Design of Model Predictive Controller of Nuclear Steam Generator

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1. Introduction

MPC is applied to the steam generator feedwater and level control system. Two MPC controllers are designed. First, the MPC controller of the feedwater station is determined. Then another MPC controller for the level control is designed. The constraints arising from actual operation are taken into account. And through the simulation it is found that the designed MPC controllers give a good dynamic performance.

2. MPC Controller for Steam Generator Feedwater Control System

2.1 Steam generator feedwater and level control system

The overall system is a kind of regulating system in that the level variation should be kept constant. The steam flow rate change and other feedbacked signals generate a driving signal that controls the feedwater flow rate to keep the level constant. The feedwater station is a servo system in which the feedwater flow rate follows the steam flow rate.

The steam generator is represented by a set of MIMO (multi input, multi output) transfer functions which reflect all the important thermal hydraulic behavior of the system [1],[2].

2.2 MPC controller

MPC presents a series of advantages over other methods, amongst which the following stand out: (1) it handles multivariable control problems naturally; (2) it can take account of actuator limitations; (3) it allows operation closer to constraints, which frequently leads to more profitable operation; (4) control update rates are relatively low in these applications, so that there is plenty of time for the necessary on-line computation.

The importance of being able to take account of constraints arises for several reasons. The reason cited most often is that the most profitable operation is often obtained when a process is running at an output constraint of controlled variable, or even at more than one output constraint. Constraints on the control signals, that is, inputs to the process, or manipulated variables, are also present. Most commonly these constraints are in the form of saturation characteristics and limited slew rates [3]. In addition, in the nuclear plant, many constraints are imposed both on controlled and manipulated variables to satisfy the safety issues.

2. 3 Application to steam generator feedwater and level control system

To apply MPC method to the steam generator feedwater and level control, the overall system structure is rearranged as in Figs. 1(a) and (b).

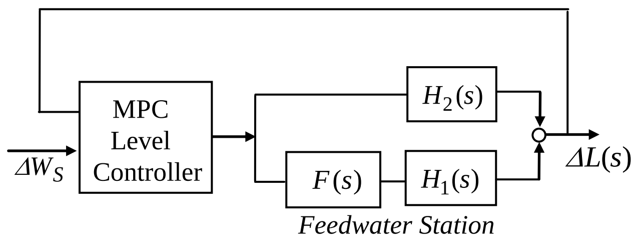

Fig. 1(a). Overall system

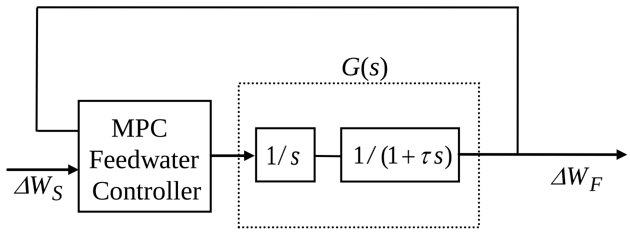

Fig. 1(b). Feedwater station, $F(s)$, of Fig. 1(a)

2.3.1 Feedwater controller

The MPC structure of the feedwater station is described in Fig. 1(b), and the design of MPC controller is an optimization problem of:

Determine $\Delta u(k|k)$, $\Delta u(1{+}k|k)$, $\cdots, \Delta u(m\text{-}1\text{-}k|k)$

To minimize the cost of :

$$\sum_{i=0}^{p-1}\left[\sum_{j=1}^{n_y}\left|w_{i+1,j}\left(y_j(k+i+1|k)-r_j(k+i+1)\right|^2\right]$$
$$+\sum_{i=0}^{p-1}\left(\sum_{j=1}^{n_u}\left|w_{i,j}\left(\Delta u_j(k+i|k)\right|^2\right)\right.$$
$$+\sum_{i=0}^{p-1}\left(\sum_{j=1}^{n_u}\left|w_{i,j}\left(u_j(k+i|k)-u_{j,target}(k+i)\right|^2\right)\right. \qquad (1)$$

With the horizons of p=10, m=2, and sampling period of T_s =0.1sec, the weights are determined by the modified genetic algorithms developed in Ref. [4]. For the weights of $\left[w_y\ w_{\Delta u}\ w_u\right]$ = [2 4 1], with the constraints of $|u| \le 1$, $|\Delta u| \le 3$, the system responses are presented in Fig. 2.

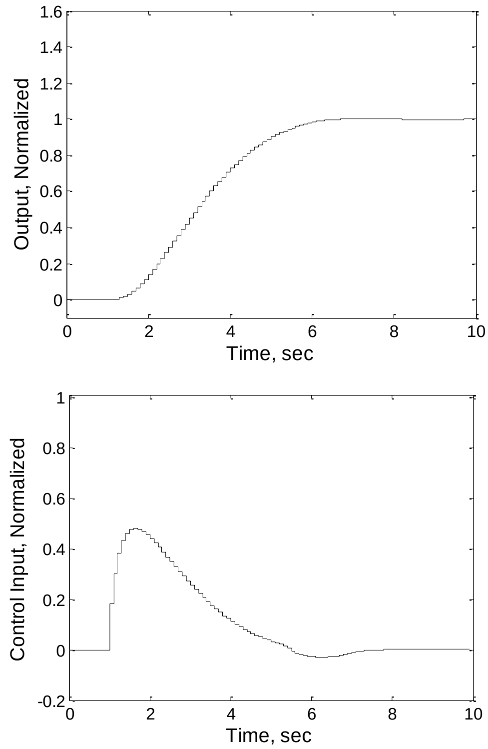

Fig. 2. System responses of feedstation - output and control effort

2.3.2 Level controller

The relation between the level and these variables in the steam generator is:

$$\Delta L(s) = \Delta W_S(s) \cdot F(s) \cdot H_1(s) + \Delta W_S(s) \cdot H_2(s) + O(s) \quad (2)$$

The calculation procedure for determining the MPC level controller is the same as that of feedwater controller. With the weights of $\left[w_y \; w_{\Delta u} \; w_u \right]$=[10 16 1], the MPC controller is described by the 9th order transfer functions.

Figure.3 shows the level variation when the power ramp changes from 5% to 10% during 60seconds. The feedwater follows the steam flow rate almost exactly. Although the level increases rather rapidly at the initial period, due to the low power level, the peak value of level is still much less than the permitted set point value and it settles down from about 400 seconds into the transient.

3. Conclusion

A nuclear steam generator presents difficulties of level control, particularly at low power. Because of the adverse thermal hydraulic effects, the steam generator shows non-minimum phase, in terms of control, at low power, and the control is made by an operator.

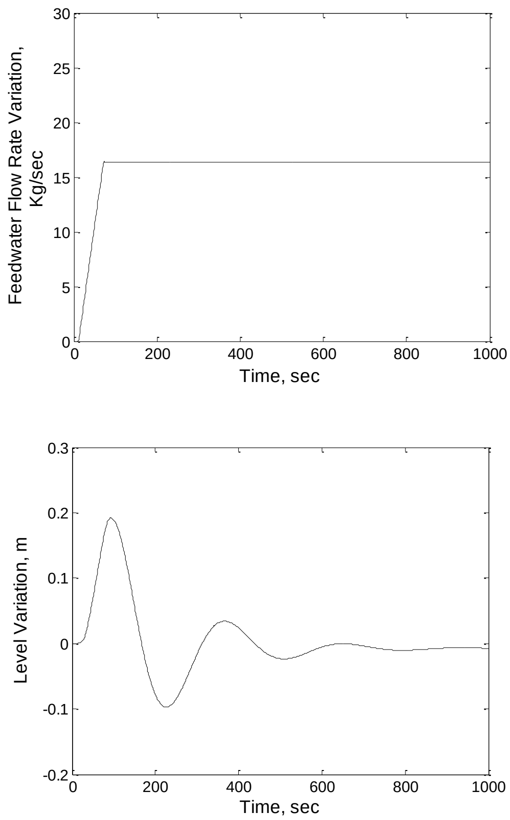

Fig. 3. System responses – feedwater flow rate variation and level variation

The MPC strategy is very similar to the control strategy of the operator. The operator knows the desired reference trajectory for a finite control horizon and, by taking into account the plant characteristics, decides which control actions to take to follow the desired trajectory.

For the application of MPC method to the control of steam generator level, the design procedure is divided into two steps. First, the MPC controller of feedwater station is determined, and then the MPC controller of the whole system, including the feedwater station, is designed. The simulations show that the resulted controllers give good dynamic performances.

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