CHAPTER 1
INTRODUCTION

1.1 AUTOMATIC GENERATION CONTROL PROBLEM

An interconnected power system consists of control areas which are connected to each other by tie lines. In a control area, all the generators speed up or slow down together to maintain the frequency and relative power angles to scheduled values in static as well as dynamic conditions. In an interconnected power system, any sudden small load perturbation in any of the interconnected areas causes the deviation of frequencies of all the areas and also of the tie line powers.

The main objectives of Automatic Generation Control (AGC) are:
1. To maintain the desired megawatt output and the nominal frequency in an interconnected power system.
2. To maintain the net interchange of power between control areas at predetermined values.

A perturbation like adding a block of load in a single area power system operating at nominal value of frequency creates the power mismatch in generation and demand. This mismatch is initially compensated by an extraction of kinetic energy from the system, which causes a declining system frequency. As the frequency goes on decreasing, the power taken by old load also goes on decreasing. In large power systems, the equilibrium may be obtained inherently by themselves at a point when the new load is compensated by the reduction in power taken by old load plus the power corresponding to kinetic energy extracted from the system. Obviously this equilibrium is obtained at the cost of a reduction in frequency. This equilibrium is self managed by the system and it does not require any governor action. The frequency decline under such a condition is quite large.
However, if the mismatch is large enough, the governors come into action and the output of generators is increased. Now the equilibrium is obtained at a point when the new load is compensated with the reduction in the power taken by old load plus the increased generation due to governor action. Thus, amount of kinetic energy extracted from the system is reduced to a greater extent, although not totally. Hence for this type of equilibrium, the decline in frequency still exists, but in this case it is quite smaller than the case mentioned above. Such equilibrium is normally obtained within 10-12 seconds after the addition of load. The action of governors is thus a primary control.

Since despite the action of governors the frequency is still different than nominal value, it is further needed to bring the frequency back to nominal value by another precise control strategy. This is done conventionally with the help of Integral Controllers. This is a secondary control (which operates after allowing the primary control to act) brings back the frequency to nominal or very close to nominal value. However, the conventional integral controllers are basically slow in action.

In case of an interconnected power system having two or more areas connected through tie lines, each area supplies its control area and tie lines allow electric power to flow among the areas. However, a load perturbation in any of the areas affects output frequencies of all the areas as well as the power flow on tie lines. Hence the control system of each area needs information about transient situation in all the other areas to restore the nominal values of area frequencies and tie line powers. The information about each area is found in its output frequency and the information about other areas is in the deviation of tie line powers. For example, for a two area interconnected power system, this information is taken as $B_i\Delta f_i + \Delta P_{tie} \ldots \ldots$ (i = 1, 2), where $B = \text{tie line frequency bias}, f = \text{nominal frequency}$
and $P_{\text{tie}} = \text{tie line power}$. This is called as the area control error (ACE) and the same is fed as input to the integral controller of corresponding area.

Thus, an AGC scheme for an interconnected power system basically incorporates suitable control system, which can bring the area frequencies and tie line powers back to nominal or very close to nominal values effectively after the load perturbations.

### 1.2 INTERCONNECTED POWER SYSTEMS

From a practical viewpoint, the problems of frequency control of interconnected areas are more important than those of isolated (single) areas. However, for understanding the theory and concept of an interconnected system, the knowledge of single area is equally important.

Practically all power systems today are tied together with neighboring areas and the problem of automatic generation control becomes a joint undertaking. Following are the basic operating principles of an interconnection of power systems.

1. Under normal operating conditions, each control area should strive to carry its own load, except such scheduled portions of the other members’ loads as have been mutually agreed upon.

2. Each control area must agree upon adopting regulating and control strategies and equipment that are mutually beneficial under both normal and abnormal situations.
Advantages of interconnection:

1. **Effect of size:** This is one of the major advantages for the total interconnected system. As soon as a block of load is added, during the first moments, the required energy is borrowed temporarily from the kinetic energy of the system. Obviously, the larger the system is, the more is the energy available. Hence the static frequency drop is comparatively less. However, the same amount of change in load may cause a higher frequency drop in an isolated or small power system, which may even make the entire system unstable.

2. **Reduced need of reserve capacity:** Since the peak demands can occur at various hours of the day in various areas, the ratio between peak and average load for a large system is smaller than that of smaller systems. It is therefore obvious that, all the interconnected areas can benefit from a reduced need of reserve capacity by a scheduled arrangement of energy interchange.

### 1.3 A TWO AREA INTERCONNECTED POWER SYSTEM

As two area interconnected power system connected through a tie line is shown in Fig. 1.1. Each area feeds its control area and tie line allows electric power to flow between the areas.

![Diagram of a two area interconnected power system](image)

**Fig. 1.1: A two area interconnected power system**
A single control area is characterized by the same frequency throughout. In other words, the area network is ‘rigid’ or ‘strong’. In the case of a two area system, it is assumed that each area is individually ‘strong’ and the two areas are connected by a ‘weak’ tie line.

An interconnected power system may consist of any number of subsystems or areas.

1.4 MAJOR DRAWBACKS OF CONVENTIONAL INTEGRAL CONTROLLERS

The drawbacks of conventional integral controllers can be summarized as:

1. They are slow in action.

2. They do not take into account the inherent nonlinearities of various power system components. Some of the causes of non-linearity are, governor dead band effects, use of reheat type of steam turbines in thermal systems, generation rate constraints (GRCs) etc.

3. While the load changes continuously during the daily cycle, the operating point also changes accordingly. This is in fact the inherent characteristic of a power system. For better results, the integrator gain has to be changed frequently as per the changes in operating point and it is also to be ensured that, the value of gain best compromises between low overshoot in dynamic response and fast transient recovery. This is quite difficult to achieve practically. Thus, an integral controller is basically a fixed controller, which is optimal under one condition but unsuitable at another operating point.
Therefore, the control rule to be imposed must cope up with the dynamics of a power system. A controller based on intelligent system would therefore be suitable for controlling the system.

1.5 NEED OF INTELLIGENT CONTROL TECHNIQUES

Intelligent control techniques are of great help in implementation of AGC in power systems. Today’s power systems are more complex and require operation in uncertain and less structured environment. Consequently, secure, economic and stable operation of a power system requires improved and innovative methods of control. Intelligent control techniques provide a high adaption to changing conditions and have ability to make decisions quickly by processing imprecise information. Some of these techniques are rule based logic programming, model based reasoning, computational approaches like fuzzy sets, artificial neural networks, evolutionary programming and genetic algorithms. In this research work, the artificial neural network (ANN) technique has been used for AGC of interconnected power systems.

1.6 ADVANTAGES OF ANN CONTROLLERS OVER CONVENTIONAL INTEGRAL CONTROLLERS

An ANN controller has many advantages over conventional integral controller viz.,

1. It quickly adapts to changing operating points and calculates optimal control commands.
2. It can perform effectively even with nonlinearities.
3. The system parameters are not required during starting.
4. It can function even if system inputs are temporarily lost or errors are introduced.
5. If telemetry failure occurs, ANN controller continues to function without needing any decision support software.
1.7 PROBLEMS ADDRESSED IN THE THESIS WORK

1. To show that the ANN controllers can replace the conventional integral controllers with many advantages and that, the ANN technique can be conveniently applied to restore the nominal values of area frequencies and tie line powers in interconnected power systems after the load perturbations.

2. To demonstrate the application of ANN technique for AGC of interconnected power systems with different area characteristics.

3. To develop models of different types of interconnected power systems with integral controllers as well as optimal controllers. To obtain continuous time state equations & control equations using state space analysis and to study these models for stability. To obtain state equations and control equations in discrete time form for both integral control and optimal control strategies for each model.

4. To design and develop ANN controllers operating with full state feedback as well as with incomplete state feedback (output feedback) for each of the power system models under consideration.

5. To compare the performance of ANN controllers with that of optimal and conventional integral controllers.

In this research work, feedforward neural network controllers capable of working in real time have been developed using MATLAB programming. They have been trained using Lavenberg-Marquardt (LM) back propagation algorithm under supervised training method with adequate amount of generated data. The training data has been obtained from optimal control strategy. Once trained properly, these controllers can work with the power system to give the desired outputs which act as control inputs of the power system. These ANN controllers can successfully bring back the excursions in area frequencies and tie line powers within acceptable limits in smaller time periods, with lesser transients & lower overshoots as compared to the performance of integral controllers under same load disturbance conditions.
1.8 ORGANIZATION OF THE THESIS

The thesis is organized as follows.

Chapter 1 includes a brief description of automatic generation control problem, introduction to interconnected power systems, drawbacks of conventional integral controllers, need of intelligent control systems, advantages of ANN controllers over conventional integral controllers and the problems addressed in the thesis.

Chapter 2 deals with comprehensive & critical survey and review of literature on AGC studies related to power system models, control techniques, control strategies, digital control, adaptive and self tuning schemes, some other aspects like inter-ties, SMES units, deregulation etc. and also the literature on artificial intelligence (AI) techniques including AGC with ANN techniques.

Chapter 3 deals with the modeling of different types of interconnected power systems with integral control, state space modeling of these power systems with optimal control strategy, design of optimal controllers and stability studies of these power system models. The discrete versions of these models have also been obtained.

The theory of artificial neural networks, their types, various network learning/training methods and algorithms, backpropagation principle and applications of neural networks are included in Chapter 4.

Chapter 5 deals with the design and development procedure of the proposed ANN controllers including their specifications, their interface with power systems in training and controller modes and step by step procedure adopted with the help of programs in MATLAB for i) generating the training data ii) training of controllers
with full state and incomplete state feedback and iii) obtaining performances of neural, optimal and integral controllers under same load disturbance conditions.

Chapter 6 gives the results in the form of graphs of dynamic responses of crucial system states, obtained by action of ANN controllers trained with full state as well as with incomplete state feedback (output state feedback) in comparison with performances of optimal and integral controllers. The discussion of the results is also included for each power system model under consideration.

Conclusions of the research work and scope for further work are given in Chapter 7.

Finally, for the completeness of the thesis, references and an appendix showing the nominal values of power system parameters are given at the end.