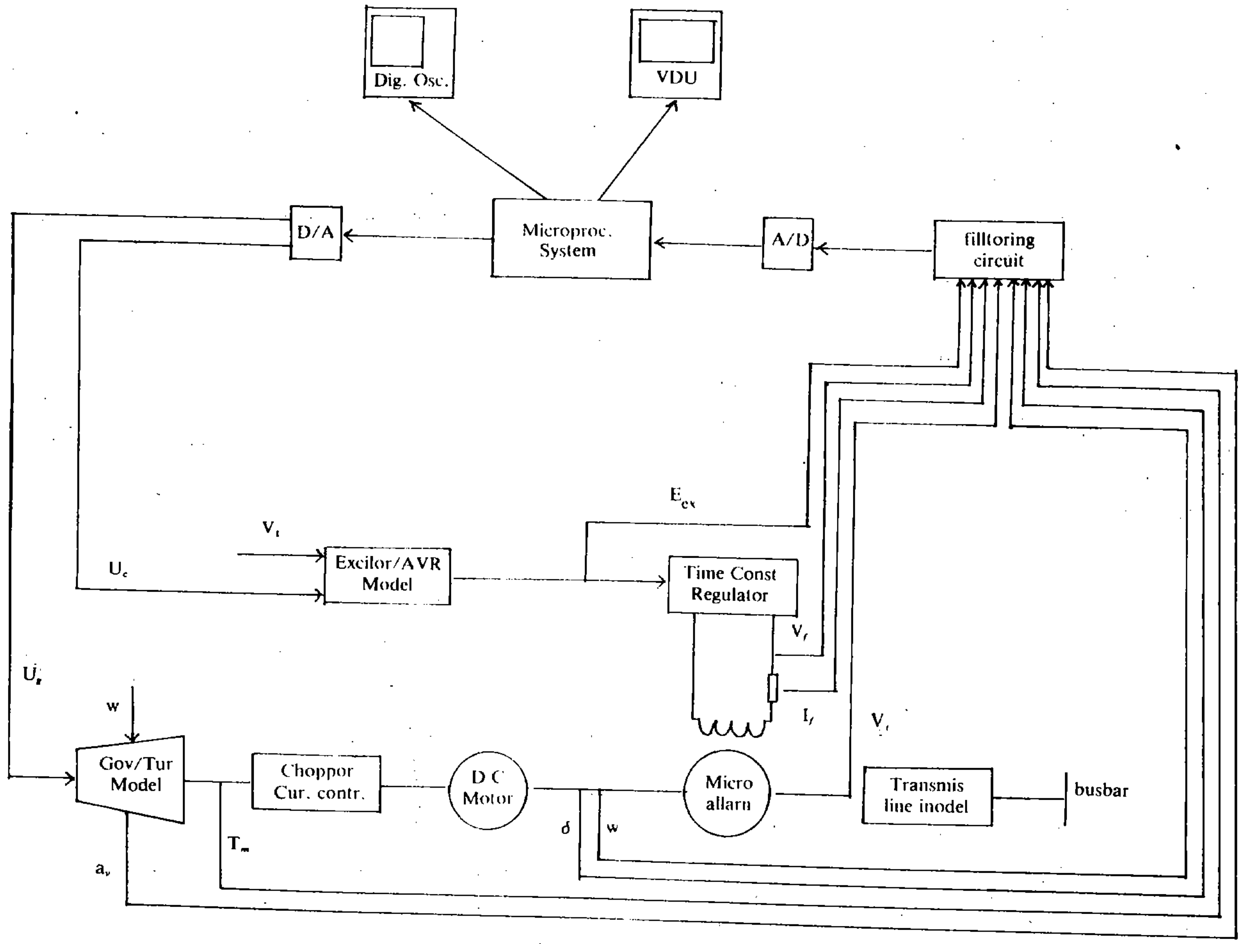

Fig. 7. **Turbogenerator and control laboratory system**

U_s = speed reference
U_c = excitation reference
T_m = mechanical tarque
a_v = valve position
δ = motor angle
w = speed
I_f = field current
V_f = field voltage
E_{ex} = excitation model output
V_t = terminal voltage

Micromachine Laboratory System

The turbogenerator system has a specification as mentioned below, it has :

— a 3 kVA, 220 V, 4 poles microalternator specially designed to represent a scaled model of large generator.
— a time constant regulator which is used to regulate the value of machine's time constant T'd, T' do.
— an analog model of Exciter/AVR system based on the representation of IEEE.
— a separately excited DC motor prime-mover 1500
— rpm, 110B, 10KW, which is functioning to simulate the governor/turbine system.

This turbogenerator is connected to the laboratory busbar by autotransformer and a model of double-circuit overhead transmission line which is made of group of series-cored colls and shunt capacitances.

The sensor devices provide facilities for measurement. As the result there are 9 output signals which 2 of it is part of the governor/turbine model, another 2 is part of the Exciter/AVR model, and the rest (in this case only 5) namely : the terminal voltage, the excitation current, the field voltage, the speed and the rotor angle are from the microalternator system.

The hardware implementation consists of :

— a microcomputer system using a single board of INTEL ISBC 80/24.
— a data acquisition system ADAC 735
— an Input/Output devices.

Experimental Results

For the implementation, the simulation program is written in Assembler Language and was developed for the application in the problem of disturbances to one of the input references and short-circuit in the middle of the transmission line. The output measured every 20 ms is performed. The system is supported by a supplementary signal which is designed based on the LOC and the pole-shifting techniques.

Fig. 8. shows the system response of 12% a sudden increase on the voltage reference and Fig. 9. represents the rotor angle after a short-circuit. The disturbance responses are improved, especially for the short-circuit disturbance, an improvement is considerably achieved.

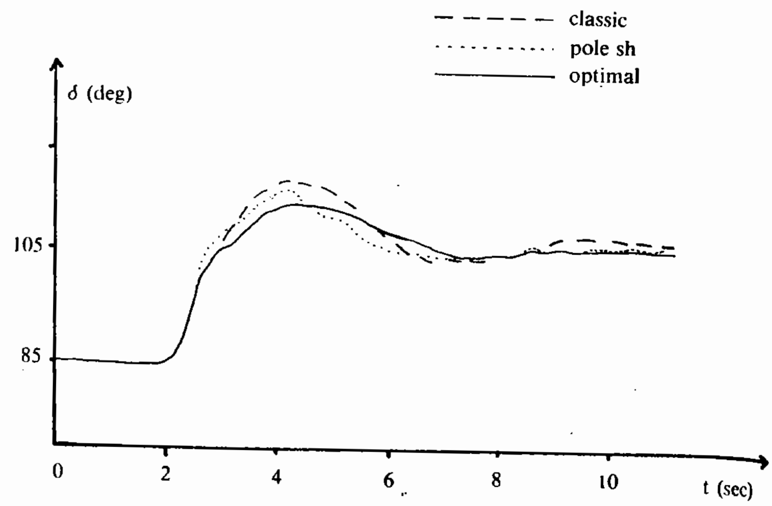

Fig. 8. System response to a-12% step in reference voltage

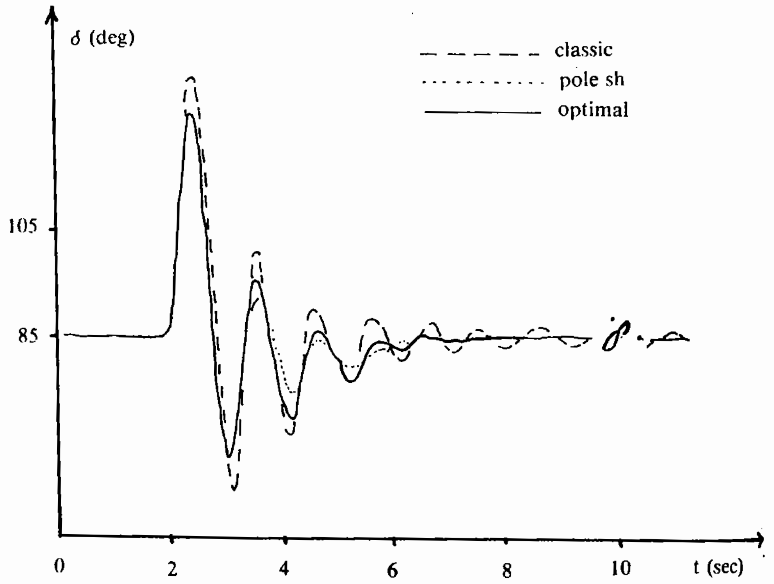

Fig. 9. Rotor angle after a short circuit

Conclusion

The adaptive stabilisers discussed in this paper have simple forms. The derived control laws are based on the linear system, however with certain engineering constraints, they are applicable on nonlinear systems. A very good damping of large system swings could be obtained.

A self-tuning property was demonstrated. An identification turn off during severe faults provided a fast convergence of the parameter variations.

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