ROBUST PID STABILIZER DESIGN USING GENETIC ALGORITHMS

Musa Usman Otaru, Naji A. Al-Musabi, Samir A. Al-Baiyat

Department of Electrical Engineering
King Fahd University of Petroleum and Minerals
Dhahran, Saudia Arabia
*E-mail: motaru@kfupm.edu.sa, almusabi@ieee.org, sbaiyat@kfupm.edu.sa

ABSTRACT

In this paper, the design of a PID type stabilizer is investigated using Genetic algorithms. The proposed stabilizer is applied to a single machine infinite bus system subjected to a load disturbance. Comparison with Conventional lead-lag Power System Stabilizer (CPSS) and other design methods of PID stabilizers shows the out performance of the proposed design. Furthermore, the proposed stabilizer shows robust behavior for variations in the operating conditions.

1. INTRODUCTION

Much effort has been invested in recent years in improving the damping performance of power systems using power system stabilizers (PSS). PSS provides a supplementary excitation control signal that enhances the damping capabilities of synchronous machines [1]. The choice of proper parameters for the PSS is important as it affects the overall dynamic performance of the power system. Furthermore, there are various forms of PSS; the most famous types are lead-lag compensator (CPSS) and PID [2]. PID controllers are widely used in industry due to their simplicity and robust performance in wide range of operating conditions. However, it has been quite difficult to tune properly the gains of the PID controllers [3]. Over the years, various heuristic techniques were proposed for tuning the PID controllers. One of the earliest methods utilizes the classical Ziegler and Nichols rules. Nevertheless, it is often difficult to determine optimal or near optimal parameters with the Ziegler-Nichols formula in industrial plants [4].

Recently, research on application of Genetic algorithms (GA) to power system stabilizer has gained much attention [5, 6]. Genetic Algorithm methods have been applied successfully to solve complex optimization problems and its application in control systems has won the attention of researchers for the simple reason of its high potential for global optimization.

The objective of this paper is to study the application of GA in searching for the optimal PID stabilizer parameters and evaluate its performance by comparing it with a PID stabilizer designed by pole placement in [7]. Furthermore, comparison with CPSS is also included in the study. The linearized model of a synchronous generator connected to an infinite bus through a transmission line given in reference [1] was used. However, the operating conditions of the system is varied to observe the robustness of the proposed controller.

2. PID POWER SYSTEM STABILIZER

The system considered in this paper is that of a synchronous generator connected to an infinite bus, Figure 1(a). To design the PID controller, a linearized model [1] of the machine is used, Figure 1(b). Both of the electrical loop, down, and mechanical loop, top, are shown in the figure. This model is sufficient for low-frequency oscillations studies. The state equation [1, 7] of the machine with these loops, can be written as follows:

$$\dot{X} = AX + BU + Fr \qquad (1)$$

$$Y = CX \qquad (2)$$

Where $X = \left[\Delta\omega, \Delta\delta, \Delta e_q^{'}, \Delta e_{FD}\right]^T$ is the state vector, $Y = \left[\Delta\omega, \Delta v_T\right]^T$ is the measure output vector, $r = \left[\Delta v_{ref}, \Delta T_m\right]$, and A, B, F and C are constant matrices given by

$$\mathbf{A} = \begin{bmatrix} 0 & -K_A/M & -K_2/M & 0 \\ \omega_b & 0 & 0 & 0 \\ 0 & -K_4/T_{d0}^{'} & -1/(T_{d0}^{'}K_3) & 1/T_{d0}^{'} \\ 0 & -K_AK_5/T_A & -K_AK_6/T_A & -1/T_A \end{bmatrix} \qquad (3)$$

$$B = \begin{bmatrix} 0 & 0 & 0 & K_A/T_A \end{bmatrix} \qquad (4)$$

$$C = \begin{bmatrix} 1 & 0 & 0 & 0 \\ 0 & K_5 & K_6 & 0 \end{bmatrix} \qquad (5)$$

$$F = \begin{bmatrix} 0 & 0 & 0 & K_A/T_A \\ 1/M & 0 & 0 & 0 \end{bmatrix}^T \tag{6}$$

The control signal u comes from the PID stabilizer, Figure 2, and can be written in s-domain as follows:

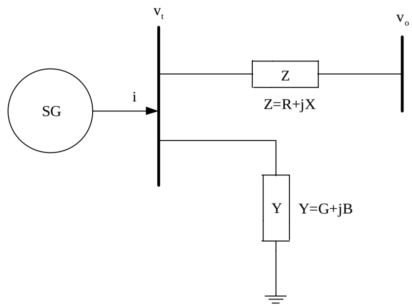
$$\begin{aligned} u(s) &= (P + \tfrac{1}{s}Q + sD)Y(s) \\ &= H(s)Y(s) \end{aligned} \tag{7}$$

where $P = [p_1 \quad p_2]$, $Q = [q_1 \quad q_2]$, and $D = [d_1 \quad d_2]$ are the gains of the PID controller, and $H(s)$ is defined to be $H(s) = (P + \frac{1}{s}Q + sD)$. Equations (1) and (2) can be written in s-domain as follows:

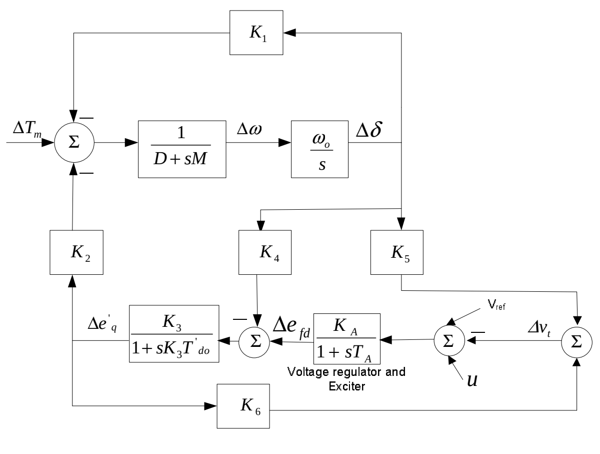
$$sX(s) = AX(s) + BU(s) + FR(s) \tag{8}$$

$$Y(s) = CX(s) \tag{9}$$

The closed loop system with PID-stabilizer can be expressed in s-domain by combining equations (7), (8), and (9):



(a)



(b)

Figure 1. (a) Single machine infinite bus system **(b)** Transfer function block diagram for low-frequency oscillation studies

$$Y(s) = \left[C(sI - A - BH(s)C)^{-1} F \right] R(s) \tag{10}$$

The poles of the closed loop system are the roots of the fifth order characteristic polynomial:

$$\Delta(s) = \left| sI - (A + BH(s)C \right| \tag{11}$$

In [7], a combination of pole placement and ITAE (integral of time multiplied by the absolute value of error) criterion was used to obtain the gains of the PID stabilizer. This method involved empirical experiments to find the suitable values for the gains.

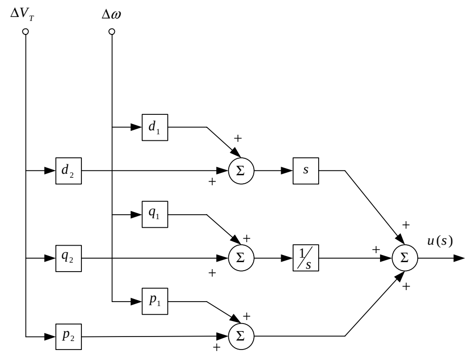


Figure 2. Transfer Function Block Diagram for the PID Power Stabilizer

3. OVERVIEW OF GENETIC ALGORITHMS

Genetic Algorithms (GA) are powerful domain independent search technique inspired by Darwinian theory of evolution [8]. It was invented by John Holland and his colleagues in 1970s [9] and was successfully applied to many engineering and optimization problems [10] and to various areas of power system such as economic dispatch [11], unit commitment [12], and reactive power planning [13]. GA is an adaptive learning heuristic that imitate the natural process of evaluation to progress toward the optimum by performing an efficient and systematic search of the solution space. A set of solutions, described as a population of individuals, are encoded as binary strings, termed as *chromosomes*. This population represents points in the solution space. A new set of solutions, called *offsprings*, are created in a new generation (iteration) by crossing some of the strings of the current generation. This process is called *crossover*. Furthermore, the crossover is repeated at every generation and new characteristics are introduced to add diversity. The process of altering some of the strings of the offsprings randomly is known as *mutation*.

The basic steps of GA can be described as follows:

Step 1: Generation of initial population of solutions represented by chromosomes.

Step 2: Evaluation of the solutions generated using the fitness function which is usually the objective function of the problem under study.
Step 3: Selection of individual solutions that have higher fitness value. There are different selection methods such as Roulette wheel selection, Stochastic selection, and Ranking-based selection [10].
Step 4: Generation of new offsprings from the selected individual solutions. This is done for certain number of generations using two main operations:
- *Crossover*: There are various crossover operators; the most common is the *one-point crossover*. In one-point crossover, one bit in each solution, of two given binary coded solutions, is determined randomly and then swapped to generate two new solutions.
- *Mutation*: Incremental random changes applied in the selected offsprings by altering randomly some of its bits. Mutation is usually probabilistically applied to only few members of the population and therefore has a small value.
Step 5: Steps 2 to 4 are repeated until a predefined number of generations have been produced.
Figure 3 shows the flow chart of the GA algorithm.

4. PROPOSED DESIGN OF PID STABILIZER USING GA

The gains of the PID stabilizer, Figure 2, are designed optimally using GA. The following procedure is adopted to achieve the optimal settings of the stabilizer:

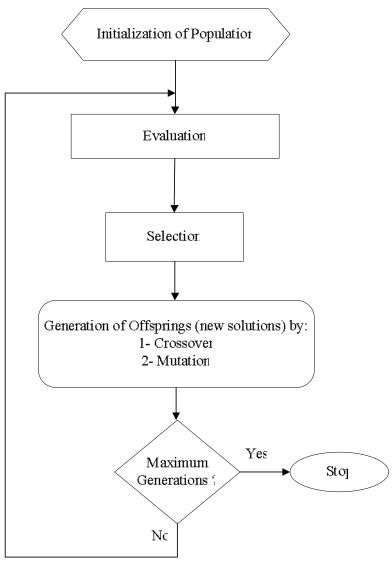


Figure 3. Flow chart of GA

1) Generate initial random values for PID gains, P , Q, and D.
2) Evaluate the initial solutions using a performance index that reflects the objective of the design. In this study the following objective function was used:

$$J=\int_{0}^{\infty} t\left(|\Delta\omega|+|\Delta\delta|+|\Delta e^{'}|+|\Delta e_{FD}|\right)dt \qquad (12)$$

This objective function guarantees the damping of oscillations in the crucial parameters of synchronous machine system and ensures its stability.
3) Use GA (selection, crossover, and mutation) to generate new values (offsprings) for the PID gains, P, Q, and D as described in section 3.
4) Evaluate the performance index in step 2 for the new PID gains. Stop if the maximum number of iterations is reached; otherwise go to step 3.

5. SIMULATION RESULTS

The synchronous machine connected to an infinite bus of Figure 1 was simulated with following typical values of the machine's parameters, exciter, and the line [1]:

a) *Machine:* M=9.26 s T'_{do} = 7.76s D = 0 x_d = 0.973 p.u. x'_d = 0.190 p. u. x_q = 0.55 p.u.
b) *Excitation*: K_A = 50 T_A =0.05 s
c) *Line and Load*: R = -0.034 p.u. X = 0.997 p.u. G = 0.249 p.u. B = 0.262 p.u.
d) *Initial state*: P_{eo} = 1.0 p.u. Q_{eo} = 0.015 p.u. v_{to} =1.05
The system was subjected to 0.01 p.u. load disturbance (ΔT_m). The GA (Population size = 300, Maximum generations = 500, Crossover = 0.8, Mutation = 0.001) design procedure of section 5 was applied to find the optimal settings of the PID controller. The convergence of the performance index is shown in Figure 4. The optimal gains of the PID stabilizer are found to be:

p_1 = 150 d_1 = -2 q_1 = 1392.3
p_2 = -5.1206 d_2 = -0.1266 q_2 = -38.6212

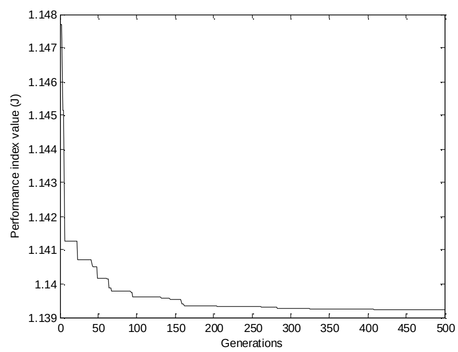


Figure 4. Convergence of performance index

Figure 5 shows the frequency deviation of the system after load disturbance with the proposed PID stabilizer. Comparison with other PID designs and conventional PSS validates the outperformance of the GA-PID stabilizer. Furthermore, the robustness of the GA-PID stabilizer is tested by varying the loading conditions of the system. This is shown in Figure 6. The proposed stabilizer is robust to changes in the loading of the machine.

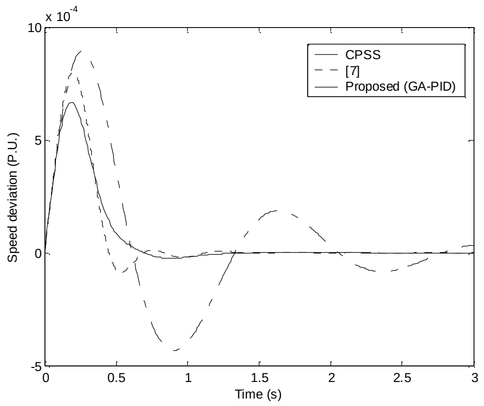


Figure 5. Frequency deviation

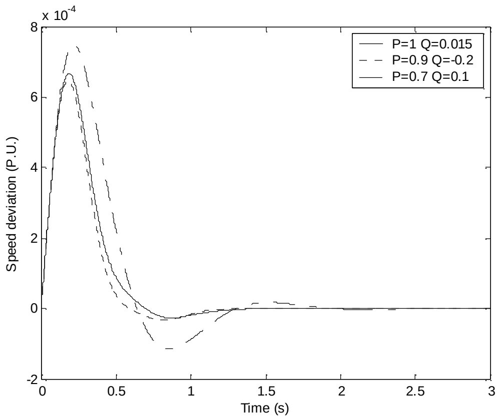


Figure 6. Variation of loading conditions

6. CONCLUSIONS

A robust PID stabilizer design was proposed in this paper. The proposed design utilizes GA to arrive at the optimal settings of the controller. This method provides a simpler way of obtaining the suitable settings of the PID stabilizer and improves the dynamical behavior of the stabilizer in damping out oscillations that might appear in the synchronous machine infinite bus system.

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