Optimal Control Techniques in Applicable Values of Turbine Speed Governor Regulation

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ABSTRACT: *Optimal control is a branch of modern control theory that deals with designing controls for dynamic systems by minimizing a performance index that depends on the system variables. The paper is concerned with power system automatic generation control AGC in dynamic and steady state conditions. A design technique allows all roots of the system characteristic equations to be placed in desired locations, a regulator with constant gain vector K, and the Algebraic Riccati Equation ARE solution. Other approach to the design of optimal controllers by Pole Placement Techniques for* feeding back the state variables through a regulator with constant gains. *Optimal control deals with designing controls for dynamic systems by minimizing a performance index that depends on the system variables. Application of these optimal controls to power systems control is given through a state space model. The effects of the governor speed regulation on the system stability of a two area systems by Matlab Toolbox.*

Keywords - *Speed Governor Regulator, Optimal Control, Automatic Generation Control AGC, Area Control Error ACE, Pole Placement.*

I. INTRODUCTION

The objective of modern power systems is to transfer enough high quality real and reactive power produced by generating units to customers through transmission lines. In an interconnected power system, the synchronous generators should rotate at the same speed and power flows over tie-lines should remain constant under normal operating conditions. Load frequency control LFC is a very important in power system operation and control for supplying sufficient and reliable electrical power with good quality, especially interconnected power systems [1-2]. Automatic generation control AGC or LFC is the mechanism by which the energy balance is maintained. The following summarizes the basic AGC objectives for an interconnected power system [3-4]: Regulating system frequency error to zero and keep the system frequency in its scheduled value, Maintain accurate real time, Any area in need of power during emergency should be assisted from other areas, Maintain net interchange power equal to scheduled values, and Minimize equipment wear. Each of two areas including steam turbines contains governor, reheated stage of steam turbine and generation rate constraints [5]. The tie-line power flow appears as a load increase in one area and a load decrease in the other area, depending on the direction of the flow. When a load change occurs in any area, a new steady state operation can be obtained only after the power output of every turbine generating unit in the interconnected system reaches a constant value.

In a power system consisting of interconnected areas, each area agrees to export or import a scheduled amount of power through transmission line interconnections to its neighboring areas. The LFC problems are characterized by stochastic disturbances, variable and unpredictable inputs, unknown parameters, nonlinearity and changes in plant transfer function. In order to improve LFC system problem, advance control techniques such as adaptive control [6], variable structure control [7], fuzzy PI controller [8, 9] and linear feedback optimal control [10] have been proposed. A completely decentralized controller for the LFC operated as a load following service proposes in [11]. An application of layered artificial neural network controller to study LFC problem in three-area interconnected power system that two areas include steam turbines and the other area includes a hydro turbine is shown in [12]. A fuzzy control scheme for a LFC in two-area power system, which accepts change in frequency and changes in generator output as its inputs and generates a required control signal, is proposed in [13]. The LQR design is considered the foundation of the linear quadratic Gaussian/loop transfer recovery (LQG/LTR) methodology of robust control systems. The LQG design performs the state variable estimation for optimal feedback, and the LTR performs the LQR robustness feature recovery that is lost due to the insertion of the state observer. The importance of the LQR method can be measured by its scientific and technical impacts that are reported in [14–16].

Two main branches that are directly involved in the LQR control design synthesis; one is related to the selection of the weighting matrices, and the other one is related to the solution of the Algebraic Riccati Equation ARE. Basically, two main issues of the LQR problem have been the subject of investigation since the 1960s until nowadays: the choice of the Q and R weighting matrices [17] and the solutions of the ARE [18-19]. It is known that the two tasks are strongly time dependent on the dynamic system order and on certain operational conditions. A fusion of two CI paradigms [20] is developed to solve the QR matrix search [21] and the ARE [22]. Recently, LFC under new deregulation market LFC with communication delay [23], and LFC with new energy systems received much attention [24]. For a complete review of recent philosophies in AGC [25]-[27].

The focus of this paper, we employ modern control designs that require the use of all state variables to form a linear static controller. A new control design is especially useful in multivariable systems. One approach in new control systems accomplished by the use of state feedback is known as pole placement design. Improved performance might be expected from the advanced control methods, however, these methods require either information on the system states or an efficient online identifier thus may be difficult to apply in practice. It was known long time ago that the Americans used regulation constant of 5%, while European used 4% for regulation, without clear reasoning in the literature [28]. The aim of this paper is to model, analysis and simulation of AGC system adjusts continually the real power according to the deviation in the turbine speeds or to the system frequencies excursions. This study is to prove the optimality of these values over others. This paper is to model, analysis and simulation of load frequency control in two area power systems, and parameters variation effects.

The remainder part of this paper is organized as follows. In section II the optimal control techniques are described. A two area power system functions in section III are studied. The effects of the governor speed regulation on the system stability by pole placement techniques in different cases using Matlab are calculated in section IV. Finally, the results are discussed in section V.

II. Optimal Control Techniques

1. The Optimal Regulator Design:

The object of the optimal regulator design is to determine the optimal control law u*(x,t) which can transfer the system from its initial state to the final state such that a given performance index is minimized. The performance index is selected to give the best trade-off between performance and cost of control. The performance index that is widely used in optimal control design is known as the quadratic performance index and is based on minimum error and minimum energy criteria. Consider the plant described by:

$$\dot{x}(t) = Ax(t) + Bu(t) \tag{1}$$

The problem is to find the vector K(t) of the control

$$u(t) = -K(t)x(t) \tag{2}$$

Which minimizes the value of a quadratic performance index J of the form:

$$J = \int_{t_0}^{t_f} (x'Qx + u'Ru)dt \tag{3}$$

Where: Q is a positive semi-definite matrix, and R is a real symmetric matrix.

To obtain a formula solution, we can use the method of Lagrange multipliers. The constraint problem is solved by augmenting equations (1) into (3) using an n vector of Lagrange multipliers, λ. The problem reduces to the minimization of the following unconstrained function.

$$\begin{aligned}\ell(x,\lambda,u,t) = &[x'Qx + u'Ru] \\ &+ \lambda'[Ax + Bu - \dot{x}]\end{aligned} \tag{4}$$

The optimal values (denoted by the subscript *) are found by equating the partial derivative to zero.

$$\begin{aligned}\dot{x}^* &= AX^* + BU^* \\ u^* &= -0.5R^{-1}\lambda' B \\ \dot{\lambda} &= -2Qx^* - A'\lambda\end{aligned} \tag{5}$$

Assume that there exists a symmetric, time varying positive definite matrix p(t) satisfying:

$$\lambda = 2p(t)x^* \tag{6}$$

The optimal closed loop control law is defined:

$$u^*(t) = -R^{-1}B'p(t)x^* \tag{7}$$

Obtaining the derivative of equation (6), we have:

$$\dot{\lambda} = 2\left(\dot{p}x^* + p\dot{x}^*\right) \tag{8}$$

Finally:

$$\begin{aligned}\dot{p}(t) &= -p(t)A - A'p(t) - Q \\ &\quad + p(t)BR^{-1}B'p(t)\end{aligned} \tag{9}$$

The above equation is referred to as the matrix Riccati equation. The boundary condition for equation (9) is $p(t_f)=0$. Therefore, equation (9) must be integrated backward in time. Since a numerical solution is performed forward in time, a dummy time variable $\tau=t_f-t$ is replaced for time t. The optimal controller gain is a time varying state variable feedback. Such feedbacks are inconvenient to implement, because they require the storage in computer memory of time varying gains. An alternative control scheme is to replace the time varying optimal gain K(t) by its constant steady state value. In most practical applications, the use of the steady state feedback gain is adequate. For linear time invariant systems, since, $\dot{p}=0$ when the process is of infinite duration, that is $t_f=\infty$ equation (9) reduces to the algebraic Riccati equation:

$$pA + A'p + Q - pBR^{-1}B'p = 0 \tag{10}$$

2. The Optimum Controller Design Procedure:

There are many criteria by which system performance might be judged. Steady state or transient response, reliability, cost, energy consumption, and weight are all possible criteria. For analytical design, we must be able to relate the performance criterion mathematically to the design parameters to be selected. A popular performance index involves the integral of the sum of squares of several system variables. Such indices are called quadratic performance criteria. One attractive feature of these criteria is that they are mathematically traceable. The performance index is expressed in the general form:

$$P.I. = \int_0^\infty \sum_{i=1}^{k} f_i^2(t)\,dt \tag{11}$$

Where the $f_i(t)$ are various signals of importance. In this section, we consider a special case of the general quadratic performance index in which the $f_i(t)$ are either weighted plant state variables $x_i(t)$ or weighted plant inputs $u_j(t)$:

$$P.I. = \int_0^\infty \left[\sum_{i=1}^{k} q_i x_i^2(t) + \sum_{j=1}^{m} r_j u_j^2(t)\right] dt \tag{12}$$

Using the matrix representation for state variables and inputs:

$$X \triangleq \begin{bmatrix} x_1(t) \\ x_2(t) \\ . \\ . \\ . \\ x_n(t) \end{bmatrix}, \text{ and } U \triangleq \begin{bmatrix} u_1(t) \\ u_2(t) \\ . \\ . \\ . \\ u_m(t) \end{bmatrix} \tag{13}$$

Equation (12) can be written in compact form as follows:

$$P.I. = \int_0^\infty \left(X^T Q X + U^T R U\right) dt \tag{14}$$

Where:

$$Q \triangleq \begin{bmatrix} q_1 & 0 & \dots & 0 \\ 0 & q_2 & \dots & \dots \\ \dots & \dots & \dots & 0 \\ 0 & \dots & 0 & q_n \end{bmatrix}$$

$$\text{and } R \triangleq \begin{bmatrix} r_1 & 0 & \dots & 0 \\ 0 & r_2 & \dots & \dots \\ \dots & \dots & \dots & 0 \\ 0 & \dots & 0 & r_m \end{bmatrix} \tag{15}$$

A more general index can be considered, where Q and R have off-diagonal entries. However, the diagonal case is usually easier to understand physically, and thus is most often used in practice. The plant is described in state form by:

$$\dot{X} = AX + BU \text{ , and } X(0) = X^0 \tag{16}$$

We shall further restrict the problem by requiring U, the control input to the plant, to be constructed form the state variables by linear, time-invariant feedback.

$$U = KX \tag{17}$$

Where K is an m×n matrix of constants.

The problem then is one of parameter optimization. Choose K to minimize the performance index P.I. of Equ. (14), we see from the performance index that we are penalized for both large deviations in the state variables from zero and for the use of large control inputs. A system designed in this manner is called an optimum state regulator or controller. The derivation of the optimal K is straight forward, although it involves some matrix calculus and the details are given elsewhere. The result is the following: the optimal matrix K minimizing the performance index, P.I. is given by:

$$K = -R^{-1}B^T P \qquad (18)$$

Where R is given in the performance index of Equ. (14), (notice that R-1 always exists), and B is given in the plant model (Equ. (16)). The matrix P is the positive definite, symmetric solution to the matrix Riccati equation.

$$A^T P + PA\text{-}PBR^{-1}B^T P + Q = 0 \qquad (19)$$

With A from Equ. (16) and Q from Equ. (14). Since P is an n×n matrix, Equ. (19) represents n^2 simultaneously, non-linear (quadratic), algebraic equations for the n^2 element of P. However, since P is symmetric, not all of these equations are different. In fact, since there are n2 elements in P, and n elements on the diagonal, there are (n^2-n) off-diagonal elements, of which half are distinct. Thus there are:

$$\frac{\left(n^2 - n\right)}{2} + n = \frac{n(n+1)}{2} \qquad (20)$$

Distinct elements of the P matrix to be found from Equ. (19), since the equations are quadratic, many different sets of roots occur. It can be shown that there is a unique positive definite solution, and that this P determines the optimum K. It is interesting to observe that the optimum parameter matrix K is independent of the initial condition X^0. Thus K can be computed once and for all, and will be optimum no matter what the initial conditions are. A block diagram of the optimum controller system is given in Fig. (1). It should to be noted that the optimum state-controller can be shown to be stable, that is, the eigenvalues are always in the left s-plane. Now we shall illustrate the optimum controller problem by a two area electric power system applications.

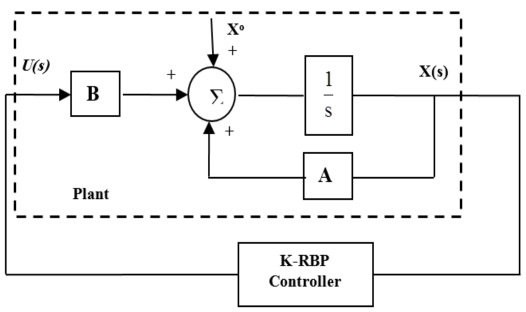


Fig. (1) Block diagram of optimum state-controller system

III. TWO-AREA ELECTRIC POWER SYSTEM MODEL

In this section, the two-area studied system for AGC is discussed. Fig. (2) shows the block diagram model with ACE. The state space model can be obtained by writing the differential equations for each block shown in Fig. (2) as:

$$\dot{x}_1 = \left(\frac{-1}{T_{P1}}\right)x_1 + \left(\frac{K_{P1}}{T_{P1}}\right)x_2 - \left(\frac{a_{12}K_{P1}}{T_{P1}}\right)x_g - \left(\frac{K_{P1}}{T_{P1}}\right)d_1 \qquad (21)$$

$$\dot{x}_2 = \left(\frac{-1}{T_{t1}}\right)x_2 + \left(\frac{1}{T_{t1}}\right)x_3 \qquad (22)$$

$$\dot{x}_3 = \left(\frac{-1}{R_1 T_{g1}}\right)x_1 - \left(\frac{1}{T_{g1}}\right)x_3 + \left(\frac{1}{T_{g1}}\right)u_1 \qquad (23)$$

$$\dot{x}_4 = B_1 x_1 + x_g \qquad (24)$$

$$\dot{x}_5 = \left(\frac{-1}{T_{P2}}\right)x_5 + \left(\frac{K_{P2}}{T_{P2}}\right)x_6 + \left(\frac{a_{12}K_{P2}}{T_{P2}}\right)x_g - \left(\frac{K_{P2}}{T_{P2}}\right)d_2 \qquad (25)$$

$$\dot{x}_6 = \left(\frac{-1}{T_{t2}}\right)x_6 + \left(\frac{1}{T_{t2}}\right)x_7 \qquad (26)$$

$$\dot{x}_7 = \left(\frac{-1}{R_2 T_{g2}}\right)x_5 - \left(\frac{1}{T_{g2}}\right)x_7 + \left(\frac{1}{T_{g2}}\right)u_2 \qquad (27)$$

$$\dot{x}_8 = B_2 x_5 - T_{12} x_9 \qquad (28)$$

$$\dot{x}_9 = 2\pi T_{12} x_1 - 2\pi T_{12} x_5 \qquad (29)$$

From the above nine equations, the matrices A, B, and F are obtained as:

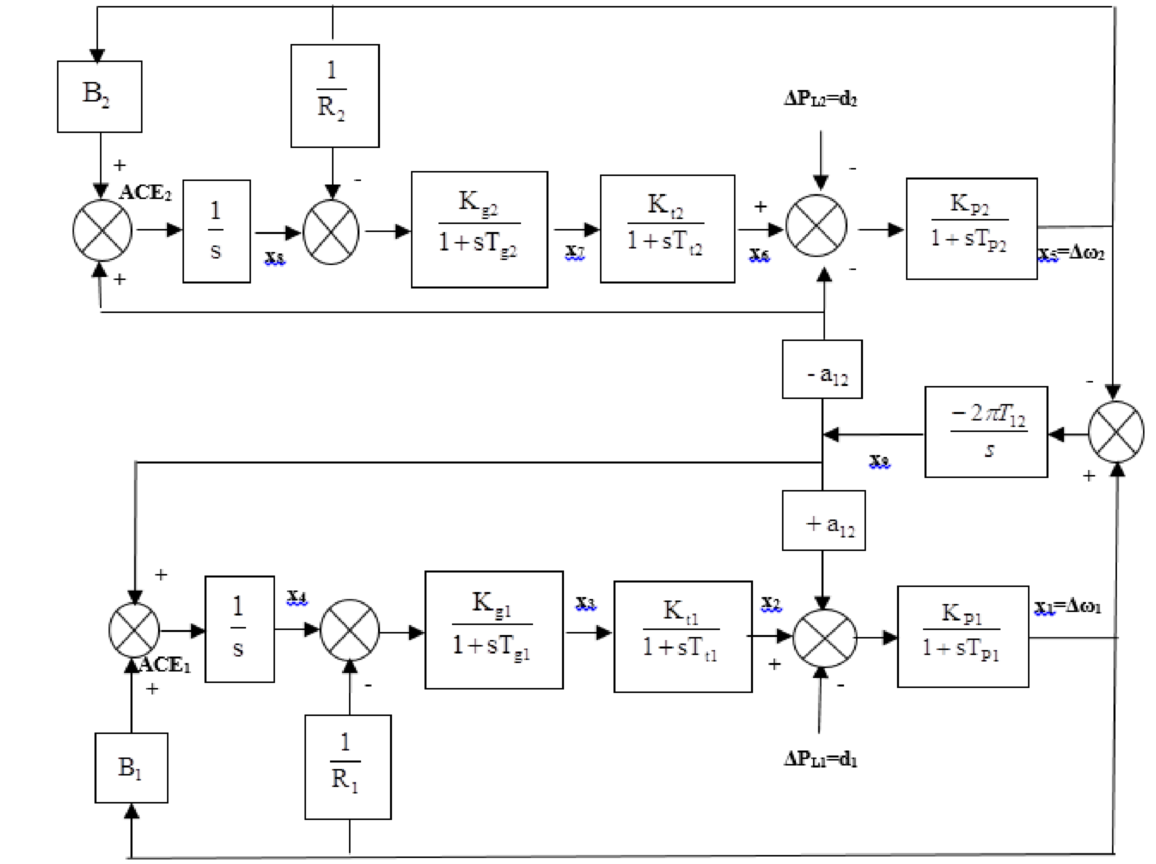


Fig. (2) Block diagram model of two-area system with ACE technique

$$A \triangleq \begin{bmatrix} \frac{-1}{T_{P1}} & \frac{K_{P1}}{T_{P1}} & 0 & 0 & 0 & 0 & 0 & 0 & \frac{-a_{12}K_{P1}}{T_{P1}} \\ 0 & \frac{-1}{T_{t1}} & \frac{1}{T_{t1}} & 0 & 0 & 0 & 0 & 0 & 0 \\ \frac{-1}{R_1T_{g1}} & 0 & \frac{-1}{T_{g1}} & 0 & 0 & 0 & 0 & 0 & 0 \\ B_1 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 1 \\ 0 & 0 & 0 & 0 & \frac{-1}{T_{P2}} & \frac{K_{P2}}{T_{P2}} & 0 & 0 & \frac{a_{12}K_{P2}}{T_{P1}} \\ 0 & 0 & 0 & 0 & 0 & \frac{-1}{T_{t2}} & \frac{1}{T_{t2}} & 0 & 0 \\ 0 & 0 & 0 & 0 & \frac{-1}{R_2T_{g2}} & 0 & \frac{-1}{T_{g2}} & 0 & 0 \\ 0 & 0 & 0 & 0 & B_2 & 0 & 0 & 0 & -T_{12} \\ 2\pi T_{12} & 0 & 0 & 0 & -2\pi T_{12} & 0 & 0 & 0 & 0 \end{bmatrix} \quad B \triangleq \begin{bmatrix} 0 & 0 \\ 0 & 0 \\ \frac{1}{T_{g1}} & 0 \\ 0 & 0 \\ 0 & 0 \\ 0 & 0 \\ 0 & \frac{1}{T_{g2}} \\ 0 & 0 \\ 0 & 0 \end{bmatrix} \quad F \triangleq \begin{bmatrix} \frac{-K_{P1}}{T_{P1}} & 0 \\ 0 & 0 \\ 0 & 0 \\ 0 & 0 \\ 0 & \frac{-K_{P2}}{T_{P2}} \\ 0 & 0 \\ 0 & 0 \\ 0 & 0 \\ 0 & 0 \end{bmatrix} \qquad (30)$$

We shall at this stage not repeat the whole discussion and simply we switch over to the formation of the performance index. With the reasoning given in single area system our performance index is:

$$P.I. = \int_0^\infty \left\{ \begin{aligned} &\left(a_{12}x_9' + B_1x_1'\right)^2 \\ &+\left(-a_{12}x_9' + B_2x_5'\right)^2 \\ &+\left(x_4' + x_8'\right)^2 + r\left(u_1'^2 + u_2'^2\right) \end{aligned} \right\} \qquad (31)$$

We can find out the feedback gain K from the solution of matrix Ricatti equation. The various coefficients K_{ij} of K evidently represent weight factors, the relative magnitudes of which measure the importance of including the corresponding state variables in the control force U. In practice, we adopt the scheme of employing only local states of the area and neglect the states of the far distant area (i.e. Area #2). Such a type of control is known as sub-optimal load frequency control. The idea of neglecting the weight factors of the distant area is that it is very difficult to get the information of the state of the distant area.

IV. Pole Placement Techniques

The control is achieved by feeding back the state variables through a regulator with constant gains. Consider the control system presented in the state variable form:

$$\begin{aligned} \dot{x}(t) &= A\,x(t) + B\,u(t) \\ y(t) &= C\,x(t) \end{aligned} \tag{32}$$

Now consider the block diagram of the system shown in Fig. (3) with the following state feedback control:

$$u(t) = -Kx(t) \tag{33}$$

Where: K is constant feedback gains.

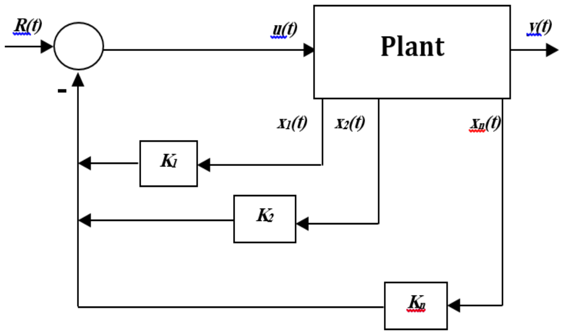


Fig. (3) Control system design via pole placement technique

The control system input R(t) is assumed to be zero. The purpose of this system is to return all state variables to values of zero when the states have been perturbed. From equation (32) and (33), the compensated system state variable representation becomes:

$$\dot{x}(t) = (A - BK)\,x(t) = A_f\,x(t) \tag{34}$$

And the compensated system characteristic equation is:

$$|sI - A + BK| = 0 \tag{35}$$

Assume the system is represented in the phase variable canonical form as follows:

$$\begin{bmatrix} \dot{x}_1 \\ \dot{x}_2 \\ . \\ . \\ \dot{x}_{n-1} \\ \dot{x}_n \end{bmatrix} = \begin{bmatrix} 0 & 1 & 0 & . & . & 0 \\ 0 & 0 & 1 & . & . & 0 \\ . & . & . & . & . & . \\ . & . & . & . & . & . \\ 0 & 0 & 0 & . & . & 1 \\ -a_0 & -a_1 & -a_2 & . & . & -a_{n-1} \end{bmatrix} \begin{bmatrix} x_1 \\ x_2 \\ . \\ . \\ x_{n-1} \\ x_n \end{bmatrix} + \begin{bmatrix} 0 \\ 0 \\ . \\ . \\ 0 \\ 1 \end{bmatrix} u(t) \tag{36}$$

Substituting for A and B into equation (35), the compensated characteristic equation for the control system is found:

$$\begin{aligned} |sI - A + BK| &= s^n + (a_{n-1} + k_n)s^{n-1} + \ldots \\ &\quad + (a_1 + k_2)s + (a_0 + k_1) = 0 \end{aligned} \tag{37}$$

For the specified closed loop pole locations $-\lambda_1, \ldots, -\lambda_n$, the desired characteristic equation is:

$$\begin{aligned} \alpha_c(s) &= (s + \lambda_1)\ldots(s + \lambda_n) \\ &= s^n + \alpha_{n-1}s^{n-1} + \ldots + \alpha s + \alpha_0 = 0 \end{aligned} \tag{38}$$

The design objective is finding the gain matrix K such that the characteristic equation for the controlled system is identical to the desired characteristic equation. Thus, the gain vector K is obtained by equating coefficient of equation (37), and (38), and for the i^{th} coefficient we get:

$$k_i = \alpha_{i-1} - a_{i-1} \tag{39}$$

If the state model is not in the phase variable canonical form, we can use the transformation technique to transform the given state model to the phase variable canonical form. The gain factor is obtained for this model and then transformed back to conform with the original model. This procedure results in the following formula, known as Ackermann's formula:

$$K = \begin{bmatrix} 0 & 0 & . & . & 0 & 1 \end{bmatrix} S^{-1} \alpha_c(A) \tag{40}$$

Where: The matrix S is given by:

$$S = \begin{bmatrix} B & AB & . & . & A^{n-2}B & A^{n-1}B \end{bmatrix} \tag{41}$$

And the notation $\alpha_c(A)$ is given by:

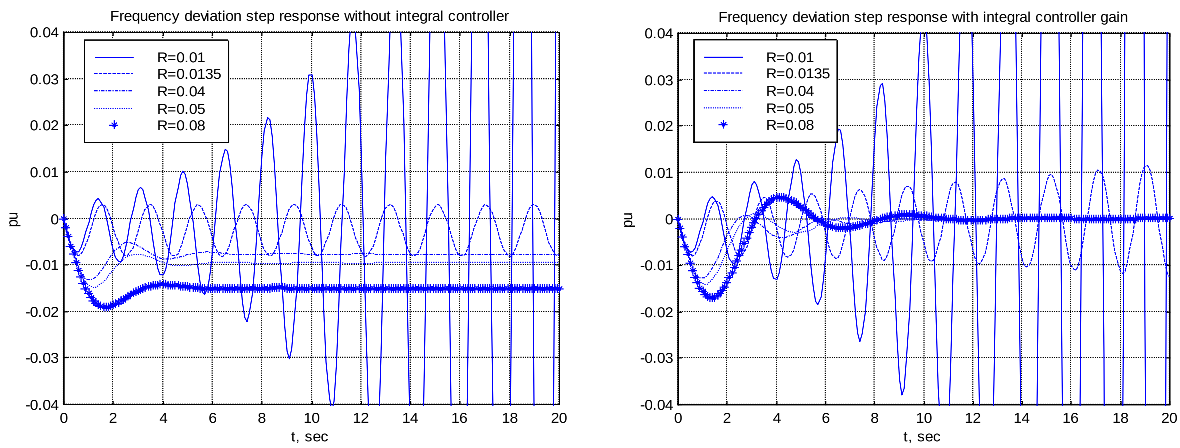
$$\alpha_c(A) = A^n + \alpha_{n-1}A^{n-1} + \ldots + \alpha_1 A + \alpha_0 I \qquad (42)$$

V. Results And Discussion

1. System behavior with and without Integral Controller Gain

The Routh-Hurwitz array is used to find the range of governor speed regulation R for control system stability. The MATLAB software is used also to obtain the time-domain performance specifications and the frequency deviation step response. The frequency deviation step response for a sudden load change of 0.2 per unit without integral controller and with the integral controller gain to K_I=7.0 is given in Table (1). It is noticed that R setting less than (0.04 or 0.05) i.e. up to 0.0135, the system becomes unstable and at R=0.0135 becomes critically stable. Above R=0.05, the system stability is weakened and higher values than R=0.2 the system becomes unstable.

This is why they adopted R=0.04pu in Europe and R=0.05pu in USA. Fig. 4(a) shows unstable oscillations with R=0.01pu, sustained oscillations with constant amplitude with R=0.015pu and very well damped oscillations with R=0.04 and 0.05pu. Over compensated damped oscillations with R=0.08pu. This affirms once more that R=0.04, 0.05 are the optimal values. With integral controller the variable Δω reaches the original value at steady state. Fig. 4(b) shows the response without integrator. Δω reaches another lower value at steady state, with R=0.04 or 0.05. It is unstable with lower values or higher values of R.



(a) without integral controller gain (b) with integral controller gain

Fig. (4) The frequency deviation step response for a sudden load change with/without integral action

Table (1) Applicable values of turbine speed governor regulations

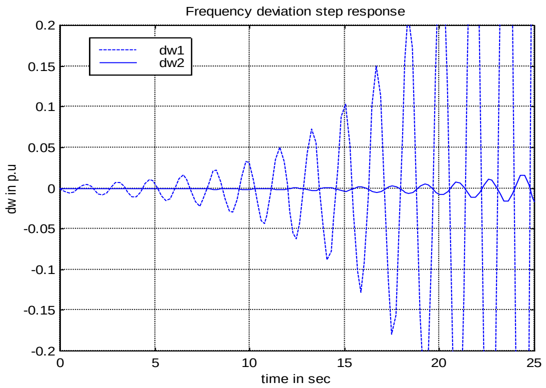
R p.u	Roots	Time Response	R p.u	Roots	Time Response
0.01 (*)	-7.4721 0.1961+ 3.6677i 0.1961 - 3.6677i	Unbounded response	0.07	-5.6901 -0.6950+ 1.4725i -0.6950 - 1.4725i	Pt = 1.526 Pos= 33.77 Rt = 0.604 St = 4.676
0.013	-7.0800 -0.0000+3.2496i -0.0000- 3.2496i	Pt =669043 Pos= 35.72 Rt =440687 St=1846880	0.08	-5.6226 -0.7287+ 1.3544i -0.7287 - 1.3544i	Pt = 1.688 Pos= 26.92 Rt = 0.70 St = 4.94
0.015	-6.9562 -0.0619+ 3.1137i -0.0619- 3.1137i	Pt = 0.63 Pos=188.97 Rt = 0.12 St = 73.34	0.09	-5.5676 -0.7562+ 1.2520i -0.7562 - 1.2520i	Pt = 1.85 Pos= 21.53 Rt = 0.793 St = 5.091

0.02	-6.6417 -0.2192+0.7569i -0.2192- 2.7569i	Pt = 0.73 Pos= 146.4 Rt = 0.137 St =20.213	0.10	-5.5218 -0.7791 + 1.1614i -0.7791 - 1.1614i	Pt = 2.028 Pos= 17.21 Rt = 0.899 St = 4.95
0.03	-6.2641 -0.4080+2.2984i -0.4080- 2.2984i	Pt = 0.907 Pos= 98.69 Rt = 0.245 St = 9.535	0.20	-5.2915 -0.8943 + 0.5444i -0.8943 - 0.5444i	Pt = 4.91 Pos= 0.753 Rt = 2.225 St = 3.299
0.04	-6.0388 -0.5206+2.0003i -0.5206- 2.0003i	Pt = 1.076 Pos= 72.02 Rt = 0.327 St = 7.722	0.30 (*)	-5.2031 -1.2322 -0.6447	Rt = 3.831 St = 6.592
0.05	-5.8863 -0.5968+1.7825i -0.5968- 1.7825i	Pt = 1.223 Pos= 54.82 Rt = 0.419 St = 6.803	0.40 (*)	-5.1561 -1.4962 -0.4278	Rt = 5.28 St = 9.351

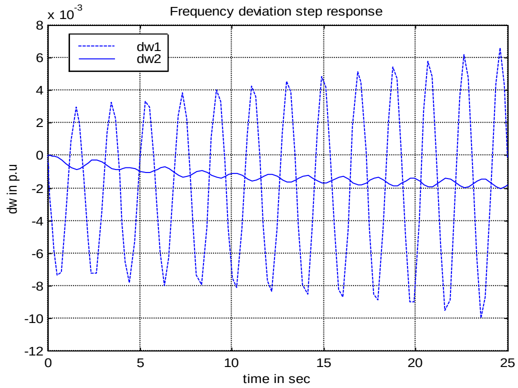
Notes: (*) Unstable Case,
Pt = peak time, Pos = peak overshoot, Rt = rise time, and St = settling time

2. Effects of the Governor Speed Regulation on the System Stability on Frequency Response

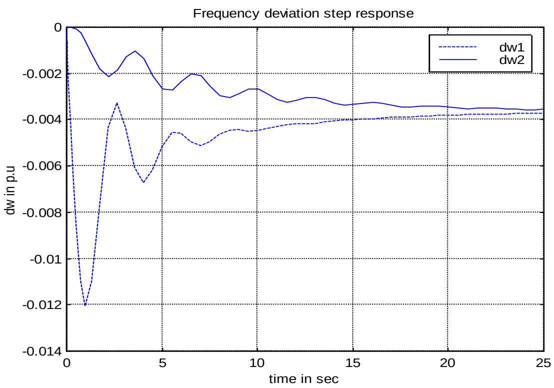
Two-area systems analysis holds for steam turbine generation, for hydro turbines, the large inertia of the water must be accounted for and the analysis is more complicated. The representation of two area systems connected by a tie-line is shown in Fig. (2). The general analysis is as before except for the additional power terms due to the tie-line. The machines in the individual power systems are considered to be closely coupled and to possess one equivalent rotor. The frequency response is plotted for four groups of regulation (R_1=0.01, R_2=0.04), (R_1=0.0135, R_2=0.04), (R_1=0.04, R_2=0.04), and (R_1=0.08, R_2=0.04) without ACE are plotted in Fig. (5) and with ACE in Fig. (6). The response shows case of instability when R_1=0.01, case of sustained oscillation with R=0.0135 which refer to critically stable case, while it shows good stability with (R_1=0.04, R_2=0.04). More undershoot, large settling time is recorded with (R_1=0.08). It is to be noted that even with using ACE signals still the system unstable with (R_1=0.01, R_1=0.0135). Therefore the values of (R_1=0.04 and 0.05) are the best values.



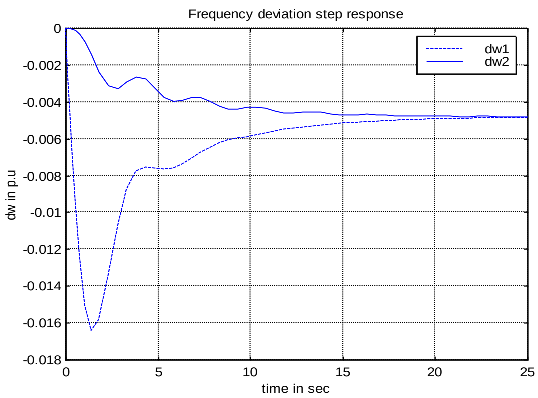
(a) R_1=0.01 and R_2=0.04 per unit



(b) R_1=0.0135 and R_2=0.04 per unit

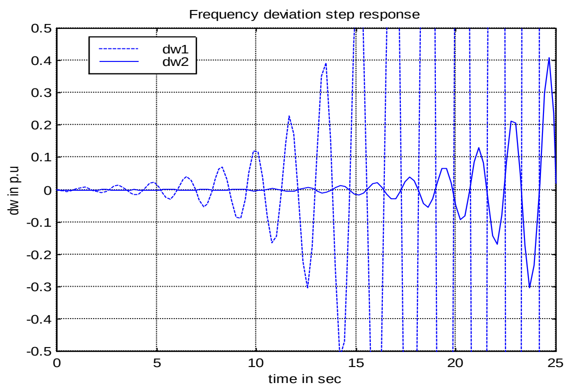


(c) R_1=0.04 and R_2=0.04 per unit

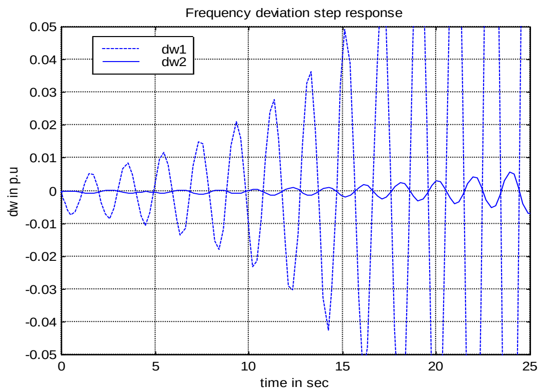


(d) (R_1=0.08 and R_2=0.04 per unit

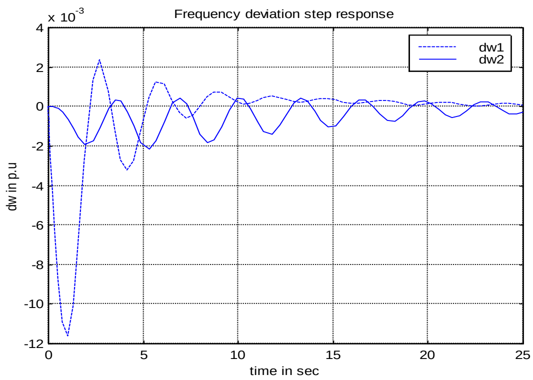
Fig. (5) The frequency deviations step responses for a sudden load change occurs in area #1 without ACE



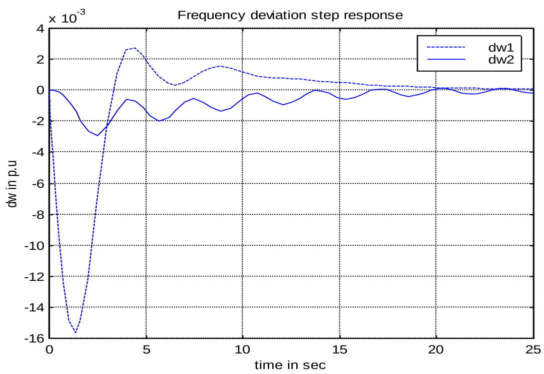
(a) R_1=0.01 and R_2=0.04 per unit



(b) R_1=0.0135 and R_2=0.04 per unit



c) R_1=0.04 and R_2=0.04 per unit



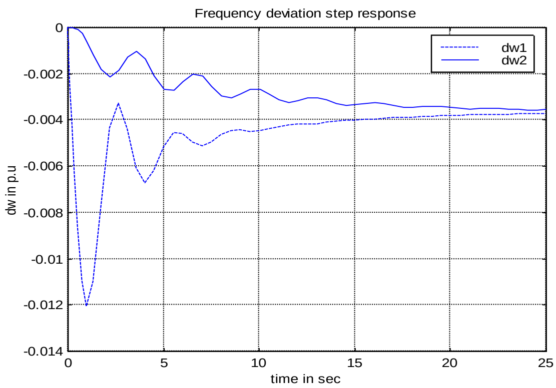
(d) R_1=0.08 and R_2=0.04 per unit

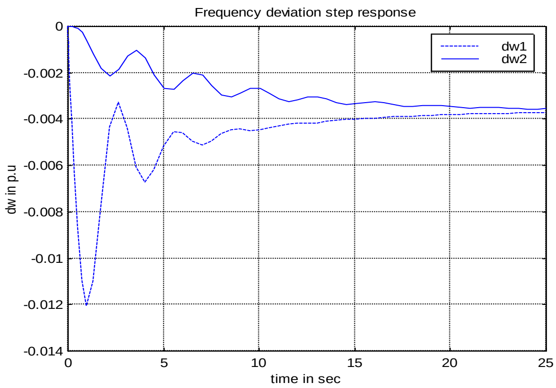
Fig. (6) The frequency deviations step responses for a sudden load change occurs in area #1 with ACE

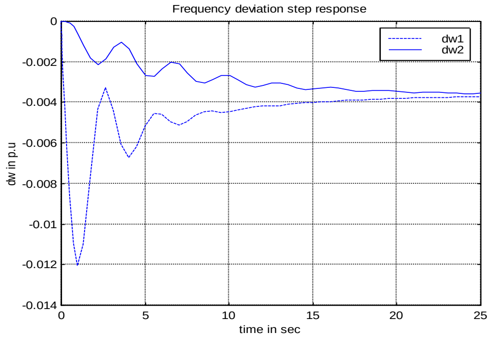
3. Effects of the Governor Speed Regulation on the System Stability by Pole Placement Techniques

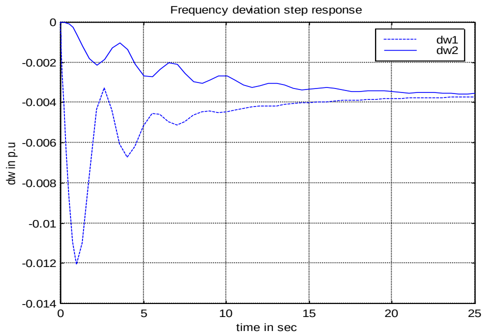
To obtain the frequency deviation step response for a sudden load change of 20% as the same in before, without pole placement or (uncompensated) using the state space model and substituting the parameters of the system in the state space equation with $\Delta P_{ref}=0$. The frequency deviation step response result is shown in Fig. (7) for a different values of governor speed regulation.

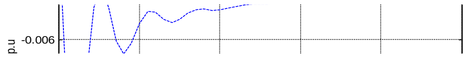
For uncompensation results, which is the same as the response obtained in above using the transfer function method. We are seeking the feedback gain vector K to place the roots of the system characteristic equation at -2±j6 and –3. Or by using pole placement (compensated) to place the compensated closed loop pole. Thus, for nominal value of governor speed regulation R=0.04, the state feedback constants K_1=3.36, K_2=0.44, and K3=0.8 result in the desired characteristic equation roots, and the response settles to a steady state value of Δss=-0.0017 per unit in about 2.5 seconds. Similarly, for R=0.01, K=[0.84, -0.64, 0.8], for R=0.0135, K=[1.134, -0.514, 0.8], for R=0.05, K=[10.2, 0.8, 0.8], and for R=0.08, K=[6.72, 1.88, 0.8]. Thus, the transient response is improved and identical as shown in Fig. 7(f) for different values of governor speed regulation.

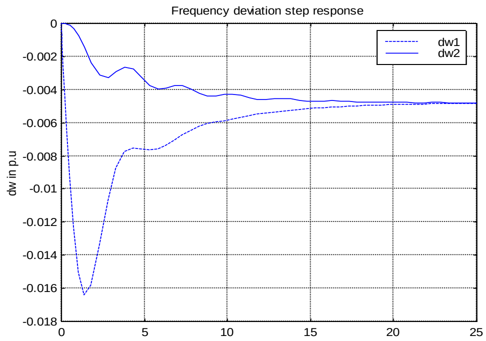


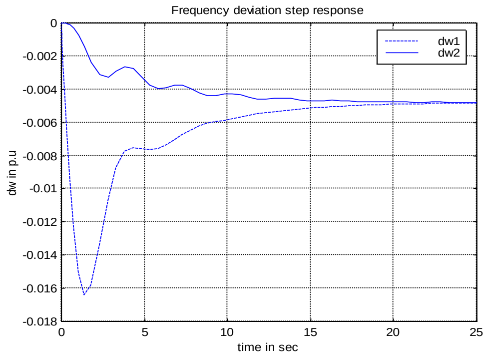


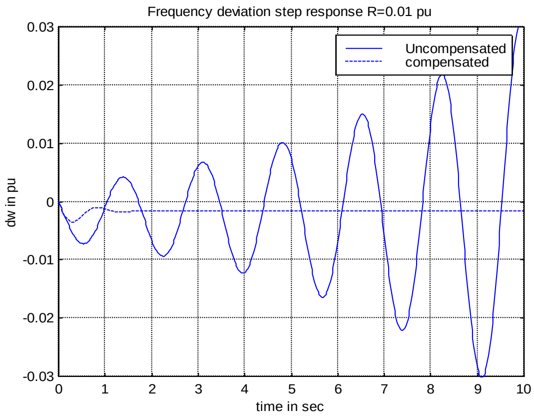




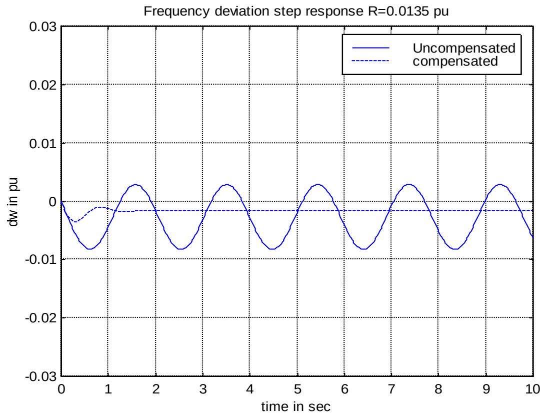




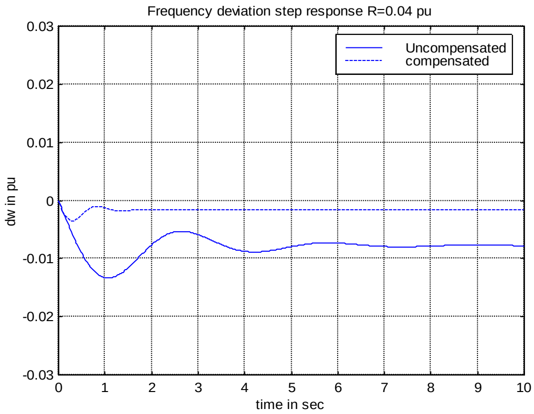




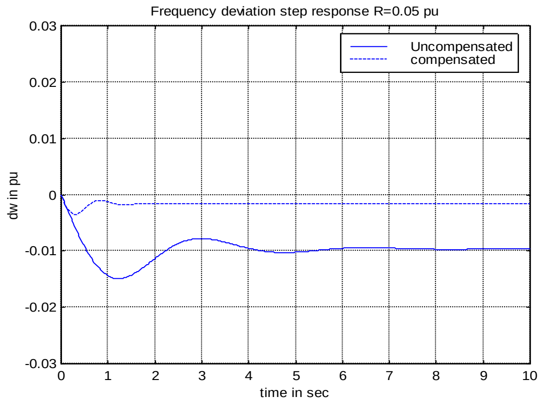
(a) with R=0.01 pu.



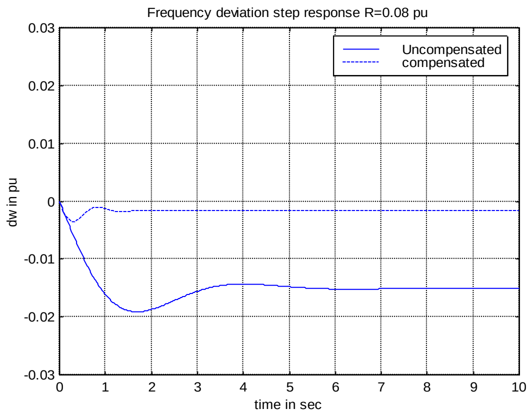
(b) with R=0.0135 pu.



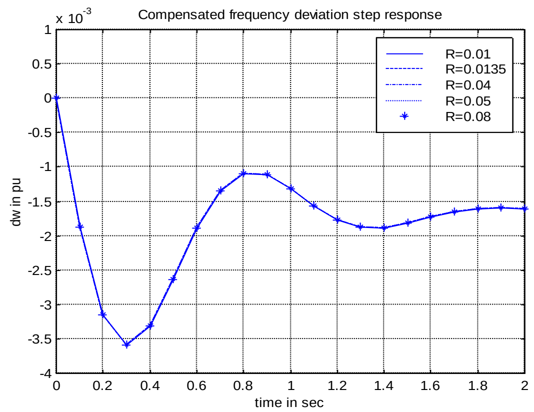
(c) with R=0.04 pu.



(d) with R=0.05 pu.



(e) with R=0.04 pu.



(f) with different values of R

Fig. (7) The frequency deviation step response for a sudden load change with/without compensation using pole placement technique

VI. CONCLUSION

A design technique allows all roots of the system characteristic equations to be placed in desired locations, a regulator with constant gain vector K, and the Algebraic Riccati Equation ARE solution for power system automatic generation control AGC in dynamic and steady state conditions. Other approach to the design of optimal controllers by Pole Placement Techniques for feeding back the state variables through a regulator with constant gains. The design techniques allows all roots of the system characteristic equations to be placed in desired locations, and a regulator with constant gain vector K. Optimal control deals with designing controls for dynamic systems by minimizing a performance index that depends on the system variables. The governor speed regulation must be greater than 0.02 and less than 0.08 per unit. Based on the obtained results, optimum speed governor regulation values are 0.04 and 0.05 p.u. that lead to the power system stability.

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