A Novel approach for tuning of Power System Stabilizer (SMIB system) using Genetic Local Search Technique
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Abstract--- The genetic local search technique (GLS) hybridizes the genetic algorithm (GA) and the local search (such as hill climbing) in order to eliminate the disadvantages in GA. The parameters of the PSS (gain, phase lead time constant) are tuned by considering the single machine connected to infinite bus system (SMIB). Here PSS are used for damping low frequency local mode of oscillations. Eigen value analysis shows that the proposed GLSPSS based PSS have better performance compared with conventional and the Genetic algorithm based PSS (GAPSS). Integral of time multiplied absolute value of error (ITAE) is taken as the performance index of the selected system. Genetic and Evolutionary algorithm (GEA) toolbox is used along with MATLAB/SIMULINK for simulation.

Keywords: Genetic local search, Power system oscillations, Power system stabilizer, Genetic algorithms, SMIB, K-constants

I. INTRODUCTION

Power systems experience low-frequency oscillations due to disturbances. These low frequency oscillations are related to the small signal stability of a power system. The phenomenon of stability of synchronous machine under small perturbations is explored by examining the case of a single machine connected to an infinite bus system (SMIB). The analysis of SMIB [4] gives physical insight into the problem of low frequency oscillations. These low frequency oscillations are classified into local mode, inter area mode and torsional mode of oscillations. The SMIB system is predominant in local mode low frequency oscillations. These oscillations may sustain and grow to cause system separation if no adequate damping is available. In recent years, modern control theory have been applied to power system stabilizer (PSS) design problems. These include optimal control, adaptive control, variable structure control, and intelligent control.

Despite the potential of modern control techniques with different structures, power system utilties still prefer the conventional lead-lag PSS structure. The reasons behind that might be the ease of on-line tuning and the lack of assurance of the stability related to some adaptive or variable structure techniques.

Unlike other optimization techniques, Genetic Algorithm (GA) works with a population of strings that represent different potential solutions therefore, GA has implicit parallelism that enables it to search the problem space globally and the optima can be located more quickly when applied to complex optimization problem. Unfortunately, recent research has identified some deficiencies in GA performance. This degradation in efficiency is apparent in applications with highly epistatic objective functions, i.e. where parameters being optimized are highly correlated. In addition, the premature convergence of GA represents a major problem.

In this proposed genetic local search (GLS) [7] approach, GA is hybridized with a local search algorithm to enhance its capability of exploring the search space and overcome the premature convergence. The design problem with mild constraints and an eigenvalue-based objective function.

The GLS algorithm is employed to solve this optimization problem and search for the optimal settings of PSS parameters. The proposed design approach has been applied to SMIB system. Eigen value analysis and simulation results have been carried out to assess the effectiveness and robustness of the proposed GLSPSS to damp out the electromechanical modes of oscillations and enhance the dynamic stability of power systems.

II. SYSTEM INVESTIGATED

A single machine-infinite bus (SMIB) system is considered for the present investigations. A machine connected to a large system through a transmission line may be reduced to a SMIB system, by using the Thevenin’s equivalent of the transmission network external to the machine. Because of the relative size of the system to which the machine is supplying power, the dynamics associated with machine will cause virtually no change in the voltage and frequency of the Thevenin’s voltage (infinite bus voltage). The Thevenin equivalent impedance shall henceforth be referred to as equivalent impedance (i.e. Re+jXe).

The synchronous machine is described as the fourth order model. The two-axis synchronous machine representation with a field circuit in the direct axis but without damper windings is considered for the analysis. The equations describing the steady state operation of a synchronous generator connected to an infinite bus through an external reactance can be linearized about any particular operating point as follows(eq:1-4):

\[
\Delta T_m - \Delta P = M \frac{d^2 \Delta \delta}{dt^2} 
\]

\[
\Delta P = K_1 \Delta \delta + K_2 \Delta E_q
\]

\[
\Delta E_q = \frac{K_3}{1 + s T_{d0} K_3} \Delta E_{qd} - \frac{K_4 K_5}{1 + s T_{d0} K_5} \Delta \delta
\]

\[
\Delta V_r = K_5 \Delta \delta + K_6 \Delta E_q
\]

The K-constants are given in appendix. The system data are as follows [8]:

Machine (p.u):

\[x_d = 0.973, \ x_d' = 0.19\]

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The linearized differential equations can be written in the form

\[ X(t) = A \cdot x(t) + B \cdot U(t) \]  

(12)

Where,

\[ X(t) = [\Delta \delta \Delta \omega \Delta \dot{\delta} \Delta \dot{\omega}]^T \]

(13)

\[ A = \begin{bmatrix} 0 & 314 & 0 & 0 \\ -D/M & -K_s/M & -K_e/M & 0 \\ -K_e & 0 & -1/K_s & -1/T_A \\ -K_s/T_e & K_e & 0 & -K_s/T_e & K_e & 1/T_A \end{bmatrix} \]

(14)

\[ B = \begin{bmatrix} 0 & 0 & 0 & K_A \\ T_A \end{bmatrix}^T \]

(15)

System state matrix A is a function of the system parameters, which depend on operating conditions. Control matrix B depends on system parameters only. Control signal U is the PSS output. From the operating conditions and the corresponding parameters of the system considered, the system eigenvalues are obtained.

In this paper Integral of time multiplied absolute value of error (ITAE) [4] will be minimized through the application of a genetic algorithm, as will presently be elucidated. The GA works on a coding of the parameters (K, T) to be optimized rather than the parameters themselves. In this study Gray coding was used where each parameter was represented by 16 bits and a single individual or chromosome was generated by concatenating the coded parameter strings. In contrast to traditional stochastic search techniques the GA requires a population of initial approximations to the solution. Here 30 randomly selected individuals were used to initialize the algorithm.

A. Fitness determination

The first step of the GA procedure is to evaluate each of the chromosomes and subsequently grade them. Each individual was evaluated by decoding the string to obtain the Lead-lag compensator parameters which were then applied in a Simulink representation of the closed-loop system.

1) The five fittest individuals were automatically selected while the remainders were selected probabilistically, according to their fitness. This is an elitist strategy that ensures that the next generation’s best will never degenerate and hence guarantees the asymptotic convergence of the GA.

2) Using the individuals selected above the next population is generated through a process of single-point crossover and mutation. Mutation was applied with a very low probability of 0.001 per bit. Reproduction through the use of crossover and mutation ensures against total loss of any genes in the population by its ability to introduce any gene which may not have existed initially, or, may subsequently have been lost.

3) This sequence was repeated until the algorithm was deemed to have converged (50 iterations). As was indicated previously the simulation and evaluation of the GA tuned Lead-Lag compensator was achieved using the MATLAB/Simulink environment.

B. GLS algorithm

Step 1: set the generation counter k=0 and generate randomly n initial solutions, \( X_0 = \{x_i, i=1, \ldots, n\} \). The ith initial solution xi can be written as xi = [p1 p2 \ldots pj \ldots pm], where the jth optimized parameter pj is generated by randomly selecting a value with uniform probability over its search space [pimin ,pimax]. These initial solutions constitute the parent population at the initial generation x0. Each individual of x0 is evaluated using objective function J. set x=x0;

Step 2: optimize locally each individual in x. replace each individual in x by its locally optimized version. Update the objective function values accordingly.

Step 3: search for the optimum value of the objective function, Jmin, set the solution associated with Jmin as the best solution, xbest with an objective function of Jbest.

Step 4: check the stopping criteria. If one of them is satisfied then stop, else set k=k+1 and go to step 5.

Step 5: set the population counter i=0;

Step 6: draw randomly, with uniform probability, two solutions x1 and x2 from x. apply the genetic crossover and
mutation operators obtaining $x_3$;
Step 7: optimize locally the solution $x_3$ and obtain $x_3$;
Step 8: check if $x_3$ is better than the worst solution in $x$ and different from all solutions in $x$ then replace the worst solution in $x$ by $x_3$ and the value of objective by that of $x_3$;
Step 9: if $i=n$ go to step 3, else set $i=i+1$ and go back to step 6; To demonstrate the effectiveness and robustness of the proposed GLSPSS over a wide range of loading conditions are verified.

III. COMPARISON OF VARIOUS DESIGN TECHNIQUES
The linearized incremental state space model for a single machine system with its voltage regulator with four state variables has been developed. The single machine system without PSS is found unstable with roots in RHP. The system dynamic response without PSS is simulated using Simulink for 0.05 p.u disturbance in mechanical torque.
MATLAB coding is used for conventional PSS, Genetic PSS, and Genetic local search (GLS) PSS design techniques. The final values of gain ($K$), and phase lead time constant ($T$) obtained from all the techniques are given to the simulink block. The dynamic response curves for the variables $\Delta \omega$, $\Delta \delta$ and $\Delta V_t$ are taken from the simulink. The system responses curves of the conventional PSS (CPSS), GA based PSS as well as GLS based PSS are compared. Shaft speed deviation is taken as the input to the all the Power system stabilizers. So the PSS is also called as delta-omega PSS. The system dynamic response with PSS is simulated using these Simulink diagrams for 0.05 p.u step change in mechanical torque $\Delta T_m$. The dynamic response curves for the variables change in speed deviation ($\Delta \omega$), change in rotor angle deviation ($\Delta \delta$) and change in terminal voltage deviation ($\Delta V_t$) of the single machine system with PSS are plotted for three different types of power system stabilizers (PSS) are shown in Figs. 3 – 5. It is observed that the oscillations in the system output variables with PSS are well suppressed. The Table I shows various types of PSS and its parameters after tuned by conventional, genetic and genetic local search technique.

<table>
<thead>
<tr>
<th>PSS type</th>
<th>PSS parameters</th>
</tr>
</thead>
<tbody>
<tr>
<td>CONVENTIONAL LEAD-LAG PSS</td>
<td>$K = 7.6921$</td>
</tr>
<tr>
<td></td>
<td>$T = 0.2287$</td>
</tr>
<tr>
<td>GA BASED PSS</td>
<td>$K = 26.5887$</td>
</tr>
<tr>
<td></td>
<td>$T = 0.2186$</td>
</tr>
<tr>
<td>GLS BASED PSS</td>
<td>$K = 35.1469$</td>
</tr>
<tr>
<td></td>
<td>$T = 0.2078$</td>
</tr>
</tbody>
</table>

Table 1. PSS parameters of various pss for single machine system

IV. SIMULATION RESULTS
Performance of fixed-gain CPSS is better for particular operating conditions. It may not yield satisfactory results when there is a drastic change in the operating point.
Dynamic response shows that the GA based PSS has optimum response and the response is smooth and it has less overshoot and settling as compared to conventional PSS.
As compared to the conventional PSS & GA based PSS the proposed genetic local search (GLS) based design of PSS gives the optimum response and the response is smooth and it has reduced settling time.

The time multiplied absolute value of the error (ITAE) performance index is considered. The simulation results show the proposed Genetic local search based PSS can work effectively and robustly over a wide range of loading conditions over the conventional and GA based design of PSS.
The response curves shows that GLS PSS has less overshoot and settling time as compared to the GA PSS and the traditional Lead-lag PSS.

V. CONCLUSION
In this study, a genetic local search algorithm is proposed to the PSS design problem. The proposed design approach hybridizes Genetic Algorithm with a local search to
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VI. APPENDIX

A. Derivation of k-constants

All the variables with subscript 0 are variables of values evaluated at their pre-disturbance steady-state operating point from the known values of P0, Q0 and V0.

\[ i_{q0} = \frac{P_0 V_{m0}}{\sqrt{(P_0 x_q^2 + (V_{r0}^2 + Q_0 x_q) \frac{V_{q0}}{V_{r0}})}} \]  
(16)

\[ v_{dq0} = i_{q0} x_q \]  
(17)

\[ v_{q0} = \frac{\sqrt{V_{r0}^2 - v_{d0}^2}}{v_{q0}} \]  
(18)

\[ i_{d0} = \frac{Q_0 + x_q i_{q0}^2}{v_{q0}} \]  
(19)

\[ E_q0 = v_{q0} + i_{d0} v_{xq} \]  
(20)

\[ E_0 = \sqrt{(v_{d0} + x_i i_{q0})^2 + (v_{q0} - x_i i_{d0})^2} \]  
(21)

\[ \delta_0 = \tan^{-1} \left( \frac{v_{d0} + x_i i_{q0}}{v_{q0} - x_i i_{d0}} \right) \]  
(22)

\[ K_1 = x_q - x_d \frac{x_q E_0 \sin \delta_0 + E_0 E_0 \cos \delta_0}{x_c + x_q} \]  
(23)

\[ K_2 = \frac{E_0 \sin \delta_0}{x_c + x_q} \]  
(24)

\[ K_3 = \frac{x_q - x_d}{x_d + x_c} \]  
(25)

\[ K_4 = \frac{x_q - x_d}{x_c + x_d} \]  
(26)

\[ K_5 = \frac{E_0 \sin \delta_0}{x_c + x_q} \]  
(27)

\[ K_6 = \frac{E_0 \sin \delta_0}{x_c + x_q} \]  
(28)

VI. NOMENCLATURE

All quantities are per unit on machine base.

D Damping Torque Coefficient

M Inertia constant

\( \omega \) Angular speed

\( \delta \) Rotor angle

I\(_d\), I\(_q\) Direct and quadrature components of armature current

X\(_d\), X\(_q\) Synchronous reactance in d and q axis

X\(_d\)'s, X\(_q\)'s Direct axis and Quadrature axis transient reactance

E\(_{FD}\) Equivalent excitation voltage

K\(_A\) Exciter gain

T\(_A\) Exciter time constant

T\(_m\), T\(_e\) Mechanical and Electrical torque

T\(_{do}\) Field open circuit time constant.

V\(_d\), V\(_q\) Direct and quadrature components of terminal voltage

K1 Change in \( T_e \) for a change in \( \delta \) with constant flux linkages in the d axis

K2 Change in \( T_e \) for a change in d axis flux linkages with constant \( \delta \)

K3 Impedance factor

K4 Demagnetising effect of a change in rotor angle

K5 Change in \( V_e \) with change in rotor angle for constant E\(_q\)

K6 Change in \( V_e \) with change in E\(_q\)'s constant rotor angle

REFERENCES


