SIMULTANEOUS DESIGN OF TCSC BASED DAMPING CONTROLLER AND PSS TO DAMP POWER SYSTEM OSCILLATIONS USING BACTERIAL FORAGING ALGORITHM

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Abstract- This paper develops an optimization procedure for tuning of power systems stabilizer (PSS) and Thyristor controlled Series capacitor (TCSC) based the power oscillation damping controller (POD) to enhance Power System stability. Bacterial foraging algorithm (BFA) tries to minimize an Eigen value based multi objective function in which some loading conditions are considered concurrently to ensure robust design. Time domain simulations in MATLAB/SIMULINK environment carried out on 2area four machine Power System over various loading conditions shows that improvement in damping of Power System oscillations have been acquired by using various PSS-POD controllers.

Keywords- Power System Stabilizer (PSS), BFA, TCSC Controller, damping of Power System Oscillations, Small signal stability.

I. INTRODUCTION

Nowadays Damping of Power System oscillation is a major concern in the power system field. These oscillation may be poorly damped in certain cases resulting in unacceptable variation in power across transmission lines and fatigue at the machine. For these reasons better damping control by utilizing various controllers are of utmost importance. Application of PSS alone may not provide sufficient damping especially in case of inter area oscillation. Therefore other effective solutions are to be considered. To solve this problem, FACTS controllers like TCSC, help in regulating the power flow on a line, damping inter area oscillation, thereby improving the transient stability. Thyristor controlled series capacitor (TCSC) device consists of a fixed capacitor (FC) located directly in series with transmission line that is parallel with thyristor controlled reactor (TCR). As a result, no intermediate equipment such as high voltage transformer is needed. Thus the TCSC is the most economic device among other flexible ac transmission system (FACTS) devices to release the power transfer capacity of the transmission lines. Easy and straightforward design and tuning of TCSC-based lead-lag power oscillation damping (POD) controllers lead to power systems applications are more partial to make use of these linear controllers till now.

POD controllers located in a particular power system may have harmful and destabilizing interactions between them even restrict the operating power of the generators. To improve the overall system stability coordination of stabilizers controller are very essential. In this paper, an optimization based timing algorithm is developed to coordinate PSS and TCSC based damping controller using Bacterial foraging algorithm.

II. POWER SYSTEM MODEL

In this section, model of 2A4M system and required components are reviewed.

A. Shaft speed stabilizer (CPSS)

Fig. 1 shows the IEEE type PSS1A stabilizer with shaft speed input signal that is called CPSS in literature. Parameter $T_d$ may be employed to indicate the transducer time constant. The gain and washout time constant of the stabilizer are set by $K_w$ and $T_w$, respectively. The washout block is a high-pass filter to remove steady state output of the PSS. The two blocks associated with $T_l$ to $T_4$ time constants provide required phase compensation characteristics.

Earlier days, conventional lead – lag controllers are used by power utilities for effective damping to low frequency oscillations but the problem of conventional lead lag POD controller design is a multi-modal optimization problem. Hence conventional optimization techniques are not suitable for such problem. Although it has been demonstrated that separate application of PSSs or FACTS POD controllers can improve power system stability in general, uncoordinated design of PSSs and FACTS
B. Delta P stabilizer

Here active power input is used as the input signal to the PSS. In figure 1, instead of $\Delta w$, $\Delta P$ is used as input signal. But this type of PSS is not stable.

C. Two area Four machine system

System shown in figure 2 is considered as test system. The synchronous machine modelling are done by third order model consisting of rotor swing and internal voltage. The 2A4M system shown in Fig. 2 is considered as test system. The synchronous machines are modelled by the third-order model comprising the rotor swing and the internal voltage.

The two areas of 2A4M system (Area 1 and Area 2) are joined together by a 220Km length tie-line which a power transfer exists from Area 1 to Area 2. Each area comprises two constant mechanical power synchronous generators in rating of 900 MVA and 20 kV which are equipped with IEEE type ST1A static excitation systems that they include first order high-response AVR. The generators are connected to the 230 kV transmission lines with shown lengths by means of 900 MVA and 20/230kV step-up transformers. Two constant impedance loads and two shunt capacitors are connected to the system at bus 11 and 12. The system details and required data can be found in.

Fig.2 Two area four machine system

D. TCSC based POD controller

Fig. 3 illustrates the block diagram of TCSC-based POD controller in which $K_{ps}$ is the POD gain; $T_m$ is transducer time constant; and $T_w$ is the washout time constant. Two next blocks permit required phase compensation characteristics as set by time constants $T_1$ to $T_4$. Normally in small-signal stability studies the TCSC is expressed by first order differential equation as:

$$X_{esc}^* = \frac{1}{T_s} (K_s (X_{ref}^* - U_{esc}) - X_{esc})$$  \hspace{1cm} (1)

where $K_s$ and $T_s$ are gain and inherent time constant of the TCSC that describe its dynamic behavior. Parameter $X_{esc}^*$ depicts the steady state reference reactance of TCSC which is determined by power flow calculations. The damping signal provided by POD controller is $X_{esc}$

Fig.3 TCSC POD controller

E. Excitation model

A static excitation system contributes an effective solution in stability of an interconnected power system as a result of its rapid acting capability to cause a high initial response to the variations in the network operating conditions. In this study to generate the dc field requirement of the generators, conventional form of IEEE type ST1A excitation system as shown in Fig. 4 is preferred. The excitation system can be shown as:

Fig.4 IEEE ST1A excitation system

Where $K_A$ and $T_A$ are gain and time constant of voltage regulator; $V_{ref}$ is reference voltage; $U_{PSS}$ is supplementary signal from PSS, and $V$ is terminal voltage.

III. IMPLEMENTATION

In this part the controllers are designed using BFO. Then they are outsourced by eigenvalue analysis and time domain simulations. The PSS placement is done by participation factor (PF) analysis.

A. Participation Factor (PF) Analysis

For finding the best location of PSS, participation factor analysis is done here. The PF analysis on open loop 2A4M power system shows three EM modes, one in inter-area and two in local frequency ranges, as shown in TABLE I.

<table>
<thead>
<tr>
<th>EMmode</th>
<th>$\zeta$</th>
<th>HF</th>
<th>EM type</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.0232±3.0159i</td>
<td>-0.0077</td>
<td>0.4800</td>
<td>Inter-area</td>
</tr>
<tr>
<td>-0.7704±7.0459i</td>
<td>0.1087</td>
<td>1.1214</td>
<td>Local 1</td>
</tr>
<tr>
<td>-0.6789±6.8807i</td>
<td>0.0982</td>
<td>1.0951</td>
<td>Local 2</td>
</tr>
</tbody>
</table>

TABLE I. EM MODES OF OPEN LOOP 2A4M SYSTEM

Based on these EM modes, generators with largest PF will be the best location for PSS installation.

C. Adjustable parameters of Controllers

The parameters to be optimized by BFO are $K_p$, $T_1$ and $T_3$. The given values of the controllers are: $T_1=T_2=T_3=0.02$pu; $T_m=5$sec; $T_w=0.1$sec; $\Delta U_{PSS} = -\Delta U_{PSS}$ = 0.3pu.

D. Objective Function

In this paper, eigen value based multi-objective function is used as:

$$J = 10 \sum_{i=1}^{n} \sum_{j \neq i}^{m} (\xi_j - \xi_i)^2 + \sum_{i=1}^{n} \sum_{j \neq i}^{m} (\sigma_j - \sigma_i)^2$$
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Where $\sigma_i$ and $\zeta_i$ are the real and damping ratio of $i$th eigenvalue of $i$th operating point. $N$ is the total number of operating points. $\sigma_0$ and $\zeta_0$ are chosen thresholds that depict the desirable degree of system damping performance. In this work, $\sigma_0$ and $\zeta_0$ are selected to be -2.0 and 0.4, respectively. According to the objective function, it is tried to put the relocated eigenvalues restricted within a $D$-shaped area for which, $\sigma_{ij} < \sigma_0$ and $\zeta_{ij} > \zeta_0$. It is invariable to mention that just unstable or lightly damped local oscillation modes are adjusted here. Moreover, all lead time constants ($T_i$, $T_o$) should be adjusted above the given values of corresponding lag time constants ($T_i$, $T_o$) to fully compensate the phase lag in the excitation system.

The design problem is to minimize $J$ subject to constraints pertain to adjustable gains and time constants limits. Also the gains are tuned in range of (0.1, 10).

**Bacterial Foraging Algorithm**

Bacteria Foraging Optimization Algorithm (BFOA), proposed by Passino, is a new comer to the family of nature-inspired optimization algorithms. For over the last five decades, optimization algorithms like Genetic Algorithms (GAs), Evolutionary Programming (EP), Evolutionary Strategies (ES), which draw their inspiration from evolution and natural genetics, have been dominating the realm of optimization algorithms. Recently natural swarm inspired algorithms like Particle Swarm Optimization (PSO), Ant Colony Optimization (ACO) have found their way into this domain and proved their effectiveness. Following the same trend of swarm-based algorithms, Passino proposed the BFOA.

Application of group foraging strategy of a swarm of E.coli bacteria in multi-optimal function optimization is the key idea of the new algorithm. Bacteria search for nutrients in a manner to maximize energy obtained per unit time. Individual bacterium also communicates with others by sending signals.

A bacterium takes foraging decisions after considering two previous factors. The process, in which a bacterium moves by taking small steps while searching for nutrients, is called chemotaxis and key idea of BFOA is mimicking chemotactic movement of virtual bacteria in the problem search space. During foraging of the real bacteria, locomotion is achieved by a set of tensile flagella. Flagella help an E.coli bacterium to tumble or swim, which are two basic operations performed by a bacterium at the time of foraging. When they rotate the flagella in the clockwise direction, each flagellum pulls on the cell. That results in the moving of flagella independently and finally the bacterium tumbles with lesser number of tumbling whereas in a harmful place it tumbles frequently to find a nutrient gradient. Moving the flagella in the counterclockwise direction helps the bacterium to swim at a very fast rate. In the above-mentioned algorithm the bacteria undergoes chemotaxis, where they like to move towards a nutrient gradient and avoid noxious environment. Generally the bacteria move for a longer distance in a friendly environment.

**F. Time Domain Simulations**

All simulations are done in MATLAB/SIMULINK. A step increase of 5% in the reference voltage $V_{ref}$ of 1 and 4 generators at instant of 10.0sec is considered as small disturbance. In order to verify the behavior of the equipped power system under severe transient condition, a three-phase six-cycle fault at the middle of one of the parallel lines between bus 1 and 11 is cleared by disconnecting the line. The robustness of
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controllers is found by considering different operating points in the simulations.

Fig 6 simulation circuit of two area four machine system

Fig 9 local speed of four machines with PSS and TCSC

Fig 7 TCSC phasor model

TABLE 2 SHOWS STABILISED EIGEN VALUES AFTER OPTIMIZATION USING BFA

<table>
<thead>
<tr>
<th>EM OSCILLATION FREQUENCY</th>
<th>EM DAMPING RATIO</th>
<th>EM REAL VALUE</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.882675</td>
<td>0.368301</td>
<td>-5.954981</td>
</tr>
<tr>
<td>1.84734</td>
<td>0.361797</td>
<td>-5.719931</td>
</tr>
<tr>
<td>1.293095</td>
<td>0.558546</td>
<td>-7.217872</td>
</tr>
<tr>
<td>1.217639</td>
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<td>-7.82187</td>
</tr>
<tr>
<td>0.464079</td>
<td>0.274855</td>
<td>-1.049688</td>
</tr>
<tr>
<td>0.434092</td>
<td>0.488175</td>
<td>-1.976629</td>
</tr>
<tr>
<td>0.42948</td>
<td>0.492456</td>
<td>-1.980065</td>
</tr>
<tr>
<td>0.287168</td>
<td>0.515482</td>
<td>-1.415096</td>
</tr>
</tbody>
</table>

CONCLUSION

In this paper, coordinated design of the PSS-POD controllers has been performed to enhance dynamic stability of 2A4M power system remarkably in comparison with the CPSS. With TCSC power oscillation characteristics are improved. Thus it can be concluded that superior enhancement has been acquired in small-signal stability of power system by employing this controllers.

REFERENCES

Simultaneous Design of TCSC based Damping Controller & PSS to Damp Power System Oscillations Using Bacterial Foraging Algorithm

References:


APPENDIX

Synchronous machine equations are given by:

\[
\delta_i = \omega_i (\omega_i - 1) \quad (A)
\]

\[
\omega_i = \frac{1}{J_i} (P_{mi} - P_{el} - D_i (\omega_i - 1)) \quad (B)
\]

\[
E_{q0}^i = \frac{1}{T_{q0}} (E_{f0} - (x_{di} - x_{q0})d_i - E_{q0}) \quad (C)
\]

Where \( P_{mi} \) and \( P_{el} \) are mechanical and electrical powers of ith generator both in per unit; \( M_i \) and \( D_i \) are inertia constant in second and damping coefficients;

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