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SELF-TUNING CONTROL APPLICATION TO A NUCLEAR POWER PLANT

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1. INTRODUCTION

Nowdays the use of nuclear power generation is spreading and the nuclear capacity grows beyond the minimum demand on the grid. The larger the fraction of nuclear generation in a power system, the more important it is for the nuclear units to be able to operate in a load-following mode. Inability of the plants to adjust to load changes and system's spinning reserve requirements will impose an upper limit on the nuclear share of the system.

In this paper a method is proposed to deal with this problem. A special kind of adaptive control i.e. self-tuning control is used to cope with this problem. The self-tuning controller with the generalized minimum variance method [1] is applied here due to its flexibility in load following situations.

A simplified but still reasonably realistic model of the nuclear power plant is simulated digitally. A direct control design based on this highly nonlinear, redundant, high-order model is hardly suitable to obtain a simple, adequate and robust controller that could be easily implemented on a process computer. Instead, in this paper, a controller is designed based on a simple low-order model (2nd-order model). Instead of the estimation of unknown process parameters, the control parameters are tuned online, so that the control input applied to the real plant is adapad at every sampling instant.

2. THE SYSTEM

The system considered here is a PWR power plant. A mathematical descrition of the system dynamics can be obtained from [2] .

The main disturbances are load variations that enter the model as variations of the percent steam flow P. Such a variation of the steam flow leads to an eqivalent variation of the average coolant temperature T_r. Without any closed-loop control, these variations of T_r and the resulting variations of the fuel temperature T_f and steam temperature T_s would be unacceptable because they produce thermal stresses and could lead to damage to the equipment involved. Therefore, the reactor coolant temperature T_r is chosen as the controlled variable in a load-following control system of a PWR power station.

The appropriate control variable considered in this application is the position of the(neutrons absorbing) control rods, measured as a number of displacement speps. Control rod withdrawl is necessary during a load increase to balance the change in reactivity due to feedback from the fuel and coolant temperatures. In the similar way, control rod insertion is also necessary during a load decrease.

The purpose of the control system is to hold the temperature T_r as near as possible to a time-varying reference value T_{rw} despite the disturbances.

3. CONTROL CONCEPT

3.1 Problem statement

A general discrete time model of the system to be controlled is of the form:

$$Ay(t)=q^{-k}Bu(t)+q^{-l}Dv(t)+C\xi(t) \quad ...(1)$$

where A,B,C, and D are polynomials in the backward shift operator q^{-1}, with $a_o=c_o=1$ and $b_o\neq0$, $d_o\neq0$ and k and l represent the process time delay in sample instants associated with u and v, respectively. y(t), u(t), and v(t) are the process output, input and measurable disturbance, respectively. $\xi(t)$is an uncorrelated zero-mean random sequence which disturbs the system but is not measurable. The arguement of the variables corresponds to the sampling instant.

A controller will be designed which minimises the following cost function:

$$I=E\left\{\phi^2(t+k)/Y^t\right\} \quad ....(2)$$

where $\phi(t+k)$ is a function of system output, input and setpoint w(t) given by:

$$\phi(t+k)=Py(t+k)+Qu(t)-Rw(t) \quad ....(3)$$

and $E\{/Y^t\}$ denotes the expectation value. This value is conditional on all data acquired up to time t. P,Q, and R are polynomials in the shift operator q^{-1} with $p_o=1$.

3.2 Controller design for known system parameters

It can be shown that the function of $\phi(t+k)$ can be written as follows.

$$\phi(t+k)=\overset{*}{\phi}(t+k/t)+F\xi(t+k) \quad ..... (4)$$

where $\overset{*}{\phi}(t+k/t)$ is the k-step ahead optimal predicted value of $\phi(t+k)$ at time t based on all data available up to time t and $F\xi(t+k)$ is the prediction error.
F is a polynomial in q^{-1} of order k-1 given by the identity:

$$\frac{PC}{A}=F+q^{-k}\frac{G}{A} \quad .... (5)$$

The prediction $\phi^*(t+k/t)$ is given by Eq.(6)

$$\phi^*(t+k/t)=\frac{1}{C}\left\{Hu(t)+Gy(t)+q^{k-1}Lv(t)+Ew(t)\right\} \quad ..... (6)$$

where H,G,L, and E are polynominals in q^{-1} and are given as:

$$H=FB+CQ$$
$$L=FD \quad ..... (7)$$
$$E=-CR$$

G is as defined in Eq.(5)

If the current value of the input u(t) is chosen such that

$$Hu(t)+Gy(t)+q^{k-1}Lv(t)+Ew(t)=0 \quad .... (8)$$

then the prediction $\overset{*}{\phi}(t+k/t)=0$, and the cost function as defined by Eq(2), will have been minimised. This controller contains both feedback terms (from y), feedforward terms (from v) and referenced signal terms (from w).

The closed-loop description is obtained by substituting for u(t) from the control law of Eq.(8) into Eq.(1), to give, after some manipulations:

$$y(t)=\frac{RB}{BP+QA}w(t-k)+\frac{QD}{BP+QA}V(t-1)+\frac{BF+QC}{BP+QA}\xi(t) \quad .... (9)$$

This equation shows how the closed-loop performance is influenced by the polynomials P,Q, and R in the cost function given by Eq.(3).

For a zero steady-state error, the reference weighting polynomial R can be chosen sucl that

$$\left[\frac{BR}{BP+QA}\right]_{q^{-1}=1} = 1 \quad .... (10)$$

Furthermore, state disturbance rejecttion can be ensured by requiring that

$$\left[\frac{QD}{BP+QA}\right]_{q^{-1}=1} = 0$$

When the system parameters are known, Eq.(5) may be solved for G and F, and control law polynomials of Eq.(8) found for the given P, Q, and R.

3.3 Controller design for unknown system parameters.

When the system parameters are not known the approach adopted in the previous section cannot be used for the controller design. However, if a digital computer is used for control it is possible to estimate process related parameters on-line, and required controller to provide a specified performeance can be determined automatically.

After appropriate use of Eq.(6), Eq.(4) can be rewritten to give the current value of the function $\phi(t)$ as:

$$\phi(t)=Hu(t-k)+Gy(t-k)+Ew(t-k)+Lv(t-1)+F\xi(t)+(1-c)\,\phi^{*}(t/t-k) \quad .... (12)$$

If u(t-k) was chosen to satisfy Eq.(8), then $\phi^{*}(t/t-k)=0$, and

$$\phi(t)=Hu(t-k)+Gy(t-k)+Lv(t-1)+Ew(t-k)+F\xi(t) \quad ..... (13)$$

Also since $\phi(t)$ can be evaluated from Eq.(3), Eq.(13) can be used to estimate the parameters of H,G,L,E, and F for the self-tunung controller. Several algorithms are available for the parameter identification. [3] However, for on-line identification and minimal computation, the extended least-squares method is appropriate for identifying the coefficients of H,G,L,E, and F.

And from Eq.(8) u(t) is chosen such that

$$\hat{\phi}^{*}(t+k/t)=\hat{H}(t)u(t)+\hat{G}(t)y(t)+\hat{L}(t)v(t+k-1)+\hat{E}(t)w(t)=0 \quad ..... (14)$$

where $\hat{H}(t)$, $\hat{G}(t)$, $\hat{L}(t)$ and $\hat{E}(t)$ are estimated values of H,G,L and E at the t-th sampling instants.

4. APPLICATION TO NUCLEAR POWER PLANT

A mathematical model of the nuclear power plant consists of a large number of linear differential equations, together with some nonlinear effects, two transport lags, and some algebraic equations. This system is simulated on a digital computer. The transport lags are simulated by second-order pade approximations[4].

Thus a ninth-order model is employed.

A sampling period of 3sec. is found to be appropriate, giving rise to a pure time delay in the model. The sampling period of 3sec. is relatively short compared with the response time of the system. With very short sampling periods, control difficulties can result, and in some self-tuning applications a sampling period approaching the system fundamental time constant has been used. The sampling period of 3 sec. adopted here not give rise to any control difficulties. The desired(T_{rw}) and the uncontrolled real(T_r) coolant temperature are shown in Fig.1. The controlled temperature together with its desired value are shown in Fig.2. During transient periods a static error can be observed, due to the perturbations of estimated parameters during initial transient periods.

5. CONCLUSION

An adaptive control system for the nuclear and thermal parts of a PWR nuclear power plant is developed with the use of a self-tuning algorithm based on a generalized minimum variance. This control system is also designed with a second-order linear approximate model of the complex system dynamics.

The study is mainly a preliminary investigation of the application possibilities of an adaptive control method. The results are quite satisfactory and show that, provided suitable safeguards are incoporated against a malfunction, the use of adaptive control is feasible, and in many ways, an attractive proposition.

6. REFERENCES

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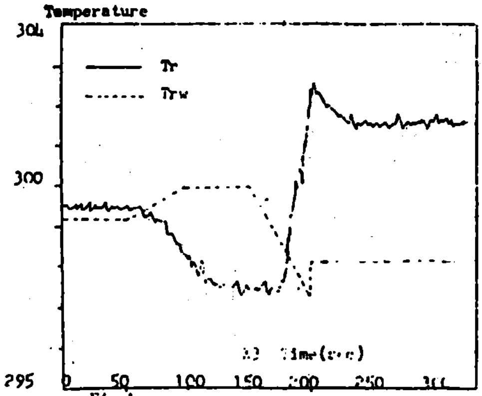

Fig.1

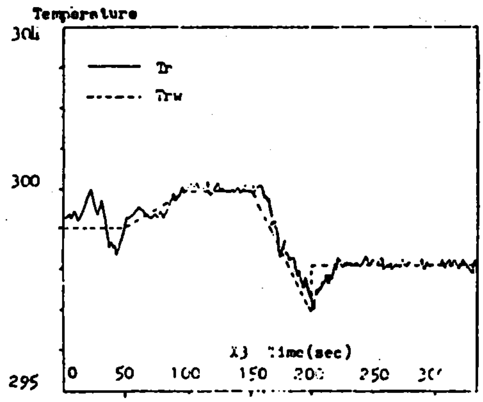

Fig.2