OPTIMAL SENSITIVITY METHOD FOR MULTI-MACHINE DIGITAL CONTROL SYSTEMS

دوال الحساسيه للتحكم الرقمى الامثل فى نظم الشبكات متعددة الالات

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يقدم البحث نظريه لتصميم محكمات رقميه مثاليه لنظم القوى الكهربيه متعددة الات التوليد. والمحكم المقترح لا يتطلب وصف رياضى للنظام فيما عدا المحكم الذى يجب توصيله كذلك فهو مناسب للتطبيق على نماذج النظم او على النظم الحقيقيه اثناء خدمتها. والمحكم المقترح يتغذى باشارات رجعيه من الة التوليد المثبت عليها فقط غير معتمد على اشارات باقى الالات الاخرى مما يجنب الكثير من مشاكل نقل الاشارات. وقد طبق النظام المقترح على شبكة كهربائيه مكونه من ثلاث الات توليد واثبتت النتائج مدى فاعليه النظريه المقترحه.

ABSTRACT

This paper concerns the development of a sensitivity method for the optimization of multi-machine system performance by which the estimated values of the parameter settings are optimal. This method does not require a mathematical description of the system under control, except for the controllers which need to be identified. The method is suitable for implementation on model system and on real control systems in service. Also it is capable of producing a control law which is derived only from the machine signals independent on other machine signals.

INTRODUCTION

The complexity of interconnected power system with multi generating units and long transmission lines have made the stability and control problems more difficult than ever. The problems arised from structural perturbations between inter conected generating units. Though, it is essential for t[illegible] reliability of interconnected power system to design controll[illegible] which guarantee system stability under small signal pertur tions.

Untill recentely there has been no available control theory for multi-machine process and work to date [1-5] has emphasised state space considerations of stability and control. Yu.Y.N. proposes an optimal linear regulator design technique using dominant eigen-value shift for determinning the weighting matrix Q. Rahim introduces quasi-optimal control technique based on the concept of quasi-linearization and bang-bang control strategy given by (kelly). Chan developes an optimal variable structure controller for improving the dynamic stability on the multi machine system by minimizing a quadratic performance index in the sliding mode operation. However,most of these technique suffer from high computational effort and faced with implementation problem. Moreover none of such techniques offers on line optimization of multi-machine control systems.

This paper introduces a method which involves the use of parameter sensitivity functions technique given by El- Desoky to yield parameter settings of the multi-machine controller. The control law for each machine is derived from its signal independent on other machine signals.

SENSITIVITY METHOD FOR MULTI-MACHINE CONTROL SYSTEMS

The linearized system equations for a single input contol of a z machines system . used in deriving the sensitivity functions may be described as:

$$\begin{vmatrix} \dot{y}_1 \\ \dot{y}_2 \\ -- \\ \dot{y}_z \end{vmatrix} = \begin{vmatrix} A_{11} & A_{12} & --- & A_{1z} \\ A_{21} & A_{22} & --- & A_{2z} \\ --- & --- & --- & --- \\ A_{z1} & A_{z2} & --- & A_{zz} \end{vmatrix} \begin{vmatrix} y_1 \\ y_2 \\ -- \\ y_z \end{vmatrix} + [\; b_1 \quad b_2 \; -- \; b_z \;] \begin{vmatrix} V_1 \\ V_2 \\ -- \\ V_z \end{vmatrix} \qquad (1)$$

This matrix equation can be written in the following compact form:

$$\dot{y} = A\,y + b\,V \qquad (2)$$

$$V = k_r - U \qquad (3)$$

$$U = K\,y \qquad (4)$$

where:

- A is zn x zn square matrix
- $A_{11}, A_{22}, ---A_{zz}$ are n x n square matrices,
- y_i n state vector,
- y zn state vector,
- b zn x z constant matrix,
- U z control vector,
- k_r is a zn coloumn vector containing variable size step disturbances, and
- k is the zn feedback vector,consist of z feedback sub-vector (k) of n elements

equations (2),(3) and (4) when restated in phase variable form give:

$$y_i(s) = w_i(s) \; . \; v(s) \qquad \text{for } 1 \leqslant i \leqslant zn \qquad (5)$$

$$v(s) = k_r / s - \sum_{j=1}^{zn} k_j \; . \; y_j(s) \qquad (6)$$

Where $w_i(s)$ is the i-th transfer function of the system which is being controlled, k_r is a variable size disturbance of magnitude given by [6] :

$$k_r = 1 + \sum_{j=1}^{zn} k_j \; . \; y_{fj} \qquad (7)$$

Where y_f is the final value of the states and it can be calculated from equation(2) by setting y and U equal zeros.

$$y_f = A^{-1} \; b \qquad (8)$$

The time response of variable i after small changes Δk in the feedback vector K $y_i(t, k+\Delta k)$ is related to the time response before the changes $y_i(t,k)$ by :

$$y_i(t,k_o+\Delta k) = y_i(t,k_o) + \sum_{j=1}^{zn} \Delta k_j \; . \; \frac{\delta y_i(t,k_o)}{\delta k_j} + R\, y_i(t) \qquad (9)$$

where, $R\, y_i(t)$ is the residual corresponding to higher order terms If the sensitivity functions of the i-th state variable y(t) with respect to a small change in j-th feedback parameter k_j of the control system is defined as :

$$S^{y_i}_{k_j}(t) = \delta y_i(t) \,/\, \delta k_j \tag{10}$$

Then equation (9) can be rewritten as :

$$y_i(t, k_o + \Delta k_j) = y(t.k_o) + \sum_{j=1}^{zn} \Delta k_j \,.\, S^{y_i}_{k_j}(t) + R\, y_i(t) \tag{11}$$

The sensitivity function are used to estimate the feedback parameter changes which are necessary to alter the state variable response from its present form towards its final value form 'given by equation (8)' . This is accomplished by making the parameter changes Δk_j for all j giving.

$$y_i(t,\ k_o + \Delta k_j) = y_{ei}(t)$$

i.e

$$y_{ei} = y(t,k_o) + \sum_{j=1}^{zn} \Delta k_j \quad S^{y_i}_{k_j}(t) + R\, y_i(t)$$

Substituting equation (5) into equation (6) gives:

$$y_i(s) = x_i(s)\,.\, k_r \qquad \text{for} \qquad 1 \leqslant i \leqslant zn \tag{12}$$

$$\text{where, } x_i(s) = \frac{W_i(s)}{1 + \sum_{j=1}^{zn} k_j \,.\, W_j(s)} \tag{13}$$

The sensitivity of variable y_i with respect to parameter k_j is then:

$$S^{y_i}_{k_i} = \frac{\delta y_i}{\delta k_j} = \frac{\delta x_i(s)}{\delta k_j} \,.\, k_r + x_i(s) \,.\, \frac{\delta k_r}{\delta k_j} \tag{14}$$

When this equation is expanded and restated in sampled data form it becomes:

$$S^{y_i}_{k_j}(\alpha \cdot \Delta t) = \frac{1}{k_r}\left[\sum_{\beta=1}^{\alpha} \frac{y_i(\beta \cdot \Delta t) - y_i((\beta-1)\cdot \Delta t)}{\Delta t}\right]$$

$$[y_j(\alpha \cdot \Delta t - \beta \cdot \Delta t)] + \frac{1}{k_r} \cdot y_{ej} \cdot y_i(\alpha \cdot \Delta t) \quad \text{for } 1 \leqslant \alpha \leqslant ns \qquad (15)$$

where : ns = number of samples
Δt = sampling interval
$y_i(0) = 0$ for $1 \leqslant i \leqslant zn$

If the i-th desired and synthesised changes in the state variable response were respectively defined as :

$$y_{di} = y_{ei} - y_i(t, k_o) \qquad (16)$$

and

$$y_{mi}(t) = \sum_{j=1}^{zn} S^{y_i}_{k_j} \Delta k_j$$

Then equation (9) can be written as:

$$Ry_i(t) = y_{di}(t) - y_{mi}(t) \qquad (18)$$

It is then desired to compute the parameter change Δk so as to minimize $Ry_i(t)$. Minimization of $Ry_i(t)$ is made in the following integral least squared error form :

$$L = \int_0^t Q_i \; Ry_i(t)^2 \; dt \qquad i=1,2 \cdots zn \qquad (19)$$

or alternatively in the discrete form as :

$$L = \sum_{l=1}^{\alpha} \sum_{i=1}^{zn} Q_i \left[y_{di}(l \cdot \Delta t) - \sum_{j=1}^{zn} S^{y_i}_{kj}(l \cdot \Delta t) \cdot \Delta k_j \right]^2 \Delta t \qquad (20)$$

The performance index L is minimized with respect to the parameter channges Δk_j by differentiating L with respect to each of the parameter changes in term and setting the derivatives to zero :

$$\frac{\delta L}{\delta k_j} = 0 \qquad \text{for } 1 \leqslant j \leqslant zn \qquad (21)$$

This process results in a set of zn linear equations in the unknowns Δk_j in the form :

$$\sum_{j=1}^{zn} Q_i \sum_{l=1}^{\alpha} y_i(l\cdot\Delta t)\, S_{k_j}^{y_i}(l\cdot\Delta t) = \sum_{j=1}^{zn} k_j \sum_{i=1}^{zn} Q_i \sum_{l=1}^{\alpha} S_{k_j}^{y_i}(l\cdot\Delta t)\, S_{k_j}^{y_i}(l\cdot\Delta t) \qquad (22)$$

or alternatively of the matrix form:

$$Y = Z\cdot\Delta K \qquad (23)$$

Solution of the above system equations gives the required set parameter changes . The processes of parameter change calculation followed by implementation of these changes on the system are repeated until the performance index L is minimized.

EXAMPLE

The optimal sensitivity method developed in this paper is now applied to a multi-machine system consisting of three machines and an infinite bus [3]. The linearized system takes the form given by equation (1) and for the data given in [3] the numerical values of the A and b matrices are.

$$A11 = \begin{vmatrix} -.922 & 1 & -.266 & -.009 \\ -2.75 & -2.78 & -1.36 & -.037 \\ 0 & 0 & 0 & 1 \\ -4.95 & 0 & -55.5 & -.039 \end{vmatrix} \quad A12 = \begin{vmatrix} .024 & 0 & -.087 & .002 \\ -.158 & 0 & 1.11 & -.011 \\ 0 & 0 & 0 & 0 \\ .222 & 0 & 8.17 & .004 \end{vmatrix}$$

$$A13 = \begin{vmatrix} .027 & 0 & -.25 & .003 \\ -.46 & 0 & 2.8 & -.02 \\ 0 & 0 & 0 & 0 \\ .924 & 0 & 17.5 & .02 \end{vmatrix} \quad A21 = \begin{vmatrix} .021 & 0 & .121 & .003 \\ -1.1 & 0 & -1.62 & -.015 \\ 0 & 0 & 0 & 0 \\ -2.43 & 0 & 1.37 & -.034 \end{vmatrix}$$

$$A_{22} = \begin{vmatrix} -.21 & 1 & -1.6 & -.005 \\ -1.09 & -1.8 & 9.3 & -.12 \\ 0 & 0 & 0 & 1 \\ -3.1 & 0 & -56 & .032 \end{vmatrix} \quad A_{23} = \begin{vmatrix} .06 & 0 & .46 & .002 \\ -1 & 0 & 1.49 & -.04 \\ 0 & 0 & 0 & 0 \\ .12 & 0 & 29.8 & -.028 \end{vmatrix}$$

$$A_{11} = \begin{vmatrix} -.002 & 0 & .083 & 0 \\ 6.78 & 0 & -10.1 & -.09 \\ 0 & 0 & 0 & 0 \\ -1.24 & 0 & .498 & -.017 \end{vmatrix} \qquad A_{22} = \begin{vmatrix} .011 & 0 & .22 & 0 \\ -2.1 & 0 & 1.7 & -.123 \\ 0 & 0 & 0 & 0 \\ -.07 & 0 & 6.37 & -.011 \end{vmatrix}$$

$$A_{33} = \begin{vmatrix} -.197 & 1 & -1.2 & -.003 \\ -54.4 & -20 & 70.1 & -2.37 \\ 0 & 0 & 0 & 1 \\ -3.4 & & -21 & -.017 \end{vmatrix}$$

$$b = \begin{vmatrix} 0 & 36.1 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 78.9 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 1000 & 0 & 0 \end{vmatrix}$$

The responses of the three plants under the proposed control system are shown in figure (1) . The figure shows that the proposed controller gives damped response for the three plants.

CONCLUSIONS

A method based on parameter sensitivity functions and suitable for multi-machine control systems has been presented. Such a method offers the possibilty of tunning the parameters of multi-machine controller which have been installed on real systems. Simulation studies of an interconnected power system consists of three machines have shown improved system performance for all machines. The method might also be applied to simulations of , perhaps, large systems which include non-linearity and could provide a basis for final parameter value computation following conventional studies on simplified, linearized system models. .

REFRENCES

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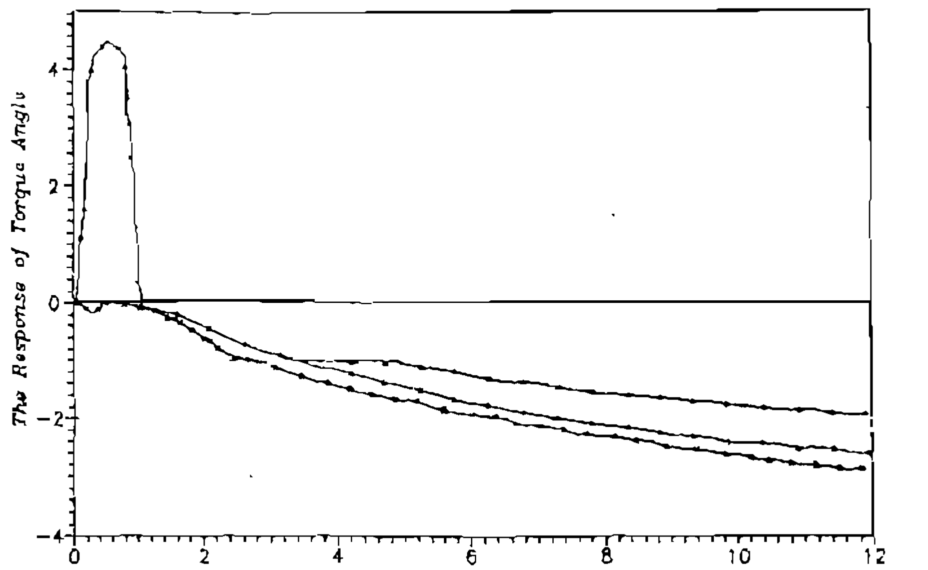

Figure (1) : A

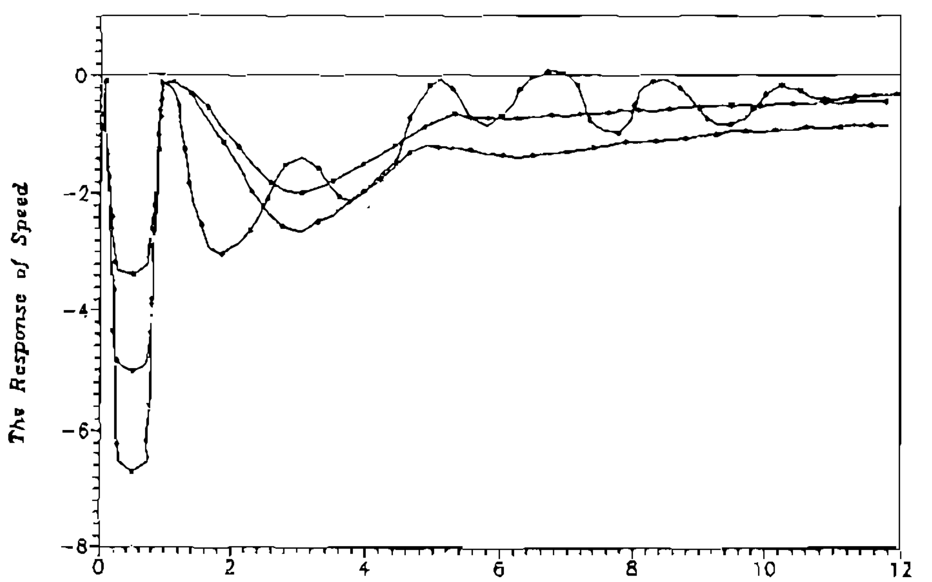

Figure (1) · B

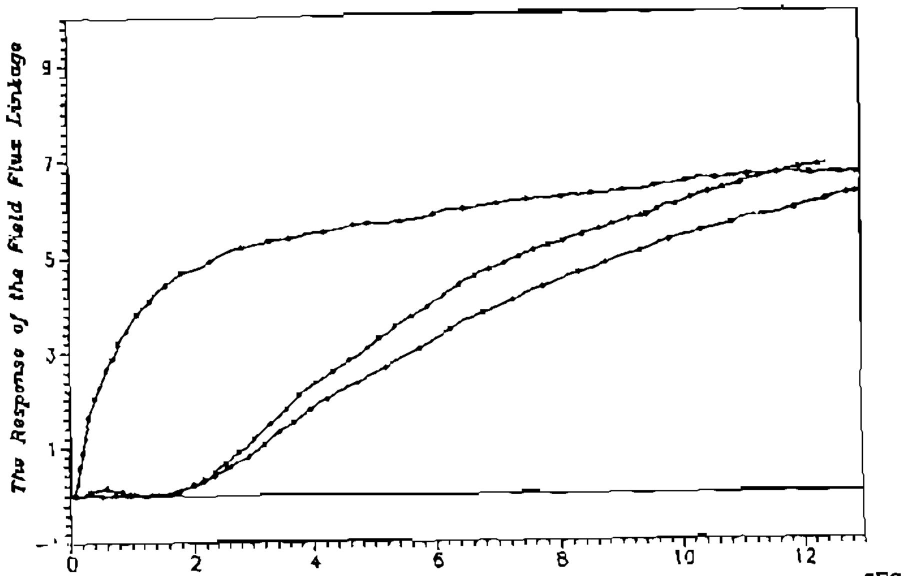

Figure (1) : C

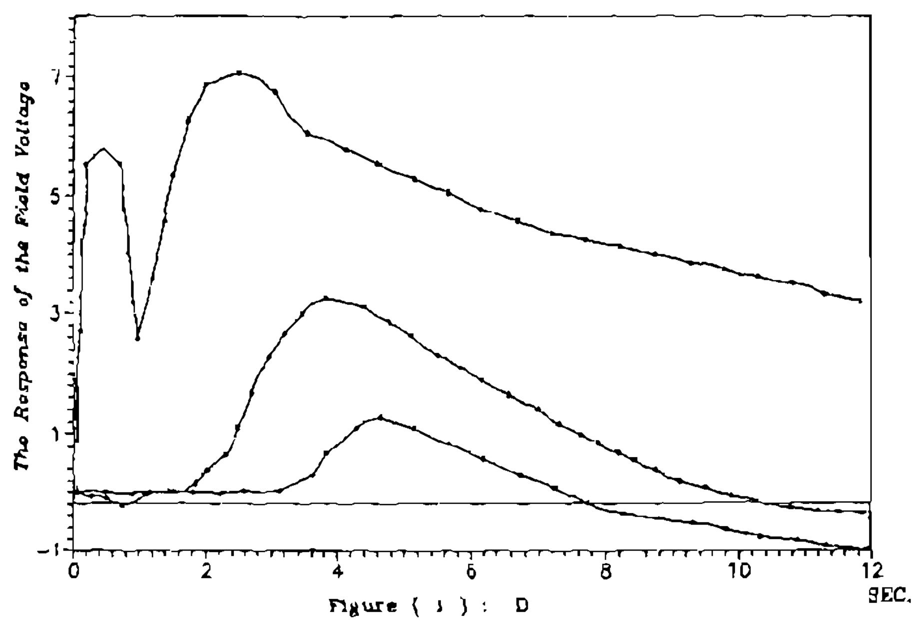

Figure (1) : D