CHAPTER 4

PID CONTROLLER TUNING POWER SYSTEM STABILIZER

4.1. INTRODUCTION

The electrical energy is a primary prerequisite for economic growth. The demand for electric power has considerably increased due to large-scale industrialization. Modern power system operates under many stressed conditions because of increase in demand and deregulation of electric power system. This leads to many problems associated with operation and control of power systems. The economics of energy production has a major concern for the power utilities. Therefore, the power utilities always need new technology to solve its problems (Modi et al. 2006). The complexity of power systems is continuously growing due to the increasing number of generation plants and load demand. Power systems are becoming heavily stressed due to the increased loading of the transmission lines and due to the difficulty of constructing new transmission systems as well as the difficulty of building new generating plants near the load centers. All of these problems lead to the voltage stability problem in the system (El-Dib et al. 2006).

An interconnected power system consists of several essential components. They are namely the generating units, the transmission lines, and the loads. During the performance of the generators, there may be some disorders such as sustained oscillations in the speed or periodic variations in the torque that is utilized to the generator. These disruptions may result in voltage or frequency fluctuation that may impress the other components of the interconnected power system. External factors, such as lightning, can also cause disturbances to the electrical system. All these
disturbances are termed as faults. When a fault occurs, it causes the generators to lose synchronism. With these factors in mind, the basic condition for a power system with stability is synchronism. Besides this condition, there are other significant conditions such as steady-state stability, transient stability, harmonics and disturbance, the collapse of voltage and the loss of reactive power (Pai 1981).

The stability of a system is defined as the tendency and ability of the power system to develop restoring forces equal to or greater than the disturbing forces to maintain the state of equilibrium (Saadat 1999). There are many major blackouts caused by instability of a power system which illustrates the importance of this phenomenon (Bayliss and Hardy 2007). The stability has been acknowledged as a significant problem for secure system operation since the 1920's (Sauer 1997).

In this previous chapter, the observed that the MultiBand PSS performed superior to other types of PSS. In this chapter focuses the dynamic stability analysis of multiband PSS (MB-PSS) Power System is investigated using PID controller. Gain settings of the PID controller is optimized by minimizing an objective function using soft computing algorithm (BAT). The analysis reveals that the tuning of PID with PSS gives better dynamic performances as compared with convention PSS. PID controller design tested on the proposed power system and proved its effectiveness.

**4.2 DESIGN OF POWER SYSTEM STABILIZER**

IEEE Std 421.5 as revised by the IEEE excitation system subcommittee will introduce a new type of power system stabilizer model, the multiband power system stabilizers (PSSs). Although it requires two inputs, like the widely used IEEE PSS2B, an integral of accelerating power PSS introduced at the beginning of the nineties as
the first practical implementation of a digital PSS, the underlying principle of the new IEEE PSS4B makes it sharply different. As in the case of the previous design method, we find that the introduction of the voltage regulator eliminates the steady state error and makes the system much faster. However, it also introduces low-frequency oscillations in the system. Hence we have to design the PSS loop taking input as the perturbation in rotor angular speed ($\Delta\omega$). The block diagram of a single-input PSS is shown in Fig.4.1.

![Fig.4.1 Structure of PID-PSS](image)

Various structures of PSS can be implemented. The common structures are:

Lead –Lag Structure of PSS

$$u_{PSS} = K \frac{sT_w}{1 + sT_w} \left( \frac{l + sT_1}{l + sT_2} \right)^p y$$  \hspace{1cm} (4.1)

Where $y$ is the input signal

PID structure is

$$u_{PSS} = K \frac{sT_w}{1 + sT_w} \left( K_p + \frac{K_i}{s} + K_ds \right) y$$  \hspace{1cm} (4.2)

The common input signals used are the speed, frequency, electric and accelerating power deviations.
4.2.1 Multiband – PSS

The disturbances occurring in a power system induce electromechanical oscillations of the electrical generators. These oscillations, also called power swings, must be effectively damped to maintain the system's stability. Electromechanical oscillations can be classified into four main categories:

- Local oscillations: between a unit and the rest of the generating station and between the latter and the rest of the power system. Their frequencies typically range from 0.8 to 4.0 Hz.

- Interplant oscillations: between two electrically close generation plants. Frequencies can vary from 1 to 2 Hz.

- Interarea Oscillations: between two major groups of generation plants. Frequencies are typically in a range of 0.2 to 0.8 Hz.

- Global Oscillation: characterized by a common in-phase oscillation of all generators as found in an isolated system. The frequency of such a global mode is typically under 0.2 Hz.

The need for effective damping of such a wide range, almost two decades, of electromechanical oscillations motivated the concept of the multiband power system stabilizer (MB-PSS).

As its name reveals, the MB-PSS structure is based on multiple working bands. Three separate bands are used, respectively dedicated to the low-, intermediate-, and high-frequency modes of oscillations: the low band is typically
associated with the power system global mode, the intermediate with the inter-area modes, and the high with the local modes.

Each of the three bands is made of a differential bandpass filter, a gain, and a limiter (see the figure called Conceptual Representation). The outputs of the three bands are summed and passed through a final limiter producing the stabilizer output Vstab. This signal then modulates the set point of the generator voltage regulator so as to improve the damping of the electromechanical oscillations.

To ensure robust damping, the MB-PSS should include a moderate phase advance at all frequencies of interest to compensate for the inherent lag between the field excitation and the electrical torque induced by the MB-PSS action.

Fig.4.2 Multiband PSS structure
Only a few of the lead-lag blocks in this figure should be used in a given PSS application. Two different approaches are available to configure the settings to facilitate the tuning process:

4.2.2 Simplified settings:

Only the first lead-lag block of each frequency band is used to tune the Multiband Power System Stabilizer block. The differential filters are assumed to be symmetrical band-pass filters respectively tuned to the center frequency \( F_L \), \( F_I \), and \( F_H \). The peak magnitude of the frequency responses (refer the Fig. 4.3) can be adjusted independently through the three gains \( K_L \), \( K_I \), and \( K_H \). Only six parameters are therefore required for a simplified tuning of the MB-PSS.

4.2.3 Detailed settings:

The designer is free to use all the flexibility built into the MB-PSS structure to achieve nontrivial controller schemes and to tackle even the most constrained problem (for example, multi-unit plant including an inter-machine mode, in addition to a local
mode and multiple inter-area modes). In this case, all the time constants and gains appearing in the figure called Internal Specifications have to be specified in the dialog box.

PSS models in this study refer to the IEEE 421.5 standard, known as Multi-Band Power System Stabilizer (MB-PSS), as shown in Fig.4.3. In the MB-PSS applied three kinds of filters are low-pass filter, intermediate-pass filter, and high-pass filter, which serves to dampen the local oscillation, the oscillation between networks, and global oscillations (Sauer Pai, 1998) By using this type of PSS, the effect on the stability of the signal due to changes in the turbine power can also be suppressed.

The main parameters for setting the MB-PSS is: gain band: KL = 3, KI = 5.5, KH = 53, the frequency band centers: FL = 0.1076 Hz, FI = 1.1958 Hz, FH = 12 Hz. MB-PSS was designed to quell disturbances that occurred in the electric power system. Disturbances caused oscillations in the electromechanical generator in the power system. Electromechanical oscillations can be classified: 1). Local Oscillation. These oscillations are caused by disorders that occur between one generator unit is active and the inactive generator in a power station. The oscillation frequency ranges in the range between 0.8 to 4.0 Hz. 2). The oscillation between stations. This oscillation is caused by interference between two adjacent power stations. The oscillation frequency ranges in the range between 1 Hz to 2 Hz. 3). Oscillations between areas. This oscillation is caused by a disturbance between two groups of generation stations in a power system. The oscillation frequency ranges in the range between 0.2 to 0.8 Hz. 4). Global Oscillation. This oscillation is characterized by oscillations in the same phase in the entire generator. The global oscillation frequency is generally below 0.2 Hz. This oscillation also called power swing, and efficiently
should be suppressed to maintain the stability of the power system. MB-PSS oscillation damping action using the three fields of different frequencies to dampen the entire spectrum frequency oscillations that can occur in the power system is achieved. There are three areas of the frequency used, each of which is used to handle low-frequency oscillation mode low, medium, and high. Field of low frequency (low band) is associated with global fashion power system. Field intermediate frequency related to the mode of the inter-area power system. Medium field of high frequency is associated with a local mode (in a generating station). Furthermore, IEEE standards-based PSS models applied in Matlab Simulink software as shown in Fig. 4.4.

![Fig.4.4 PSS Model Based on IEEE 421.5](image)

### 4.3 PID TUNING FOR POWER SYSTEM STABILIZER

PID controllers have been used for several decades in industries for process control applications. The reason for their broad popularity lies in the simplicity of design and good performance including low percentage overshoot and small settling time for slow process plants. The most appreciated feature of the PID controllers is their relative easiness of use because the three involved parameters have a clear
physical meaning. This makes their tuning possible for the operators also by trial and error and in any case, a large number of tuning rules have been developed.

Although all the existing techniques for the PID controller parameter tuning perform well, a continuous and an intensive research work is still underway towards system control quality enhancement and performance improvements. A PID controller is essentially a generic closed loop feedback mechanism. In working principle is that it monitors the error between a measured process variable and the desired setpoint; from this error, a corrective signal is computed and is eventually feedback to the input side to adjust the process accordingly.

![Fig.4.5 Basic structure of PID](image)

**Fig.4.5 Basic structure of PID**

PID - a most widely used type of controller for industrial applications. Moreover, exhibit robust performance over a wide range of operating conditions. The three most important parameters involved are Proportional (P), Integral (I) and Derivative (D).

The proportional part is responsible for following the desired set-point, while the integral and derivative part account for the accumulation of past errors and the rate
of change of error in the process respectively. PID controller’s algorithms are mostly used in feedback loops. PID controllers can be implemented in many forms. It can be applied as a stand-alone controller or as part of Direct Digital Control (DDC) package or even Distributed Control System (DCS). The latter is a hierarchical distributed process control system which is widely used in process plants.

The PID controller is

\[ u(t) = K_p e(t) + K_i \int_0^t e(t)\,dt + K_d \frac{d}{dt}e(t) \]  

(4.3)

Where \( u \) is the control signal and \( e \) is the control error \((e = r - y)\). The reference value is also called the set point. The control signal is thus a sum of three terms: the P-term (which is proportional to the error), the I-term (which is proportional to the integral of the error), and the D-term (which is proportional to the derivative of the error). The controller parameters are proportional gain \( k_p \), integral gain \( k_i \), and derivative gain \( K_d \). The controller can also be parameterized as,

\[ u(t) = k \left( e(t) + \frac{1}{T_i} \int_0^t e(t)\,dt + T_d \frac{de(t)}{dt} \right) \]  

(4.4)

Where \( T_i \) is called integral time and \( T_d \) derivative time. The proportional part acts on the present value of the error, the integral represents an average of past errors and the derivative can be interpreted as a prediction of future errors based on linear extrapolation, shown in Fig.4.1.
4.3.1 Proportional Action

The response of the output to a unit step in the command signal for a system with pure proportional control. The output never reaches the steady state error. Let the process and the controller have transfer functions $P(s)$ and $C(s)$. The transfer function from reference to output is given by equation 4.3 and 4.4,

$$G_{yr} = \frac{P(s)C(s)}{1 + P(s)C(s)}$$  \hspace{1cm} (4.5)

The steady state gains with proportional control $C(s) = k$ is

$$G_{yr}(0) = \frac{P(0)k}{1 + P(0)k}$$  \hspace{1cm} (4.6)

4.3.2 Integral Action

Integral action guarantees that the process output agrees with the reference in steady state. This can be shown as follows. Assume that the system is in steady state with a constant control signal ($u_0$) and a constant error $e_0 \neq 0$. It follows from Equation 4.5 that,

$$u_0 = ke_0 + k_ie_0t$$  \hspace{1cm} (4.7)

The left-hand side is constant, but the right-hand side is a function of $t$. We thus have a contradiction and $e_0$ must be zero. Notice that in this argument the only assumption made is that there exists a steady state.
4.3.3 Derivative Action

The derivative action can improve the stability of the closed-loop system. The input-output relation of a controller with proportional and derivative action is,

\[ u(t) = k_e(t) + k_d \frac{de(t)}{dt} = k_e \left( e(t) + T_d \frac{de(t)}{dt} \right) = k_e p(t) \quad (4.8) \]

Where \( T_d = k_d / d \) is the derivative time. The action of a controller with proportional and derivative action can be interpreted as if the control is made proportional to the predicted process output.

Thus, the PID controller algorithm is described by a weighted sum of the three times functions were the three distinct weights are: \( K_p \) (Proportional gain) determines the influence of the present error value on the control mechanism, \( I \) (integral gain) decides the reaction based on the area under the error time curve up to the present point and \( T_d \) (derivative gain) account for the extent of the response to the rate of change of the error with time (K. Astrom and T. Hagglund, 1994).

![Diagram of PID-PSS](image)

**Fig. 4.6 Structure of PID-PSS**

For simplicity, a PID type PSS is modeled by some identical stages, PID which is represented by a gain \( K_p \), \( K_i \) and \( K_d \), washout function, the value of \( T_w \) is not critical and may be in the range of 1 to 20 seconds and the output limits \( V_{smax} \) and
\( V_{\text{min}} \) (N. M. Tabatabaei, 2010). The structure of the PID type power system stabilizer, to modulate the excitation voltage is shown in Fig. 4.1.

The gain values are tuned in the any one of Soft Computing algorithm. Here, the optimization algorithm used for finding the best gain values of PID Controller by achieving good dynamic performance tuned in the proposed Multiband PSS. A Bat algorithm is used to find the optimized gain values of the PID Controller and the gain parameters Values are shown in Table 4.1 and the corresponding design is shown in Fig 4.2.

**Table 4.1 Optimal Gain Values of PID Controller**

<table>
<thead>
<tr>
<th>Parameters</th>
<th>Gain Values</th>
</tr>
</thead>
<tbody>
<tr>
<td>Kp</td>
<td>1.9245</td>
</tr>
<tr>
<td>Ki</td>
<td>2.8940</td>
</tr>
<tr>
<td>Kd</td>
<td>0.1574</td>
</tr>
</tbody>
</table>

The detailed analysis of Bat algorithm and in objectives function, theory are discussed in further chapter 6.

*Fig. 4.7 BAT-PID Controller design*
4.4 RESULTS AND DISCUSSION

The traditional method of tuning does not guarantee optimal parameters and in most cases, the tuned parameters need improvement through trial and error. The optimal tuning for determining the PID Controller parameters was carried out. To evaluate the effectiveness of the proposed Bat Algorithm (BAT) on PID-PSS to improve the stability of the power system, the dynamic performance of the proposed algorithm was examined under different loading conditions. For comparison, however, the PID controller parameters were also obtained using the conventional tuning technique. The conventional rules were used to form the intervals for the design parameters in tuning the controller by minimizing an objective function. Through the simulation results, it is clearly shown that the proposed Bat algorithm tuned PID controller can perform an efficient search to obtain optimal PID controller parameter that can achieve better performance criterion. It is recognized that the highest magnitude of power system disturbance is caused by the three phase fault. The PID-PSS can track the system operating conditions, and thus, as seen from the results in figures below, can adjust and provide a uniformly excellent performance over a wide range of operating conditions and disturbances. The following observations are made on the stability of the system.

4.4.1 Symmetrical Case

The symmetrical fault analysis of the proposed system without PSS, with PSS and with PID-PSS implementation of the four machine two area power system with multiband PSS shown in Figs. 4.8 to 4.11 The Figure shows the Voltage response and active power transfer, rotor angle deviation, rotor speed response and power loss at generators respectively with respect to time.
Fig. 4.8 Voltage response of Bus1 and Bus2 and active power transfer between them for a symmetrical fault at the period of 1 – 1.2 sec.

Fig. 4.9 Rotor angle deviation on generator 4 for a symmetrical fault at the period of 1 – 1.2 sec.
Fig. 4.10 Rotor speed response of generator 1, 2, 3 & 4 for a symmetrical fault at the period of 1 – 1.2 sec.

Fig. 4.11 Power loss at generator 1, 2, 3 & 4 for a symmetrical fault at the period of 1 – 1.2 sec.

4.4.2 Asymmetrical Case

For this case, vulnerable condition occurred where a three phase fault is assumed to happen at the transmission line. Asymmetrical fault analysis of the proposed system without PSS, with PSS and with PID-PSS implementation of the four machine two area power system with multiband PSS shown in Figs. 4.12 to 4.19. The Figure shows the Voltage response and active power transfer, rotor angle...
deviation, rotor speed response and power loss at generators respectively with respect to time.

Fig. 4.12 Voltage response of Bus1 and Bus2 and active power transfer between them for L-G fault at the period of 1 – 1.2 sec.

Fig. 4.13 Rotor angle deviation on generator 4 for L-G fault at the period of 1 – 1.2 sec.
Fig. 4.14 Rotor speed response of generator 1, 2, 3 & 4 for L-G fault at the period of 1 – 1.2 sec.

Fig. 4.15 Power loss at generator 1, 2, 3 & 4 for L-G fault at the period of 1 – 1.2 sec.

Fig. 4.16 Voltage response of Bus1 and Bus2 and active power transfer between them for LL-G fault at the period of 1 – 1.2 sec.
Fig. 4.17 Rotor angle deviation on generator 4 for LL-G fault at the period of 1 – 1.2 sec.

Fig. 4.18 Rotor speed response of generator 1, 2, 3 & 4 for LL-G fault at the period of 1 – 1.2 sec.

Fig. 4.19 Power loss at generator 1, 2, 3 & 4 for LL-G fault at the period of 1 – 1.2 sec.
By looking at Figs. 4.12 to 4.19, the PID-PSS controller greatly improved the speed deviation and rotor angle deviation within 3 seconds compared without PSS and with PSS methods which took a longer time to achieve the same steady state performance. Bat algorithm tuned method shortened the rotor angle settling time to almost 3.6 seconds. The comparison above shows that the BAT tuning method of PID controller has better performance in every aspect when the power system is subjected to symmetrical and asymmetrical conditions. Hence, the PID controller with BAT tuning significantly suppresses the oscillations in the system and provides excellent damping characteristics to low frequency oscillations by stabilizing the system much faster. The Table 4.2 and 4.3 shows voltage response and speed deviation of the proposed system.

**Table. 4.2 Bus voltage response of proposed PSS system**

<table>
<thead>
<tr>
<th>Control</th>
<th>Fault Type</th>
<th>( V_{6} ) (pu)</th>
<th>( V_{10} ) (pu)</th>
<th>( P_{6-10} ) (MW)</th>
</tr>
</thead>
<tbody>
<tr>
<td>With PSS</td>
<td>Asymmetrical LG</td>
<td>0.9576</td>
<td>0.9692</td>
<td>401.2</td>
</tr>
<tr>
<td></td>
<td>LLG</td>
<td>0.9554</td>
<td>0.9675</td>
<td>401.7</td>
</tr>
<tr>
<td></td>
<td>Symmetrical LLLG</td>
<td>0.9519</td>
<td>0.9655</td>
<td>399.3</td>
</tr>
<tr>
<td>With PID + PSS</td>
<td>Asymmetrical LG</td>
<td>0.9868</td>
<td>0.9950</td>
<td>420.6</td>
</tr>
<tr>
<td></td>
<td>LLG</td>
<td>0.9650</td>
<td>1.001</td>
<td>456.8</td>
</tr>
<tr>
<td></td>
<td>Symmetrical LLLG</td>
<td>0.9832</td>
<td>0.9955</td>
<td>424.4</td>
</tr>
</tbody>
</table>
Table. 4.3 Speed deviation of proposed PSS system

<table>
<thead>
<tr>
<th>Control</th>
<th>Fault Type</th>
<th>$\omega_1$ (pu)</th>
<th>$\omega_2$ (pu)</th>
<th>$\omega_3$ (pu)</th>
</tr>
</thead>
<tbody>
<tr>
<td>With PSS</td>
<td>Asymmetrical</td>
<td>1.003</td>
<td>1.003</td>
<td>1.003</td>
</tr>
<tr>
<td></td>
<td></td>
<td>1.003</td>
<td>1.003</td>
<td>1.003</td>
</tr>
<tr>
<td></td>
<td>Symmetrical</td>
<td>1.003</td>
<td>1.003</td>
<td>1.003</td>
</tr>
<tr>
<td>With PID + PSS</td>
<td>Asymmetrical</td>
<td>1</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td></td>
<td></td>
<td>1</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td></td>
<td>Symmetrical</td>
<td>1</td>
<td>1</td>
<td>1</td>
</tr>
</tbody>
</table>

4.5 SUMMARY

The Bat algorithm based approach to optimal design of PID-PSS (multiband PSS) to present the enhancement of the dynamic stability of a two-area four-machine interconnected power system has been studied. The PID parameters searched by this method results in a better computation efficiency and accuracy than the previous methods tested. The simulation results show that the proposed controller can perform an efficient search that achieves better performance criterion through multiple iterations of computational steps. Also, the BAT-PID controller design is more superior regarding consistency and robust stability. With better stability and faster recovery after a fault has occurred, the system can perform smoother and better. Therefore, the effectiveness of proposed Bat algorithm tuned PID Controller tuning for PSS and its dynamic performance are better.