Load Frequency Control by Optimization and Eigenvalues assignment

A.El-Kashlan

Academy for Science and Technology
Dept.Electrical Eng. and Computer Control
P.O.Box 1029, Abo keir, Alexandria, EGYPT.

ABSTRACT

Many control system design problems can be formulated as multi-objective problems: that is there are several competing objectives that need to be simultaneously satisfied (system step response, rise time, overshoot, disturbance rejection, or integral absolute error). These objectives are imbedded in system's eigenvalues that are measures of system stability and robustness. The load frequency control (LFC) problem for two interconnected area system is considered, and the objective is to design an appropriate controller based on linear quadratic regulator and/or eigenvalues assignment techniques for achieving zero steady state error due to step input, as well as a desired transient response. The paper addresses two equally important topics: load frequency control and controller design for stable operation. The resulting controller is of proportional state plus integral output type. The two control signals will not interface, since the integral action is usually much slower than the proportional action. An illustrative example is presented and solved by the three algorithms.

Keywords: Linear control systems, optimal control, eigenvalues assignment, load frequency control, proportional plus integral controller.

I. Introduction

In highly structured systems like multi-area power systems the active power generation within each area has to be controlled so as to maintain scheduled power interchange and frequency close to their nominal values, despite load variations. This important control function in power system operation, commonly referred to as load frequency control (LFC), may be conveniently met by adopting a global centralized strategy. Taking into consideration that the need for disturbance rejection and stabilization creates the need for feedback control. A number of state feedback controllers based on linear optimal control theory have been proposed so as to achieve better performance and insensitivity to plant parameter variations. The most widely used strategy is based on proportional plus integral (PI) controller, this is because they are often available at little extra cost since they are often incorporated into the programmable logic controllers (PLC's) that are used to control most industrial processes. Advanced control applications as applied to power systems include robustness, disturbance rejection, command following, fault tolerance, self autonomy, and so on. Intensive research work over the last few decades yielded a powerful set of algorithms for systems and control. Research on power system small-signal stability has produced valuable contributions to eigenanalysis [1]. Power plant operation and control provides one of the most challenging environments for industrial operations. Because of changing electrical demand, stringent emissions regulations and pressures to reduce generating costs resulting from deregulations and competitive environment, power industry is facing greater demands on maintaing unit performance, operation flexibility and availability. The optimal power flow (OPF) problem attempts to minimize some function of power system variables. Minimizing the cost of real power generation or minimizing real power losses in the system are examples of (OPF) objective function which are constrained optimization problem. Since there are operating limits on voltage magnitudes and other system variables, the solution to the problem is a power system steady-state operating point which may **not** be stable since the constraints included in the (OPF) problem are not stability constrains. Three power system stability conditions are precisely defined in [2] according to different operating conditions, namely *steady state*, *transient*, and *dynamic*. At steady state operating point, one can linearize the set of differential equations, the algebraic equations, and the network equations to describe the power system dynamic response for small deviations from operating point.

If the complex conjugate eigenvalues of the linearized system have negative real parts, then the power system can withstand small disturbances and is considered stable in the small-signal sense. Each eigenvalue is a function of power system variables, if one of these variables change, eigenvalues will experience some changes depending on their sensitivities. Alternatively when the system is subjected to large disturbances, there needs to be a mechanism to adapt the controller to the new operating conditions and ensure that the system stability is preserved. Adaptive control is an illustration based on estimating the linearized model from monitored data [3]. Eigenvalues analysis is a useful tool in both voltage collapse analysis at each intermediate equilibrium stage of the collapse ('snapshots') ,and finding a power system operating point that is both economically optimal and stable in the small-signal sense. As an extension to this issue [4] presented an approach to stabilize power system transient processes based on left shifting the real parts of the dominant eigenvalues via an optimization procedure. The drawback of the procedure is that it is limited to small or relatively infrequent change in the operating conditions.

In practice power system stability can be enhanced by improving damping of power swings in the system. This can be provided by power system stabilizers (PSS) supplementing excitation control of generators. Recently, several approaches based on modern control theory have been applied to (PSS) design problems [5]. The advent and wide spread use of high power semiconductors switches at the utilization, distribution, and transmission levels introduced FACTS devices (Flexible AC Transmission Systems) to achieve several goals. Linked to the improvements in semiconductor technology FACTS opened up new opportunities for controlling power and enhancing the usable capacity of existing transmission lines. Moreover it may be used for active as well as reactive power or voltage control, beside their capabilities in steady state or dynamic stability and damping inter-area oscillations [2]. Current work is looking at FACTS devices from both power electronics and power systems respectively. The former is to design devices in order to minimize the harmonic content of the waveform, while the latter is concerned with optimal application of FACTS devices and their control algorithms. The LFC is performed by automatic generation control (AGC). It serves to fulfill three important functions, first the frequencies of the various bus voltages and currents are maintained at or near specified nominal values, second the tie-line power flows among the interconnected areas are maintained at specified levels (LFC), and third the total power requirement on the system as a whole is shared by individual generators in an economically optimum fashion (active power dispatch) [6].

A solid analytical basis for the formulation, analysis, and evaluation of LFC performance criteria is presented in [7]. The cross fertilization between control system theory and power system analysis has been very fruitful towards improving electric power quality [8].

Along this direction the present paper presents a controller design approach on the basis of state variable model of the power system based on optimal control theory and eigenvalues assignment techniques where the overall power system is controlled and optimized as a whole not in sequential steps. The paper is organized as follow; section II introduces the system model. In an attempt towards the achievement of both satisfactory acceptable transient and steady state performance for the power system two design perspectives are presented. Section III presents the optimal control theory in designing the controller, while section IV presents two design algorithms based on eigenvalues assignment techniques for achieving the desired specifications. The proposed controller combines the features of the proportional state plus integral output feedback control. The corresponding gains are calculated through optimization techniques and/or eigenvalues assignment techniques. An illustrative numerical example in each section is presented for synthesizing the appropriate feedback gains for two identical interconnected power systems.

II. System model (State space description)

A two area power system can be modeled by a set of linearized differential equations (augmenting governer, turbine, generators, load, and tie-line) as

$$\dot{x} = A\,x(t) + B\,u(t) + L\,w(t) \qquad (1\text{-a})$$

$$y(t) = C\;x(t) \qquad (1\text{-b})$$

Where x (t) is the entire state vector composed of measurable components defined as

$$x(t) = [\,f_1\;\; p_{t1}\;\; p_{v1}\;\; p_{tie}\;\; f_2\;\; p_{t2}\;\; p_{v2}\,]' \in \Re^n \qquad (1\text{-c})$$

And the time dependence of the components is understood.

f_i is the frequency deviation (i=1,2), p_{ti} is the power output from the i-th generator, p_{vi} is the deviation in the governor valve opening, p_{tie} is the perturbation in the real power flowing along the line from area one to area two. The matrices A, B, C, and L are constants and of compatible dimensions. The two inputs are:

$$u(t) = [p_{c1} \;\; p_{c2}]' \in \Re^{m} \quad (1\text{-}d)$$

And the unknown but constant disturbance

$$w(t) = [p_{d1} \;\; p_{d2}]' \in \Re^{m} \quad (1\text{-}e)$$

Where p_{ci} is the speed changer position, and p_{di} is the load disturbance at subsystem i, i=(1,2). The overall output $y(t)$ is given as

$$y(t) = [y_1(t) \;\; y_2(t)]' \in \Re^{q} \quad (1\text{-}f)$$

$y_i(t)$ is the i-th area control error (ACE). It is assumed that the system is completely controllable, observable. For disturbance rejection purpose using optimal control techniques let the quadratic performance index J is

$$J = \int_0^{\infty} (\, x'(t)\, Q\, x(t) + u'(t)\, R\, u(t)\,)\, dt \quad (2)$$

Where Q is an nxn symmetric positive semi definite state weighting matrix and R is an mxm symmetric positive definite control weighting matrix. This index may represent economic costs, system security, or other objectives. The optimal control problem is to find the input u(t) for all $t \geq 0$ such that the state x(t) is driven from a given initial value x(0) to the origin of the state space while minimizing the index J. This problem is well known and often referred to as linear quadratic regulator (LQR) [9]. It is logical to assume that step change of load is often the case, in order to achieve the rejection of the effects of finite constant load disturbance w(t), let us differentiate (1-a) once to get

$$\dot{z}(t) = A\, z(t) + B\, \dot{u}(t) \quad (3)$$

Where $z(t) = \frac{d\, x(t)}{dt}$, define an augmented state vector $x_a(t) \in \Re^{n+q}$ as

$$x_a(t) = [z'(t) \;\; y'(t)]' = [\dot{f}_1 \;\; \dot{p}_{t1} \;\; \dot{p}_{v1} \;\; \dot{p}_{tie} \;\; \dot{f}_2 \;\; \dot{p}_{t2} \;\; \dot{p}_{v2} \;\; \dot{y}_1 \; \dot{y}_2]' \quad (4)$$

It allows the expression for the augmented system as

$$\dot{x}_a = A_a\, x_a(t) + B_a \dot{u}(t) \quad (5\text{-}a)$$

$$y_a(t) = C_a\, x_a(t) \quad (5\text{-}b)$$

Where the augmented matrices are given as

$$A_a = \begin{bmatrix} A & 0 \\ C & 0 \end{bmatrix}, \quad B_a = \begin{bmatrix} B \\ 0 \end{bmatrix}, \quad C_e = \begin{bmatrix} C & 0 \end{bmatrix} \quad (6)$$

It turns out that the augmented system (5) is controllable and observable as long as the original system is. The modified performance index for the augmented system is defined as

$$J_a = \int_0^{\infty} (\, x'_a(t)\, Q_a\, x_a(t) + \dot{u}'(t)\, R\, \dot{u}(t)\,)\, dt \quad (7)$$

Where Q_a is a symmetric positive semi-definite (n+q)x(n+q) matrix. To this purpose we abstract from the details concerning the augmented system and its modified index that the problem is to find the control $\dot{u}(t)$ for all $t \geq 0$ such that the augmented state vector $x_a(t)$ is driven from a given initial state to the origin of the augmented state space while minimizing the index (7).

III. Optimal Load Frequency Controller

Basically the need for disturbance rejection creates the need for feedback control. A fundamental control structure that is well suited to compute and implement is the state feedback from the augmented states. Moreover it is natural to focus the feedback on the accumulated information in the output, i.e., the part that originates from disturbances, measurement errors, and model error. The solution of the quadratic optimal control problem is well known [9] and is given as

$$\dot{u}(t) = -R^{-1} B_a' P x_a(t) = -K_a \, x_a(t) \qquad (8)$$

Where the gain K_a is a unique mx(n+q) matrix, P is an (n+q)x(n+q) symmetric positive definite matrix being the solution of the algebraic Riccati equation (ARE)

$$A_a' P + P A_a - P B_a R^{-1} B_a' P + Q_a = 0 \qquad (9)$$

Interestingly, equation (8) may be written as $\dot{u}(t) = -K_a \left[z'(t) \quad y'(t) \right]' \qquad (10\text{-a})$

Where $K_a = [K_1 \quad K_2 \quad]$; $K_1 \in \Re^{mxn}$; and $K_2 \in \Re^{mxq} \qquad (10\text{-b})$

As all the elements of the augmented state vector are measurable by appropriate transducers, it will be possible to combine the transducer outputs to generate the input signal as

$$u(t) = -K_1 \; x \; (t) - K_2 \int_0^{\infty} y(t) \; d(t) \qquad (11)$$

The control law derived above has the form proportional state plus integral output (past values of the output rather than the error signal). It ensures that the steady state value of the state $x_a(t)$ tends to zero as time goes large. Consequently the output y(t) tends to zero as it is part of $x_a(t)$. This in turn ensures that both frequency and tie-line flow deviations of each area tend to zero as time goes large following load disturbance. In spite of such controller simplicity, it has some disadvantages, such as its sensitivity to variation of system parameters or limited range of controllable disturbances and also the computational burden is of the order $(n+q)^3$ [9].

Example 1: Consider a power system with two identical areas having the following matrices [6].

$$A = \begin{bmatrix} -0.05 & 6.00 & 0 & -6 & 0 & 0 & 0 \\ 0 & -3.33 & 3.33 & 0 & 0 & 0 & 0 \\ -5.21 & 0 & -12.5 & 0 & 0 & 0 & 0 \\ 0.45 & 0 & 0 & 0 & -0.545 & 0 & 0 \\ 0 & 0 & 0 & 0 & -0.0.5 & 6 & 0 \\ 0 & 0 & 0 & 0 & 0 & -3.33 & 3.33 \\ 0 & 0 & 0 & 0 & -5.21 & 0 & -12.5 \end{bmatrix}, \quad B = \begin{bmatrix} 0 & 0 \\ 0 & 0 \\ 12.5 & 0 \\ 0 & 0 \\ 0 & 0 \\ 0 & 0 \\ 12.5 & 0 \end{bmatrix}$$

$$C = \begin{bmatrix} 1 & 0 & 0 & 1 & 0 & 0 & 0 \\ 0 & 0 & 0 & -1 & 1 & 1 & 1 \end{bmatrix}$$

The open loop system eigenvalues are

$$\langle -0.8312 \pm 2.8855\,i\ ,\ -1.2953 \pm 2.5123\,i\,,\ -0.9386,\ -13.2789,\ -13.2895 \rangle$$

I. Construct the augmented state vector $x_a(t)$ (eqn.4) together with the associated matrices A_a, B_a, C_a (eqn.6).

II. To minimize the modified index (eqn.7), let $Q_a = I_q$, and $R = I_2$ (13)

The extended system eigenvalues are those of the open loop in addition to two eigenvalues at origin.

III The unique optimal controller gains (eqn.11) obtained via linear quadratic regulator technique are :-

The proportional state feedback gain is

$$K_1 = \begin{bmatrix} 0.9607 & 1.5875 & 0.6869 & -1.5873 & 0.07907 & -0.221 & -0.0088 \\ -0.1785 & -0.0875 & -0.0088 & -1.3332 & 1.0479 & 1.6607 & 0.7449 \end{bmatrix} \quad (14)$$

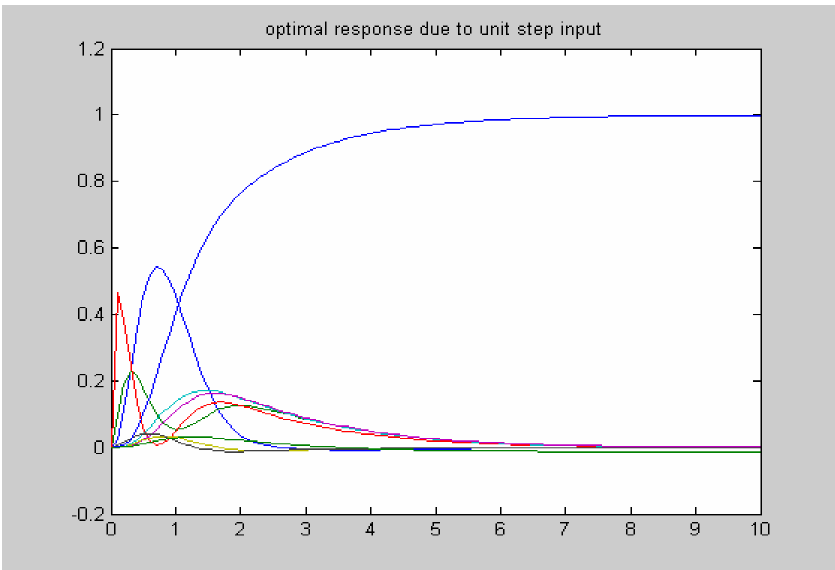
And the integral output feedback gain superimposed onto the proportional control is

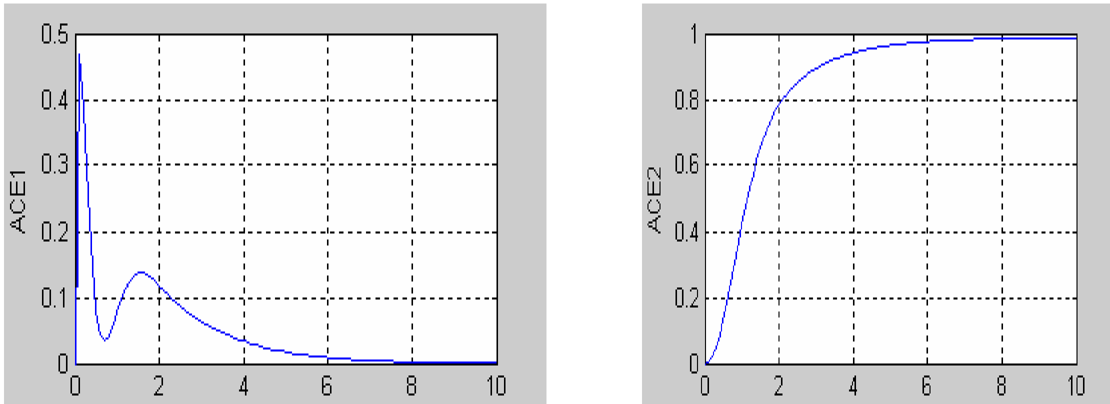
$$K_2 = \begin{bmatrix} 0.9999 & -0.0131 \\ 0.0131 & 0.9999 \end{bmatrix} \quad (15)$$

It may be verified that the optimal closed loop eigenvalues (those of the matrix $A_e - B_a K_a$) are

$$\langle -2.3800 \pm 2.7812\,i\,;\ -3.0642 \pm 2.5078\,i;\ -0.6924; -0.8906; -1.5175; -17.8400; -17.8239 \rangle$$

As it is well known, the objective of the voltage control in power system is to maintain the voltage profile within specified limits thus minimizing transmission losses and preventing cases of instability [10].





IVController Design via Eigenvalues Assignment

In this section and the next, two different procedures will be presented to generate the proportional state plus integral output controller based on eigenvalues assignment techniques. Assuming that the selected spectrum achieves some closed loop specifications or performance objectives indicating proper performance of the overall closed loop system.

The evaluation of the small signal stability of power system requires the calculation of eigenvalues and sometimes the eigenvectors (eigenpairs).

1. Algorithm I

The design procedure utilizes freedom existing in nonunique feedback gains for the multivariable system; it allows not only for a systematic application of the feedback matrix for the system under consideration but also can be readily adapted for numerical solution to improve the efficiency of computations. Consider the augmented system given by (eqn.5), apply a state feedback of the form $\dot{u}(t) = - K_a \, x_a(t)$ (17)

Where K_a is nonunique mx(n+q) real matrix, the closed loop system is

$$\dot{x}_a(t) = (A_a - B_a \, K_a) \, x_a(t) \qquad (18)$$

The purpose in applying such a feedback is to assign a finite prescribed symmetric self conjugate spectrum { λ_i } (i=1,…,(n+q)) which is specified in order to achieve some desired system specifications. In this case the closed loop eigenvalues are assigned but are not optimized. Based on the above let $P_a(\lambda)$ be the closed loop characteristic equation, hence

$$P_a(\lambda) = \left| \, A_a - B_a K_a - \lambda_i \, I_{n+q} \, \right| = 0 \qquad (i = 1,...,(n+q)) \qquad (19)$$

With some manipulations; $P_a(\lambda) = \left| \left[A_a - \lambda_i \, I_{n+q} \right] \left[I_{n+q} - (A_a - \lambda_i I_{n+q})^{-1} B_a K_a \right] \right| = 0$ (20)

Let $\phi_a(\lambda_i) = (A_a - \lambda_i I_{n+q})^{-1}$ and $\psi_a(\lambda_i) = \phi_a(\lambda_i) \, B_a$

Equation (20) yields $\left| A_a - \lambda_i I_{n+q} \right| \left| I_{n+q} - \phi_a(\lambda_i) B_a K_a \right| = 0$ (21)

Using the well known identity $\left| I_{n+q} + X \, Y \right| = \left| I_m + YX \right|$ where X is (n+q)xm, and Y is mx(n+q) matrix to rewrite (eqn.21) as

$$\left| A_a - \lambda_i I_{n+q} \right| \left| I_m - K_a \phi_a(\lambda_i) \, B_a \right| = 0 \qquad (22)$$

It shows a considerable reduction in computational complexity.

There are several ways of choosing the gain K_a to satisfy (eqn.22), one possible selection is the sufficient condition

$$K_a \psi_a(\lambda_i) = I_m \qquad (23)$$

This relation has two significant consequences. First, one may use the inherent flexibility in the assignment process. Second, the amount of memory required for computations is minimal; hence one can handle large scale power system problems.

For the j th column of (eqn.23) to be zero;

$$K_a \psi_{aj}(\lambda_i) = -e_j \qquad (24)$$

Where $\psi_{aj}(\lambda_i)$ is the j th column of the matrix $\psi_a(\lambda_i)$, and e_j is the j th column of I_m. If the desired eigenvalues are distinct, one can arbitrarily find (n+q) linearly independent columns for the (n+q)x(n+q) matrix $\lfloor \psi(\lambda_1) \;\; \psi(\lambda_2) .....,....., \psi(\lambda_{n+q}) \rfloor$ to form the matrix G as

$$G = \lfloor \psi_{j1}(\lambda_1) \;\; \psi_{j2}(\lambda_2) ,.....,....., \psi_{j(n+q)}(\lambda_{n+q}) \rfloor \qquad (25)$$

Hint: Controllability of the pair $((A_a, B_a)$ implies rank $\psi(\lambda_i) = m$ [11].

Here a candidate feedback matrix is calculated as

$$K_a = \left[e_{j1} \;\; e_{j2} \;\; ..... \;\; ..... \;\; e_{j(n+q)} \right] G^{-1} \qquad (26)$$

For the complex conjugate eigenvalues same column of $\psi_a(\lambda_i)$ is selected twice (once for the complex eigenvalue and once for its conjugate) [11]. This available high degree of freedom is best utilized to achieve some additional requirements e.g. robust eigenvalues, improved sensitivity, conditioned eigenvectors.

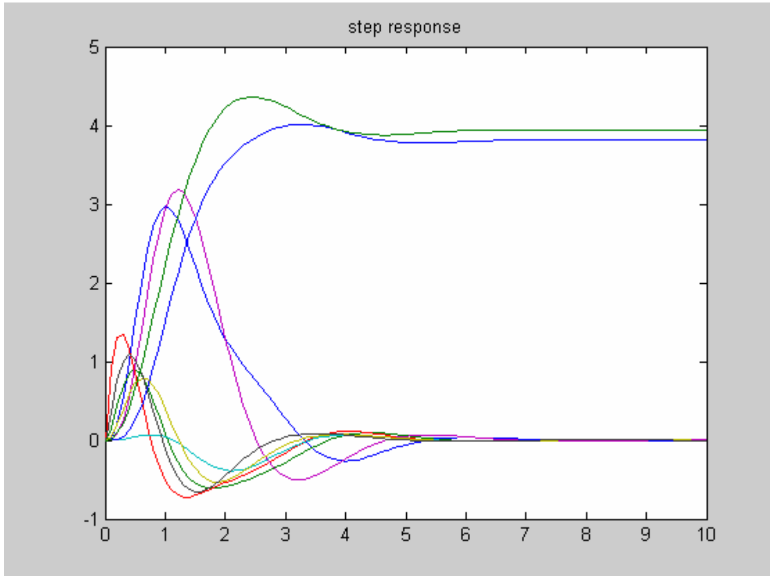
Example 2: To illustrate the above procedure let us reconsider the LFC of the two interconnected power systems quoted from [6]. Let the entire closed loop response which the power system is required to track be expressed as the location of the closed loop eigenvalues specified as $(-1.3 \pm 2.7\,i \;, -2.1 \pm 2.88\,i, -0.914 \pm 1.44i, -3.11 \pm 0.99i, -24)$. Using MATLAB [12] the numerical computations results the gain matrix K_a as

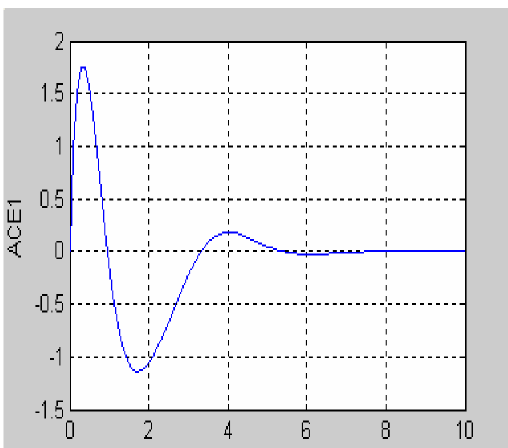
The proportional state feedback gain is

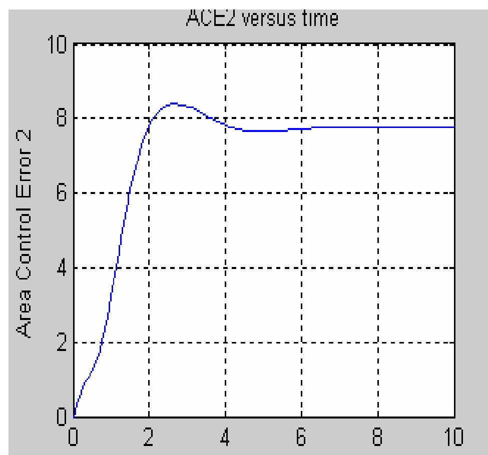
$$K_1 = \begin{bmatrix} 0.1303 & -0.4027 & 0.5331 & 0.3875 & -0.0381 & -0.0054 & 0.0016 \\ 1.6182 & 1.61431 & 0.9881 & -5.3235 & 0.0348 & -0.0607 & -1.1001 \end{bmatrix} \qquad (27)$$

And the integral output feedback gain $K_2 = \begin{bmatrix} -0.3015 & 0.0379 \\ 5.3733 & -5.2031 \end{bmatrix}$ (28)

Interestingly this procedure results in a closed loop system with good sensitivity characteristics. The system response due to step input is shown.







I1. AlgorithmII

The analysis and synthesis in this subsection rely on exploiting the available freedom for shaping the eigenvectors associated with the prescribed set of eigenvalues. Again consider the augmented system (5) , the associated control law (10), and the closed loop (18). Like the previous subsection, let the desired spectrum be specified as $\{\lambda_i\}$, and the associated eigenvectors as $\{V_i\}$ (i=1,…,…,(n+q)). The closed loop eigenvalues and eigenvectors are related by

$$(A_a - B_a K_a)\, V_i = \lambda_i\, V_i \qquad (29)$$

It can be readily expressed in the form $\left[(A_a - \lambda_i I) \quad B_a\right] \begin{bmatrix} V_i \\ \\ W_i \end{bmatrix} = 0 \quad (30)$

Where $W_i = K_a V_i$ is an m-dimensional vector. In order to satisfy (eqn.30) the vector $\begin{bmatrix} V_i' & W_i' \end{bmatrix}'$ must lie in the null space of the (n+q)x(n+q+m) matrix $\begin{bmatrix} A_a - \lambda_i I & B_a \end{bmatrix}$ which is m-dimensional space as long as (A_a , B_a) is a controllable pair. By repeated use of (eqn.30) and rearranging the associated vectors it follows that

$$\begin{bmatrix} W_1 & W_2 \text{ ....,.....,} W_{(n+q)} \end{bmatrix} = K_a \begin{bmatrix} V_1 & V_2 \text{ ....,......,} V_{(n+q)} \end{bmatrix} \quad (31)$$

Hence the required gain matrix K_a is obtained as

$$\begin{bmatrix} W_1 & W_2 \text{ ....,......,} W_{(n+q)} \end{bmatrix} \begin{bmatrix} V_1 & V_2 \text{ ....,......,} V_{(n+q)} \end{bmatrix}^{-1} = K_a \quad (32)$$

Noting that prescribed symmetric self conjugate eigenvalues results in linearly independent self conjugate corresponding eigenvectors, this ensures the existence of the indicated inverse, and also self conjugate symmetric vectors W_i. The sets of symmetric self conjugate spectrum results in real feedback matrix K_a. The procedure steps are:

Step 1. Let $g_i \in \text{Null}\begin{bmatrix} A_a - \lambda_i I & B_a \end{bmatrix}$; g_i is (n+q+m)xm matrix. Let v_{ij} be the upper (n+q) element of the j th column of g_i, and w_{ij} be the lower (m) element of the same column, j=1,…,m).

Step 2. Repeat step 1 for i=1,…,…,(n+q),and j=1,…,…,m then arrange the vectors correspondingly as

$$\begin{bmatrix} w_{1j} & w_{2j} \text{ ....,......,} w_{(n+q)j} \end{bmatrix} \begin{bmatrix} v_{1j} & v_{2j} \text{ .....,.......,} v_{(n+q)j} \end{bmatrix}^{-1} = K_a \quad (33)$$

Recall that $K_a = \begin{bmatrix} K_1 & K_2 \end{bmatrix}$ (10-b).

Note that while both algorithms provide same closed loop eigenvalues, it is difficult to compromise which is best without further constraints. The present algorithm exploits the freedom on selecting the eigenvectors within a subspace of the augmented system null space.

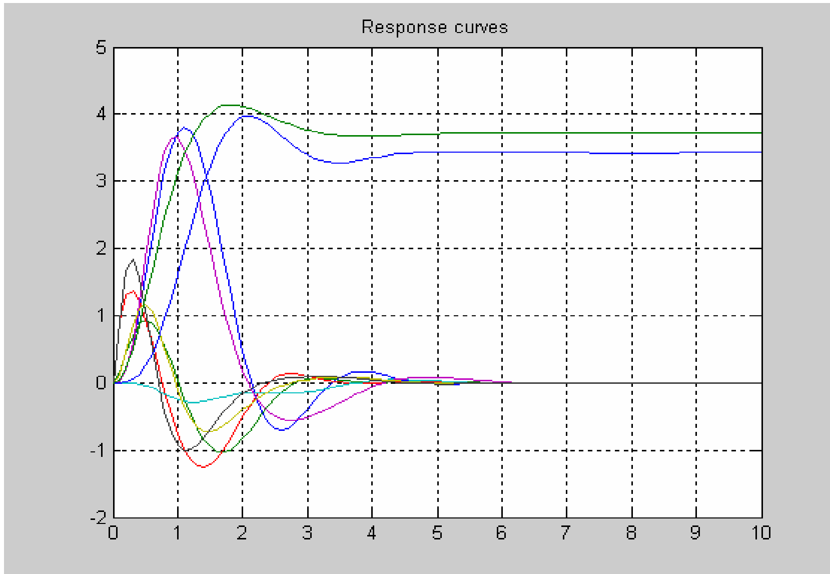
Example 3: Again consider same power system quoted from [6]. The required control law is to achieve same symmetric self conjugate eigenvalues set as specified in example 2, following the steps of the above algorithm II results in the feedback gains as

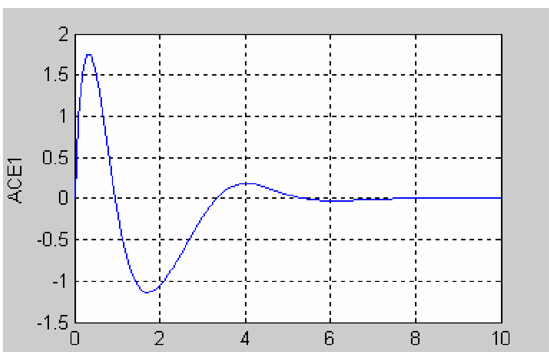
The proportional state feedback gain is

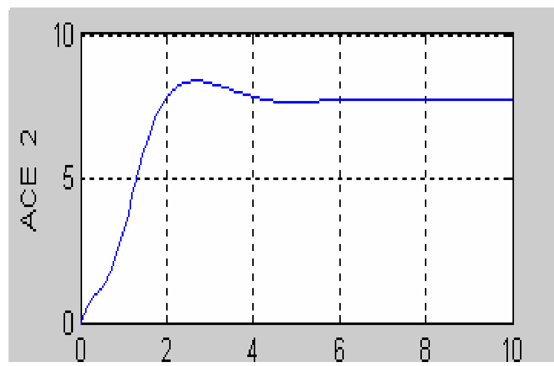
$$K_1 = \begin{bmatrix} 0.1435 & -0.3558 & 0.5325 & 0.6149 & -0.0139 & 0.0000 & -0.0154 \\ 2.3432 & 1.6881 & 2.9014 & -4.7672 & -0.5017 & -0.0890 & -1.0995 \end{bmatrix} \quad (34)$$

And the integral output feedback gain is

$$K_2 = \begin{bmatrix} -0.4042 & 0.1032 \\ 5.0819 & -4.6746 \end{bmatrix} \quad (35)$$







Interesting applications of such a controller are
(▪)At a given time the control signal is not dictated only by the state at that time.
(▪▪)The control signal depends on both the state and duration period to and until the time of interest.

Conclusions

Electric power systems are typical complex dynamic systems, controller parameters that are optimum for one set of operating conditions may not be optimum for another set of operating conditions. The system configuration also keeps changing either due to switching actions, sudden loading,…, etc. In an interconnection, there are many control areas, each of which performs its AGC with the objective of maintaining the magnitude of ACE sufficiently close to zero using various criteria. The control problem of interest in the power system is to find a controller that will cause deviations in the area frequencies, and tie line flow go to zero following the introduction of load disturbance. A framework is suggested for interconnected power system which integrates control design by whatever method (optimum, or eigenvalues assignment) for load frequency control. It is feasible to develop and implement improved controllers based on modern, more sophisticated techniques Controllers based on linear quadratic regulator and eigenvalues assignment techniques are presented in the paper. Three proposed design algorithms are conveniently illustrated by synthesizing appropriate proportional state superimposed by integral output feedback controller designed for load frequency control. In order not to interface both signals, the integral output control is much slower than the proportional control signal. However it is claimed in the literature that complete rejection of disturbance and insensitivity to parameter variation can be achieved through variable structure systems with some confusion about robustness. A more practical problem is that several performance indices can be dealt with, typically the subsequent problem of deciding what weighting to give the various indices to achieve satisfactory performance rather than optimal.

References

[1] Impact of interactions among power system controls,"CIGRE, Paris, France, 166, 2000, and IEEE Control systems magazine, vol.20, no.4, August 2000.

[2] R.M.Miller, J.H. Malinowski, *Power system operation,* MC-Graw Hill Int.3rd edition, 1993.

[3] C.Wen and D.J.Hill," Adaptive linear control of nonlinear systems," IEEE Trans.Automat.Contr., vol.35, no.11, pp.1253-1257, November 1990.

[4] Y.V.Makarov, D.H. Popovic, and D.J .Hill," Stabilization of transient processes in power systems by an eigenvalue shift approach," IEEE Trans.Power Systems, vol.13, no.2,pp.382-388, May 1998.

[5] Kwang Y.Lee, Mark Perakis, Donald R.Sevick, N.I Wan Santoso, Gerhard K.Lausterer, and Tariq Samad," Intelligient distributed simulation and control of power plants,' IEEE Trans. Energy Conversion, vol.15, no.1, pp.116-123, March 2000.

[6] A.k. Mahalanabis, D.D.Kothari, and S.I.Ahson, *Computer aided power system analysis and control,* Tata Mc Graw-Hill Ltd. New Delhi.1991.

[7] G.Gross and J.W.Lee," Analysis of load frequency control performance assessment criteria," IEEE Trans. Power systems, vol.16, no.3,pp.520-525, August 2001.

[8] Nelson Martins, and Paulo E.M.Quintao,"Computing dominant poles of power system multivariable transfer functions," IEEE Trans.Power systems,vol.18,no.1,pp.152-159,February 2003.

[9] Anderson ,B.D.O, and J.B. Moore, *Linear optimal control*, Prentice Hall,N.J.1971.

[10] Hadi Sasdat,*Powerm system analysis,* Mc-Graw Hill-1991.

[11] William L.Brogan, *Modern control theory,*Prentice Hall Inc. Englewood Cliffs,N.J.3rd edition,1991.

[12] Mathworks,*2002 ,MATLAB User's Guide*,the Mathworks.Inc.