State Feedback Controller Synthesis: An Optimum Intelligent method using Gravitational Search Algorithm (GSA)

Mousarreza Behravan Far[1], Najmeh Eghbal[2], Soroosh Shooshtarian[3]

1-Student of Sadjad University of Technology

Email: behravan@yahoo.com

2- Assistant Professor of Electrical Department of Sadjad University of Technology

Email: najmeh.eghbal@sadjad.ac.ir

3-Student of Sadjad University of Technology

Email: soroosh.sh7@gmail.com

Abstract: One of the most common issues in studies of dynamical power systems is stabilization using power system stabilizers. There is an introduction about design of state feedback controller using GSA algorithm, afterwards it has been designed a power system stabilizer (PSS) in this method. Furthermore, purpose of using this way of control is the guarantee of closed loop system stability in presence of the possible uncertainties. Consequently, these uncertainties may be caused by non-linearity of the real system in the effect of load, turbulences and other variation. Also its resistance will be evaluated after designing the controller in order to evaluate its effectiveness with applying the load variation in power system model. Despite the results of simulation and implementation of sample system according to the proposed algorithm, it shows the stability and its proper performance.

Keywords: Power system stabilizers, State Feedback controller, GSA, Linear matrix inequality (LMI)

Introduction

In power systems, proper design of controller for controlling the frequency load and electric voltage is done with two independent control loops [1,2]. In practice, the existence of low-frequency oscillations in the absence of appropriate damper torque in system will cause poor performance and even system instability. Therefore, despite the two loops, power stabilizer is used to increase damping and removing low-frequency oscillations improper effects [3-5]. To implement the controller stabilizer with attention to the mechanical elements in the frequency load loop control, designing of controller will be done on the voltage loop control [6,7]. On the other hand, we consider the load variation nature in system and direct relation between system performance and its load for designing a well-functioned system and range of load variations for designing the output feedback stabilizer controller.

Then according to the nominal model system, it will be discussed about nominal load to robust controller design into load variation in the desired range. In order to model the load variations beside the nominal loading performance, two heavy and light loading situations are considered for the changing ranges [8,9].

2-The state feedback design of controller

According to the algorithm proposed in the paper [6] with free desired controller degree of designing method, the design of controlling signal is done on a way that system poles are replaced under the mentioned controller on the left side of axis "$s=\frac{\alpha}{2}$" instead of left side of imaginary axis[10,11] .

In result the following inequality is formed:

$$P(A+BFC)+(A+BFC)^T P-\alpha P+Q < 0 \quad (1)$$

If we find a negative "α", the stabilization problem is solved [12] .Solving the nonlinear equation matrix will be difficult because of being non-convex [14]. However, we can simply convert these inequalities to a linear matrix inequality with defining a new variable and we can minimize the variable "α" by providing an iterative algorithm as long as the negative value is obtained. To robust system due to δ uncertainty parametric values and designing controller with free desired degree method we must find a link between α values and

parametric uncertainty of system [5]. The algorithm for designing the controller is provided as below:
1- At first we choose a randomly "Z" value:

$$P = Z^T Z$$

2- The primary Lyapunov is defined.
3-By solving the following linear matrix inequality for minimum alpha, we have minimum alpha and F values.

$$P(A+BFC)+(A+BFC)^T P-\alpha P+Q < 0$$

4- By solving the following optimization problem, we obtain new P. Consequently, with using GSA algorithm we have:

$$J = \min_Z \alpha^*(z) \quad (2)$$

It will be continued as long as the proper "Z" will be obtained.
(The proper Z is the value that J is hid in it)
In last part the designed system is able to maintain system in constant situation.

Static state feedback (SSF-PSS)

While applying the controller on the linear system and heavy load process, system performance is evaluated. The obtained parameters are:

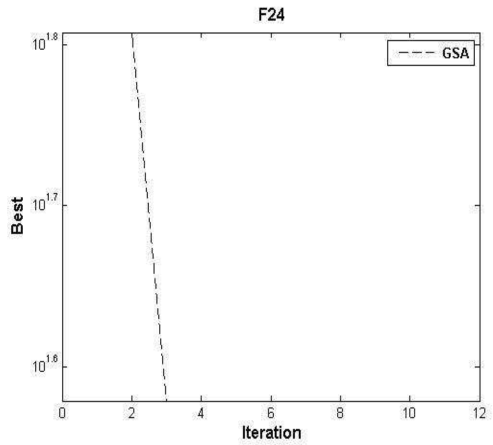
$$F = [\,-1.4125 \quad -0.1353 \quad -8.1281 \quad -0.6683] \quad (3)$$

$$\alpha = -1.e+09 \quad (4)$$

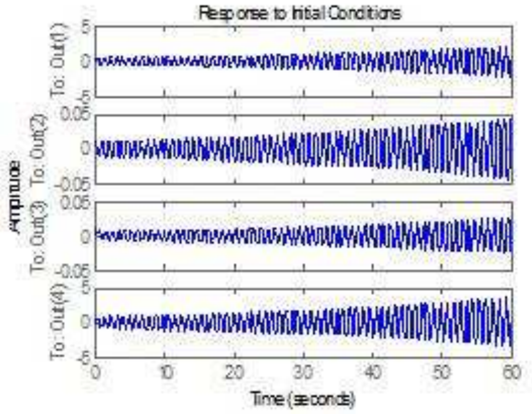
And the closed loop system eigenvalues are:

{-6.8625 + 0.0000i, -0.0017 + 0.0668i,-0.0017 - 0.0668i,-0.0224 + 0.0000i }(5)

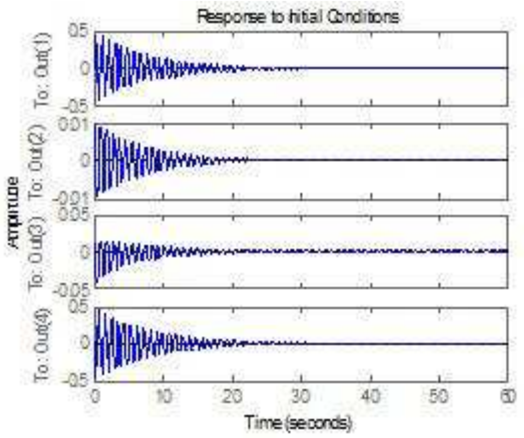
Figure number 2-1 shows the minimization process of " α * " by GSA algorithm.
Also the controller on the non-linear system is examined on heavy load. Furthermore, the result of this shape can be seen in figure one.



2-1-Figure one: The obtained values α in the algorithm iteration



2-2-Figure two: The state outputs without PSS



2-3- Figure three: The state outputs with PSS

3-System simulation

In order to design PSS controller, the lineate-model that is discussed will be considered around the equilibrium four-order points [6]. The model is obtained due to equilibrium points with type of load system. The "k1-k6" parameters are shown in the paper. These parameters are related to load system situation and "Q , P" powers. Furthermore the operating points are shown in range of (0.4,1) and (0.1, 0.5).
Simulated linear system:

$$x = [\Delta\delta \quad \Delta\omega \quad \Delta E_q' \quad \Delta E_{fd}] \quad (6)$$

$$\dot{x} = Ax + Bu, y = Cx \quad (7)$$

$$A = \begin{bmatrix} 0 & \omega_0 & 0 & 0 \\ \frac{-k_1}{M} & 0 & \frac{-k_2}{M} & 0 \\ \frac{-k_4}{T_{do}'} & 0 & -\frac{1}{T} & \frac{1}{T_{do}'} \\ -\frac{k_5 k_E}{M} & 0 & -\frac{k_6 k_E}{M} & -\frac{1}{T_E} \end{bmatrix} \quad (8)$$

$$B = \begin{bmatrix} 0 & 0 & 0 & \frac{k_E}{T_E} \end{bmatrix}, C = \begin{bmatrix} 1 & 0 & 0 & 0 \\ 0 & 1 & 0 & 0 \\ 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix}, T = k_3 T'_{do} \quad \textbf{(9)}$$

4- GSA

GSA optimization is used in this kind of simulation. In this algorithm the optimization is done with gravity laws and moving in an artificial system with discrete time.

According to the law of gravity each mass understand location and situation of other masses through the gravitation of gravity law. So it can be used as a tool for exchanging the information. Designed optimized finder can be used for solving any optimization problem in which the solution of the problem is definable as a position in space and its similarity to other solutions as a definable distance [15-17].

The masses are determined with objective function. The objective function in here is ILMI that include solving the equation (1) by numerical method.

The aim of minimization is “ α” value and reaching to a negative value for it.

Robust SOF-PSS

The success of the controller in system stabilization can be stated in using Lyapunov theorem indirectly even though the design was based on a linear system. So the theorem of real nonlinear behavior system is very similar to its linear estimation that none of its eigenvalues is not on the imaginary axis. Meanwhile the designed controller shows proper resistance to operating points changing.

Conclusion

In conclusion a new algorithm is proposed to stabilize linear time-invariant systems via static output feedback. The iterative algorithm combines the GSA and LMI. Also the algorithm is effective and convergent. The numerical procedure may be useful to solve this kind of bilinear matrix inequality matrix problem. In this paper, the essential part is to obtain an iterative condition. The proposed GSA-ILMI algorithm has low dimension because no additional variable is imposed. A sufficient condition has been suggested for feedback controller design by using GSA algorithm & LMI iterative solution. This method obtains the PSS for linearized model of a single machine infinite bus system. The cost function mentioned before is made in Matlab. In this function, it has been used CVX toolbox for solving linear matrix inequality [18,19]. The advantage of this tool is solving LMI in a simple and well-performance method in solving numerical solution of these inequalities. In order to run the algorithm completely it is needed to install CVX software in Matlab.

References

[1] P. Kundur, “Power System Stability and Control,” McGraw Hill, New York, 1994.

[2] G. Guo, Y. Wang and D. Hill, “Nonlinear Output Stabili-zation Control for Multi-Machine Power Systems,” *IEEE Transactions on Circuits and Systems*, Vol. 47, No. 1, 2000, pp. 46-53. doi:10.1109/81.817388

[3] Z. Qu, J. Dorsey, J. Bond and J. McCalley, “Application of Robust Control to Sustained Oscillations in Power Systems,” *IEEE Transactions on Circuits and Systems*, Vol. 39, No. 2, 1992, pp. 470-476.

[4] R. You, H. J. Eghbali and M. H. Nehrir, “An Online Adaptive Neuro-Fuzzy Power System Stabilizer for Mul-timachine Systems,” *IEEE Transactions Energy Conver-sion*, Vol. 18, No. 1, 2003, pp. 117-125.

[5] H. M. Soliman, A. Elshafei, A. Shaltout and M. Morsi, “Robust Power System Stabilizer,” *IEE Proceeding Gen-eration, Transmission, and Distribution*, Vol. 147, No. 2, 2000, pp. 285-291. doi:10.1049/ip-gtd:20000560

[6] B. Pai and B. Chaudhuri, “Robust Control in Power Sys-tems,” Springer, New York, 2005.

[7] C. J. Zhu, M. Khammash, V. Vittal and W. Qiu, “Robust Power System Stabilizer Design using H∞ Loop Shaping Approach,” *IEEE Transactions on Power Systems*, Vol. 18, No. 2, 2003, pp. 810-818. doi:10.1109/TPWRS.2003.811176

[8] V. Bandal, B. Bandyopadhyay and A. M. Kulkarni, “Decentralized Sliding Mode Control Technique Based Power System Stabilizer (PSS) for Multimachine Power System,” *Proceedings Control Applications*, Toronto, 28-31 August 2005, pp. 55-60.

[9] A. I. Zecevic and D. D. Šiljak, “Control of Complex Sys-tems: Structural Constraints and Uncertainty,” Springer, London, 2009.

[10] R. Gupta, B. Bandyopadhyay and A. Kulkarni, “Robust Decentralized Fast-Output Sampling Technique based Power System Stabilizer for a Multi Machine Power Sys-tem,” *International Journal of Systems Sciences*, Vol. 36, No. 5, 2005, pp. 297-314. doi:10.1080/00207720500089440

[11] S. Rao and I. Sen, “Robust Pole Placement Stabilizer Design using Linear Matrix Inequalities,” *IEEE Transac-tions Power Systems*, Vol. 15, No. 1, 2003, pp. 313-319. doi:10.1109/59.852138

[12] I. Kamwa, R. Grondin and Y. Hebert, “Wide-Area Meas-urement Based Stabilizing Control of Large Power Sys-tems—A Decentralized/Hierarchical Approach,” *IEEE*

Transactions Power Systems, Vol. 16, No. 1, 2001, pp. 136-153. doi:10.1109/59.910791
[13] C. Liu, J. Jung, G. T. Heydt and V. Vittal, "The Strategic Power Infrastructure Defense (SPID) System," *IEEE Control System Magazine*, Vol. 20, No. 1, 2000, pp. 40- 52.
[14] H. M. Soliman, M. Morsi, M. F. Hassan and M. Awadal-lah, "Power system reliable stabilization with actuator failure," *Electric Power Components and Systems*, Vol. 37, No. 1, 2009, pp. 61-77. doi:10.1080/15325000802322020
[15] H. M. Soliman, H. E. Ehab, E. H. E. Bayoumi and M. A. Awadallah, "Reconfigurable Fault-Tolerant PSS and FACTS Controllers," *Electric Power Components and Systems*, Vol. 38, No. 10, 2010, pp. 1446-1468. doi:10.1080/15325001003735200
[16] H. M. Soliman, A. Dabroum, M. S. Mahmoud and M. Soliman, "Guaranteed-Cost Reliable Control with Re-gional Pole Placement of a Power System," *Journal of the Franklin Institute*, Vol. 348, No. 4, 2011, pp. 884-898. doi:10.1016/j.jfranklin.2011.02.013
[17] Y. Y. Cao, J. Lam and Y. X. Sun, "Static Output Feed-back Stabilization: An ILMI Approach," *Automatica*, Vol. 34, No. 12, 1998, pp. 1641-1645. doi:10.1016/S0005-1098(98)80021-6
[18] Y. He and Q. G. Wang, "An Improved ILMI Method for Static Output Feedback Control with Application to Mul-tivariable PID Control," *IEEE Transactions Automatic Control*, Vol. 51, No. 10, 2006,pp.2356-2361. doi:10.1109/TAC.2006.883029
[19] K. E. Parsopoulos and M. N. Vrahatis, "On the Computa-tion of All Global Minimizes Through Particle Swarm Optimization," *IEEE Transactions Evolutionary Compu-tation*, Vol. 8, No. 3, 2004, pp. 211-220. doi:10.1109/TEVC.2004.826076