MULTIVARIABLE ROBUST CONTROL OF A POWER PLANT DEAERATOR

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Abstract– The paper addresses the design of a robust controller for the deaerator of the Experimental Breeder Reactor-II (EBR-II) using the Linear Quadratic Gaussian with Loop Transfer Recovery (LQG/LTR) procedure. At present, classical PI controllers are used to control the deaerator. When the operating condition changes, the system is disturbed, or a fault occurs, the PI controllers may fail to maintain the desired performance which in turn deteriorates the performance of other components of the condensate system. This was a motivation to design a robust controller that can accommodate system faults and obtain a reasonable behavior for a wide range of model uncertainty. The designed controller has the following desirable features: (a) it provides the desired performance despite a considerable change in the operating condition, (b) it accommodates some of the failures that can occur, and (c) it provides the choice of penalizing one variable over another. The controller design is tested for robustness by varying the system operating condition and simulating a steam valve failure. The set of non-linear simulations using the Modular Modeling System (MMS) and the Advanced Continuous Simulation Language (ACSL) is included.

Keywords– Nuclear power plant control; power plant control; deaerator control; robust control.

1. INTRODUCTION

The Penn State Intelligent Distributed Control Research Laboratory (IDCRL) is equipped with a modern distributed microprocessor-based control system which is interfaced to real-time simulations of power plant processes [1]. Research into implementation issues of hierarchical and distributed control for large-scale power plant systems are now more fully explored at the university level. The microprocessor-based control system has also been interfaced to the PSU TRIGA nuclear research reactor and enables research in optimal, robust, intelligent, and other advanced control techniques for nuclear power plants.

This paper deals with one of the control techniques, namely ***multivariable robust control***, developed for the Experimental Breeder Reactor-II (EBR-II). The EBR-II is a small but complete nuclear power plant. The Department of Energy (DOE) Argone National Laboratory EBR-II in Idaho Falls, Idaho delivers 20 Mwe to the commercial power grid. The condensate system is one of six subsystems that compose the steam plant.

The deaerator is the heater number 2 in the condensate system. It is a vertical open feedwater heater, in which the feedwater and the condensing steam come in contact and are mixed. Its purpose is to improve plant efficiency and to provide the necessary head for the feedwater pump by performing three major services:

1- removing non-condensable gases;
2- heating the feedwater; and
3- providing feedwater storage [2].

The deaerator is modeled using the Modular Modeling System (MMS) [2] and the Advanced Continuous Simulation Language (ACSL) [3]. At present, the deaerator is controlled using conventional PI controllers which generally fail to preserve a desired performance when uncertainties occur or the operating conditions change.

To fulfill different design objectives, many control theories evolved in the past decades, i.e., classical control, adaptive control [4], optimal control [5], etc. In the past decade, the theory of robust control came into the picture with many desirable features such as accommodation of plant uncertainties which used to be a main concern for many years. Some applications of this theory have been reported [6,7].

This paper presents a study to design a robust controller for the deaerator using the Linear Quadratic Gaussian with Loop Transfer Recovery (LQG/LTR) procedure. The main purpose of the study is to develop a multivariable controller that accommodates a wide range of model uncertainty, provides a "good" performance in different operating conditions, and accommodates some of the failures that might occur.

In this paper, Section 2 reviews the control design method, Section 3 describes the model, and Section 4 presents the simulation results. The study conclusions are in Section 5.

2. ROBUST CONTROL DESIGN VIA LQG/LTR

Figure 1 shows a block diagram of a standard feedback configuration where G denotes the plant, K is a dynamic controller, R is a command signal, D is the disturbance, and N is the measurement noise.

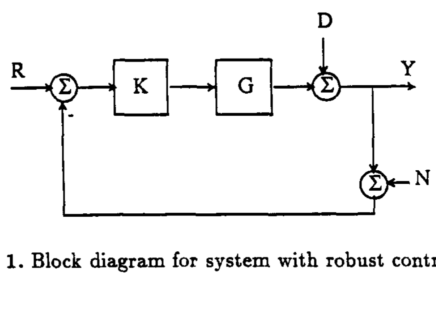

Figure 1. Block diagram for system with robust controller

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The goal is to construct a controller $K(s)$ that compensates for all perturbed processes $G'(s)$, of $G(s)$, provided that $G'(s)$ does not stray too far from $G(s)$. Thus, the control system design objectives in the presence of uncertainty are [8]

i. For nominal feedback system, $GK(I+GK)^{-1}$, stability is achieved.

ii. Stability robustness is also achieved; the perturbed system, $G'K(I+G'K)^{-1}$, is also stable for all possible G' allowed by the uncertainty bounds.

iii. Performance objectives are satisfied for all possible G' allowed by the uncertainty bound; the command is followed nicely, the disturbance is attenuated, and the performance is insensitive to sensor noise.

iv. Avoid "excessive" control to prevent non-linearities (and instabilities) due to control input commands.

2.1. Stability Conditions

In controller design, the stability of the closed loop system is a primary concern. This section is devoted to stating the robust control stability conditions. Detailed derivation is found in [9]. Without loss of generality, a perturbed process is represented by $G'(s) = [I+\Delta(s)]G(s)$, where Δ represents the multiplicative uncertainty.

The stability conditions are given by (i) and (ii) above which mean that in Single-Input-Single-Output (SISO) case $\det(I+GK)$ and $\det(I+G'K)$ are both non zero for all possible $G'(s)$. This is the same as [10]

$$0 \; < \; \underline{\sigma}[I+GK]$$

where $\underline{\sigma}$ denotes the minimum singular value of the given matrix. Setting the bound on the uncertainty to be

$$\overline{\sigma}(\Delta) \; < l_m(\omega) \qquad \forall \, \omega \geq 0$$

where $\overline{\sigma}$ is the maximum singular value, Δ represents the multiplicative uncertainty, and l_m is the bound, we obtain

$$\overline{\sigma}\left[GK(I+GK)^{-1}\right] \; < \frac{1}{l_m(\omega)} \tag{1}$$

for $0 \leq \omega \; < \infty$.

2.2. Performance Conditions

The performance condition is given by the design objective (iii), which means that in SISO case the eigenvalues should be less than a chosen negative value. In the Multi-Input-Multi-output (MIMO) case, this could be expressed as [8]

$$\begin{aligned} L(\omega) \; &\leq \; \underline{\sigma}[I+G'K] \\ &\leq \; \underline{\sigma}[I+(I+\Delta)GK]. \end{aligned}$$

where $L(\omega)$ is a (large) positive function representing the lower bound. Using properties of singular values and equation (1), we get

$$\frac{L}{1-l_m} \; \leq \; \underline{\sigma}[GK(j\omega)], \tag{2}$$

for all ω such that $l_m(\omega) \; < 1$ and $\underline{\sigma}[GK(j\omega)] \gg 1$.

Equation (2) is a MIMO generalization of the known SISO design rule: if the nominal loop gains are made sufficiently large, then the model variations can be compensated and the performance objectives can be met. The Singular Values play an important role in the design much like Bode plot for SISO. $\overline{\sigma}(I+GK)$ is the minimum return difference magnitude of the closed loop system, $\underline{\sigma}(GK)$ and $\overline{\sigma}(GK)$ are the minimum and the maximum closed-loop gains, and $\overline{\sigma}[GK(I+GK)^{-1}]$ is the maximum closed-loop frequency response. These singular values can be plotted as a function of frequency to analyze the MIMO design. The plots sometimes are called *σ-plots* [8]. Figure 2 is an example of σ-plot that displays equations (1) and (2) for the robust control design graphically.

The designer must find a loop transfer function matrix GK for which the loop is stable and whose maximum and minimum singular values clear the ones given by conditions (1) and (2). The high bound is mandatory but the low is only desirable for good performance, and, of course, l_m influences both of them.

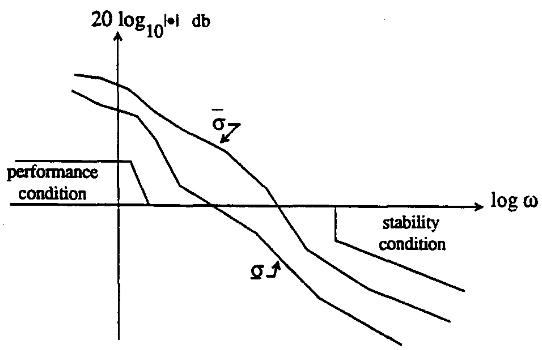


Figure 2. Design trade-off for GK

2.3. The LQG/LTR Design Procedure

The design procedure involves two steps. The first step is the filter design and the second step is the controller design.

a. Filter design

Consider the following model:

$$\dot{x} = Ax + Bu + Gw \tag{3}$$

$$z = Hx + \mu I v \tag{4}$$

$$y = Cx \tag{5}$$

where I is the identity matrix, w and v are zero mean Gaussian white-noise processes with covariances Q and R, respectively, z are the measurements available, y are the controlled plant outputs, and μ and G are the design parameters that are used in the LQG/LTR procedure to synthesize a compensator that would meet the desired specifications. We will consider $C = H$ for convenience. The Kalman filter equations for the state estimate, the error, and the gain are

$$\dot{\hat{x}} = A\hat{x} + K_F[z - H\hat{x}] \tag{6}$$

$$\dot{e} = [A - K_F H]e + Gw - K_F v \tag{7}$$

$$K_F = PH^T R^{-1} \tag{8}$$

where R, a function of μ, is the measurement noise covariance and P is the solution of the Riccati equation

$$\dot{P} = AP + PA^T + GQG^T - PH^TR^{-1}HP, \ P(0) = P_o. \quad (9)$$

The goal is to design a Target Feedback Loop (TFL), G_{KF}, with desired loop shape using the Kalman filter and vary the Kalman filter gain, K_F, in order to get a desired loop shape for $G_{KF}(s)$.

The filter design step is known as the Linear Quadratic Gaussian (LQG) step which, as the name suggests, consists of a finite dimensional linear plant model, a quadratic performance measure, and a Gaussian distributed noise signal.

b. Controller design

This step is an optimal control problem. We need to solve for the full state feedback regulator gains K_O via the optimal control technique to recover for the TFL transfer function. The optimal control performance measure is chosen as

$$J = \int_0^\infty [qy^TQ_oy + \rho u^TR_ou] \, dt \quad (10)$$

where T denotes the matrix transpose,

$$Q_o = Q_o{}^T \geq 0 \quad (11)$$

$$R_o = R_o{}^T > 0 \quad (12)$$

and $q > 0$ and $\rho > 0$ are scalar design parameters. The optimal control law is given by

$$u = -K_Ox$$

with

$$K_O = R_o{}^{-1}B^TP$$

where P satisfies the algebraic Riccati equation

$$0 = PA + A^TP + qC^TQ_oC + \frac{1}{\rho}PB^TR_o{}^{-1}BP.$$

The dynamics of the robust controller $K(s)$ are shown in Figure 3 where K_F is found in the first step and K_O is obtained from the second step. If one is able to

i. adjust K_F so that $G_{KF}(s)$ has the desired loop shape; and

ii. construct a K_O so that $GK_O(s) \simeq G_{KF}(s)$ over the band of frequencies relevant to our concerns of performance and robustness, then the $K(s)$ is a robust compensator.

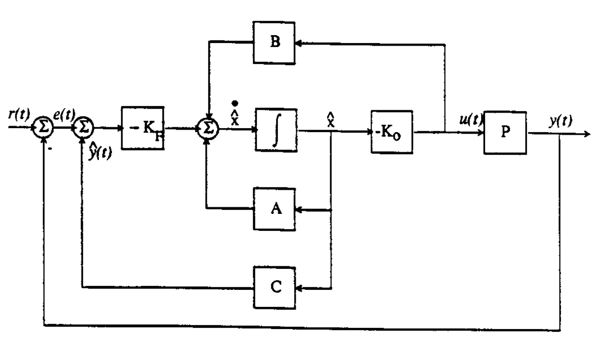


Figure 3. Dynamics of the robust controller

3. THE DEAERATOR MODEL

The dynamics of the deaerator is summarized here. A detailed development of the model mathematics is given in [1,9].

3.1. The Non-linear Model Equations

The first differential equation is obtained using the conservation of mass

$$\dot{h} = \frac{1}{\frac{\partial\rho}{\partial h}} \left[\frac{w_e - w_l}{3600 \, v_t} - \frac{\partial\rho}{\partial p} \dot{p} \right]. \quad (13)$$

Using the conservation of energy under the assumption of fixed control volume with no heat transfer or shaft work, and neglecting kinetic energy effect, the second differential equation is found to be

$$\dot{p} = \frac{(w_e - w_l)\left[\frac{\rho}{\frac{\partial\rho}{\partial h}} + h \right] - (w_eh_e - w_lh_l)}{3600 \, v_t \left[\frac{\rho\frac{\partial\rho}{\partial p}}{\frac{\partial\rho}{\partial h}} + \frac{144}{778} \right]} \quad (14)$$

where

$$w_e = w_c + w_s \quad (15)$$

$$w_c = c_{qc}\sqrt{\rho_c(p_c - p)} \quad (16)$$

$$w_s = \frac{19}{30}c_{vs}\sqrt{\rho_s(p_s - p)} \quad (17)$$

$$c_{qc} = \frac{1}{\sqrt{\frac{1}{c_{vc}{}^2} + \frac{1}{c_{pc}{}^2}}} \quad (18)$$

$$c_{vs} = y_s{}^3c_{vsmax} \quad (19)$$

$$c_{vc} = y_c{}^3c_{vcmax}. \quad (20)$$

In the above equations, the variables are defined as follows:

p : pressure ($psia$)
w : flowrate (lb/hr)
h : enthalpy (Btu/lbm)
y : valve position (in percent)
ρ : bulk density over the entire vessel (lbm/ft^3)
w_e : flowrate entering, feedwater + steam, (lbm/hr)
w_l : flowrate leaving (lbm/hr)
h_e : enthalpy of fluid entering the vessel (Btu/lbm)
h_l : enthalpy of fluid leaving the vessel (Btu/lbm)
v_t : total volume of deaerating and storage tanks (ft^3)
c_v : valve conductance

c_p : pipe conductance
c_{vmax} : maximum valve conductance

where the subscript c stands for condensate and s stands for steam [2]. The unit of conductance is $\left((\frac{lb}{hr}) \sqrt{\frac{ft^3}{psi}} \right)$

3.2. The linear model equations

Equations (13)-(20) describe the deaerator model for controller design. These equations are linearized around an equilibrium point (set point) to obtain the linear description of the system. The model is linearized using ACSL. The linearization is dependent on five variables: the pressure in the deaerator, the enthalpy in the deaerator, the feedwater level, the condensate valve position, and the steam valve position. For every equilibrium point, there is a set of these five variables and hence a resulting linear system. For the normal operation, the deaerator equilibrium is given by

$p =$ 165.0 *psia*
$h =$ 342.5 *Btu/lbm*
$y_c =$ 76.6215 (*percent open*)
$y_s =$ 75.1740 (*percent open*)
level = 144.0 *inches*.

The resulting state space representation of the deaerator model is, then, given by:

$$\dot{x}(t) = Ax(t) + Bu(t) \tag{21}$$
$$y(t) = Cx(t). \tag{22}$$

where x, u, and y are, respectively, state, control, and output vectors. The deaerator is in general a second order, multivariable, and highly non-linear system. The states are pressure and enthalpy, the outputs are pressure and level, and the manipulated or control variables are condensate valve and steam valve positions. For the above linearized model, the matrices A, B, and C at the normal operating condition are found by ACSL and they are

$$A = \begin{pmatrix} -1.9 \times 10^{-3} & 0 \\ -1.0 \times 10^{-3} & 0 \end{pmatrix} \tag{23}$$

$$B = \begin{pmatrix} 1.8716 & -0.8295 \\ 0.9905 & -0.4822 \end{pmatrix} \tag{24}$$

$$C = \begin{pmatrix} 1.0000 & 0 \\ 8.2400 & -15.3110 \end{pmatrix}. \tag{25}$$

4. SIMULATION RESULTS

In practice, the open-loop deaerator is marginally stable. Therefore, PI controllers were first designed not only to stabilize it but also to improve performance to a certain extent. The PI controllers that are used in practice were designed for the normal operating condition of the deaerator which is 165 *psia* for pressure and 144 *inches* for level. However, this operating point changes whenever a failure occurs or a different operating condition is desired. In such situations, the PI controllers cannot guarantee even the stability of the system unless the proportional and integral gains are changed appropriately. The robust controller, on the contrary, is expected to perform "well" within a range of an uncertainty region.

4.1. Robust Controller Design

The open-loop system has no zeros in the right half plane and the transfer function has no time delay, hence, the system is clearly of minimum phase. Moreover, the number of inputs is equal to the number of outputs. Therefore, the LQG/LTR theory can be applied to design a robust controller for the deaerator. The design parameters were chosen to be

$$Q = B \begin{pmatrix} 10 & 0 \\ 0 & 2 \end{pmatrix} B^T \qquad R = \begin{pmatrix} 1 & 0 \\ 0 & 1 \end{pmatrix}$$
$$Q_o = C^T C \qquad R_o = \begin{pmatrix} 1 & 0 \\ 0 & 1 \end{pmatrix}$$

where Q and R are the Kalman filter covariance matrices in equation (9) and Q_o and R_o are the state and the control weighting matrices in equation (10) for the optimal control. The weighting matrix for the loop transfer recovery is chosen to be

$$Q_{LTR} = Q_o + q\, C^T W C,$$

where W is a weighting matrix. A good performance and robustness was obtained using $q = 1000$ and

$$W = \begin{pmatrix} 10^4 & 0 \\ 0 & 10^{-15} \end{pmatrix}.$$

The matrix W is not included in most presentations of the LQG/LTR procedure. The reason for inserting the matrix W is that we wanted pressure to be more tightly controlled than level.

The robust controller presented in Section 2.3 is designed using MATLAB Robust Control Toolbox [11]. The closed-loop deaerator control system is

$$A_o = \begin{pmatrix} -95.3 & 41.7 & -2904.8 & 19.9 \\ 41.7 & -19.6 & 1262.9 & 34.8 \\ 1.9 & -0.8 & -5.3 & 3.5 \\ 1.0 & -0.5 & -2.1 & 0.5 \end{pmatrix}$$

$$B_o = \begin{pmatrix} 3.03 & 0.90 \\ -0.40 & 1.36 \\ 3.46 & 0.23 \\ 1.85 & 0.03 \end{pmatrix}$$

$$C_o = \begin{pmatrix} 95.3 & -41.7 & 2894.3 & -6.2 \\ -41.7 & 19.6 & -1273.7 & -14.0 \end{pmatrix},$$

resulting in closed-loop eigenvalues of

$$\lambda_{1,2} = -56.893 \pm i\, 56.893$$
$$\lambda_{3,4} = -1.742 \pm i\, 1.742$$
$$\lambda_{5,6} = -0.550 \pm i\, 0.550$$

$$\lambda_{7,8} = -0.676 \pm i\,0.676$$

Which clearly indicates that for the nominal feedback system stability is obtained and, hence, our first design objective is achieved.

4.2. Robustness Verification

The robustness of the designed controller is verified via linear simulation and non-linear simulation.

a. Linear simulation

The linear simulation was done using MATLAB [11]. In this simulation, a set of four extreme operating conditions was chosen for the robustness verification as shown in Figure 4.

Point O in Figure 4 represents the normal operating condition for which the controller was designed. The non-linear deaerator was operated at the four extreme operating points Q, R, S, and T in Figure 4. For each point, a linearized model was obtained using ACSL. The dynamics of the system are different from one operating point to another due to non-linearities. The difference in dynamics between point O and some of the points in the grid is significant and a non-robust controller is expected to fail if forced to operate in such operating conditions.

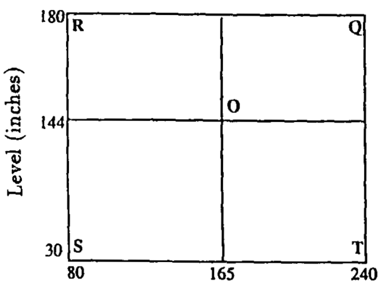
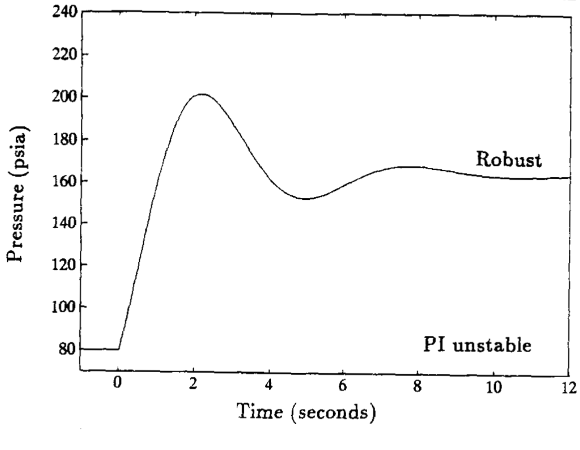


Figure 4. Operating conditions for robustness verification

A comparison between the robust controller and the PI controller is illustrated by operating the system at points R and Q. The resulting performances are shown in Figures 5 and 6.

Figure 5 represents the transition from the operating point R (80 *psia*, 180 *inches*) to the normal operating point O (165 *psia*, 144 *inches*). It clearly shows the advantage of the robust controller. While the PI controlled system becomes unstable, the robust controlled system preserved the desired performance despite the significant change in the operating condition.

Figure 6 represents the transition from the operating point Q (240 *psia*, 180 *inches*) to the normal operating point O (165 *psia*, 144 *inches*). In Figure 6, with the PI controllers, a steady state error was observed. This error was very large especially in the level response. In contrast, the robust controller kept a desirable performance despite the system variation.



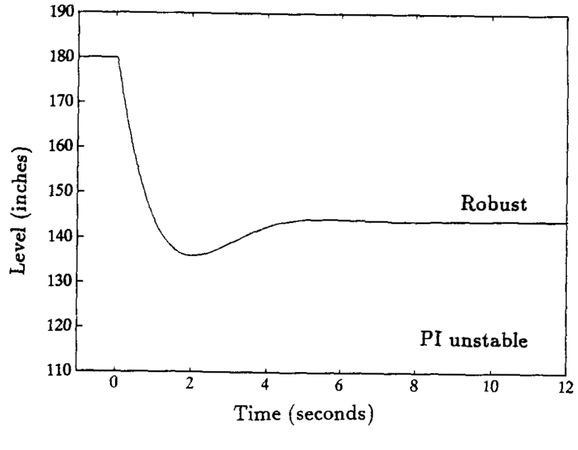


Figure 5. Output at operating point R: a) pressure, b) level

b. Non-linear simulation

Since the deaerator model is non-linear, the non-linear simulation represents a more realistic verification of the robust controller. The non-linear simulation was conducted by implementing the controller on the MMS/ACSL deaerator model and the behavior was observed for different operating conditions. The performance of the robust controller is compared to that of the PI.

The first non-linear simulation for robustness verification is the failure in the steam valve. This valve is assumed to fail at 10% open which reduces the amount of steam entering the deaerator and, consequently, the pressure will drop. Figure 7 shows the plot of the deaerator pressure for the case of robust control and the case of PI control. The resulting level and condensate valve position for both cases are shown in Figure 8.

Figures 7 and 8 show that the robust controller can also better accommodate failures in the system. During the steam valve failure, the robust controller succeeded in reducing the rate of pressure decrease by sacrificing the feedwater level. By reducing the flow of relatively cool condensate in proportion

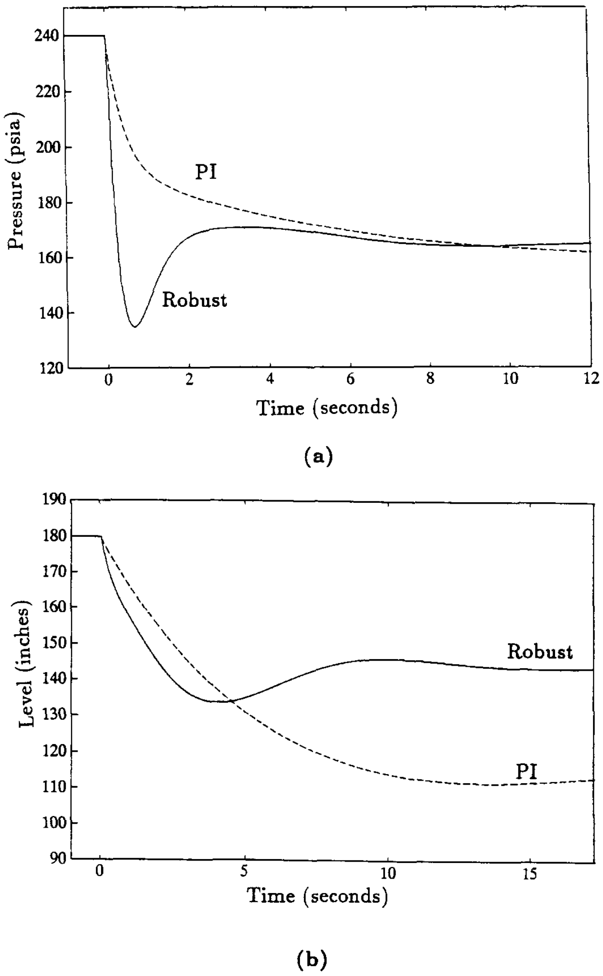


Figure 6. Output at operating point Q: a) pressure, b) level

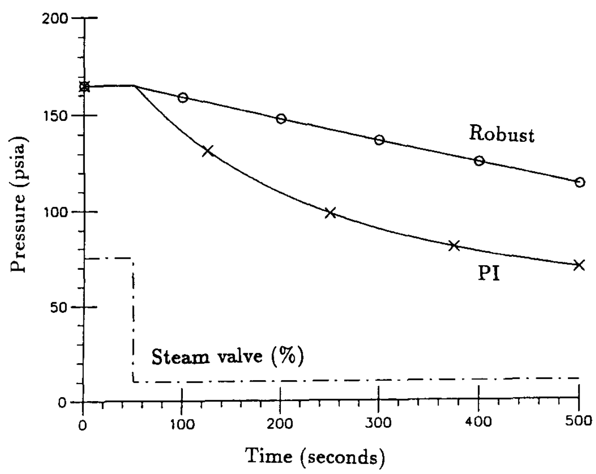


Figure 7. Deaerator pressure during steam valve failure

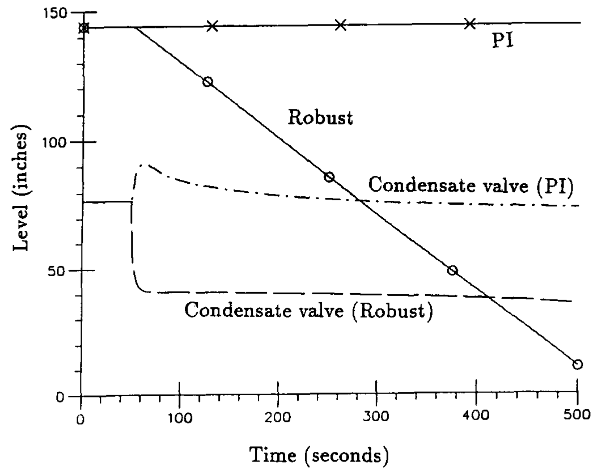


Figure 8. Deaerator level during steam valve failure

to the reduction in steam flow, pressure can be maintained for a longer time while level is sacrificed. In contrast, in the case of the PI controllers, the pressure decreased relatively fast because the feedwater level was not sacrificed. This brings up another advantage of the robust control which is the option of giving more importance to one variable over another. In this case, pressure control has the higher priority.

The second non-linear simulation is a step change in the pressure setpoint from the normal operating condition pressure (165 *psia*) to 180 *psia*. The deaerator pressure behavior is plotted in Figure 9. The figure shows that even in normal step

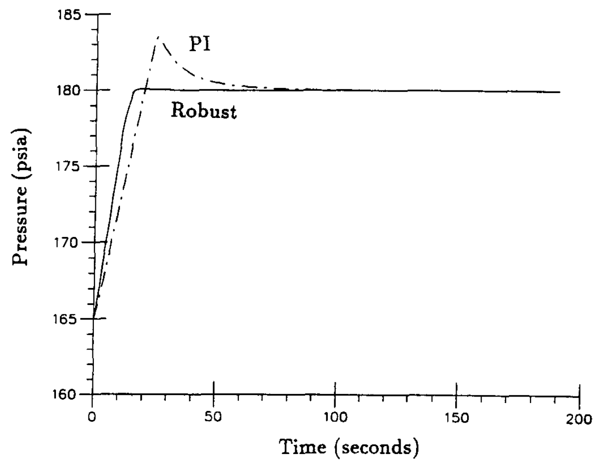


Figure 9. Deaerator step change from 165 *psia* to 180 *psia*

changes, the robust controller has a more desirable response than the PI, i.e., faster response with no overshoot.

The robust controller was also designed for the plant (deaerator) when it has embedded classical PI controllers, resulting in a Multi-Input-Multi-Output-Multi-layer (MIMOM-L) control [12,13]. Although not shown here, the robustness of the controller was verified when the PI feedback loop failure was introduced.

5. CONCLUSIONS

Application of the LQG/LTR robust control approach to the deaerator has been demonstrated via linear and non-linear simulations. The resulting controller was compared to the conventional PI. The linear simulation was used for the controller design and initial testing. The robustness of the controller was verified by modifying the operating conditions and examining the sensitivity of the system. Two non-linear simulations were also conducted: a steam valve failure and a pressure step change.

The robust controller was demonstrated to have more desirable performance and robustness in all the simulated cases. It was also shown to be fault accommodating.

ACKNOWLEDGEMENTS

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REFERENCES

[1] R. M. Edwards, J. A. Turso, K. Y. Lee, H. E. Garcia, and A. Ray, "The Penn State Intelligent Distributed Control Research Laboratory," *IEEE Power Engineering Society Winter Meeting*, New York, NY, January 26-30, 1992, # 92 WM 075-2-EC.

[2] Modular Modeling System (MMS-02) Vols. 1-3b, Babcock and Wilcox Corporation, Lynchburg, Virginia, 1985.

[3] ACSL Reference Manual, Mitchell and Gauthier Associates, Concord, Mass., 1987.

[4] K. S. Narendra and A. M. Annaswamy, *Stable Adaptive Systems*, Englewood Cliffs, New Jersey: Prentice-Hall Inc., 1989.

[5] D. E. Kirk, *Optimal Control Theory: an Introduction*, Englewood Cliffs, New Jersey: Prentice-Hall Inc., 1970.

[6] P. Dorato, *Robust Control*, vol. 1, New York, New York: IEEE Press, 1985.

[7] P. Dorato, *Robust Control*, vol. 2, New York, New York: IEEE Press, 1987.

[8] J. C. Doyle and G. Stein, "Multivariable Feedback Design: Concepts for a Classical/Modern Synthesis," *IEEE Trans. Automat. Contr.*, vol. AC-26, pp. 4-16, Feb. 1981.

[9] A. Ben-Abdennour, "Robust Control of the EBR-II Deaerator Using LQG/LTR," A Master's Thesis in Electrical Engineering, The Pennsylvania State University, December 1991.

[10] J. M. Maciejowski, *Multivariable Feedback design*, Reading, Mass.: Addison-Wesly Publishers Ltd., 1990.

[11] PC-MATLAB, The Mathworks, Sherborn, Massachusetts, 1987.

[12] A. Ben-Abdennour, R. M. Edwards, and K. Y. Lee, "MIMOML Robust Control for Accommodating EBR-II Feedwater System Faults," *AI91: Frontiers in Innovative Computing for the Nuclear Industry*, Jackson, Wyoming, September 1991.

[13] R. M. Edwards, A. Ben-Abdennour, and K. Y. Lee, "Robust Control Design Verification Using the Modular Modeling System," *EPRI 1991 International Conference on Power Plant & Power System Training, Simulators, & Modeling*, Miami Beach, Florida, April 1991.

BIOGRAPHIES

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He has been on the faculties of Michigan State University, Oregon State University, University of Houston, and the Pennsylvania State University, where he is Associate Professor of Electrical Engineering. He is currently in charge of Power Engineering Program and Power Systems Control Laboratory at Penn State. His interests are system theory and its application to large scale system, and power system.

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