CHAPTER 4

GA BASED PID GAIN TUNING FOR LFC AND AVR

4.1 INTRODUCTION

In recent years, electricity has been used to power more sophisticated and technically complex manufacturing processes, computers and computer networks, operation theatres in hospitals and a variety of other high-technology consumer goods. These products and processes are sensitive not only to the continuity of power supply but also on the quality of power supply such as voltage and frequency. Hence, the modern power supply needs to operate at constant frequency and voltage with more reliability (Prasanth and Jayaramkumar 2005). Power system frequency is the best indication of the balance between generation and load at any given time. Operating a power system is basically the process of maintaining several sets of balances. Two of those balances are load vs generation and scheduled tie-line flows vs actual tie-line flows. The load-generation balance is determined by frequency constancy. If frequency is low, generation must be increased; if the actual outflow is greater than the scheduled outflow, generation is decreased. The main objective of AGC is to regulate the system frequency and maintain the scheduled power interchanges between tie-lines. The voltage regulator senses the changes in the terminal voltage of the generator and takes corrective action to drive the exciter to maintain the system voltage. Hence, the performance of the excitation system depends on the performance of the regulator.
As load constantly varies, the power system operating conditions are always changing and hence precise manual control of these balances would be impossible. PID control offers the simplest and yet most efficient solution to many real-world control problems. Three-term functionality of PID controller covers treatment of both transient and steady state responses. Conventional PID controller was widely employed for proper tuning of gains in LFC and AVR in power system. The PID controller is simple for implementation but generally gives large frequency deviations. The conventional controllers used today are fixed gain controllers and are insufficient because of change in operating points during a daily cycle. As the operating point of a power system change continuously, a fixed gain controller may no longer be suitable in all operating conditions. The speed-governor system should be operated within the restricted control range of feedback gains due to the system instability. Moreover, in the deregulated environments, frequent on-off controls of large capacity units may bring about large amount of power disturbances. Van Overschee and De Moor (2000) reported that more than 80% of PID controllers used in the industries are not tuned properly. Hence modified PID control system based on optimal tracking approach is required. So to keep system performance near its optimum, it is desirable to track the operating conditions and use updated parameters to compute the control. For an optimal or near optimal performance, it is necessary that the feedback gains should be changed quickly in response to the system changes, thereby increasing the capabilities of PID controllers.

Several investigations in the AGC resulted in development of novel and intelligent control techniques for efficient control of frequency and voltage. The evolutionary techniques such as genetic algorithm and simulated annealing (SA) have received much interest for achieving high efficiency and searching global optimal solution in problem space. The GA method is
usually faster than the SA method because the GA has parallel search techniques, which emulate natural genetic operations [Goldberg2003]. Due to its high potential for global optimization, GA has received great attention in control system such as search of optimal PID controller parameters. GA has been proved as a tool for solving optimization problems in almost every branch of science and engineering to find an optimal solution (Gallapher and Sambridge 1994), (De Jong 1992), (Wang et al 2006), (Chang 2007). A higher order robust dynamic performance is achieved with LFC designs based on GA and linear matrix inequalities (Rerkpreedaping et al 2003). The desired control parameters have been obtained by coordinating GA with linear matrix inequalities. Ghosal (2004) developed a new GA based AGC scheme for multiarea thermal generating system. The scheme is capable of evaluating the fitness of GA optimization by selecting a function like “figure of merit” which directly depends on transient performance characteristics like settling time, undershoot, overshoot etc.,. Robandi and Nishimorier (2001) proposed a new search method using GA for a complex power control system. The method gave a new alternative procedure in time-varying feedback control to improve the stability performances. Oysal (1999) proposed GA to optimize the parameters of PI and PID for two-area power system. The simulation results proved to be effective in improving the transient response of the system.

Ceyhun Yildiz et al (2006) developed a method to optimize PID parameters using GA for LFC of power generating system. The computer simulations indicated that the proposed method decreases the frequency of oscillation and improves the performance of the controller. Herrero et al (2002) presented a powerful and flexible method for tuning PID controllers using GA. Flexibility was demonstrated in tuning the gains under different operating conditions of the plant. Milani and Mozafari (2010) presented an advanced genetic algorithm based method to obtain optimal gains of PID
controller for a fixed load two-area interconnected power system. Simulation results in comparison with respective conventional methods confirm the efficiency of proposed method through fast damping steady-state deviations in frequency with presence of step load disturbance. Manisha and Pankaj (2006) presented a systematic approach for the design of power system stabilizer using genetic algorithm and investigated the robustness of the GA based power system stabilizer (PSS). It is found that the dynamic performance with the GA based system shows improved results, over conventionally tuned PSS over a wide range of operating conditions. Mastorakis and Dubey (2006) designed GA based power system damping control for tuning the parameters of power system stabilizer. The simulation results reveal that the proposed controller robust to wide variations in loading conditions and provides adequate damping to excitation system.

Venkata Prasanth and Jayaram Kumar (2008) proposed a new robust load frequency controller for two areas interconnected power system to quench the deviations in frequency and tie line power due to different load disturbances. The results proved that the proposed Genetic Algorithm controller is superior in terms of fast response with very less undershoots and negligible overshoot. Mohammad Monfared et al (2008) recommended a novel control strategy for the load frequency control (LFC) system. The developed method includes a genetic algorithm (GA) based self-tuning PID for online control. The simulation results indicate that the proposed strategy improves the system dynamics remarkably.

The objective of this research is to highlight the GA based tuning method that would result in obtaining the optimum gain values for the PID controller in LFC and AVR of the power generating system. The application of GA-PID controller improves the overall performance of the system by providing reduced settling time, oscillations and overshoot. Genetic
Algorithm is a stochastic global search method that emulates the process of natural evolution. GA has been shown to be capable of locating high performance areas in complex domains without experiencing the difficulties associated with high dimensionality.

The large scale power systems are divided into coherent areas and each area is interconnected through tie-lines for contractual energy exchange and to provide inter-area support during abnormal operations. (Ibraheem et al 2005) (Mathur and Manjunath 2006) reported LFC for interconnected power system and the simulation results proved to be feasible for an optimal AGC scheme. Venkataprasanth and Jayaramkumar (2008) proposed GA based controller for LFC of two areas interconnected system and the frequency response characteristics is proving to be better with less overshoot and reduced time to reach the steady state level.

In this thesis, the design is extended in developing GA based PID control for LFC in a two area interconnected power system. To demonstrate the effectiveness of proposed method, the step responses of a closed loop system were compared with that of the conventional controllers. Model of the plant has been developed using the MATLAB simulink package and simulated for different load and regulation parameters. Simulation results are presented to show the effectiveness of the proposed method in handling processes of plant under different operating characteristics.

This chapter is organized as follows. Section 4.2 describes the design of GA based PID controller. Section 4.3 describes the Simulink model. Simulation results are presented in section 4.4. Comparative analysis is discussed in section 4.5. Summary of the chapter is discussed in section 4.6.
4.2 DESIGN OF GA BASED PID CONTROLLER

Designing and tuning a PID controller for application that needs multiple objectives is a difficult task for a design engineer. The conventional PID controller with fixed parameters usually derives poor control performance. When gain and time constants change with operating conditions, conventional controllers result in sub-optimal corrective action and hence fine tuning is required. This necessitates the development of tools that can assist engineers to achieve the best PID control for the entire operating envelope of a given process. A genetic algorithm (GA) belongs to the family of evolutionary computational algorithms that have been widely used in control engineering applications. It is a powerful optimization algorithm that works on a set of potential solutions, which is called population. GA finds the optimal solution through cooperation and competition among the potential solutions.

4.2.1 Overview of GA

Genetic Algorithm is a global search technique based on the operations of natural genetics and a Darwinian survival of the fittest with a randomly structured information exchange. Genetic Algorithm search techniques are rooted in mechanisms of natural selection, a biological process in which stronger individuals are likely to be winners in a competing environment. GA related search has received increasing interest owing to its advantages over conventional PID optimization techniques. It uses directed algorithms based on the mechanics of biological evolution such as inheritance, natural selection and recombination or crossover. In recent years, there has been extensive research on heuristic search techniques like GA, Simulated Annealing, Particle Swarm Optimization and Ant Colony Optimization, etc., for optimization of the PID gains (Dubey and Gupta
2005). Given an optimization problem, GA encodes the parameters concerned into a finite bit binary string called a chromosome. A chromosome population is subsequently formed, each representing a possible solution to the optimization problem. Each chromosome is then evaluated according to its fitness function (Karnavas and Papadopoulos 2002).

Three basic operators of GA are ‘reproduction’, crossover’ and ‘mutation’. The reproduction task randomly selects a new generation of chromosomes. The crossover involves exchanging parts of two chromosomes. With the crossover operation, more chromosomes are generated and genetic search space is extended and completely filled. Mutation is the random alteration of the bits in the string. For the binary representation, mutation task simply flips the state of a bit from 1 to 0 or, vice versa. The mutation operation is usually associated with helping to re-inject any information that may be vital to the performance of a search process.

GA, capable of searching for a population of chromosomes rather than a single chromosome, can arrive at the global optimal point rapidly and simultaneously avoid locking at local optima. In addition, GA deals with coding of parameters and not just the parameter itself, thereby freeing itself from the limitations of conventional PID technique. GA which is a part of evolutionary computation has shown to be a valuable and robust technique in assisting engineers to solve complex problems. After the evaluation process, generated solution space is transformed to another genetic operator such as selection, crossover and mutation (Juang and Lu 2004), (Jang et al 2006). The genetic algorithm starts with limited knowledge of the correct solution and depends entirely on responses from its environment and evolution operators such as reproduction, crossover and mutation to arrive at the best solution.
4.2.2 Genetic Algorithm Operators

A simple genetic algorithm that yields good results in practical optimization problems is composed of three operators namely, reproduction, crossover and mutation. In each generation, the genetic operators are applied to selected individuals from the current population in order to create a new population. By using different probabilities for applying these operators, the speed of convergence can be controlled. Crossover and mutation operators must be carefully designed, since their choice highly contributes to the performance of the whole genetic algorithm.

In reproduction stage, the performances of individuals are measured by the objective function, and it is used to bias the selection process. Highly fit individuals will have been increasing opportunities to pass on genetically important material to successive generations. In this way, the genetic algorithm searches from many points in the search space at once and yet continually narrows the focus of search to the areas of the observed performance.

The selection of individuals is then modified through the application of genetic operators in order to obtain the next generation. Genetic operators manipulate the characters [genes] that constitutes the chromosomes directly. Three main categories of Genetic operators are,

1. Reproduction: Selects the fittest individuals in the current population to be used in generating the next population.

2. Cross-over: Causes repairs, or larger groups of individuals to exchange genetic information with one another.

3. Mutation: Causes individual genetic representations to be changed according to the probability.
The reproduction task randomly selects a new generation of chromosomes, and cross-over involves exchanging parts of two chromosomes. With the cross-over operation, more chromosomes are generated. Reproduction is an obvious property of extant species that have the great reproductive potential that their population size would increase at an exponential rate if individuals of the species were to reproduce successfully. Reproduction is accomplished through the transfer of an individual’s genetic program to progeny. The genetic search space is thus extended to all possible sets of controller parameter values to minimize the objective function, which in this case is the error criterion. GA is used to minimize the error criteria of PID controller in each iteration. The integral square error is used to define the PID controller’s error criteria.

4.2.3 GA Design Procedure

GA based controllers have the ability to adapt to a time varying environment and may be able to maintain good closed-loop system performance. In the design of PID controller, the performance criterion or objective function is first defined based on the desired specification such as time domain specifications. As a mathematical means for optimization, GA’s can be naturally applied to the optimal tuning of classical PID controllers. The PID controller parameters are optimized offline by GA at all possible operating conditions. The optimized PID gains are used in LFC and AVR control loop for efficient control of frequency and voltage. The frequency and voltage profile of the generator validates the design of the GA based tuning algorithm. The closed loop system consisting of proposed GA based PID controller and plant depicting LFC/AVR is illustrated in Figure 4.1.
The transfer function of a standard PID controller structure is given in Equation (4.1)

\[ G(s) = K_P (1 + K_I/s + K_D s) \]  

where, \( K_P \) is the proportional gain providing overall control action, \( K_I \) is the integral gain reducing the steady state error and \( K_D \) is the differential gain improving the transient response of the system. The fitness function \( f(x) \) depends on the problem type i.e, maximization or minimization. The fitness function used for tuning PID controller is the minimization of integral of time multiplied by the absolute value of error (ITAE) as shown in Equation (4.2).

\[ F(x) = \int e(t) \, dt \]  

The role of PID controller is to drive the output response of LFC and AVR within the tolerance limit set in the under frequency and under voltage relays. Here, Genetic algorithm is used to optimize the proportional, integral and derivative gains of the PID controller such that the system will have a better performance in terms of settling time, peak overshoot and oscillations. For each operating condition, GA is used to optimize the PID controller parameters in order to minimize the performance index. The control
system is given a step input, and the error is assessed using the appropriate error performance criteria, i.e., ITAE. Each chromosome is assigned an overall fitness value according to the magnitude of error, the smaller the error the larger the fitness value. The performance index is calculated over a time interval ‘T’, normally in the region of $0 \leq T \leq t_s$, where $t_s$ is the settling time. Hence, the optimum values of $K_p$, $K_i$ and $K_d$ are obtained for single and two area power system for efficient control of voltage and frequency. For two area LFC system, considering ACE as the system output, the control vector for a PID controller in a continuous form can be given as in Equation (4.3)

$$U_i = - (K_P \text{ACE}_i + K_D \text{ACE}_i + K_I \dot{\text{ACE}}_i) \tag{4.3}$$

where, the $K_p$, $K_i$, $K_d$ is the proportional, derivative and integral gains. Since the performance index is related to time and error, the optimum gain values are suitable for controlling under different operating load and regulation parameters.

The Genetic Algorithm steps to tune gain values for the PID controller (Ismail 2006) are as follows:

1. Randomly choose the genetic pool of parameters $K_P$, $K_I$, $K_D$

2. Compute the fitness of all population.

3. Choose the best subset of the population of the parameters: $K_P$, $K_I$, $K_D$

4. Generate new strings using the subset chosen in step 3 as parents and the “single point crossover” and “uniform mutation” as operators.
5. Verify the fitness of the new population members

6. Repeat steps 3 to 5 until the fixed amount of fitness is attained.

A stopping criterion terminate the algorithm after s specified number of iterations have been performed or until the solution is encountered with specified accuracy. To simplify the analysis, the optimal parameter values for two interconnected areas are considered as,

\[ K_{P1} = K_{P2} = K_P, \quad K_{I1} = K_{I2} = K_I, \quad K_{D1} = K_{D2} = K_D \]  (4.4)

The best fitness function value in a population is defined as the smallest value of the objective in the current population. The fitness function is a measure of how well the candidate solution fits the data and it is the entity that focuses the GA towards the solution. Minimization of the fitness function by genetic algorithm results in reduced settling time and overshoots. A flow chart of the genetic algorithm optimization procedure is given in Figure 4.2. Selecting an objective function is the most difficult part of designing a genetic algorithm. In this research, the objective function is required to evaluate the best PID controller for LFC and AVR. An objective function could be created to find the optimum gains of a PID controller that gives the smallest overshoot, faster settling time and reduced oscillations. By combining all these objectives, an error minimization function is selected that will reduce the deviation in frequency and voltage of the generating system. The convergence criterion of a genetic algorithm is a user specified condition. E.g. the maximum number of generations when the string fitness value exceeds the threshold limit.
4.3 SIMULINK MODEL

The transfer function approach is followed in modeling the LFC and AVR for a power system with GA-PID controller. The optimum gains of the PID controller are obtained by running the M-file and the values are
stored in the workspace. Series of experiments are conducted with different parameter settings before actual runs to collect the results. The parameters used in the simulations are summarized in Table 4.1. The computational efficiency is extremely important in optimization techniques like GA, where the generation of solution takes more time with a large amount of data. The mean CPU time taken for completing the fixed number of iterations is measured. The genetic algorithm is initialized with a population of 25 and was iterated for 500 generations. The crossover and mutation rate is set to 4 and 18 respectively. For the given parameter values, the computational time taken by the algorithm to generate optimum value of PID gains is 54 seconds. The optimized PID gains are transferred to the simulink models of LFC and AVR of the isolated power generating system. Investigation is extended to two-area LFC to validate the performance of the proposed controller.

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Population Size</td>
<td>25</td>
</tr>
<tr>
<td>Number of Generations</td>
<td>500</td>
</tr>
<tr>
<td>Crossover Rate</td>
<td>4</td>
</tr>
<tr>
<td>Mutation Rate</td>
<td>18</td>
</tr>
<tr>
<td>Probability of Selection</td>
<td>0.18</td>
</tr>
</tbody>
</table>

4.3.1 Model of Single Area system

The dynamic model of the power system given by Elgerd (1983) is used for implementation of the proposed controller. In this research, the simulink model for LFC and AVR with PID controller is designed with the nominal values for each parameter. The nominal parameters for AVR model
are $K_a=10$, $K_e=1$, $K_g=1$, $K_r=1$, $T_a=0.1$, $T_e=0.4$, $T_g=1$, $T_r=0.05$. Since, the generator is driven by steam turbine, the governor and turbine time constants are selected as $T_g=0.2$ and $T_t=0.5$ respectively. In the absence of a speed governor, the system response to a load change is determined by the inertia constant and the damping constant. The inertia constant $H$ and damping constant $D$ are maintained as 10 and 0.8 respectively. The steady-state speed deviation is such that the change in load is exactly compensated by the variation in load due to frequency sensitivity. The Simulink model of LFC and AVR is shown in Figures 4.3 and 4.4, respectively. The AVR model consists of a step input, PID controller based on GA, an amplifier that amplifies the exciter signal which in turn controls the voltage of the generator and a scope to display the terminal voltage. It also contains a sensor that determines the difference between load demand and power generated and feeds it to the controller based on the load changes. The LFC model in Figure 4.3 consists of a step input, PID controller based on GA, a governor to control the speed of the turbine that drives the generator and the scope that shows the frequency deviation.

Figure 4.3 Simulink Model of LFC with GA Based PID Controller
4.3.2 Model of Two Area System

In interconnected systems, a group of generators are connected internally to form a coherent group. The LFC loop can be represented for the whole area, referred to as control area. Consider two areas in Figure 4.5, interconnected by lossless tie-line of reactance \( X_{\text{tie}} \), with the power flow \( P_{12} \) from area 1 to area 2. For LFC studies, each area may be represented by an equivalent generating unit exhibiting its overall performance. The Simulink model of LFC for a two area power system is shown in Figure 4.6, with each area represented by an equivalent inertia \( M \), load-damping constant \( D \), turbine and governing system with speed droop \( R \). This model depicts the interconnection of two power systems with LFC, and the results are analyzed from the scope that displays the combined output of the frequencies of the two systems.
If the areas are equipped only with primary control of the LFC, a change in load in one area is met with, change in generation in both areas, change in tie-line power and a change in the frequency. Hence, a supplementary control is necessary to maintain the frequency at nominal value. A two area interconnected power system of non-reheat type turbine with GA based PID controllers is shown in Figure 4.6. The optimum gain values for the PID controller are tuned using GA and transferred to simulink model for obtaining desired frequency response.

![Simulink Model of LFC for a Two Area Power System with GA Based PID Controller](image)

**Figure 4.6** Simulink Model of LFC for a Two Area Power System with GA Based PID Controller

### 4.4 SIMULATION RESULTS

The quality of power supply depends on the constancy of voltage and frequency under all operating points of a power system. The operating point of power system changes with time, and hence experiences deviation in
nominal values of frequency and voltage. An attempt is made in this research to control the frequency and voltage of the power system using governor and exciter of the synchronous machine. To enhance the performance of the control loop, a supplementary controller is added in the secondary loop. The dynamic performance of the power system is improved by the excitation and turbine-governor controls, and its success has led to a greater expectations about its capability. The increasing complexity of the modern control systems has emphasized the idea of applying intelligent controllers to enhance the power system. The most desirable performance requires the controllers to have the smallest possible value for rise time, overshoot and the settling time. GA is used to enrich the performance of two important control loops of the power system. To validate the performance of GA based PID controller, it is tested with LFC and AVR models.

The Simulation was carried out using the Simulink Package Version 6.3 available in MATLAB 7.1. The models are simulated on Pentium 4 (2.4 MHz), 1 GB RAM desktop PC. The results are presented to quantify the benefits of GA based PID controller as compared to conventional PID and fuzzy Controller. The simulation results demonstrate that the optimally tuned PID controller is successful in reducing the overshoot and provide a better transient response. The investigation is carried to find the superiority of the controller when compared with conventional PID and fuzzy logic based controllers. The models are simulated and the effects are analyzed for various changes in loads and speed regulations. The small signal and large signal analysis are justified for studying the system response for small and large perturbations. Later, a two-area interconnected power system consisting of two identical power plants of non-reheat turbines are considered for investigation. The feasibility of an optimal controller is selected based on the comparative analysis between the conventional PID, fuzzy logic controller and GA based controllers.
4.4.1 PID Controller for Single Area System

The Simulink model for single area power system with conventional PID controller was simulated for a change in load of 0.10 p.u, 0.30 p.u and 0.8 p.u. The simulations are repeated for speed regulations 75, 100 and 125, and the response is plotted for a time period of 100 seconds. The frequency deviation and terminal voltage responses obtained for a change in load of 0.10 p.u and speed regulation of 75 are shown in Figures 4.7 and 4.8 respectively.

![Figure 4.7 LFC with PID Controller for R=75 and ΔP_L=0.10 p.u](image)

It is observed from Figure 4.7 that the settling time for frequency deviation 48.4 seconds. The frequency deviation varies from 0 to -0.0108 for the PID Controller.

![Figure 4.8 AVR with PID Controller for ΔP_L=0.10 p.u](image)
From Figure 4.8, it is observed that the terminal voltage takes 38 seconds to settle in its optimum value. The terminal voltage response of the single area power system with PID controller does not have any transient overshoots. The performance of PID controller for various load changes and speed regulations are tabulated in Table 4.2, from which it is inferred that frequency deviation does not have any positive peak overshoots.

### Table 4.2 Performance Analysis of PID Controller for Single Area Network

<table>
<thead>
<tr>
<th>Parameters</th>
<th>R=100</th>
<th>R=125</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>ΔP_L=0.30</td>
<td>ΔP_L=0.80</td>
</tr>
<tr>
<td>Settling Time (sec)</td>
<td>45.5</td>
<td>36.65</td>
</tr>
<tr>
<td>Overshoot (Hz)</td>
<td>-0.0155</td>
<td>0</td>
</tr>
<tr>
<td>Oscillation (Hz)</td>
<td>0 to 0.0155</td>
<td>0 to 1</td>
</tr>
</tbody>
</table>

### 4.4.2 GA Based PID Controller for Single Area System

To evaluate the effectiveness of the proposed controller, dynamic performance of the LFC and AVR are examined. The performance is compared with conventional PID and Fuzzy controller for validating need for proposed system. The optimum values of K_p, K_i and K_d values are obtained by executing the GA code in M-file. The optimum gain values are included in the PID controller in a secondary control loop of LFC and AVR. The simulation results are plotted for a time period of 100 seconds with GA based PID controller. The performance of GA-PID was tested and verified for speed regulations 75, 100 and 125 and for change in load of 0.10 p.u to 0.90 p.u.
A step increase in load of 10% is applied and the dynamic response of GA based LFC is analyzed. The frequency deviation and terminal voltage responses obtained for a change in load of 0.10 p.u and speed regulation of 75 is shown in Figures 4.9 and 4.10 respectively.

**Figure 4.9** LFC with GA Based PID Controller for $R=75$ and $\Delta P_L=0.10$ p.u

The response of LFC for load perturbation of 10% is plotted in Figure 4.9. It is observed that the frequency ($\Delta F$) oscillates between -0.0030 to 2.4629e-006 and settles at 8.7 seconds.

**Figure 4.10** AVR with GA Based PID Controller for $\Delta P_L=0.10$ p.u

It can be interpreted from Figure 4.10, that voltage regulator senses the changes in the terminal voltage and initiates corrective action to drive the
exciter to maintain the rated output within 10.5 seconds. The AVR is a continuously acting type so that corrective action is taken proportional to deviations in terminal voltage. Hence, a fast acting exciter with high gain AVR reduces the oscillations and provides stable operation of the power system. Behavior of changing frequency and voltage for various loads and regulations is presented in Table 4.3. The transient response of LFC and AVR can be analyzed and compared with conventional PID controllers. During restoration, the power system should be operated at nominal voltage. The voltage deviations should be maintained at a minimum possible level to reduce charging currents. Hence enough care must be taken to ensure that fast-acting AVR is installed on each generator. The stability of the system depends on the restoration progress of the generating system. Hence alternative controls on generators should be placed in a position to ensure instantaneous responses to changes in voltage and frequency. The feasibility of an optimal control scheme is based on the improvement in performance characteristics with respect to the parameters tabulated viz. settling time, overshoot and oscillations. The settling time for LFC with change in load of 0.30 and R value of 100 is reduced by 80.48% when compared to conventional PID and 58.69% with respect to a fuzzy logic controller. The overshoot and oscillations are reduced by 52.9% and 51.4% with respect to conventional PID and fuzzy logic controllers respectively. GA based PID controller achieves better performance with respect AVR by achieving 69.44% reduction in settling time in comparison with conventional PID and 15% when compared with fuzzy based controller. The investigation carried out for single area network under different load perturbation and regulations reveal the reliability of proposed GA based controller. In order to emphasize the advantages of the proposed controller, the computational time taken by GA to generate optimum gain values for different load regulation and change in loads are mentioned Table 4.3. For conventional PID controller based LFC and AVR, the optimum gain values are selected by trial and error method or
based on the experience of an operator. It is hard to manually tune the optimal gains of PID controller because of the higher order, time delays and nonlinearities. Even though the computational time is less when compared to GA, the conventional controller does not exhibit desired performance characteristics. For these reasons, it is proposed to increase the capability of PID controller by enhancing its features. The LFC and AVR design using modern optimization theory enables the power engineers to design an optimal control system with respect to given performance criterion.

Table 4.3 Performance Analysis of GA Based PID Controller for Single Area Network

<table>
<thead>
<tr>
<th>Parameters</th>
<th>R=100</th>
<th>R=125</th>
<th>R=100</th>
<th>R=125</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>ΔP_L =0.30</td>
<td></td>
<td>ΔP_L =0.80</td>
</tr>
<tr>
<td></td>
<td></td>
<td>ΔP_L =0.30</td>
<td></td>
<td>ΔP_L =0.80</td>
</tr>
<tr>
<td>Computational Time: 53.6 sec</td>
<td>Computational Time: 54.2 sec</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>LFC</td>
<td>8.88</td>
<td>11.2</td>
<td>14.8</td>
<td>15.3</td>
</tr>
<tr>
<td>AVR</td>
<td>11.4</td>
<td>11.25</td>
<td>14.8</td>
<td>15.7</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Settling Time(sec)</td>
<td>0.0073</td>
<td>0</td>
<td>0.054</td>
<td>0</td>
</tr>
<tr>
<td>Overshoot</td>
<td>0</td>
<td>0</td>
<td>0.0065</td>
<td>0</td>
</tr>
<tr>
<td>Oscillation</td>
<td>2.1736e-006 to -0.0073</td>
<td>0 to 1</td>
<td>0 to 0.054</td>
<td>0 to 1</td>
</tr>
</tbody>
</table>

4.4.3 Interconnected System

During normal load conditions, AGC helps to maintain the frequency at nominal value and the inter area power transfer at scheduled values. On sudden load perturbations, some areas may not be able to increase their generation due to the lack of sufficient reserve to manage the demand. Hence, tie-line power deviates from scheduled value and therefore, frequency also deviates from normal value. A global controller which exploits the possible beneficial aspects of interconnections has been applied for two areas LFC problem to achieve favorable results. The performance of two area
network is tested using GA based PID Controller for different load and speed regulations. The frequency deviation for area1 and area2 under various load changes was observed. It was shown that the optimal accommodation of load disturbances could lead to significantly better performance than that of conventional controllers.

4.4.3.1 PID Controller for Two Area Interconnected System

The Simulink model for two area power system with conventional PID controller is simulated for a change in load of 0.20 p.u in both area1 and area2 and also for a change in load of 0.20 p.u in area1 and 0.30 p.u in area 2. The simulation was carried out for a time period of 100 seconds with speed regulations 75, 100 and 125. The frequency deviation is obtained for a change in load of 0.20 p.u in both area1 and area 2 and speed regulation of 75 is shown in Figure 4.11.

![Figure 4.11](image)

Figure 4.11 LFC with PID Controller for R=75, $\Delta P_{L1} = 0.20$ p.u and $\Delta P_{L2} = 0.20$ p.u
It is clear from the response in Figure 4.11 that the system responds for frequency deviations of both areas with fewer magnitudes and settling time. When both the areas are subjected to uniform load of 0.2 p.u, it is observed that the settling time for frequency deviation in area1 and area2 is 42.6 seconds and 56 seconds respectively. The Oscillations for area 1 and area2 varies from 0 to -0.0127 and 0 to -0.0111 respectively. The voltage and frequency responses for different load and regulations in Table 4.4, shows appreciable improvement in settling time as well as magnitudes of oscillations. Generation and load should be increased in small increments to minimize the impact on the frequency deviations. The effect of controller performance is tested for load variation of 0.2 and 0.3p.u with regulation value of 100 and 125. From the results in Table 4.4, it is clear that the settling time is in the range of 50 to 60 seconds, with wide oscillations between -0.0077 to -0.0103. Hence it is recommended to apply intelligent GA based controller to match the requirements of the present day control systems.

<table>
<thead>
<tr>
<th>Parameters</th>
<th>Settling Time (sec)</th>
<th>Overshoot (Hz)</th>
<th>Oscillation (Hz)</th>
</tr>
</thead>
<tbody>
<tr>
<td>R=100</td>
<td>$\Delta P_{L1} = 0.20$</td>
<td>Area 1</td>
<td>53.4</td>
</tr>
<tr>
<td></td>
<td>$\Delta P_{L2} = 0.20$</td>
<td>Area 2</td>
<td>60</td>
</tr>
<tr>
<td>R=125</td>
<td>$\Delta P_{L1} = 0.20$</td>
<td>Area 1</td>
<td>55.5</td>
</tr>
<tr>
<td></td>
<td>$\Delta P_{L2} = 0.20$</td>
<td>Area 2</td>
<td>60</td>
</tr>
<tr>
<td>R=100</td>
<td>$\Delta P_{L1} = 0.20$</td>
<td>Area 1</td>
<td>60</td>
</tr>
<tr>
<td></td>
<td>$\Delta P_{L2} = 0.30$</td>
<td>Area 2</td>
<td>52.2</td>
</tr>
<tr>
<td>R=125</td>
<td>$\Delta P_{L1} = 0.20$</td>
<td>Area 1</td>
<td>55.9</td>
</tr>
<tr>
<td></td>
<td>$\Delta P_{L2} = 0.30$</td>
<td>Area 2</td>
<td>50.5</td>
</tr>
</tbody>
</table>
4.4.3.2 GA-PID for Two Area Interconnected System

The proposed GA based PID controller has been compared with the conventional PID system for various speed regulation and loading parameters. The two areas are loaded simultaneously and independently with load perturbations of 20% and 30%. The performance characteristics are plotted for a time period of 100 seconds to monitor the wave front of tie-line frequency. The response plots for frequency deviation of area1 and area2 with change in load of 0.20 p.u in both areas and speed regulation of 75 is plotted in Figure 4.12.

![Figure 4.12 LFC with GA based PID Controller for R=75, ΔP_{L1} =0.20 p.u and ΔP_{L2} =0.20 p.u](image)

In an interconnected power system, if large generator trips, it results in shortage of generation. The remaining unit gives up some of their rotating kinetic energy to increase the power output and then the frequency declines. In response to the frequency decline, governor opens the control valve to increase the power input to the turbines. Hence, designed controllers must be fast enough to respond to the frequency changes and initiate
controller action to vary the prime mover input. The simulation results in Figure 4.12 reveals that the proposed GA based PID controller for two areas LFC is faster in restoring the frequency to its optimum value. Frequency deviation returns to zero and remains at the same value until a new load is applied. The bar chart in Figure 4.13 illustrates the performance comparison of area 1 and area 2 with speed regulation ‘R’ of 75 and change in load of 0.20 p.u in both areas. The simulation result shows that the proposed GA based PID controller yields a reduction of 95.45% in settling time, 79.19% in peak overshoot and reduction of 77% in oscillation when compared to conventional PID controller.

Table 4.5  Performance Analysis of GA Based PID Controller for Two Area Network

<table>
<thead>
<tr>
<th>Parameters</th>
<th>Settling Time (sec)</th>
<th>Overshoot (Hz)</th>
<th>Oscillation (Hz)</th>
</tr>
</thead>
<tbody>
<tr>
<td>R=100</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Area 1 ΔP_L1=0.20 Comp.Time 55.7 sec</td>
<td>4</td>
<td>-0.0019</td>
<td>1.4454e-004 to-0.0019</td>
</tr>
<tr>
<td>Area 2 ΔP_L2=0.20</td>
<td>3.17</td>
<td>-0.0027</td>
<td>8.7985e-004 to-0.0027</td>
</tr>
<tr>
<td>R=125</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Area 1 ΔP_L1=0.20 Comp.Time 56 sec</td>
<td>2.25</td>
<td>-0.0025</td>
<td>5.3295e-004 to-0.0025</td>
</tr>
<tr>
<td>Area 2 ΔP_L2=0.20</td>
<td>1.75</td>
<td>-0.0023</td>
<td>1.2619e-004 to-0.0023</td>
</tr>
<tr>
<td>R=100</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Area 1 ΔP_L1=0.20 Comp.Time 56.8 sec</td>
<td>1.5</td>
<td>-0.0025</td>
<td>4.2800e-004 to-0.0025</td>
</tr>
<tr>
<td>Area 2 ΔP_L2=0.30</td>
<td>5.5</td>
<td>-0.0045</td>
<td>0.0023 to -0.0045</td>
</tr>
<tr>
<td>R=125</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Area 1 ΔP_L1=0.20 Comp.Time 57.1 sec</td>
<td>1.7</td>
<td>-0.0024</td>
<td>3.5490e-004 to-0.0024</td>
</tr>
<tr>
<td>Area 2 ΔP_L2=0.30</td>
<td>1.85</td>
<td>-0.0035</td>
<td>1.9075e-004 to-0.0035</td>
</tr>
</tbody>
</table>
Due to lack of precision and reliability, conventional PID design is restricted for large scale and complicated power system. Absence of a systematic and intuitive approach to select values for control parameters is a big obstacle when attempting to obtain a satisfactory control system. To solve this problem by GA, the structure and parameters of the controllers are encoded into a chromosome and define a fitness measure as a function over the performance demands, thus formulating the design problem as the minimization of an objective function with respect to the controller parameters. In this technique, the gains of PID controller are searched in a feasible region of response until the desired function is obtained. The proposed control scheme is incorporated in a single and two area LFC and AVR for isolated power generating system. This section deals with comparative analysis of conventional PID, Fuzzy and GA based PID Controller with respect to settling time, peak overshoot and oscillations.
4.5.1 Single Area Network

The frequency and terminal voltage response of GA based PID Controller is compared with fuzzy and conventional PID controller. For comparative analysis of LFC, the speed regulation and change in load are consider as 75 and 0.10 p.u respectively. The terminal voltage response is compared for a common load perturbation of 0.10p.u among the controllers. The bar chart in Figure 4.14 depicts the performance of LFC and AVT in single area power system with respect to settling time Oscillations and Peak Overshoot. When compared to conventional PID, it is observed that the settling time for frequency deviation using GA based PID controller is reduced by 81.2%. Similarly Peak Overshoot and Oscillations are reduced by 78.19% and 78.28% respectively. The settling time for terminal voltage response of GA based PID controller is reduced by 78.28% with respect to conventional PID and fuzzy controllers. When compared with fuzzy based controllers, settling time, overshoot and oscillations for LFC are reduced by 42%, 51.4% and 52.3% respectively. The proposed GA-PID controller has been shown to enhance the damping of the power system following a step change in load and gives better performance than the conventional PID and fuzzy controllers.

Figure 4.14 Comparative Analysis for the Single Area Network
4.5.2 Two Area Network

LFC for two area network is used as a test system to demonstrate the effectiveness of proposed method when compared with fuzzy and conventional PID controllers. Comparison is made between these controllers for sudden load perturbation of 20% in both area1 and area2. The comparative analysis helps in selecting a best solution based on the system constraints like, settling time, oscillations and overshoot. The proposed control strategy obtains much better frequency constancy than obtained by a speed governor itself. The controller improves the transient response in order to reduce error amplitude with each oscillation and finally settle at desired value. The performance of the area1 with speed regulation of 75 and change in load of 0.20p.u in area1 and area2 is analyzed with bar chart in Figure 4.15. In comparison with conventional PID, the settling time for frequency deviation using GA based PID Controller is reduced by 95.45%, whereas a peak overshoot and oscillations are reduced by 79.19% and 77% respectively.

![Figure 4.15 Comparative Analysis for the Area1 of Two Area Interconnected Power System](image)

Figure 4.15 Comparative Analysis for the Area1 of Two Area Interconnected Power System
When compared to the fuzzy logic controller, the settling time for frequency deviation using GA based PID Controller is reduced by 78.26%. Furthermore, peak overshoots and oscillations are reduced by 60% and 52% respectively. The bar chart in Figure 4.16 shows the performance of the area2 with the speed regulation of 75 and change in load of 0.2p.u in both areas. It is observed from the figure that the frequency response of GA based controller is reduced by 96.4% to settle when compared with conventional PID controllers. The overshoot and oscillations are reduced by 79% in contrast with conventional PID controllers. When compared with fuzzy logic controllers, GA achieves a reduction of 73.68%, 63.7%, 62.7% in settling time, overshoot and oscillations respectively. In an interconnected power system, providing the constant frequency between areas is a series operational problem. Hence fast and efficient decision making mechanism has to be installed in network control units for efficient control of voltage and frequency.

![Figure 4.16 Comparative Analysis for Area 2 of Two Area Interconnected Power System](image)

**Figure 4.16** Comparative Analysis for Area 2 of Two Area Interconnected Power System
4.6 SUMMARY

An attempt is made in this research to apply an intelligent method to optimize the PID gains for LFC and AVR of the power system. Genetic Algorithm based auto-tuning of PID controllers has been presented in this chapter. All the conventional gain tuning methods like root-locus, sliding mode, reduced order models, etc., fail to operate under varying load conditions. GA is capable of locating high performance areas in complex domains without experiencing the difficulties associated with high dimensionality or false optima.

The important challenge in the design of PID controllers is to have the smallest values of rise time, overshoot and settling time. The simulation results indicate that GA is usually faster and has parallel search techniques to emulate genetic operations. GA works effectively and provides good relationship with objective function that optimizes the PID controller. It needs little amount of information about the parameters to be controlled, but it continuously monitors the plant behavior and controls the plant efficiently.

The LFC and AVR models are tested for various load and regulation changes, to obtain robustness of GA-PID controller. As seen in simulations, with the same values of regulations and loads, GA-PID controller achieves high flexibility and improved convergence accuracy. Furthermore, it is found that it reduces complexity in designing with improved computational efficiency. The proposed controller exhibits relatively better performance with reduced computational time for convergence to produce optimum gain values. This work will serve as a valuable resource for searching and tuning problems of PID controller parameters more easily and quickly.
The work can be extended in the future by implementing Evolutionary Algorithms like, PSO, ACO, and Hybrid PSO to obtain optimum PID gains and thereby achieving better computational efficiency and improved performance characteristics. The evolutionary algorithms provide a better alternative method in terms of transient characteristics of LFC and AVR.