Tuning of Power System Stabilizer (Unitrol D) in Benghazi North Power Plant

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ABSTRACT

The use of power system stabilizers (PSSs) to damp power system swing mode of oscillations is of practical importance. The authors purpose is to retune the power system stabilizer (PSS1A) parameters in Unitrol D produced by ABB—was installed in 1995 in Benghazi North Power Plants (BNPPs) at General Electricity Company of Libya (GECOL). Power systems are steadily growing with larger capacity, so the optimal values of the power system stabilizer (PSS1A) parameters should be retuned. A particle swarm optimization technique (PSO) is used to determine the parameters of the PSS off-line. The objective is to damp the local and inter-area modes of oscillations that occur following power system disturbances. The retuned power system stabilizer (PSS1A) can cope with large disturbance at different operating points and has an enhanced power system stability. The MATLAB package with SIMULINK is used for the design and simulations.

Keywords: Lead-Lag Compensations, Particle Swarm Optimization (PSO), Power System Stabilizer (PSS), Simulink, Static Excitation System

1. INTRODUCTION

Benghazi north power plants (BNPPs) are the biggest power plants working in General Electricity Company of Libya (GECOL).

Excitation systems (Kunder, 1994) of the generators in BNPP was chosen for investigation because its work has the biggest impact on dynamic stability of the GECOL. A fast static excitation system (PID-system) UNITROL D (Klein, Rogers, & Kundur, 1991) produced by ABB was installed in 1995.

Power system are steadily growing with ever larger capacity. Formerly separated power systems are interconnected to each other. Modern power systems have evolved into systems of very large size. With growing generation capacity (Klein, Rogers, & Kundur, 1991; Kunder, Paserba, Ajjarapu, Andersson, Bose, & Canizares, 2004), different areas in a power system are added with even large inertia. As a consequence in large interconnected power systems, low frequency oscillations have an increasing importance.

The ability of a power system to maintain stability depends to a large of extent on the controls available on the system to damp the electromechanical oscillations (Klein, Rogers,
& Kundur, 1991; Kunder, Paserba, Ajjarapu, Andersson, Bose, & Canizares, 2004). Hence the study and design of controls are very important.

The basic function of an excitation system is to provide direct current to the field winding of the synchronous machine (Kunder, 1994). The protective functions ensure that capability limits of the synchronous machine, excitation system, and other equipment are not exceeded.

The excitation system also performs control and protective functions important for satisfactory performance of the power system by controlling the field voltage and by that the field current. The control functions include the control over voltage and reactive power flow (IEEE Standard 421.5-2005, 2006), and the enhancement of system stability.

The exciter is the main component in the AVR loop. It delivers the DC power to the generator field. It must have adequate power capacity (in the low megawatt range for large generators) and sufficient speed of response (rise time less than 0.1 seconds). The basic role of AVR is to provide constancy of the generator terminal voltage during normal small and slow changes in the load.

The power system stabilizer (PSS) uses auxiliary stabilizing signal to control the excitation system so as to enhance damping of power system oscillations through excitation control. Commonly used inputs are shaft speed, terminal frequency, and power. Where frequency is used as an input, it will normally be terminal frequency, but in some cases a frequency behind a simulated machine reactance (equivalent to shaft speed for many studies) may be employed.

The Power System Stabilizer (PSS) is used to improve the damping of the power system oscillations and the general stability of the power generation including transmission system. By means of power system oscillations, two modes of oscillations are to be deemed; “Local plant oscillations“ with typical range of oscillations from 0.8 to 2.0 Hz and “Inter-area oscillations“ with typical range of oscillations from 0.1 to 0.7 Hz.

The PSS designed using root-locus, frequency-domain, and state-space methods are introduced in Chow, Boukarim, and Murdoch (2004). The intelligent technologies such as Artificial Neural Network (ANN) and Fuzzy Logic have matured enough to be applied in many control fields (Fukuda & Shibata, 1992). However its difficult to implemented practically and there is no general theory available to assist the developer in the design if ANN and Fuzzy Logic. In Jalili and Mohammadi (2005) the transient stabilizer and voltage regulator is designed based on simple neuron structure and the online tuned performed by back propagation algorithm.

In this paper, particle swarm optimization technique (PSO) (Kennedy & Eberhart, 1995; Gating, 2004) is used to search for the optimal values of the AVR & (PSSIA) parameters.

The effectiveness of the IEEE standard AVR & PSS (Klein, Rogers, & Kundur, 1991) is illustrated by applying the AVR & PSS1A to single machine infinite bus. The single machine infinite bus is designed in SIMULINK with parameters of the generator no. 3 at BNPP as shown in Appendix B.

The paper proceeds as follows. In section 2 the basic idea of the fast static excitation system is presented. In section 3 introduces the (PSS1A) power system stabilizer model as IEEE standard. In section 4 the theory of the PSS is explained. In section 5 the overview of the particle swarm optimization is introduced. Section 6 system description that explained the three phase generator of BNPP is introduced. In section 7 the simulation study that explained the power system model used in study and the simulation results that shows the PSS performance is introduced.

2. ST1A EXCITATION SYSTEM MODE

The computer model of the fast static exciter potential-source controlled-rectifier excitation system shown in Figure 1 is intended to represent systems in which excitation power is supplied through a transformer from the generator terminals (or the unit’s auxiliary bus) and is regulated by a controlled rectifier (Kunder, Paserba, Ajjarapu, Andersson, Bose, &
Canizares, 2004). The maximum exciter voltage available from such systems is directly related to the generator terminal voltage.

In this type of system, the inherent exciter time constants are very small, and exciter stabilization not required.

3. TYPE PSS1A POWER SYSTEM STABILIZER MODEL

Figure 2 shows the generalized form of a PSS1A with a single input (Klein, Rogers, & Kundur, 1991). Some common stabilizer input signals, $V_{SI}$, are speed, frequency, and power. $T_6$, is transducer time constant. Stabilizer gain is set by the term $K_s$ and signal washout is set by the time constant $T_5$.

In the next block, $A_1$ and $A_2$ allow some of the low- effects of high-frequency torsional filters (not used in this stabilizers). When not used for this purpose, the block can be used to assist in shaping the gain and phase characteristics of frequency the stabilizer. The next two blocks allow two stages of lead-lag compensation, as set by constants $T_1$ to $T_4$. The lead-lag compensator the phase lag between machine terminal voltage and voltage regulator reference input.

$V_{RMAX}$ & $V_{RMIN}$ is stabilizer output limiter. The stabilizer output, $V_{ST}$, is an input to summing element of the automatic voltage regulator.

4. BASICAL PSS THEORY

A synchronous generator working on the network is principally an oscillating structure. In order to produce a torque the rotating magnetic fields of the rotor and the stator must form a certain angle (the so called load angle $\delta$). The electrical torque $Te$ increases, as the angle $\delta$ increases, just similar to a torsion spring. Because during steady-state operation the electrical torque $Te$ of the generator and the mechanical driving torque $Tm$ from the turbine are in equilibrium, the load angle $\delta$ remains in a given position.
The dynamic of the mechanical power $T_m$, electrical power $T_e$, and rotor angular speed $\omega$ of the synchronous machine is an origin for theoretical consideration and justifications of the PSS processing signal. The relationship between the above physical magnitudes is shown in the motion equation of the synchronous machine (1 and 2) (Saadat, 2004).

\[ T_m - T_e = T_a \]  

(1)

\[ T_m - T_e = 2.H \frac{d\omega}{dt} \]  

(2)

Where:

$T_m$ = Mechanical Torque [pu]

$T_e$ = Electrical Torque [pu]

$T_a$ = Acceleration Torque [pu]

$\omega$ = Rotor Angular Speed [pu]

$H$ = Inertia Time Constant [sec.]

In order to provide a better understanding of Equation (2) the following record shall show the dynamical behavior of the electrical torque $T_e$ and rotor angular speed $\omega$ after a sudden change in the grid configuration. In this simulation the driving torque has been kept constant. (Figure 3)

For the generator running at rated speed ($\omega = 1$p.u) it is allowed to re-write Equations (1) and (2) as:

\[ P_m - P_e = P_a \]  

(3)

\[ P_m - P_e = 2.H \frac{d\omega}{dt} \]  

(4)

where:

$P_e$ = Electrical Power [pu]

$P_m$ = Driving Power Applied to the Shaft [pu]

The aim of the PSS (which output acts to the Generator Voltage Regulator) is to supply an additional electric torque component (by influencing the Field Voltage) phase-synchronous with the rotor angular speed. However the influence signal of the PSS must lead the rotor angular speed $\omega$ with a certain angle to compensate the time constants lag (mainly the field time constant $T_d'$) between the influence signal and the electric torque $T_e$.

Figure 3. Electrical torque and rotor angular speed
5. OVERVIEW OF PARTICLE SWARM OPTIMIZATION (PSO)

The PSO concept (Kennedy & Eberhart, 1995) is to change the velocity of each particle toward its global (gbest) and local (pbest) locations at each iteration (Kennedy & Eberhart, 1995). The modified velocity of each agent can be calculated using the current velocity and the distance from pbest and gbest as shown below:

\[ v_{i}^{k+1} = w v_{i}^{k} + c_{1} r (pbest - s_{i}^{k}) + c_{2} r (gbest - s_{i}^{k}), \]

(5)

where,

- \( v_{i}^{k} \): Current velocity of particle \( i \) at iteration \( k \),
- \( v_{i}^{k+1} \): Modified velocity of particle \( i \),
- \( r \): Random number between 0 and 1,
- \( s_{i}^{k} \): Current position of particle \( i \) at iteration \( k \),
- \( pbest \): Pbest of particle \( i \),
- \( gbest \): Gbest of particle \( i \),
- \( w \): Weight function for velocity of agent \( i \),
- \( c_{i} \): Weight coefficient.

The current position (searching point in the solution space) can be modified by the following equation.

\[ s_{i}^{k+1} = s_{i}^{k} + v_{i}^{k+1} \]

(6)

The flow chart of PSO Lead Lag controller is shown in Figure 4.

5.1. The PSO Algorithm

The proposed algorithm to search for the optimal value of the power system stabilizer (PSS1A) parameters using PSO can be summarized as follows:

1. Initialize the swarm with initial positions and velocities.

   Calculate the fitness function of each particle by

   \[ 0.5 \times \sum (\omega - \omega_{d})^{2} \times t. \]

   (7)

   Where,
   - \( \omega \): Actual speed
   - \( \omega_{d} \): Desired speed

   3. Determine \( pbest \) and \( gbest \) positions.

   4. Update the particle velocity using Equation (5).

   5. Update the particle position using Equation (6).

   6. If the evaluation value of each particle is better than the previous \( pbest \), the value is set to \( pbest \). If the best \( pbest \) is better than \( gbest \), the value is set to \( gbest \). If the iterations are exhausted, then go to step 8. Otherwise, go to step 2.

   8. Plot \( pbest \), \( gbest \).

We select the best one which have small error Equation (7), sometimes we used the controller’s gains which got by the PSO as reference values and decreasing the error by changing these gains by trial and error. The values of the power system stabilizer parameters obtained by PSO is shown in Appendix B.

Assuming the number of particles to ten and the weighting coefficients \( C_{1} = 2, C_{2} = 2.5 \)

6. SYSTEM DESCRIPTION

A three-phase generator rated 210 MVA, 15.75 kV, 3000 rpm is connected to a 230 kV, 10,000 MVA network through a Delta-star 210 MVA transformer.

At \( t = 0.1 \) s, a three-phase to ground fault occurs on the 230 kV bus. The fault is cleared after 6 cycles (\( t = 0.2 \) s).

During this system, we will initialize the system in order to start in steady-state with the generator supplying active power and observe the dynamic response of the machine speed deviation and of its active power.
7. SIMULATION STUDY

The power system stabilizer (PSSIA) in Benghazi North Power Plant (BNPP) is implemented as shown in Figure 5. Its parameters are tuned off-lines using the particle swarm optimization (PSO) algorithm, assuming the number of particles to ten and the weighting coefficients $C_1 = 2, C_2 = 2.5$. The parameters of PSSIA tuned by PSO are in Appendix A (Figure 6).

The performance of the PSSIA in BNPP is evaluated by applying a large disturbance in the form of a three-phase fault of the transmission line. The fault occurs at 0.1 section and cleared at 0.2 section.

Three different operating points are shown here to measure the performance of the power system stabilizer (PSSIA) in Unitrol D.

Where

- $P$: Active power [pu].
- $Q$: Reactive power [pu].
7.1. Operating Point 1

\[ P = 0.75 \text{ pu}, \quad Q = 0.0123 \text{ pu} \]

Presented in Figure 7 and Figure 8.

7.2. Operating Point 2

\[ P = 0.95 \text{ pu}, \quad Q = 0.025 \text{ pu} \]

Presented in Figure 9 and Figure 10.

7.3. Operating Condition 3

\[ P = 0.47 \text{ pu}, \quad Q = 0.001 \text{ pu} \]

Presented in Figure 11 and Figure 12

As shown in Figures 7 through Figure 12 for three operating points the one noted that, the damping stability is greatly improvement when used PSO to retune power system stabilizer parameters (PSS1A).

The PSS is needed to neutralize the negative damping action of automatic voltage regulator (AVR) and the high gain of fast acting voltage regulator create negative damping, so the gain(\( K_s \)) should be selected with appropriate value.

8. CONCLUSION

As power systems have evolved through continuing growth in interconnections, use of new
Figure 7. Speed deviation for operating condition 1

Figure 8. Active power for operating point 1

Figure 9. Speed deviation for operating condition 2
Figure 10. Active power for operating point 2

![Active power for operating point 2](image1)

Figure 11. Speed deviation for operating point 3

![Speed deviation for operating point 3](image2)

Figure 12. Active power for operating point 3

![Active power for operating point 3](image3)
technologies and controls, and the increased operation in highly stressed conditions, different forms of system instability have emerged. Many major trips caused by power system instability due to power system stabilizer which need retune to adapt to new interconnected power system. So, our purpose is to retune the power system stabilizer (PSS1A) parameters in Unitrol D produced by ABB—was installed in 1995 in Benghazi North Power Plant (BNPP) at General Electricity Company of Libya (GECOL). The optimal values of the PSS1A parameters are determined off-line by a particle swarm optimization technique (PSO). The objective is to damp the local oscillations that occur following power system disturbances.

A power system stabilizer (PSS) installed in the excitation system of the synchronous generator improves the small-signal power system stability by damping out low frequency oscillations in the power system.

The simulation results shows that the retuned power system stabilizer (PSS1A) can cope with large disturbance at different operating points and has an enhanced power system stability.

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REFERENCES


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APPENDIX A

The generator parameters in per unit on rated 210 MVA and 15.75 kV base are follow:

\[ x_d = 2.53 \text{ pu} \]
\[ x_q = 2.36 \text{ pu} \]
\[ x'_d = 0.248 \text{ pu} \]
\[ x'_q = 0.4 \text{ pu} \]
\[ x''_d = 0.187 \text{ pu} \]
\[ x''_q = 0.2 \text{ pu} \]
\[ T_{do} = 10.8 \text{ S} \]
\[ R_s = 0.001 \text{ pu} \]
\[ T_{do}'' = 0.03 \text{ S} \]
\[ x_s = 0.17 \text{ pu} \]
\[ T_{qo} = 0.99 \text{ S} \]
\[ T_{qo}'' = 0.034 \text{ S} \]
\[ H = 1.29 \text{ S} \]

Where:

- \( x_i \): Leakage reactance
- \( x_d \): d-axis synchronous reactance
- \( x'_d \): d-axis transient reactance
- \( x''_d \): d-axis subtransient reactance
- \( x_q \): q-axis synchronous reactance
- \( x'_q \): q-axis transient reactance
- \( x''_q \): q-axis subtransient reactance
- \( T_{do} \): d-axis transient open-circuit time constant
- \( T_{do}'' \): d-axis subtransient open-circuit time constant
- \( T_{qo} \): q-axis transient open-circuit time constant
- \( T_{qo}'' \): q-axis subtransient open-circuit time constant
- \( R_s \): stator resistance
- \( H \): moment of inertia time constant.
APPENDIX B

PSS1A Parameters by (PSO)

\[ T_1 = 0.15 \]
\[ K_s = 2 \]
\[ T_2 = 0.03 \]
\[ T_5 = .01 \]
\[ T_3 = 0.15 \]
\[ T_6 = 1.65 \]
\[ T_4 = 0.03 \]