EFFECT OF GENETIC PID POWER SYSTEM STABILIZER FOR A SYNCHRONOUS MACHINE

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ABSTRACT

This paper focuses on the use of advanced techniques in genetic algorithm for solving power system stabilization control problems. Dynamic stability analysis of power system is investigated considering Proportional-Integral-Derivative power system stabilizer for modern power systems. Gain settings of PID- PSS are optimized by minimizing an objective function using genetic algorithm (GA). The operation of a Genetic PID with PSS controller is analyzed in simulink environment. The development of a Genetic PID with power system stabilizer in order to maintain stability and enhance the performance of a power system is described widely. The application of the Genetic PID with PSS controller is investigated by means of simulation studies on a single machine infinite bus system. Controller design will be tested on the power system to prove its effectiveness. Analysis reveals that the proposed PSS gives better dynamic performances as compared to that all of mentioned methods. The superior performance of this stabilizer in comparison to PSS and without PSS proves the efficiency of this new Genetic PID Controller with PSS controller. The comparison studies carried out for various results such as speed deviation, field voltage, rotor angle and load angle in Simulink based MATLAB environment.

Keywords: Power System Stabilizer, Genetic PID Controller, Excitation System, MATLAB Simulink.

1. INTRODUCTION

Genetic Algorithms (GAs) are a stochastic global search method that mimics the process of natural evolution. Genetic Algorithms have been shown to be capable of locating high performance areas in complex domains without experiencing the difficulties associated with high dimensionality or false optima as may occur with gradient decent techniques [1]. Using genetic algorithms to perform the tuning of the controller will result in the optimum
controller being evaluated for the system every time. The objective of this paper is to show that by employing the GA method of tuning a PID controller, an optimization can be achieved. This can be seen by comparing the result of the GA optimized PSS against the classically tuned PSS.

In power systems, low frequency oscillations are generator rotor angle oscillations having a frequency between 0.1-3.0 Hz and are defined by how they are created or where they are located in the power system. Low frequency oscillation can be created by small disturbance in the system, such as changes in the load, and are normally analyzed through the small signal stability of the power system. The oscillations were described as hunting of synchronous machines. Small oscillations were a matter of concern, but for several decades power system engineers remained preoccupied with transient stability. That is the stability of the system following large disturbances. Causes for such disturbances were easily identified and remedial measures were devised.

With bulk power transfer on long and weak transmission lines and application of high gain, fast acting AVRs, small oscillations of even lower frequencies were observed. These were described as Inter-Tie oscillations. Sometimes oscillations of the generators within the plant were also observed. These oscillations at slightly higher frequencies were termed as Intra-Plant oscillations. The combined oscillatory behaviour of the system encompassing the three modes of oscillations are popularly called the dynamic stability of the system. In more precise terms it is known as the small signal oscillatory stability of the system. The oscillations, which are typically in the frequency range of 0.2 to 3.0 Hz. might be excited by disturbances in the system or, in some cases, might even build up spontaneously [2].

These oscillations limit the power transmission capability of a network and, sometimes, may even cause loss of synchronism and an eventual breakdown of the entire system.

The problem, when first encountered, was solved by fitting the generators with a feedback controller which sensed the rotor slip or change in terminal power of the generator and fed it back at the AVR reference input with proper phase lead and magnitude so as to generate an additional damping torque on the rotor [3]. This device came to be known as a Power System Stabilizer (PSS). A PSS prepares a supplementary input signals in phase with the synchronous rotor speed deviation to excitation systems resulting in generator stability. The principles of operation of this controller are based on the concepts of damping and synchronizing torques within the generator. A comprehensive analysis of this torques has been dealt with by Klopfenstein in their landmark paper in 1971 [4]. These controllers have been known to work quite well in the field and are extremely simple to implement. However the parameter of PSS such as gain, washout and Lead Lag time plays a vital role to damp out low frequency oscillation. Many researchers concentrated for tuning these parameters through mathematical approach for different operating conditions. Tuning of PSS can be clearly defined by Larsen and Swann in 1981[5]. Most of the controllers are based on system identifications and parameter estimations therefore from computational point of view they are time consuming. It is evident from the various publications that interest in application of AI controller based PSS (AIPSS) has also grown in recent years. Low computation burden simplicity and robustness make AIPSS suitable for stabilization purposes. Different methods for designing such devices are proposed using genetic algorithm (GA) and artificial neural network [8]. All the approaches are based on tuning and optimization concepts.

This paper presents a simple MATLAB simulink model for a synchronous machine to reduce low frequency oscillation during several operating conditions such as heavy load, vulnerable conditions etc. Here, Genetic PID controller combined with PSS can guarantee a
robust minimum performance over a wide range of operating conditions. The efficacy of the proposed Genetic PID Controller with PSS in damping out low frequency oscillations have been established by extensive simulation studies on single machine infinite bus system. Various simulations have been performed in order to subject it to several types of large disturbances using a single-machine infinite bus power system.

2. MODELING OF SYNCHRONOUS GENERATOR WITH PSS

In fig.1 $P_{ref}$ is the mechanical power reference, $P_{sv}$ is the feedback through the governor $T_m$ is the turbine output torque $V_{inf}$ is the infinite bus voltage, $V_{ref}$ is the terminal voltage reference, $V_t$ is the terminal voltage $V_a$ is the voltage regulation output. $W$ is the speed deviation. $V_{pss}$ is the PSS output $V_f$ is field voltage. $V_t$ is excitation system stabilizing signal. $P$ is the active and $Q$ is the reactive power and the terminal power. The speed of the synchronous generator is governed by speed governor. The output of the rotor speed deviation governor is compared with reference power and given to turbine which is connected to the synchronous generator. The rotor speed deviation of synchronous generator is given to PSS as input whose output is used to get the stable voltage ($V_{PSS}$). The stable voltage is given to synchronous generator through the voltage regulator and exciter. The output of voltage of the exciter is given to excitation system stabilizer and compared with reference terminal voltage. The output power from the synchronous generator is given to infinite bus through transmission voltage. PSS will be doing no more work if the switch S1 is changed to zero position. Then the system will act as normal system without PSS and oscillation will not be damped out.

![Fig.1 System model configuration](image)

3. POWER SYSTEM STABILIZER

A solution to the problem of oscillatory instability is to provide damping for the generator oscillations by providing Power System Stabilizers (PSS) which are supplementary controllers in the excitation systems. The signal $V_{PSS}$ is the output from PSS which has input derived from rotor velocity, frequency, electrical power or a combination of these variables.
Structure and Tuning of PSS:

**A. Gain:**
The overall gain $K$ of the generic power system stabilizer. The gain $K$ determines the amount of damping produced by the stabilizer. Gain $K$ can be chosen in the range of 20 to 200.

**B. Wash-out time constant:**
The time constant, in seconds ($s$), of the first-order high-pass filter used by the washout system of the model. The washout high-pass filter eliminates low frequencies that are present in the speed deviation signal and allows the PSS to respond only to speed changes. The Time constant $T_w$ can be chosen in the range of 1 to 2 for local modes of oscillation. However, if inter-area modes are also to be damped then $T_w$ must be chosen in the range of 10 to 20.

**C. Lead-lag time constants: (Phase Compensation System):**
The numerator time constant $T1n$, $T2n$ and denominator time constant $T1d$, $T2d$ in seconds ($s$), of the first and second lead-lag transfer function. The phase-compensation system is represented by a cascade of two first-order lead-lag transfer functions used to compensate the phase lag between the excitation voltage and the electrical torque of the synchronous machine.

**D. Limiter:**
The output of the PSS must be limited to prevent the PSS acting to counter the action of AVR. The negative limit of the PSS output is of importance during the back swing of the rotor (after initial acceleration is over). The AVR action is required to maintain the voltage after the angular separation has increased. PSS action in the negative direction must be shortened more than in the positive direction. A typical value for the lower limit is -0.05 and for the higher limit it can vary between 0.1 and 0.2.

4. **GENETIC PID CONTROLLER**

    The genetic algorithm (GA) is an optimization and stochastic global search technique based on the principles of genetics and natural selection. A GA allows a population composed of many individuals to evolve under specified selection rules to a state that maximizes the “fitness” (i.e., minimizes the cost function). Some of the advantages of a GA are as follows:
    - Optimizes with continuous or discrete variables
    - Doesn’t require derivative information
    - Simultaneously searches from a wide sampling of the cost surface
    - Deals with the large number of variables
In the discrete GA, solution point is a binary string of 0 and 1 called “chromosome” and number of bits (Nbits) depends on desired accuracy. The string is included of \( n \) variables \((x_1, x_2, \ldots, x_n)\), hence the number of bits for each variable is \( \text{Nbits}/n \) called “gene”. A sample solution point with 8-bits and two variables \((x, y)\) is shown in below:

<table>
<thead>
<tr>
<th>Gene1 X</th>
<th>Gene2 Y</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 0 1 1</td>
<td>0 0 0 1</td>
</tr>
</tbody>
</table>

The first 4 bits are related to \( x \) and next bits are related to \( y \). To calculate the cost of solution points, they must be decoded at first. Decoded form of the mentioned string is calculated in below:

\[
X \rightarrow 1 \times 2^3 + 0 + 1 \times 2^1 + 1 \times 2^0 = 11 \Rightarrow \text{Cost} (X, Y) = \text{Cost} (11, 1)
\]

\[
Y \rightarrow 0 + 0 + 0 + 1 \times 2^0 = 1
\]

The following sections (A-E) describe GA method and its operators:

A: The population
The GA starts with a group of chromosomes known as the population. The population has \( N_{pop} \) chromosomes called population size.

B: Natural selection
Natural selection is performed on the population by keeping the “most” promising individuals, based on their fitness. In this way, it is possible to keep the size of the population constant, for convenience. First, the \( N_{POP} \) costs and associated chromosomes are ranked from lowest cost to highest cost. Then, only the best are selected to continue, while the rest are deleted. The selection rate, \( X_{rate} \), is the fraction of \( N_{POP} \) that survives for the next step of mating (crossover). The number of chromosomes that are kept each generation is:

\[
N_{Keep} = X_{rate} \times N_{POP}
\]

Natural selection occurs each generation or iteration of the algorithm.

C: Selection
In order to replace the deleted chromosomes and keep the population size constant, two chromosomes are selected from the mating pool of \( N_{Keep} \) chromosomes to produce two new offspring. Pairing takes place in the mating population until \( N_{pop} - N_{keep} \) offspring are born to replace the discarded chromosomes.

D: Crossover (Mating)
Mating is the creation of one or more offspring from the parents selected in the pairing process. The current members of the population limit the genetic makeup of the population. The most common form of mating involves two parents that produce two offspring. A crossover point is randomly selected between the first and the last bits of the parents’ chromosomes. First, parent1 passes its binary code to the left of the crossover point to offspring1. In a like manner, parent2 passes its binary code to the left of the same crossover point to offspring2. Next, the binary code to the right of the crossover point of parent1 goes to offspring2 and parent2 passes its code to offspring1 (see Table 1). Consequently, the offspring contain portions of the binary codes of both parents. The parents have produced a total of \( N_{pop} - N_{keep} \) offspring, so the chromosome population is remained constant. This method is called Single-Point-Crossover (S.P.C); there is an other type of crossover called Two-Point- Crossover (T.P.C). In T.P.C, two crossover points are randomly selected between the first and the last bits of parents.
Table 1 Process of Cross Over for Two parents

<table>
<thead>
<tr>
<th></th>
<th>Process of crossover for two parents</th>
</tr>
</thead>
<tbody>
<tr>
<td>parent1</td>
<td>1 0 0 1 1 0 1 0</td>
</tr>
<tr>
<td>parent2</td>
<td>1 1 0 0 0 1 0 1</td>
</tr>
<tr>
<td>offspring1</td>
<td>1 0 0 1 0 1 0 1</td>
</tr>
<tr>
<td>offspring2</td>
<td>1 1 0 0 1 0 1 0</td>
</tr>
</tbody>
</table>

E: Mutation

Random mutations alter a certain percentage of the bits in the list of chromosomes. Mutation is the second way a GA explore a cost surface. It can introduce traits not in the original population and keeps the GA from converging too fast before sampling the entire cost surface. A single point mutation changes a one to zero, and vice versa. Mutation points are randomly selected from the Npop×Nbits total number of bits in the population matrix (Npop×Nbits). Mutations do not occur on the best solutions. They are designed as *elite* solutions destined to propagate unchanged. Such elitism is very common in GAs. The number of bits that must be changed is determined by mutation rate $\mu$.

$$\text{Mutations} = \mu \times (N_{\text{POP}} - 1) \times N_{\text{Bits}}$$

Increasing the number of mutations increases the algorithm’s freedom to search outside the current region of variable space. It also tends to distract the algorithm from converging on a popular solution.

Flowchart of the algorithm is shown in figure 3.
5. GENETIC PID CONTROLLER WITH POWER SYSTEM STABILIZER

The transfer function of a PID controller is described as follows:

\[ G_c(s) = K_p + K_i \frac{1}{s} + K_d s \]

A set of appropriate control parameters kp,ki and kd can make a appropriate step change responses of \( \Delta \omega \) (angular velocity deviation) and \( \Delta \delta \) (load angle deviation) that will result in performance criteria minimization. A Performance criterion in the time domain includes the overshoot Mp and settling time ts. Parameters kp ,ki and kd can make a good response that will result in performance criteria minimization. In order to achieve this target, the following cost function is suggested:

\[ f(k) = (1-e^{-\beta})(M_p-1) + e^{-\beta}(t_s) \]

Where \( K \) is \([kd , kp , ki]\) and \( \beta \) is the weighting factor .If \( \beta \) is set to be smaller than 0.7 the settling time is reduced and if it set to be larger than 0.7 the overshoot is reduced. The discrete GA for searching optimal PID controller parameters is as follows:

At first, the lower and upper bounds of controller parameters are specified and initial population is produced randomly. Each solution point (each chromosome) is a 24-bits string and divided to three sections, each section related to a variable, kd, kp, ki. Total of solutions \( K \) (controller parameters) are sent to MATLAB® Simulink block and on the other hand the values of two performance criteria in the time domain namely Mp and ts are calculated for each chromosome and cost function is evaluated for each point according to these performance criteria.

Then, natural selection, selection, crossover (mating) and mutation operations are applied to population and the next iteration (generation) is started. At the end of each iteration, program checks the stop criterion. If the number of iterations reaches, the maximum or the stopping criterion is satisfied, records the latest global best solution and stop the algorithm. The best parameters of GA program are selected with trial and error method. Population size of chromosomes and number of generation (Gen.) are 10 and 40, respectively. Mutation rate is selected %5; selection rate is %60 with two-point crossover.

Advantages of Genetic PID Controller and Power system stabilizer are combining together to damp-out low frequency oscillation during severe load and vulnerable condition. The role of Genetic PID Controller with PSS is used to reduce the overshoot and settling time. The Genetic PID Controller with PSS can provide better damping characteristic than the PID, PSS even at the loading condition. This results from the fact that, during the faulted period, there will be drastic change in the operating condition. The transient stability limit of the synchronous machine can be improved by the Genetic PID Controller with PSS since the generator with PSS and PID will have more overshoot and settling time when the load is increased to 600MVA, while the one with Genetic PID Controller with PSS will still remain stable. The damping characteristic of the Genetic PID Controller with PSS is insensitive to load change while that of PSS and PID controller will deteriorate as the load changes. The Genetic PID Controller with PSS can offer better responses in field voltage as well as angular speed.

Therefore, the major disadvantage of being liable to cause too great deviation in the voltage profile when an excitation controller is employed to improve the damping can be avoided. Therefore the proposed Genetic PID Controller with PSS is relatively simpler than the other controllers for practical implementation and also produces better optimal solution.
6. MODELING OF GENETIC PID CONTROLLER WITH PSS USING SIMULINK

To analysis the performance of the PSS, Simulation model was developed in simulink block set of MATLAB. The functional block set of PSS in simulink environment shown in fig. 4. The effectiveness of Genetic PID Controller with PSS is investigated for various operating conditions using the Simulink model. Independent of the technique utilized in tuning stabilizer equipment, it is necessary to recognize the nonlinear nature of power systems and that the objective of adding power system stabilizers along with Genetic PID Controller is to extend power transfer limits by stabilizing system oscillations; adding damping is not an end in itself, but a means to extending power transfer limits. The various blocks involved in modeling the synchronous machine are:

![Block Diagram of Genetic PID Controller with PSS](image)

**Fig. 4** Block Diagram of Genetic PID Controller with PSS

7. SIMULATION RESULTS AND DISCUSSIONS

In this section the best operations of GA and associated parameters are selected, the lower and upper bound of controller parameters are adjusted to 0 and 60, respectively. Then a 5% load disturbance at time 1 second is exerted to under study power system and the GA runs in two modes, S.P.C and T.P.C in order to tune controller parameters, kp, kd, ki and weighing factor (β) is adjusted to 0.7. Results of optimal PID parameters in various modes of GA are summarized in Table 2.
Table 2. Optimum PID parameters in various modes

<table>
<thead>
<tr>
<th>Mode</th>
<th>Gen</th>
<th>NPOP</th>
<th>Xrate</th>
<th>μ%</th>
<th>Min Cost</th>
<th>Kp</th>
<th>Ki</th>
<th>Kd</th>
</tr>
</thead>
<tbody>
<tr>
<td>SPC</td>
<td>20</td>
<td>10</td>
<td>50</td>
<td>1</td>
<td>-2.86</td>
<td>49.9</td>
<td>44.1</td>
<td>25.1</td>
</tr>
<tr>
<td></td>
<td>40</td>
<td>20</td>
<td>60</td>
<td>5</td>
<td>-2.92</td>
<td>38.8</td>
<td>34.2</td>
<td>15.4</td>
</tr>
<tr>
<td>TPC</td>
<td>20</td>
<td>10</td>
<td>50</td>
<td>1</td>
<td>-2.89</td>
<td>48.7</td>
<td>43.8</td>
<td>23.2</td>
</tr>
<tr>
<td></td>
<td>40</td>
<td>20</td>
<td>60</td>
<td>5</td>
<td>-2.96</td>
<td>35.6</td>
<td>30.0</td>
<td>11.8</td>
</tr>
</tbody>
</table>

The performance of PSS and PSS with Genetic PID Controller was studied in the simulink environment for different operating conditions and the following test cases was considered for simulations.

**Case i:** System was subjected to vulnerable (fault) condition, the variation of above mentioned cases were analyzed.

**Case ii:** The variation of above mentioned cases were analyzed for PSSs when subjected to different loading condition.

The above cases are illustrated clearly, how the controller reduces the overshoot and settling time to the nominal level when subjected to PSS and Genetic PID Controller with PSS and the inference of the simulation results are as follows.

**Case I: Fault Condition:**

This illustrates the stability of the system during vulnerable condition, a three phase fault is assumed to happen at the transmission line. The fault persists in the system for 0.01 sec and it is cleared after 0.1 sec. The parameters of the system during fault condition are illustrated in Fig.5 to Fig.8.

From the Fig.5, it is observed that the PSS produced more overshoot and settles at 7 secs. The Genetic PID Controller with PSS controller gives better solution compared to PSS. The combination of Genetic PID Controller with PSS further reduces the settling time to 3 secs and also the overshoot. According to Fig.6, the overshoot was high for PSS; therefore the stability of the system was affected. The Genetic PID Controller with PSS reduces the overshoot to 50% and makes the system to reach steady state before 2 secs. From this case, it is inferred that Genetic PID Controller with PSS supports the synchronous generator to maintain synchronous speed even at severe fault conditions. During the fault condition, PSSs maintains the load angle around zero degree. Normally for the smart system the load angle should be maintained around 15 to 45 degree. The Genetic PID Controller with PSS provides better solution by maintaining the load angle around 40 degree. From the Fig.8, it is inferred that the acceleration of rotor increases with respect to Fault condition. However with the help of Genetic PID Controller with PSS, the rotor angle maintained at normal level compared to PSS.
Fig. 5 Field Voltage

Fig. 6 Speed Deviation

Fig. 7 Load Angle
Case II: Heavy Load

In this case, the Synchronous generator is subjected to three phase RLC load of 600MV in the transmission line. The performance characteristics of the system with PSS, Genetic PID Controller with PSS are illustrated from Fig.9 to 12.

From the Fig.9, the Genetic PID Controller with PSS provides better solution by reducing overshoot to 75% and the settling time around 3 secs even in heavy load condition. By this effect the field voltage will be stable and in turns maintain the system stability. According to Fig.10, the overshoot was heavy for PSS, in turn affects the stability of the system. The Genetic PID Controller with PSS reduces the overshoot to 50% and makes the system to reach steady state before 2 secs. Therefore it is inferred that Genetic PID Controller with PSS supports the synchronous generator to maintain synchronous speed even at severe fault conditions but with some negative damping. During the load condition, the Genetic PID Controller with PSS makes the system to settle at 1.5 secs. Also it boosts up the system to maintain load angle in and around 40 degree. In this case also the proposed system maintains stability. From the Fig.12, it is inferred that the Genetic PID Controller with PSS maintains the stability with small amount of damping compared to PSS. Genetic PID Controller with PSS reduces the overshoot to 25% and the system settles at 1.5 secs.
Finally the above two cases are summarized by the following points:

- The Genetic PID Controller +PSS can provide better damping characteristic than the PSS even at the loading condition. This results from the fact that, during the faulted period, there will be drastic change in the operating condition.
• As evidenced by the curves mentioned above, the transient stability limit of the synchronous machine can be improved by the Genetic PID Controller + PSS since the generator with PSS will have more overshoot and settling time when the load is increased to 600Mv, while the one with Genetic PID Controller + PSS will still remain stable.
• The damping characteristic of the Genetic PID Controller + PSS is insensitive to load change while that of PSS will deteriorate as the load changes.
• The Genetic PID Controller + PSS can offer better responses in field voltage as well as angular speed. Therefore, the major disadvantage of being liable to cause too great deviation in the voltage profile when an excitation controller is employed to improve the damping can be avoided.

8. CONCLUSION

Results from this study indicate that under large disturbance conditions, better dynamic responses can be achieved by using the proposed Genetic PID Controller with PSS controller than the other stabilizers. We could also observe in all case studies, from the MATLAB / Simulink simulation, that the Genetic PID Controller with PSS controller has an excellent response with small oscillations, while the other controller response shows a ripple in all case studies and some oscillations before reaching the steady state operating point. It was shown that an excellent performance of the Genetic PID Controller with PSS control in contrast to the other controllers for the excitation control of synchronous machines could be achieved. Modeling of proposed controller in simulink environment shown the accurate result when compared to mathematical design approach. A simple structure of a Genetic PID Controller and its wide spread use in the industry make the proposed stabilizer very attractive in stability enhancements.

REFERENCES


