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A Genetic Approach to the Selection of the Variable Structure Controller Feedback Gains

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Abstract

In this paper, a new method of determining the variable structure controller switching vector gains is presented. Contrary to the trial and error selection of the variable structure feedback gains reported in the literature, the selection in the present work is done using genetic algorithms. The proposed design has been applied to the load frequency problem of a single area power system. The system performance against step load variations has been simulated and compared to some previous methods. Simulation results show that the dynamic system performance has been improved.

1. Introduction

In recent years, there is an ongoing interest on the application of the variable structure controllers (VSC) to different engineering problems including power systems [1-9], aerospace [10-12], robotics [13,14], and many others. In all of these attempts, the VSC feedback gains were chosen by trial and error such that they will satisfy certain system performance requirements. Very recently, the problem of VSC feedback gains selection has been considered by [3]. Their approach essentially was to try all allowable values of the feedback gains and evaluate a performance index for each possible set of feedback gains. The optimal feedback gains selected are those which minimize the performance index. This approach is numerically intensive especially for large numbers of feedback gains.

Genetic algorithms (GA) are robust search and optimization techniques which have been applied to many practical problem [15,16]. The use of GA in control application is increasing considerably [17-22]. In the present work, a new approach based on GA is proposed for the selection of the VSC feedback gains. This is accomplished by formulating the VSC feedback gains selection as an optimization problem and GA are used in the optimization process. The proposed method provides an optimal and systematic way of feedback gains selection in the VSC.

In order to test the effectiveness of the proposed new method of selecting the VSC gains, it has been applied to the load frequency control (LFC) problem of a power system. Fig. 1 shows the transfer function model of the LFC for a single area power system [2]. The dynamic model in state-variable form can be obtained from the transfer function model and is given as

$$\dot{X}(t) = AX(t) + Bu(t) + Fd(t) \qquad (1)$$

Where X is 4-dimensional state vector, u is 1-dimensional control force vector, d is 1-dimensional disturbance vector, A is 4×4 system matrix, B is 4×1 input matrix, and F is 4×1 disturbance matrix

$$A = \begin{bmatrix} -\frac{1}{T_p} & \frac{K_p}{T_p} & 0 & 0 \\ 0 & -\frac{1}{T_t} & \frac{1}{T_t} & 0 \\ -\frac{1}{RT_g} & 0 & -\frac{1}{T_g} & -\frac{1}{T_g} \\ K & 0 & 0 & 0 \end{bmatrix}$$

$$B^T = \begin{bmatrix} 0 & 0 & \frac{1}{T_g} & 0 \end{bmatrix}$$

$$F^T = \begin{bmatrix} \frac{K_p}{T_p} & 0 & 0 & 0 \end{bmatrix}$$

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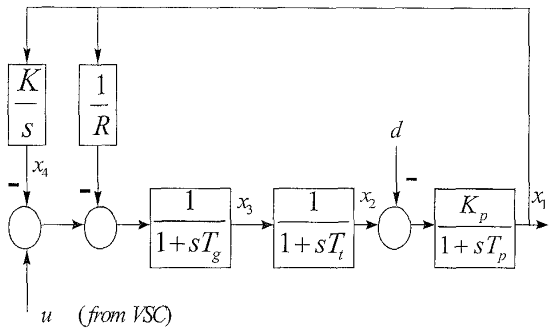

Fig. 1: Block diagram of single control area

The control objective in the LFC problem is to keep the change in frequency ($\Delta\omega = x_1$) as close to zero as possible when the system is subjected to a load disturbance (d) by manipulating the input (u).

2. Theory of VSC

The fundamental theory of variable structure systems may be found in [23]. A block diagram of the VSC is shown in Fig. 2, where the control law is a linear state feedback whose coefficients are piecewise constant functions.

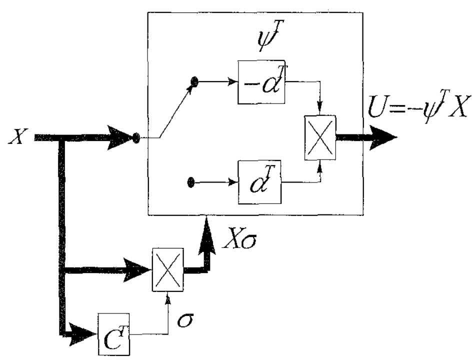

Fig. 2: Block diagram of variable structure controller

Consider the linear time-invariant controllable system given by

$$\dot{X} = AX + BU \tag{2}$$

Where X is n-dimensional state vector, U is m-dimensional control force vector, A is n×n system matrix, and B is n×m input matrix. The VSC control laws for the system of Equation (2) are given by

$$u_i = -\psi_i^T X = -\sum_{j=1}^{n} \psi_{ij} x_j;\ i = 1,2,\ldots,m \tag{3}$$

where the feedback gains are given as

$$\psi_{ij} = \begin{cases} \alpha_{ij}, & if \quad x_i\sigma_j \rangle 0;\ i = 1,\ldots,m \\ -\alpha_{ij}, & if \quad x_j\sigma_i \langle 0;\ j = 1,\ldots,n \end{cases}$$

and

$$\sigma_i(X) = C_i^T X = 0, \qquad i = 1,\ldots,m$$

where C_i are the switching vectors which are determined usually via a pole placement technique. The design procedure for selecting the constant switching vectors C_i is described below [2].

Step1: Define the coordinate transformation

$$\boldsymbol{Y = MX} \tag{4}$$

such that

$$MB = \begin{bmatrix} 0 \\ \ldots \\ B_2 \end{bmatrix} \tag{5}$$

where M is a nonsingular $n\ x\ n$ matrix and B_2 is a nonsingular $m\ x\ m$ matrix.

From (2), (4) and (5)

$$\dot{Y} = M\dot{X} = MAM^{-1}Y + MBU \tag{6}$$

Equation (6) can be written in the form

$$\begin{bmatrix} \dot{Y}_1 \\ \dot{Y}_2 \end{bmatrix} = \begin{bmatrix} A_{11} & A_{12} \\ A_{21} & A_{22} \end{bmatrix} \begin{bmatrix} Y_1 \\ Y_2 \end{bmatrix} + \begin{bmatrix} 0 \\ B_2 \end{bmatrix} U \tag{7}$$

where A_{11}, A_{12}, A_{21}, A_{22} are respectively *(n-m) x (n-m), (n-m) x m, m x (n-m)* and *(m x m)* submatrices.

The first equation of (7) together with equation (2) specifies the motion of the system in the sliding modem that is

$$\dot{Y}_1 = A_{11}Y_1 + A_{12}Y_2 \tag{8}$$

$$\sum(Y) = C_{11}Y_1 + C_{12}Y_2 \tag{9}$$

where C_{11} and C_{12} are *m x (n-m)* and *(m x m)* matrices, respectively satisfying the relation

$$\begin{bmatrix} C_{11} & C_{12} \end{bmatrix} = C^T M^{-1} \tag{10}$$

Equations (9) and (10) uniquely determine the dynamics in the sliding mode over the intersection of the switching hyperplanes

$$\sigma_i(X) = C_i^T X = 0, \qquad i = 1,\ldots,m$$

The subsystem described by equation (9) may be regarded as an open loop control system with state vector Y_1 and control vector Y_2 being determined by equation (10), that is

$$Y_2 = -C_{12}^{-1}C_{11}Y_1 \tag{11}$$

Consequently, the problem of designing a system with desirable properties in the sliding mode can be regarded as a linear feedback design problem. Therefore, it can be assumed, without loss of generality, that C_{12} = identity matrix of proper dimension.

Step 2: Equations (8) and (11) can be combined to obtain

$$\dot{Y}_1 = \left[A_{11} - A_{12}C_{11}\right] Y_1$$

Utkin and Yang [24] have shown that if the pair (A, B) is controllable, then the pair (A_{11}, A_{12}) is also controllable. If the pair (A_{11}, A_{12}) is controllable, then the eigenvalues of the matrix $\left[A_{11} - A_{12}C_{11}\right]$ in the sliding mode can be placed arbitrarily by suitable choice of C_{11}. The switching vector C_{11} can be determined by pole placement or optimal placement of the eigenvalues to achieve a specific response [2]. The feedback gains α_{ij} are usually determined by simulating the control system and trying different values until satisfactory performance is obtained.

3. Genetic Algorithms

Genetic algorithms are directed random search techniques which can find the global optimal solution in complex multidimensional search spaces. GA was first proposed by Holland [25] and have been applied successfully to many engineering and optimization problems [16]. GA employ different genetic operators to manipulate individuals in a population of solutions over several generations to improve their fitness gradually. Normally, the parameters to be optimized are represented in a binary string . To start the optimization, GA use randomly produced initial solutions created by random number generator. This method is preferred when a priori knowledge about the problem is not available.

The flow chart of a simple GA is shown in Fig. 3. There are basically three genetic operators used to generate and explore the neighborhood of a population and select a new generation. These operators are selection, crossover, and mutation. After randomly generating the initial population of say N solutions, the GAs use the three genetic operators to yield N new solutions at each iteration. In the selection operation, each solution of the current population is evaluated by its fitness normally represented by the value of some objective function, and individuals with higher fitness value are selected. Different selection methods such as stochastic selection or ranking-based selection can be used.

The crossover operator works on pairs of selected solutions with certain crossover rate. The crossover rate is defined as the probability of applying crossover to a pair of selected solutions. There are many ways of defining this operator. The most common way is called the one-point crossover which can be described as follows. Given two binary coded solutions of certain bit length, a point is determined randomly in the two strings and corresponding bits are swapped to generate two new solutions.

Mutation is a random alteration with small probability of the binary value of a string position. This operation will prevent GA from being trapped in a local minimum. The fitness evaluation unit in the flow chart acts as an interface between the GA and the optimization problem. Information generated by this unit about the quality of different solutions are used by the selection operation in the GA. The algorithm is repeated until a predefined number of generations have been produced. More details about GAs can be found in [16][25][26].

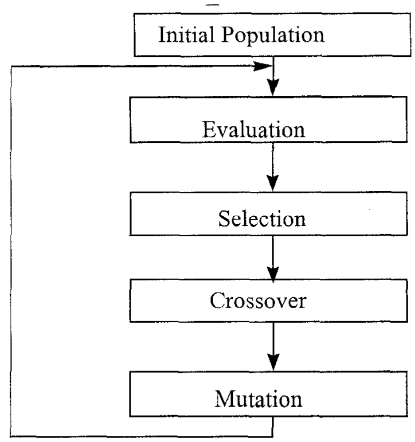

Fig.3: Flow Chart for a Simple Genetic Algorithm

4. Selection of the VSC Feedback Gains Using GA

The feedback gains of the variable structure controller are usually determined by trial and error. In this section, the proposed GA approach for the selection of the feedback gains is explained. To start the proposed GA method, a performance index must be defined. The selection of the performance index depends on the objective of the control problem. The following step by step procedure describes the use of GA in determining the feedback gains optimally for the system described in Section :

1) Generate randomly a set of possible feedback gains.
2) Evaluate the following performance index to keep the change in frequency ($\Delta\omega$) as close to zero as possible regardless of the control effort (u) when the system is subjected to a step load change for all possible feedback gains generated in step 1.

$$J = \int_0^\infty \Delta\omega^2(t) \quad dt$$

3) Use genetic operators (selection, crossover, mutation) to produce new generation of feedback gains.
4) Evaluate the performance index in step 2 for the new generation of feedback gains. Stop if there is no more improvement in the value of the performance

index or if certain predetermined number of generations has been used, otherwise go to step 3.

5. Simulation Results

A variable structure controller for the system given in Section 1 was designed in [2]. The system parameters used in the design are

$T_s = 20$ s, $\quad K_p = 120$ Hz p.u. MW^{-1}

$T_t = 0.3$ s, $\quad K = 0.6$ p.u. MW rad^{-1}

$T_g = 0.08$ s, $\quad R = 2.4$ Hz p.u. MW^{-1}

The values of the feedback gains obtained in [2] are

$$\alpha_1 = 6 \quad ,\alpha_2 = 6 \quad ,\alpha_3 = 2 .$$

Using the GA design procedure described in Section 4 with crossover and mutation probabilities of 0.7 and 0.001 respectively, the optimal feedback gains are

$$\alpha_1 = 2.0804 \quad ,\alpha_2 = 0.0856 \quad ,\alpha_3 = 1.1216 .$$

The behavior of the performance index is shown in Fig. 4. Fig. 5 shows the simulation results of the change in frequency ($\Delta\omega$) for the two designs when the system is subject to a step load change of 0.03 p. u. The value of the performance index is 3.8739 and 2.7498 for the two designs respectively. Although not much improvement is obtained in the behavior of $\Delta\omega$ for the two designs, the feedback gains obtained through the proposed GA approach are much smaller than the previous design. This has resulted in a large decrease in the magnitude of the control effort (u) as shown in Fig. 6. Moreover, the value of α_2 obtained using the proposed method is very small which can be eliminated to reduce the controller complexity. The result of selecting $\alpha_2 = 0$ is shown in Fig. 7 indicating no degradation in the controller performance.

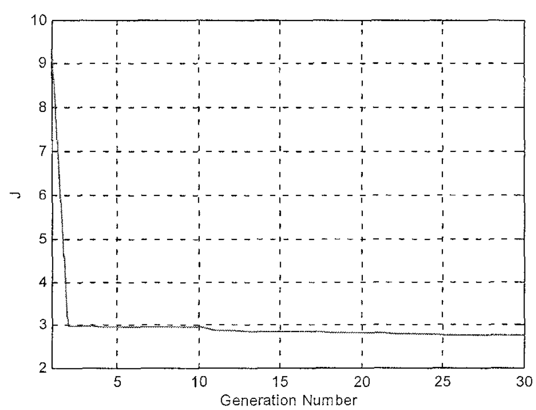

Fig. 4: Values of the Performance Index (J)

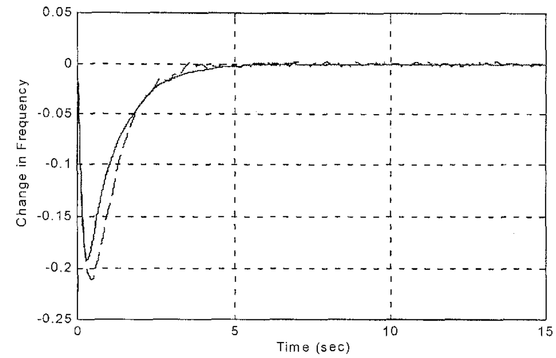

Fig. 5: Change in Frequency ($\Delta\omega$) : Proposed Method (__), Method of [2] (--)

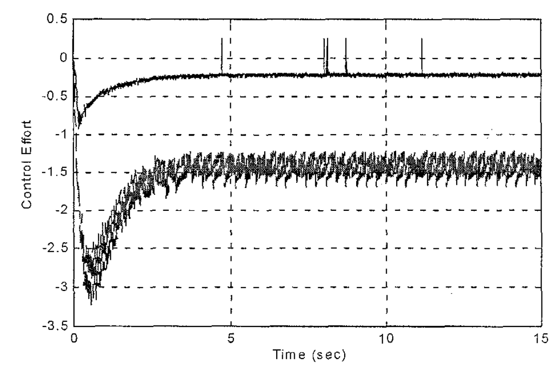

Fig. 6: Control effort (u): Proposed Method (upper), Method of [2] (lower)

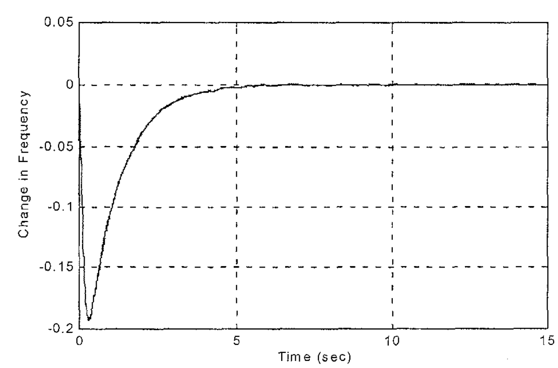

Fig. 7: Change in Frequency ($\Delta\omega$): $\alpha_2 = 0.0804$ (__), $\alpha_2 = 0$ (--)

6. Conclusion

The use of genetic algorithms in the selection of variable structure controller has been investigated in this paper. This is accomplished by formulating the VSC feedback gains selection as an optimization problem and GA are used in the optimization process. The proposed method provides an optimal and systematic way of feedback gains selection in the VSC compared to trial and error methods reported in the literature. The application of the proposed method to LFC problem reveals that superior results can be obtained.

Acknowledgments

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References

[1] Z. Al-Hamouz and Y. Abdel-Magid, "Variable structure load frequency controllers for multiarea power systems", *Int. J. Elect. Power and Energy Syst.*, Vol.15, No. 5, pp. 293-300, 1993.

[2] A.Y. Sivarmakrishnan, M.A Hariharan and M.C. Srisailam, "Design of variable structure load frequency controller using pole assignment technique", *Int. J. Control*, Vol. 40, No. 3, pp. 487-498, 1984.

[3] K. Bhattacharya, M. Kothari, and J. Nanda, "Design of discrete mode variable structure power system stabilizers", *Int. J. Elect. Power and Energy Syst.*, Vol.17, No. 6, pp. 399-406, 1995.

[4] A. Kumar, O. P. Malik and G. S. Hope, "Discrete variable structure for load frequency control of multiarea interconnected power systems", *IEE Proc., Generation, Transmission & Distribution*, Vol. 134, No. 2, pp. 116-122, 1987.

[5] Y. Abdel-Magid, Z. Al-Hamouz and J. Bakhashwain, "A variable-structure stabilizer for wind turbine generators", *Electric Power Systems Research*, Vol. 33, pp. 41-48, 1995.

[6] V. Samarasinghe and N. Pahalawatha, "Damping of multimodal oscillations in power systems using variable structure control technique", *IEE Proc., Generation, Transmission & Distribution*, Vol. 144, No. 3, pp. 323-331, 1997.

[7] T-L Chern, J. Chang, G-K. Chang, "DSP-based integral variable structure model following control for brushless DC motor drivers", *IEEE Trans. Power Elect.*, Vol. 12, No.1, pp. 53-63, 1997.

[8] T-L Chern, C-S Liu, C-F Jong and G-M Yan, "Discrete integral variable structure model following control for induction motor drivers", *IEE Proc., Electric Power Applications*, Vol. 143, No. 6, pp. 467-474, 1996.

[9] A.S. Murty, S. Parameswaran, K. Ramar, "Design of decentralized variable structure stabilizers for multimachine power systems", *Int. J. Elect. Power and Energy Syst.*, Vol.18, No. 8, pp. 535-546, 1996.

[10] X-Y Lu, S. Spurgeon and I. Postlethwaite, "Robust variable structure control of a PVTOL aircraft", *Int. J. System Science*, Vol. 28, No. 6, pp. 547-558, 1997.

[11] M. Innocenti and A. Thukral, "Robustness of a variable structure control system for maneuverable flight vehicles", *J. Guidance, Control, and Dynamics*, Vol. 20, No. 2, pp. 377-383, 1997.

[12] S. Singh, M. Steinberg and R. DiGirolamo, "Variable structure robust flight control system for the F-14", *IEEE Trans. Aerospace and Electronic Systems*, Vol. 33, No. 1, pp. 77-84, 1997.

[13] M. Zribi, L. Huang and S. Chan, "Variable structure control of two manpulators handling a constrained object", *Cybernetics and Systems*, Vol. 28, No. 4, pp. 263-286, 1997.

[14] K. Lee, S. Coates and V. Coverstone-Carroll, "Variable structure control applied to underactuated robots", *Robotica*, Vol. 15, No. 3, pp. 313-318, 1997.

[15] R. Caponetto, L. Fortuna, S. Graziani, and M. Xibilia, "Genetic Algorithms and Applications in System Engineering: a Survey", *Trans. Inst. Meas. Control*, 1993, Vol. 15, pp. 143-156.

[16] D. Goldberg, *Genetic Algorithms in Search Optimization, and Machine Learning*, Addison-Wesley, 1989.

[17] H. N. Al-Duwaish, M. Bettayeb, "Control of Nonlinear Dynamical Systems Using Genetic Algorithms", *Proceedings of the 12th IEEE International Symposium on Intelligent Control*, pp. 421-424, 16-18 July 1997, Istanbul, Turkey.

[18] A. Varsek, T. Urbancic, and B. Filipic, "Genetic Algorithms in Controller Design and Tuning", *IEEE transactions on Systems, Man, and Cybernetics*, Vol. 23, no. 5, 1993.

[19] B. Porter, and A. Jones, "Genetic Tuning of Digital PID Controllers", *Electron. Lett.*, 1992, Vol. 28, pp. 843-844.

[20] Lansberry, L. Wozniak, and D. Goldberg, "Optimal Hydrogenerator Governer Tuning with A Genetic Algorithm", *IEEE Trans.*, 1992, Vol. 7, pp. 623-630.

[21] K. Krishnakumar, and D. E. Goldberg, "Control System Optimization Using Genetic Algorithms", *Journal of Guidance, Control and Dynamics*, Vol. 15, no. 3, pp. 735-740, 1992.

[22] B. Porter, and S. S. Mohamed, "Genetic Design of Multivariable Flight Control System Using Eigenstructure Assignment", *Proc. IEEE Conf. Aerospace Control Systems*, 1993.

[23] U. Itkis, Control systems of variable structure, Keter Publishing House, Jerusalem , 1976.

[24] V. Utkin and K. Yang, "Methods for constructing discontinuity planes in multidimensional variable structure systems", *Autom. And Remote Control*, Vol. 39, pp. 1466-1470, 1978.

[25] Holland, J. H. *Adaptation in Natural and Artificial Systems*, Ann Arbor, MI: University of Michigan Press, 1975.

[26] L. Davis, *The Handbook of Genetic Algorithms*, Van Nostrand Reinhold, NY, 1991.