# STUDIES ON AUTOMATIC GENERATION CONTROL OF INTERCONNECTED MULTI-AREA POWER SYSTEM

DISSERTATION

SUBMITTED IN PARTIAL FULFILLMENT OF THE REQUIREMENTS

FOR THE AWARD OF THE DEGREE

OF

**MASTER OF TECHNOLOGY**

**IN**

**POWER SYSTEMS**

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## CANDIDATE'S DECLARATION

I, Akanksha Sayogi, Roll No. 2K20/PSY/01, M.Tech. (Power Systems), hereby declare that the project Dissertation titled **"STUDIES ON AUTOMATIC GENERATION CONTROL OF INTERCONNECTED MULTI-AREA POWER SYSTEM"** which is submitted by me to the Department of Electrical Engineering, Delhi Technological University, Delhi for the partial fulfilment of the requirement for the award of the degree of Master of Technology, is original and not copied from any source without proper citation. This work has not previously formed the basis for the award of any Degree, Diploma, Associateship, Fellowship, or any other similar title or recognition.

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## CERTIFICATE

I, Akanksha Sayogi, Roll No. 2K20/PSY/01 student of M. Tech. Power Systems (PSY), hereby declare that the dissertation/project titled **"STUDIES ON AUTOMATIC GENERATION CONTROL OF INTERCONNECTED MULTI-AREA POWER SYSTEM"** under the supervision of Prof. Narendra Kumar of Electrical Engineering Department, Delhi Technological University, Delhi in partial fulfilment of the requirement for the award of the degree of Master of Technology has not been submitted elsewhere for the award of any degree.

**Place:** Delhi

**Date:** 30/05/2022

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# ABSTRACT

The primary aim of AGC (automatic generation control) is to regulate active power production with respect to variable power requirements which helps in maintaining scheduled tie-line power flow and frequencies with the interconnected controlling areas at a desired nominal value. If there is a sudden change in frequency it may affect the magnetic currents in various motors(induction/transformer) and also leads to instability in various power systems. In a modern complex power system, automatic generation control (AGC) plays a major role and is becoming an essential part in order to deliver good quality of power supply to buyers irrespective of continuous power demand variations. When load fluctuation happens in a power system, AGC plays a crucial part in sustaining the optimal values of tie-line power interchange and frequency while considering step load perturbations. So, for delivering the standard power AGC system requires an intelligent and efficient controller as well as an optimization algorithm. The performance of various controllers depends upon the selection of used controller parameters as well as the specific optimization algorithm.

In the literature survey, design as well as performance investigation of AGC gets more enhanced by using advanced controlling strategies and intelligent metaheuristic techniques. Therefore, a lot of research is done worldwide to provide various novel controlling strategies that are used to handle AGC problem efficiently. The main aim of the proposed work is to design a new controller and to optimize its parameters using various optimization techniques. The supremacy of this proposed approach is compared with various other controllers.

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# NOMENCLATURE

| Symbols | Name of the parameter/constant |
|---|---|
| F | Frequency |
| s | Laplace operator |
| P | Population size |
| AGC | Automatic generation control |
| LFC | Load frequency control |
| $\Delta f$ | Frequency deviation |
| $\Delta Ptie$ | Tie-line power interchange |
| ACE | Area control error |
| MSMA | Multisource Multiarea |
| TLBO | Teaching leraning based optmization |
| FOPID | Fractional order PID |
| PID | Proportional-Integral-Derivative |
| T | Number of iterations |
| UB | Upper bound |
| LB | Lower bound |
| $K_P$ | Proportional Gain |
| $K_I$ | Integral Gain |
| $K_D$ | Derivative gain |

# CHAPTER 1

# INTRODUCTION

## 1.1. Introduction

In a power system electrical energy plays a crucial role. The instability between load demand and generated power makes frequency of the system to diverge from its standard value. This will lead to unintended power transfer between various interconnected systems. The power system consists of many controlling areas and these controlling areas are being connected to each other through a transmission line. In such type of controlling areas, the generators swing (i.e., accelerate or deaccelerate) together [1]. For maintaining the eminence of electrical power supply rather than storing it, is to maintain the frequency under different loaded conditions is defined as LFC (load frequency control). There will always be discrepancy between power demand and generation due to fluctuation in the load as shown in Fig. 1.1. In order to deliver reliable supply of electricity to buyers it is necessary to equalize between production of energy and demand energy. Due to environmental issues, it has become a challenging task to achieve the prerequisite levels of energy due to increase in requirement of electricity.

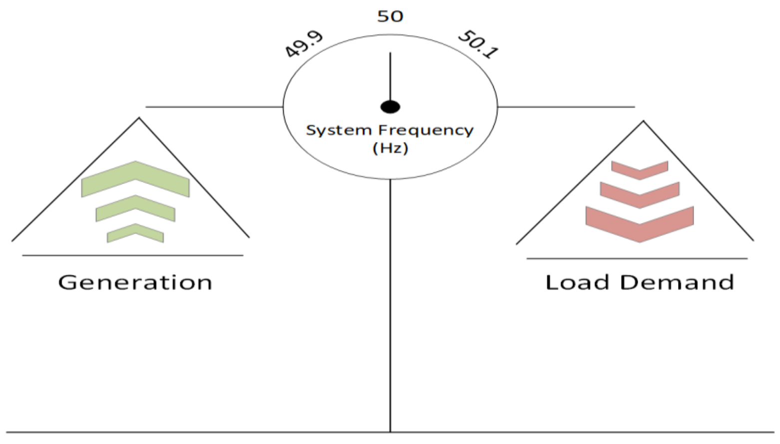


**Fig. 1.1.** Power Generation and demand balance

Modern power systems consist of several controlling areas that are interrelated to each other through a tie-line. As load demand changes during different hours of a day, the use of manual control to maintain precise balance would be ineffective. However, the balance between generation and load power demand is achieved efficiently via automatic generation control (AGC) schemes. Whenever there is a sudden disturbance or the load change in any of the area it will lead to variation of frequency and if produced active power tends to become more than the required power, the generating units frequency starts increasing and vice versa [2]. So, the system will always aim to maintain tie-line power and nominal frequency of a connected power system. To retain the systems tie-line power and frequency at their nominal values Automatic Generation Control plays a principal role in an interconnected power system [3]. However, the speed governor alone cannot obtain the constant frequency. So, a control system is required to elude the sudden changes in load and to maintain frequency at the nominal value. To improve the system performance optimal control technique is used effectively as when an integral controller is used it gives zero steady-state error in tie-line power and frequency deviations but the integral controller also unveils poor dynamic response [4].

## 1.2. Automatic Generation Control

If there is a sudden change in the load and the load in the system starts increasing then the speed of the turbine starts dropping before the governor can alter the input of the steam. The output power of electric generators within a defined area in respect to change in systems tie-line power and frequency change is regulated to maintain scheduled frequency of the system within the defined limits. For achieving the higher efficiency and to improve the quality as well stability of the electrical supply it is necessary to maintain the nominal tie-line power as well frequency deviation [2]. Whenever there is active power variation between load and generation this will lead to deviation in the frequency and deviation in voltage is due to imbalance reactive power in a power system. In a given power system by regulating the generation active power balance can be attained is termed as Automatic Generation Control (AGC) [4].

In a power system when there is a small load disruption, this will lead to a difference in real power and which will mainly affect the frequency deviation of the system but the level of the voltage remains unaffected as shown in Fig. 1.2. If there is a sudden change in reactive power this will affect the level of the bus voltage and the frequency of the system remains unaltered.

To retain the systems tie-line power and frequency at their nominal values Automatic Generation Control plays a principal role in an interconnected power system. There are few objectives of an AGC system [5]: (1) frequency of the system should be maintained at a nominal value i.e., frequency deviation (Δf) should be reduced to zero without any delay. (2) change in tie-line power (ΔPtie) must also be made zero as quickly as possible. (3) in each area the optimal scheduling of generators should be done.

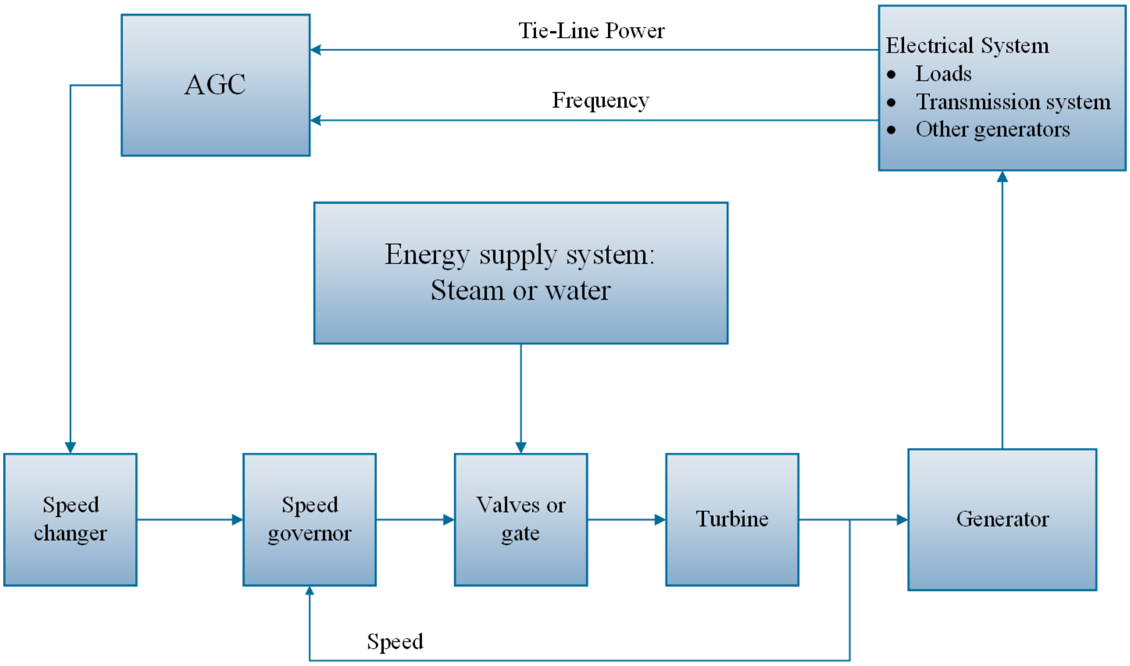


**Fig. 1.2.** Power generation and control system

The active power and reactive power flow in a transmission network are independent of each other and both demands are never balanced, they keep on changing depending upon the falling or rising movement. For determining the quality of power supply, voltage and frequency are the most important factors.

By adjusting the output of generators, LFC is required to maintain power interchange between areas. Irrespective of the conventional approach, recently new methods and controllers are being executed in the investigation and design of AGC. So, the main purpose of AGC is [6]: (1) to make sure that the bus voltages, frequencies and currents are sustained at a definite value. (2) to observe the power supply frequency and tie-line power in load sharing areas. In Table 1.1 the overall operation and controlling of the power system on time scale is shown.

**TABLE 1. 1** Time scale of control functions

| **Sr. No.** | **Control Functions** | **Time Scale** |
|---|---|---|
| 1 | Governor Action | Few Seconds |
| 2 | Unit commitment (UC) | Hours |
| 3 | Automatic generation Control (AGC) | Many Seconds |
| 4 | Economic dispatching (ED) | Minutes |

## 1.3. Various Controllers For Power System

The real power system is tended to be very complex and these systems are interconnected with various power generating sources those are hydraulic plants, thermal plants, gas turbines, photovoltaics, wind turbines and many more. For maintaining less deviation in frequency that is caused by variation in load or by different types of transients the controllers are used [6]. Irrespective of the conventional approach, recently new methods and controllers are being executed in the investigation and design of AGC. The AGC control logic for each area is shown in the given Fig. 1.3. The early studies concerning the design of automatic generation control (AGC) controllers of power systems were based on conventional control methods. Earlier the conventional approach used was Flywheel governor for controlling the frequency but this given method was not able to regulate the diverged frequency. Intelligent technique based controllers in power system consists of controller, plant and feedback system.

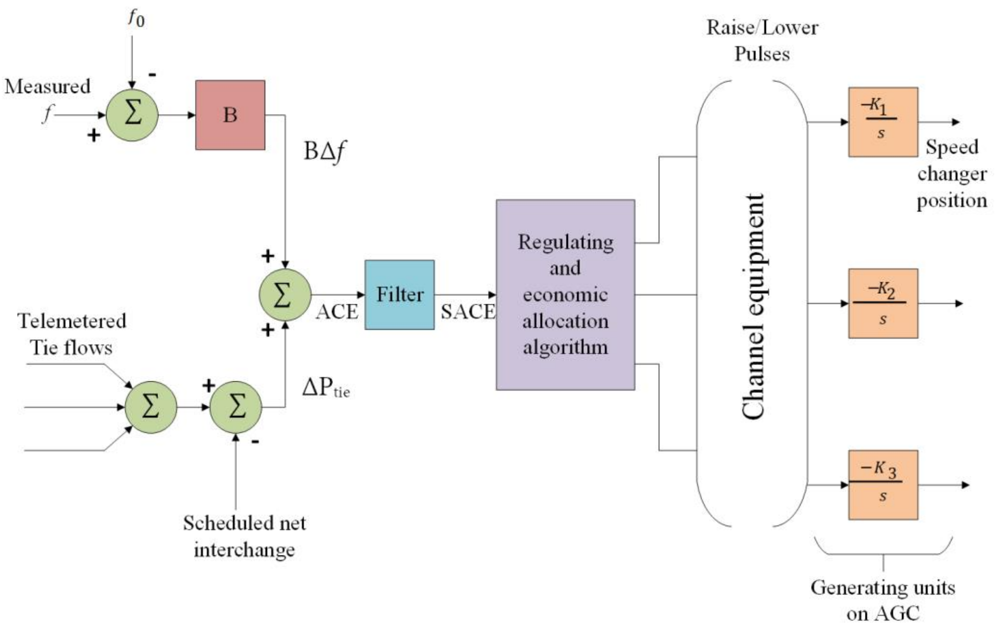


**Fig. 1.3.** Control logic of AGC

Therefore, supplementary controller was integrated with the help of area control error (ACE). This method engages two variables namely, variation in frequency and tie-line power flows. Their deviations are weighted together by a linear combination to a single variable called area control error (ACE) which is used as the input signal to a proportional integral (PI) controller. The PI gains are not based on any specific criterion, but are calculated on the basis of operator' experience. With the advent of modern optimal control theory, many concepts for AGC schemes have been presented which were having several virtues over conventional AGC designs. Secondary control has a better tuning of frequency but slower as compare to primary. The optimal controlling strategy for AGC was described by Fosha and Elgerd [7]. As there are many generators delivering power to a system by means of change in the demand of the generator. The frequency of the system is completely dependent upon the active power of the generating system [2]. So, a sudden change in frequency will be indicated throughout the given power system. For providing the primary speed control a speed governor is required at every generating unit [9]. It is cleared from the literature survey that over the past decades many researchers are proposing various novel control strategies to tackle the tie-line power interchange and frequency of AGC during step load perturbations.

Different conventional and intelligent optimization techniques [13-17], and various controllers like fuzzy [18], neural [19], optimal controllers [20], hybrid [21], controllers based on intelligent techniques [22]. The basic PI controller design for a two-area system AGC was given by Calovic [8].

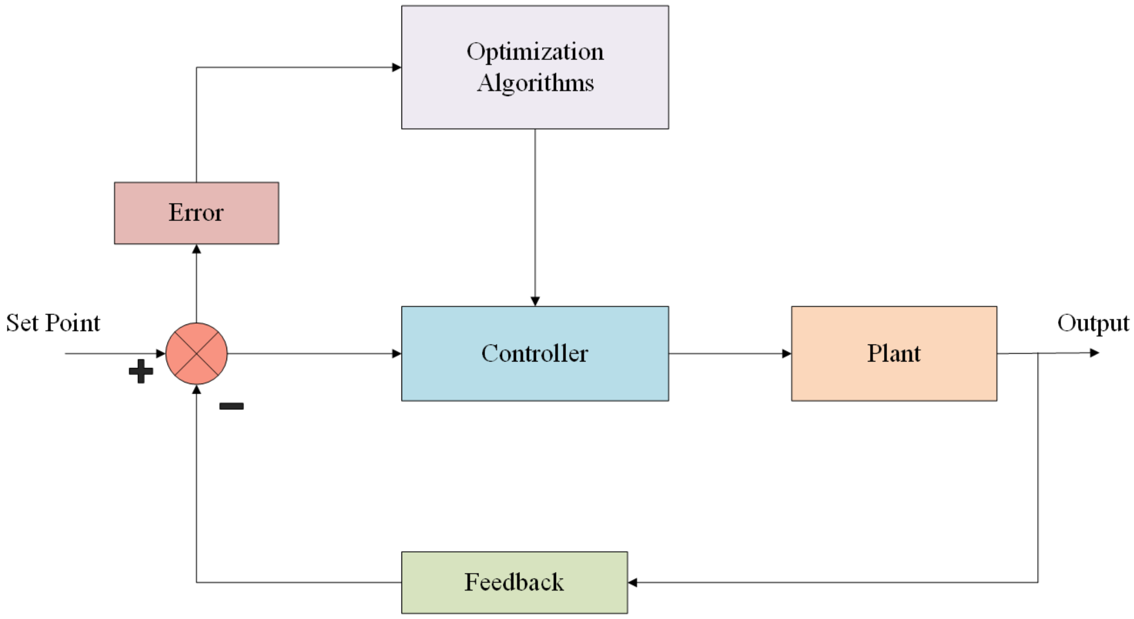


**Fig. 1.4.** Control scheme based on optimization algorithm

The error obtained from the difference of desired and attained data is fed into the used controller using a specific optimization technique as shown in Fig. 1.4. There are various standard controllers and their combinations that are used have proved to be very useful as in P(Proportional), PI(Proportional-Integral) and PID(Proportional-Integral-Derivative). Further to inflate the use of these controllers various newly illuminated AI as well as soft computing techniques are used in AGC to keep the tie-line power as well as frequency deviation within limits.

## 1.4. Objectives Of The Thesis

The main aim of the thesis is to provide a valuable understanding about the automatic generation control (AGC) by going through the literature where a stack of articles has been properly investigated for the given power system. In this various interconnected system with different sources are taken into consideration with variety of controllers and multiple optimization techniques to attain better response in terms of dynamic performance. For designing the AGC regulators various modern as well as classical controllers are integrated. To deal with certain big issues there are various investigation done by taking deregulated power system into consideration. In this the investigation of the interconnected power system is done by considering multiple sources such as thermal, hydraulic, gas, nuclear and many more. After carrying this investigation still there is an extent to execute investigation for a deregulated power system. Moreover, the stability issue arises in a power system so to keep the power system and frequency as well tie-line power within limits it is necessary to use an advance controller as well as optimizing technique. Literature survey depicts that the overall power system performance depends on the structure of the controller as well as the on the optimization technique that is used to optimize controller parameters.

In view of the above, this thesis has been worked upon to execute FOPID controller and TLBO is used as an optimization technique for optimizing the controller parameters. So, the objectives of the thesis are given as follows:

(a) Design a TLBO based FOPID controller for a MSMA hydrothermal power system.

(b) Optimize the gains of the FOPID controller by using TLBO for an interconnected MSMA system.

(c) The dynamic responses of the controllers i.e., PID, FOPID and TLBO optimized FOPID are being compared.

(d) The TLBO optimized FOPID, PID and FOPID controllers are executed for the load disturbance of 1%.

## 1.5. Outline Of The Thesis

The proposed work is systematised into seven chapters and the overview of the thesis is illustrated as follows:

**Chapter-1:** proposes a brief about the various problems and solutions associated with the interconnected power system. The best solution is to use an AGC with an optimized controller for controlling the active power. The introduction to various controllers and optimization techniques with their usage in the given power system.

**Chapter-2:** provides an idea about the literature survey for the available research on AGC.

**Chapter-3:** explains about the various transfer function models of turbines, speed governor system and that of associated with hydro-thermal power plant.

**Chapter-4:** presents a brief idea about the proposed optimization algorithm that is Teaching Learning Based Optimization algorithm (TLBO).

**Chapter-5:** explains the block diagram and working of fractional order proportional-integral-derivative (FOPID) controller and its comparison with other controllers. The optimization problem that is considered is also described.

**Chapter-6:** presents the Simulink model of a multisource multiarea (MSMA) interconnected power system. The results shown are obtained by using FOPID controller and TLBO algorithm.

**Chapter-7:** concludes the thesis after the evaluative and investigative study of the Automatic Generation Control with Teaching Learning Based Optimization algorithm. The future scope in the area of AGC of multisource multiarea power systems is also provided.

# CHAPTER 2

# LITERATURE SURVEY

## 2.1. Overview

This chapter focuses on the brief overview about the literature referring to AGC for a multisource multiarea power system with various controller and optimization techniques over a period of nine decades. Various new intelligent techniques are attaining the feasible execution over various other conventional techniques [23,24]. These theories are helping in operating the nonlinear, complex as well as uncertain power system. Apart from this modern AGC includes various new controlling strategies and optimization techniques that helps the system to simultaneously help in minimizing system tile-line power and frequency deviation. When we talk about the past works in AGC that were based on the tie-line bias control [10]. As far considering AGC multiple work has been done in this field considering it as multiarea multisource power system, multiarea multisource by considering nonlinearities, interconnected system considered with SMES (Superconducting Magnetic Energy Storage System) [25] and BESS (Battery Energy Storage Systems) [26]. The complexity in a power system tends to increase when non-linearities and uncertainties are taken into consideration. Since the working of power industry, it has come across a variety of advanced changes in terms of operational and structural.

## 2.2. Literature Review

Earlier the conventional approach used was Flywheel governor for controlling the frequency but this given method was not able to regulate the diverged frequency [3].

Therefore, supplementary controller was integrated with the help of area control error (ACE). Secondary control has a better tuning of frequency but slower as compare to primary. The modern controlling approach with various application was put forward by Fosha and Elgerd [7]. PI controller design for a two-area system AGC was given by Calovic [8]. An improved optimized controller design was projected by Kothari at al. [5]. Afterwards revised optimal AGC controllers were given in [2]. Literature survey shows that performance of power system depends on the controller structure and optimization techniques employed to optimize controller parameters.  It is cleared from the literature survey that over the past decades many researchers are proposing various novel control strategies to tackle the tie-line power interchange and frequency of AGC during step load perturbations.

From the literature study, it is observed that the performance of AGC systems depends largely on the kind of optimization method used and structure of the supplementary controller utilized. Different conventional and intelligent optimization techniques like fuzzy logic [18], artificial neural networks [27], big bang-big crunch optimization (BB-BCO) [13,14], genetic algorithm (GA) [28],hybrid differential evolution-pattern search (DEPS) [29], simulated annealing (SA) [30], artificial bee colony (ABC) algorithm [31], particle swarm optimization (PSO) algorithm [32], bacterial foraging optimization algorithm (BFOA) [33], gravitational search algorithm (GSA) [34], pattern search (PS) [35], firefly algorithm (FA) [36], bat algorithm (BA) [37], teaching-learning based optimization (TLBO) algorithm [17,56], grey wolf optimization (GWO) [38], differential evolution (DE) algorithm [39], flower pollination algorithm (FPA) [40], cuckoo search (CS) algorithm [41], ITAE optimization etc, these controllers are executed in such a way to obtain less fluctuations in the system in terms of tie-line power and frequency deviation.

Few researchers have also mentioned several complicated problems related to optimization, stabilization and regulation for a multisource multiarea power system. Few problems associated to tie-line power and frequency deviation are resolved by taking MSMA power system with diverse source and intelligent technique controllers into consideration.

Hence, proposing and implementing new controller approaches using high performance heuristic optimization algorithms to real world problems are always welcomed. Some researches show a specific explanation regarding the control of voltage in an interconnected system with the help of FACTS controller [42], TCPS [43], SSSC [44], IPFC, TCSC [45], UPFC [46] are incorporated with AGC to get improved dynamic functioning. Further evolution in renewable sources where the BESS [26] is applied with various renewable units such as hydro, thermal and solar. There are various new techniques used in AGC are as follows:

**(1) SOS Algorithm Based Fuzzy Controller:**

This algorithm is one of the newest advancements in the field of metaheuristic algorithms. This algorithm is inspired by the philosophy of nature and is equivalent to the cooperative behaviour within organisms present in nature. To adapt the changes present in the environment these organisms adopt the symbiotic relations as their approach to live in this environment. The cycle of this algorithm is having three phases such as mutualism, commensalism and parasitism phase. After executing these three phases SOS tries to move the ecosystem (population) of the solution towards the search space for the given optimal solution [47].

**(2) Big Bang-Big Crunch:**

It is also one of the newest evolutionary algorithms used for solving various problems associated with automatic generation control. Due to its accuracy and high speed in searching the solutions of various optimization problems, this technique has attained popularity among various researchers. This theory has come into picture from the big bang theory in the universe. In this after starting the iterations it tends to calculate the fitness function of each candidate, then identifies the centre mass followed by picking the best centre mass [48].

### (3) AGC with Energy storage system:

Energy sources system requires battery management system to screen and keep up with protected, ideal activity of every battery pack. Batteries are dynamic in nature, continually working external the balance state during cycling and gets debase. This degradation can be sped up by expanded temperature or overcharging. BMS controls to fulfil power need and diminish the reason of degradation. BMS have the information on condition of charge and condition of wellbeing in battery during demand response. Energy sources are classified in terms of mechanical, chemical and 29 electromechanical energy sources [49]. Various energy storage systems are used in AGC of power system. The appropriateness and helpfulness of recurrence stabilizers in the types of superconducting attractive energy storing (SMES), battery energy storage system (BESS) [26]

### (4) FACTS devices in AGC:

Few problems associated to tie-line power and frequency deviation are resolved by taking MSMA power system with diverse sources into consideration. Due to fast dynamic responses associated with FACTS devices such as TCPS, SSSC, IPFC, TCSC and UPFC has been connected with the tie-line for an interconnected system to get minimal deviations infrequency and tie-line power. These FACTS devices help in damping out the deviations occurring due to transients and fluctuations in the load. In all the above devices TCSC is one of the used FACTS devices in AGC because of its advantages such as cost-effective and the performance is very high [50].

**(5) Grasshopper optimization algorithm:**

It is the recent optimization based on swarm intelligence algorithm and is inspired by the swarming and foraging actions of the grasshopper present in the nature. This algorithm is built in such a way to reduce the problems associated with the power system. This algorithm includes hybrid variants and multi-objective. In this algorithm the modelling is done with respect to the swarming behaviour of the grasshopper by normalizing the distance between grasshopper that is present in the given range. The positions are updated according to the current position if it goes out of the bounds to get the better optimal solution [51].

**(6) Mine blast algorithm:**

It is a novel optimization algorithm that is completely based upon the population and is used for solving various engineering problems. This algorithm is unique in terms of measuring the number of evaluation functions with accuracy in functional values. The idea behind this algorithm is based upon the explosions in the mine and in which thrown pieces collide with each other resulting in explosion between them. The main aim in this algorithm is to find the most explosive optimal point by calculating shrapnel pieces, reducing the distance and then updating the piece with the best one [52].

**(7) Hybrid stochastic fractal search and pattern search technique:**

This technique is the hybrid algorithm of both stochastic fractal search and pattern search. In this technique first the algorithm parameters are specified after this initialization of population is done. The fitness of each individual is being evaluated and in addition to this the best point is being recorded. After the diffusion process the mesh size, mesh expansion factor, mesh contraction factor, maximum number of function evaluations and iterations are being specified [53].

### (8) Quasi-oppositional atom search optimization algorithm:

This algorithm is based upon the combination of two algorithms that is Quasi oppositional and atom search. The atom search is a physics inspired optimization technique that is based upon the dynamics of atoms. This is extracted from the motion of atoms that follows conventional mechanics of molecules. The substances have atoms in it which are bounded with covalent bonds and converted into molecules and distance between these atoms are attractive or repulsive. To improve the accuracy of the solution and convergence time for obtaining the global solution the quasi opposition is being used. To have the better candidate solution for the current population it creates an opposite population for each atom [54].

### (9) JAYA Algorithm:

Jaya algorithm is enthused by TLBO algorithm and in TLBO we required two phases but in Jaya we work upon only single phase that makes Jaya algorithm a very advanced and simpler technique. In this paper the Jaya algorithm is being modified for optimizing the parameters of the PID controller. Jaya Algorithm's working principle is based on the fact that the obtained numerical solution that has been attained must move towards the best solution and avoid the solutions that are inferior for the given optimization problem. The Jaya algorithm has many benefits and very easy implementation for solving various optimization problems as the tuning of the particular parameters are not required. As, the Jaya algorithm works on simpler notion that is it approaches towards the best solution and avoids the worst solution [55].

**(10) BAT Algorithm:**

It is one of the used metaheuristic techniques that is used for global optimization. This algorithm is based upon the actions of each bat when they are in search of food using echolocation. The echolocation helps each bat for upgrading their position in cognate manner. In this echo is produces when large number of ultrasonic waves are produced and if there is a delay in returning waves this helps the bats in discovering the position of their prey. By using echolocation each bat is differentiated between prey and barrier. For prey hunting each bat is positioned at a particular position so that it can fly at a particular frequency and velocity. At last, the ranking is done according to the position of each bat for finding the best one [56].

**(11) Moth Flame Optimization Algorithm:**

This algorithm is inspired from nature and navigating methods of moths is known as transverse orientation. The fascinating fact about moths is their navigation process at night. They are able to fly with the help of moon light. In this they fly by continuing a fixed angle for coving a long distance in night. In this technique it is implicit that the moths are the candidate solutions and problem variable is the location of moth in the given search space. This MFOA a population-based algorithm just like TLBO [57].

**(12) Seagull Optimization Algorithm:**

This is a novel algorithm and is bio-inspired for resolving problems that are expensive computationally. The algorithm is inspired by the attacking and migration behaviour of a seagull. This behaviour of seagull is modelled mathematically and executed for emphasizing exploitation in a given search space.

SOA is a metaheuristic technique that impressionists the hunting as well as migrating behaviour of seagull. This cannot solve discrete problems but able to solve continuous real-life problems [58].

### (13) Modified Butterfly Optimization Algorithm:

This algorithm is also a nature-based algorithm that has gained a lot of interest in past few years by many researchers. It is inspired from the food foraging behaviour of butterflies. In this algorithm butterflies work as a search agent for performing various optimization techniques. Butterflies have a sense receptor and these are used for sensing fragrance of flowers. These are dispersed all over the body parts of butterfly. This fragrance is related with fitness that means when the butterfly from one site to another in the search space, the fitness varies accordingly. Social network is formed when the generated fragrance tends to move towards other butterflies and the butterfly move towards the other best butterfly. This is known as global search phase. Also, when the butterfly is not able to sense any fragrance in the provided search space and it will start taking random steps and this particular phase will be known as local phase for the defined algorithm [59].

### (14) Artificial electric field algorithm:

This is one of the recently designed nature-inspired optimization technique in the field of algorithms. Working principle of this algorithm is same as that of coulomb's law of electrostatic force. The solution associated with the candidate is being treated as charge atom and the location of the charged particle in the given search space is possibly the solution for the defined objective function. The particles that are charged are being related to the few laws after initialization. Those laws are Coulomb's law of electrostatic force and newton's law of motion [60].

### (15) Flower Pollination Algorithm:

This algorithm is a nature-inspired metaheuristic technique. The main principle behind this algorithm is to keep alive the flowers that are fittest in all the species by means of reproduction. In this algorithm the pollen is taken as a candidate solution. When the optimization technique is carried forward, in the search space the diffusion is through cross-pollination. In the cross-pollination the motion is defined by Levy Flight and is an arbitrary movement that is drawn from Levy Distribution. This distribution has infinite mean and variance that tends to larger movements from its recent position. Thus, FPA has most effective search space [61].

### (16) RAO Algorithm:

The given algorithm is a very simple metaphor-less optimization technique. This method is used for solving various problems that are unconstrained or constrained. Also, Rao algorithm is based upon the worst and the best solution that is attained while optimization process and random interactions between solutions of the candidate. This algorithm is proposed in three forms RAao-1, Rao-2 and Rao-3 for performing this it only needs common controlling parameters as in number of iterations as well as population size. This technique does not require any algorithm-specific controlling parameters and is a very simple technique that offers real solutions for those problems which are complex [62].

**Table 2.1:** Review of previous literature based on AGC application in the power systems

| References | System Type | Controller Type | Optimization Technique | Control Area | Generating Source | Source |
|---|---|---|---|---|---|---|
| Arya et al | Regulated | Optimal PI feedback controller | - | Three area | Multi-source | Hydro, thermal and Ga |
| Sahu et al | Integrated | FPID controller | SOS | Two-area | Two source | Wind and Thermal |
| Kumar et al | Deregulated | FOPID controller | BBBC | Multi-area | Two source | - |
| Arya | Restructured | FOFPID controller | BFO | Multi-area | Multi-source | Hydro and thermal |
| Morsali et al | Interconnected | FOPID based damping controller | TCSC | Two-Area | Multi-source | Thermal, Gas and Hydrogen |
| Jagatheesan et a | Interconnected | PID controller | ACO | Multi-area | Single source | Thermal |
| Fathy et al | Deregulated | FPID controller | MBA | Multi-area | Single source | Thermal |
| Ajithapriyadarsini et al | Deregulated | Adaptive FLC | DE | Multi-area | Multi-source | Thermal, gas, and photovoltaic |
| Zhao et al | Interconnected | PO-PID + DD controller | PSO | Multi-area | Two source | Thermal, gas, and photovoltaic |

## 2.3. Conclusion

In this chapter a substantial and complete review about the literatures published in the field of automatic generation control for a multisource multiarea power system is presented. The survey gives a brief detailing about the overall published papers of AGC that are using a variety of new controllers and various optimization techniques. The main purpose of the presented research work is to achieve a superior dynamic execution for an interconnected power system in terms of frequency and tie-line power deviation. There are various AGC controllers that are planned and advanced which are easy, simple and robust in comparison to the conventional controllers. These new technologies are much easier to implement in a given interconnected power system. In terms of problem occurring with nonlinearities there are diverse controllers taken into consideration. The literature is completely based on latest evolution in the field of AGC by considering the approach related to multiple soft computing techniques like SOS, BBBC, GOA, MBA, QOASO, JAYA, BAT, MFOA, SOA, AEFA, FPA etc.

# CHAPTER 3

## DEVELOPMENT OF MATHEMATIC MODELS FOR AGC POWER SYSTEM

### 3.1. Introduction

In a modern complex power system, automatic generation control (AGC) plays a major role and is becoming an essential part in order to deliver good quality of power supply to buyers irrespective of continuous power demand variations. There are various fossil fuels in terms of coal, oil, natural gas and nuclear energy that are mostly used sources of energy in the generating power plants. The modern power system consists of multiple generating sources that deliver power such as thermal plants, gas turbines, hydraulic turbines and various energy sources that are non-conventional etc. When there is a load variation or any transient change occurring in a power system it will lead to sudden frequency deviation [4]. The power system is further classified into different control areas for the better operation and functioning. The generative plants are interconnected with grid which helps in stabilizing the frequency deviation by correcting the inertia of the system.

In this work mathematical models of hydro, thermal and gas power plants as the only area is taken into consideration. For the specific areas the dynamic model is defined as a state variable. The research work is carried out by considering multisource multiarea hydrothermal power system with thermal system consists of a Governor and Reheat Steam Turbine. The hydro system consists of Mechanical Hydraulic Governor and Hydro Turbine with specific controller used in each area with or without incorporating non-linearities [63].

From these mathematical models the transfer functions are derived in terms of Laplace transfer function. These transfer functions are derived for all the power plants and this is considered as the modelling of the provided interconnected power system. A lot of research work is done in past few decades regarding the modelling of AGC system by considering multiple interconnected systems such as the combination of hydro and thermal [24]. In this paper work thermal and hydro combination is taken as far with a proper optimization technique of a well know controller other than conventional controllers.

## 3.2. Modelling Of Power System

In a power system there are numerous of generators interconnected by a network of various transmission lines which tends to supply power to buyers at a rated frequency and voltage. The power system consists of synchronous generators that gets energy from the sources like thermal, gas and hydro and are driven by prime mover [3]. The prime movers convert these sources of energy into mechanical energy this in turn is converted to electrical energy by synchronous generators. In this study, various sources like thermal, hydro are explored in different combinations in two area or three area power systems. The prime mover transfers this energy to mechanical energy and then converts to electrical with the help of synchronous generator. In this, multiple sources such as hydro and thermal are examined in multiple sequence in multisource multiarea power systems. Modelling of various components are as follows:

### (1) Generator Model:

Swing equation of synchronous machine by applying small load change is given by,

$$\frac{2H}{w_s}\frac{d^2\Delta\delta}{dt^2} = \Delta P_m - \Delta P_e \tag{3.1}$$

or by considering minor deviation in speed

$$\frac{d\Delta\frac{w}{w_s}}{dt} = \frac{1}{2H}(\Delta P_m - \Delta P_e) \quad (3.2)$$

by expressing speed in per unit

$$\frac{d\Delta w}{dt} = \frac{1}{2H}(\Delta P_m - \Delta P_e) \quad (3.3)$$

Consider the Laplace transform of the equation 3.3, we get

$$\Delta\Omega(s) = \frac{1}{2Hs}(\Delta P_m(s) - \Delta P_e(s)) \quad (3.4)$$

The given relationship derived in equation 3.4 is shown in Fig. 3.1.

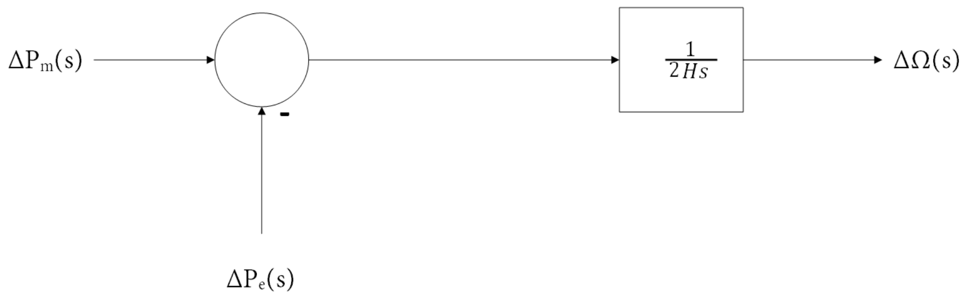


**Fig. 3.1.** Generator block diagram

## (2) Load Model:

The power system is consisting of multiple loads that are connected to the grid. Few loads are independent of frequency such as heating load, resistive load and lightning loads. The motor loads are completely dependent upon the frequency and are sensitive with change in frequency [3]. For all the specific driven devices the frequency is dependent upon the speed-load characteristics. In case of motor load requirement depends on frequency of system. The frequency dependency of load depends on the speed load characteristics of electrical device.

The attribute for the frequency dependent load is given by the equation

$$\Delta P_e = \Delta P_L + D\Delta_w \tag{3.5}$$

Here, $\Delta P_L$ is the load change and it is independent on the frequency.
$D\Delta_w$ is the load change and is frequency-sensitive.
Percentage change in load w.r.t percentage change in frequency is given by D. Generator and load block diagrams are shown in Fig. 3.2 and 3.3.

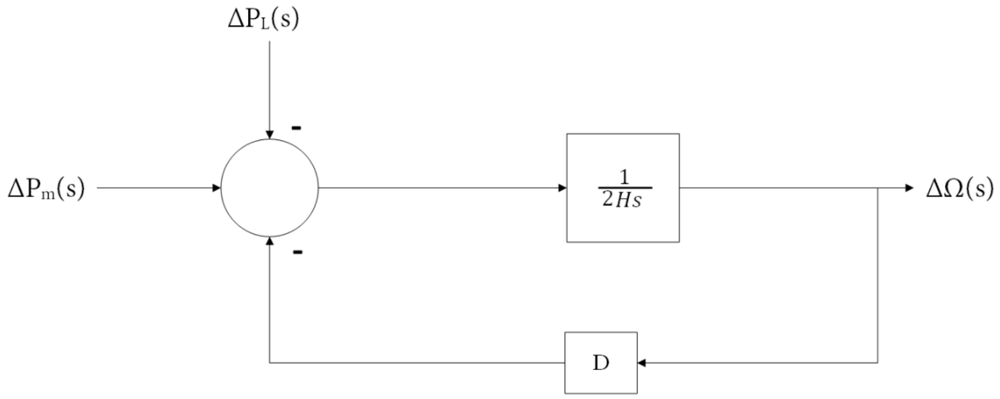


**Fig. 3.2.** Generator and load block diagram

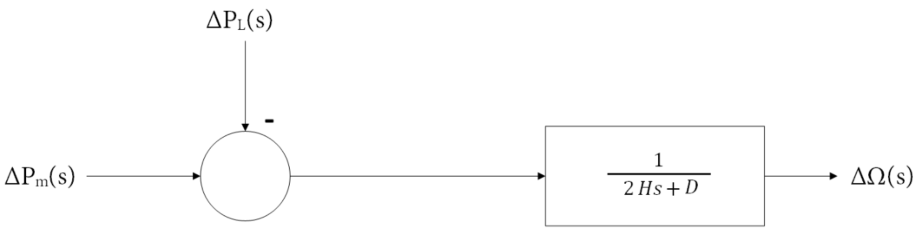


**Fig. 3.3.** Generator and load block diagram

## (3) Prime Mover Model:

Prime mover is the source of mechanical power such as steam and hydraulic turbines at waterfalls whose energy comes from gas, nuclear fuels and coal. Any particular change in the steam flow is depicted by the prime mover shaft of the given turbine with specific time constant. The prime mover model is shown in the Fig. 3.4. Here, τT is the time constant corresponding to the steam flow [3]. $\Delta P_V$ is the valve position change in per unit. Mechanical output power change in per unit is represented by $\Delta P_m$.

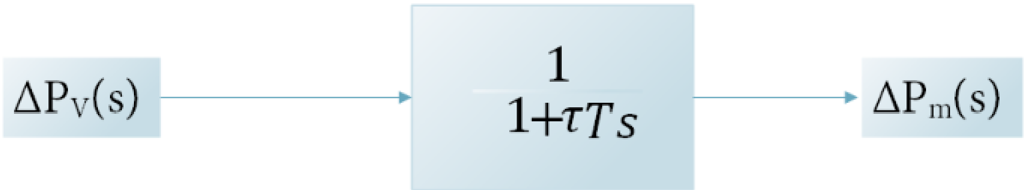


**Fig. 3.4.** Prime mover model

### 3.2.1. Modelling Of Thermal Power Plant

The major assets of electrical power in thermal are coal-based plants that is required to produce high pressure and temperature of steam in the steamer. The steam energy obtained from the boiler is converted into mechanical energy for axial flow in steam turbines. This produced mechanical energy is then converted into electrical energy. All the turbines presented are comprised of rotating as well as stationary blades. The fixed stationary blades tend to accelerate and obtain expanded Kinetic energy at a low pressure whenever the steam enters in the turbines. Steam turbines are classified into reheat or non-reheat turbines [2]. For, the given thermal power system transfer function consists of governing system and steam turbine, deepening on whether it is non-reheat or reheat as shown in Fig. 3.5 and Fig. 3.6.

Transfer function of steam turbine(non-reheat):

$$G_T(s) = \frac{1}{1 + sT_{CH}} \tag{3.6}$$

While simulating multi-source multi-area model an extra reheat block will be used. Reheat steam turbine transfer function:

$$G_r(s) = \frac{1 + sF_{HP}T_{RH}}{1 + sT_{RH}} \tag{3.7}$$

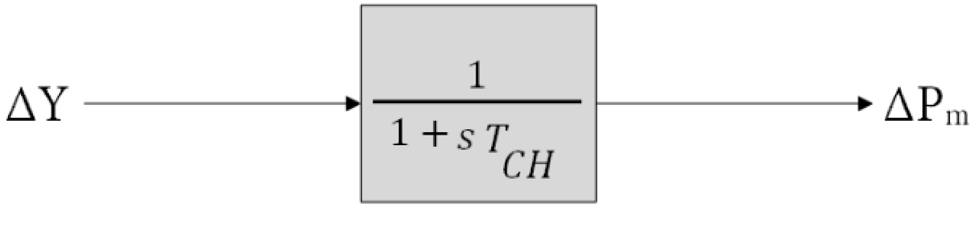


**Fig. 3.5.** Transfer function of non-reheat turbine

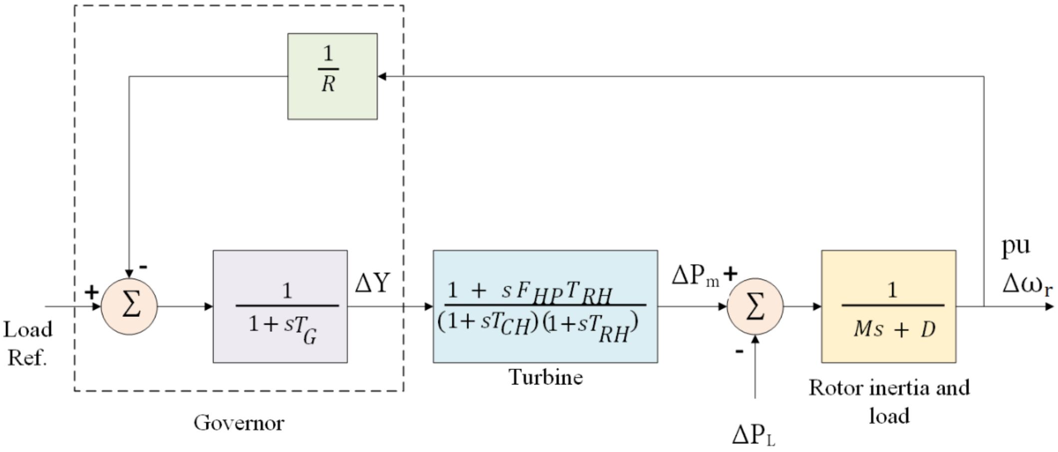


**Fig. 3.6.** Block diagram of thermal unit with reheat steam turbine

### 3.2.2. Modelling Of Hydro Power Plant

In terms of thermal unit, the hydraulic unit is much more different in terms of large inertia of water that is used as a source of energy by taking higher time lag w.r.t changes in prime mover torque and gate position. Due to variation in water inertia the speed governing attributes of the hydraulic power plant are broadly varies from the turbo governor as shown in the block diagram Fig. 3.7. The force that is applied by the water when it falls down from upper to lower reservoir that is used by Hydraulic turbines [2]. The head is the vertical distance between level of turbine and upper reservoir. The head size is used to classify hydropower plant into low, medium and high head power plants.

MSMA system has two generation units: hydraulic and reheat/non-reheat thermal unit. So, transfer function block used for hydraulic unit is as follows:

For Hydro turbine:

$$G_{HT}(s) = \frac{1 - sT_W}{1 + 0.5sT_W} \tag{3.8}$$

Transfer function of Mechanical hydraulic governor:

$$G_{HG}(s) = \left[\frac{1}{1+sT_G}\right]\left[\frac{1+sT_r}{1+s(R_T/R_P)T_R}\right] \tag{3.9}$$

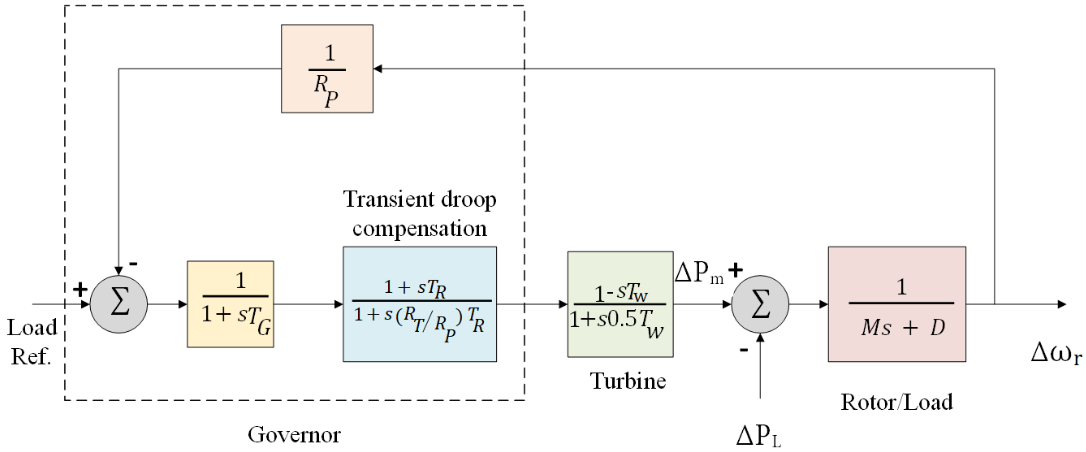


**Fig. 3.7.** Block diagram of hydraulic unit

### 3.2.3. Modelling Of Interconnected Tie-Line

For better control and working of power system, it is divided into multiple areas which are interconnected through a tie-line [3]. In transient state, the multiple power exchange between interconnected system is via tie-lines as shown in Fig. 3.8, Fig. 3.9 and Fig. 3.10.

In a multi power interconnected system, tie-line power is deliberated by taking voltage of area into consideration is given by the expression (3.10).

$$P_{tie12} = \left(\frac{E_1 E_2}{X_T}\right) \text{Sin}\ (\delta_1 - \delta_2) \tag{3.10}$$

Where, $X_T = X_1 + X_{tie} + X_2$

$$\Delta P_{tie12} = T_{12} \Delta\delta_{12}, \qquad \delta_{12} = (\delta_1 - \delta_2) \tag{3.11}$$

Synchronizing torque coefficient is given as follows,

$$T_{12} = \left(\frac{E_1 E_2}{X_T}\right) \text{Cos}\ (\delta_{10} - \delta_{20}) \tag{3.12}$$

At initial operating point, $\delta_1 = \delta_{10}$ and $\delta_2 = \delta_{20}$.

Block diagram for the Transfer function of the tie-line is shown in the figure and deviation of tie-line power is expressed as follows:

$$P_{tie12} = 2\pi T_{12} \int (\Delta F_1 - \Delta F_2) dt \tag{3.13}$$

ACE (Area control error) is taken to restore scheduled values of system frequency and tie-line power in secondary control. The equation for ACE is as follows:

$$ACE = \Delta P_{tie12} + b\ \Delta F\ in\ MW \quad (3.14)$$

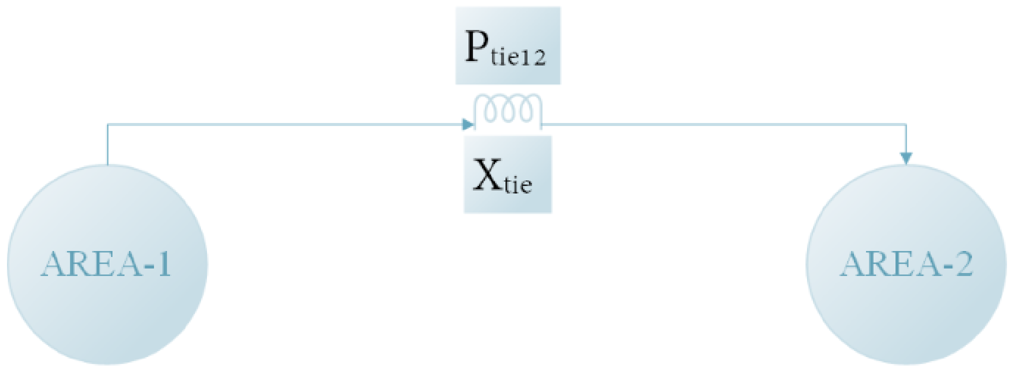


**Fig. 3.8.** Two-area interconnected system

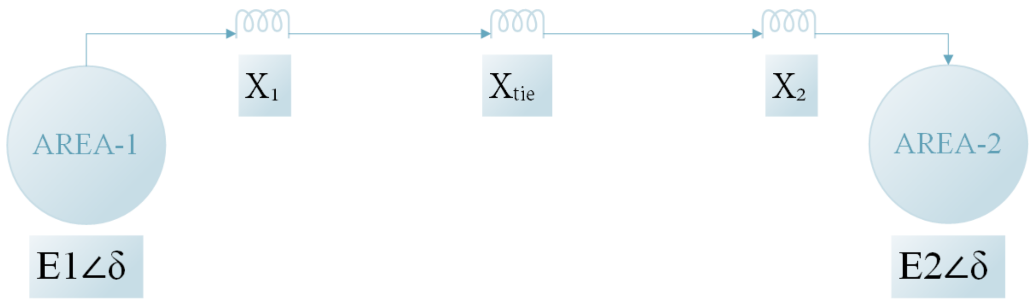


**Fig. 3.9.** Electrical equivalent of two area interconnected system

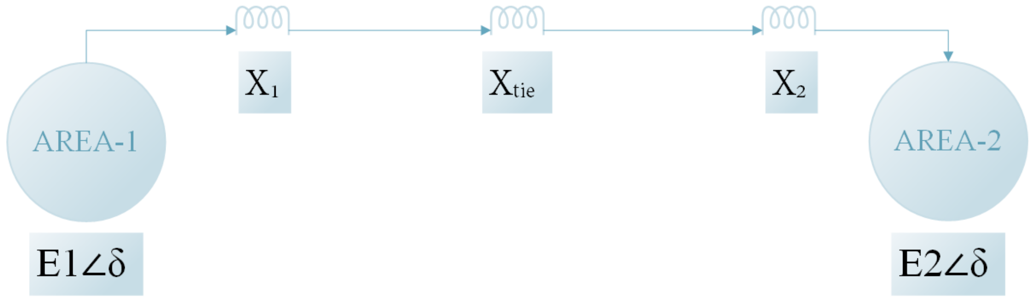


**Fig. 3.9.** Electrical equivalent of two area interconnected system

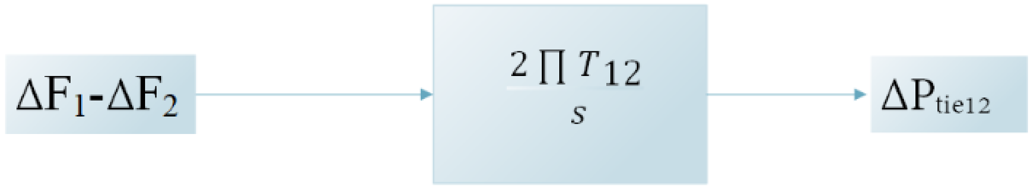


**Fig. 3.10.** Transfer function model of AC tie-line

## 3.3. System Under Investigation

The AGC system under investigation have been carried out on multi-source multi-area hydrothermal system provided with PID, FOPID and TLBO optimized FOPID controller. The hydrothermal system consists of a reheat thermal and hydro power plant with mechanical governor based on hydro unit has been taken into consideration. The areas are interconnected as shown in Fig. 3.11. Table 3.1 shows the parameters used in TLBO.

**TABLE 3. 1** Parameter Values For TLBO

| **Sr. No.** | **TLBO PARAMETERS** | **Values** |
|---|---|---|
| **1.** | No. of Iterations (T) | 100 |
| **2.** | Population Size (P) | 50 |
| **3.** | Upper Bound (UB) | +2 |
| **4.** | Lower Bound (LB) | -2 |

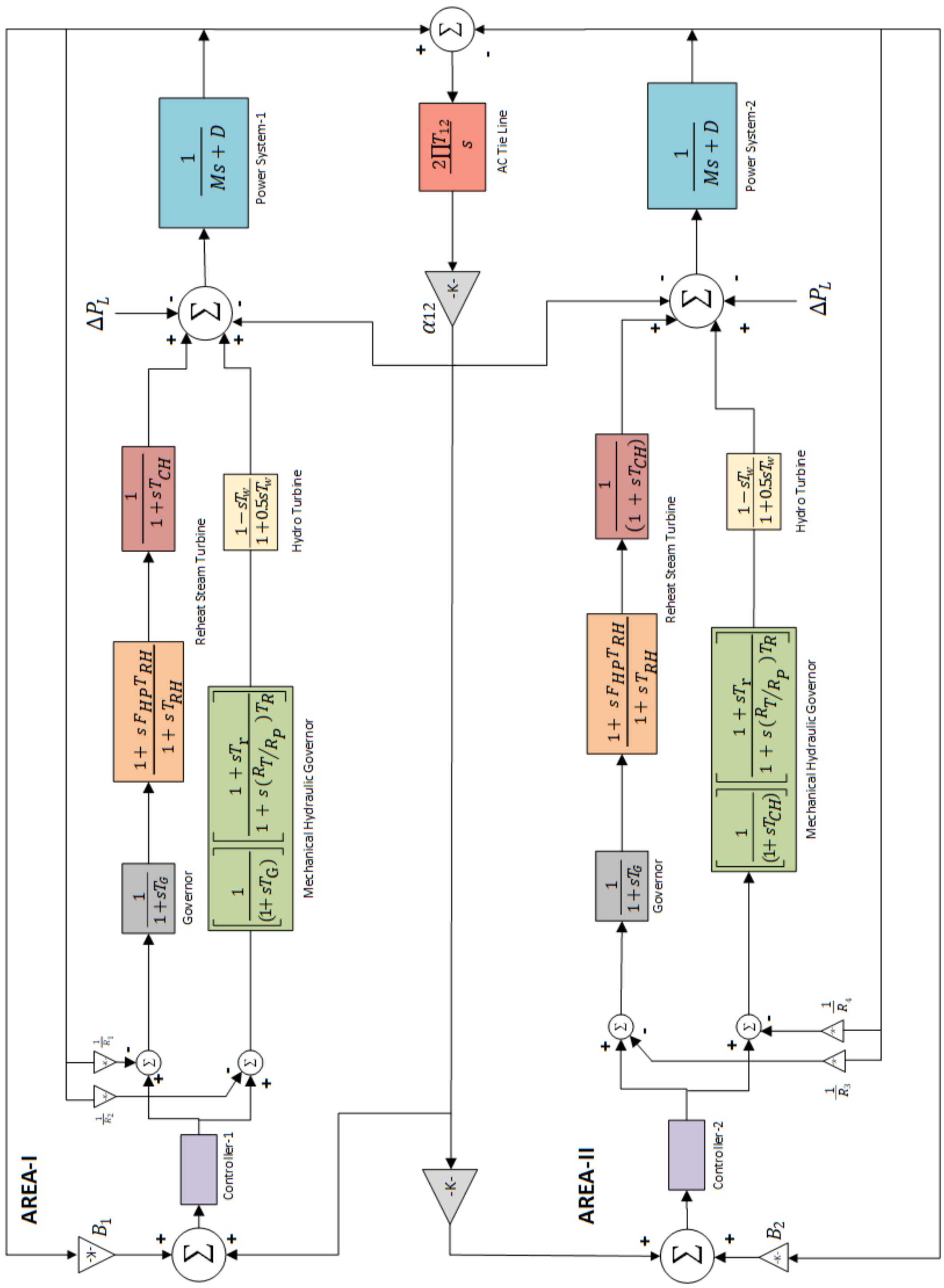


**Fig. 3.11.** Transfer function model of multi-area multi-source hydrothermal power

## 3.4. Conclusion

The transfer function modelling of hydro and thermal power system that also includes interconnected AC tie-line, governing system and block diagram as well as transfer function of other components have been described in this chapter. The design of various blocks is developed such as that of reheat, non-reheat and multi-source hydrothermal power system with controllers.

# CHAPTER 4

## OPTIMIZATION ALGORITHM

### 4.1. Introduction

In recent years, various intelligent optimization techniques that are developed and used to elude the complications which were not able to resolve by the various conventional approaches. These techniques have proved to be very efficient and reliable approach for solving the problems in an efficient way for the given AGC system. Due to robustness, reliability and simpler features of the AGC system these new optimization techniques are helping to solve the problems that are raised in a particular power system. There are various optimization techniques used in recent time and they are as follows:

Fuzzy logic based AGC schemes. (2) ANFIS based AGC schemes (3) ANN based AGC schemes (4) PSO based AGC schemes (5) GA based AGC schemes (6) ABC based AGC schemes (7) ACO based AGC schemes (8) BFOA based AGC schemes (9) DE based AGC schemes (10) FA based AGC schemes (11) HBMO based AGC schemes (12) ICA based AGC schemes (13) FPA based AGC schemes (13) I based AGC schemes and many more.

The main purpose of these described optimization techniques is to solve the problems by applying some constraints to the given or described problem. The design consists of an optimization procedure in which the design is always made by considering basic objectives such as strength, deflection, weight, wear, corrosion, etc. depending on the requirements [27-44]. For doing the optimization on a particular system it is required to know the optimization parameters of the basic system. In this work, the used controllers' parameters are being optimized by using the recent optimization algorithm.

Taxonomy of Optimization is shown in Fig. 4.1. TLBO is one of the most popular population-based metaheuristic optimization technique that is used to optimize the controller parameters and gain the optimum values for the provided controller. Therefore, the attempts must be extended to establish various new other optimization technique which is required further to solve the problems occurring in the given system.

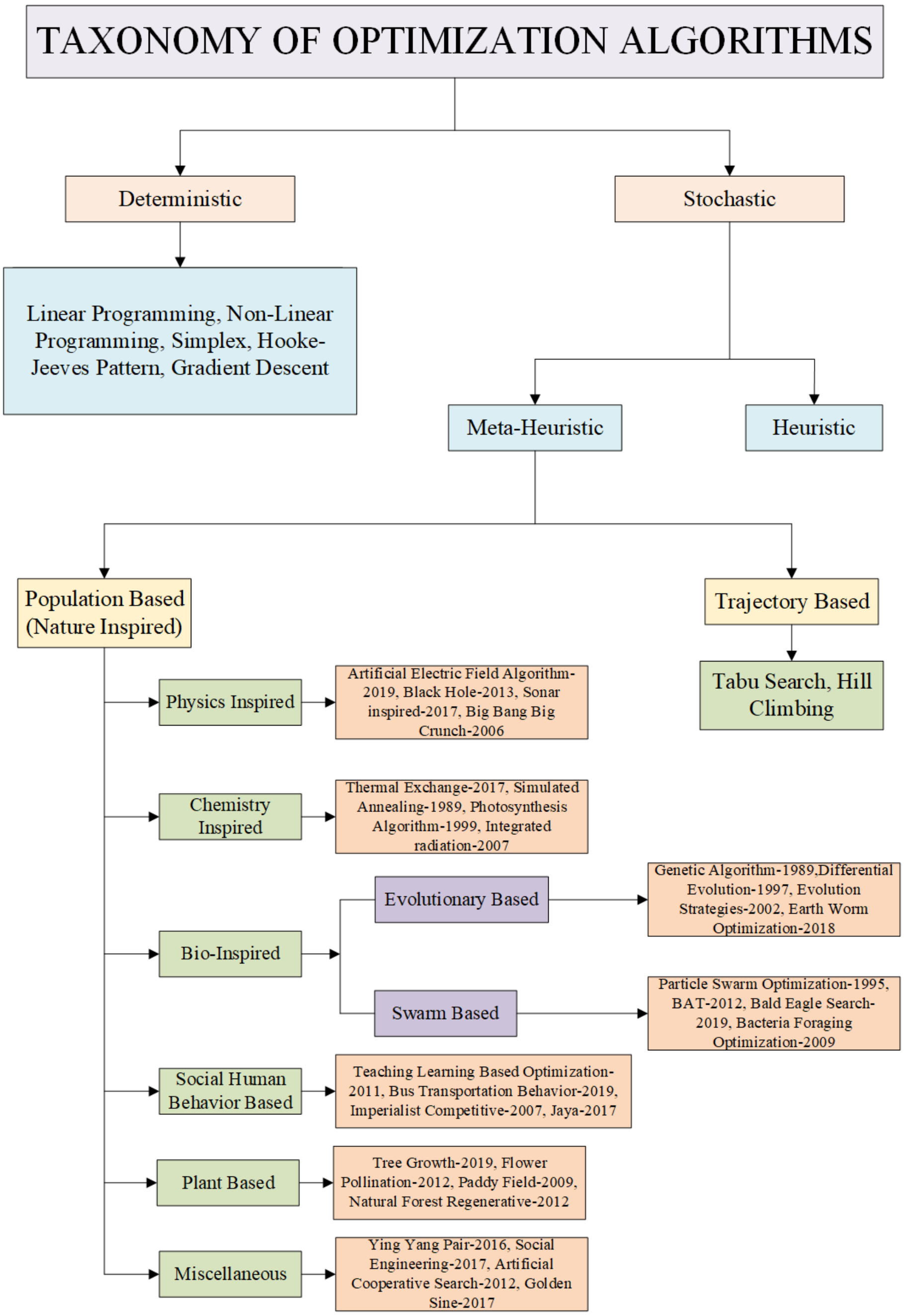


**Fig. 4.1.** Taxonomy of optimization algorithm

## 4.2. TLBO

Teaching Learning Based Optimization (TLBO) algorithm is very popular and powerful metaheuristic optimization technique [17] and was established by Rao et al. Since then, it has been a desired technique in various engineering fields and it uses the population of students, also teacher and learners phase are the two major components of the algorithm to attain the best solution in the given search space. TLBO is also a nature-influenced optimization algorithm and is suggested to get the global solution who is having less high consistency and computational effort for a particular non-linear function. This optimization technique considers the population of the given solution for proceeding the global solution. In TLBO the population is examined as the class of learners [72]. The teacher will be considered as the best solution gained up to now. Pseudocode and Flowchart of TLBO is shown in Fig. 4.2 and Fig. 4.3.

The functional operation of TLBO has two parts:

i. Teacher phase: in this learner (students) get to learn from teacher.
ii. Learners phase: In this learners interact with each other.

Steps involved in performing TLBO:

1. First, we need to define parameters: (i) Population size (no. of solution up to which technique is going to work upon). (ii) Maximum number of iterations (it tells when to stop the procedure).
2. Generate a random population within the domain of decision variables.
3. Evaluation of fitness function of this population and once it's done initialize $t=1$ to keep account of how many times we are going to repeat the cycle.
4. Check $t \leq T$: (i) if yes, then $P'(t)$= selection $P(t)$ i.e., we already have a population and we select few members from the population and perform some operation to them. (ii) if no, then we will stop.
5. The best solution will be considered to be optimal solution.

1. Input Fitness function: lb, ub, Np, T

2. Initialize a random population(P)

3. Evaluate fitness of P

4. For t= 1 to T

For i= 1 to Np

Choose *Xteacher*

Determine *Xmean*

*Xnew = Xi+r(Xteacher-(TF)XMean)*

Bound *Xnew* and evaluate its fitness *fnew*

Accept *Xnew* if it is better than *Xold*

Choose any solution randomly, *Xp.*

Determine *Xnew* as

If *fi<fp*

$Xnew = Xold + r(X_i - X_j)$

*else*

$Xnew = Xold - r(X_j - X_i)$

Bound *Xnew* and evaluate its fitness *fnew*.

Accept *Xnew* if its better than *Xi*

END

END

**Fig. 4.2.** Pseudocode of TLBO

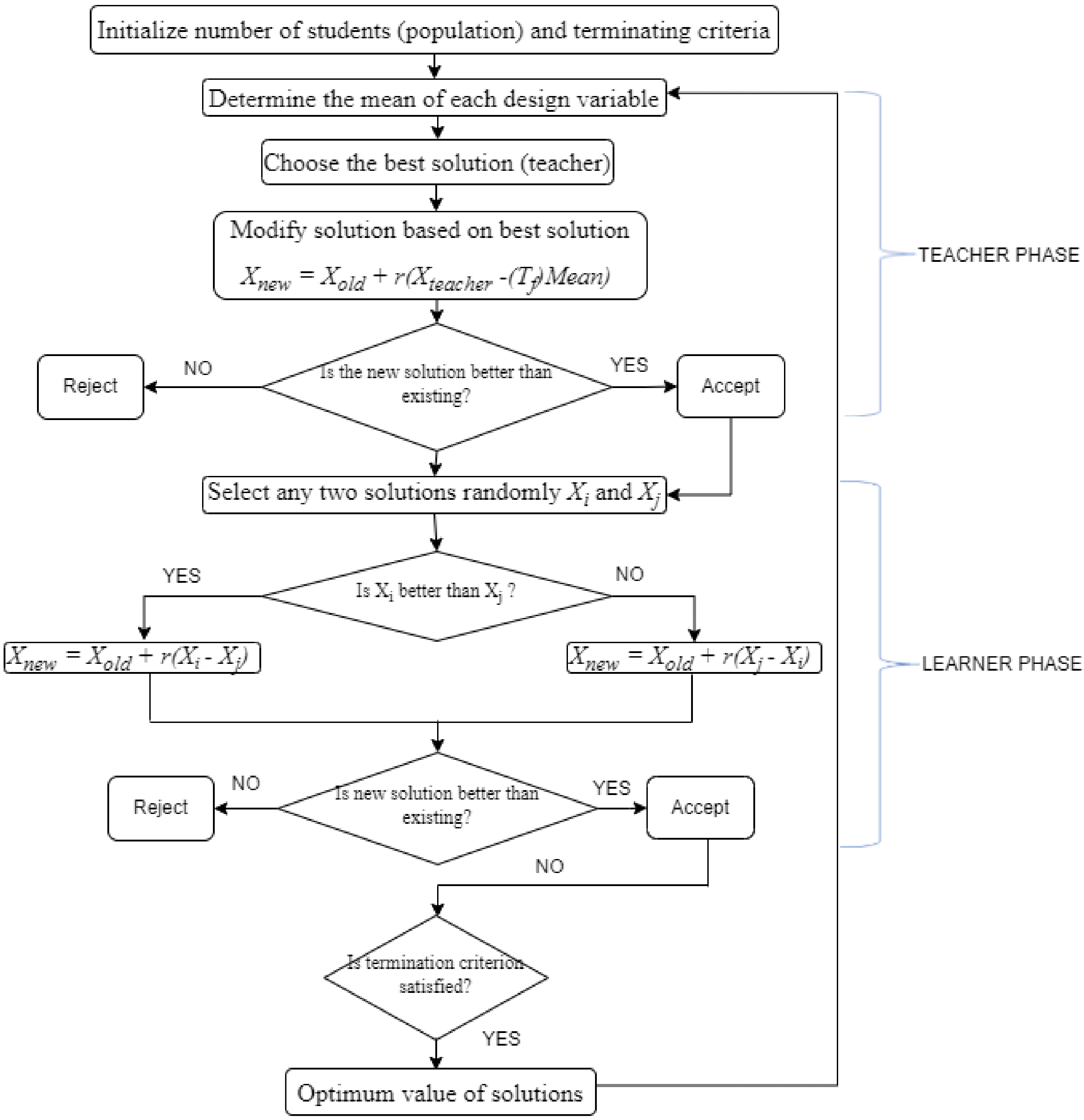


**Fig. 4.3.** Flow chart of TLBO

# CHAPTER 5

## FRACTIONAL ORDER PID CONTROLLER FOR AGC OF POWER SYSTEMS

### 5.1. Introduction

In the given chapter the idea and usage of various proposed controllers are taken into consideration. There are various controllers that can be placed in an interconnected power system to improve it and also the efficiency is enhanced by optimizing the controller parameters by using various optimization techniques. Various interconnected power systems are connected to multiple generating sources and those are thermal, hydraulic, gas plants and wind turbines etc. These controllers are used in the power system to provide less deviation in frequency and tie-line power interchange due to variations in loads or types of transients [10]. A number of research papers reported that presents a wide range of offerings in the field of controllers. There are multiple controllers that are used in various fields those are incorporated in AGC system for reducing the variations that are occurred due to the load change. These controllers are mainly fuzzy [18], optimal [18], sliding mode controller [12], hybrid controllers [29], neural [64], TID [65] and FOPID [20].

The PID controller is also used as a conventional approach in various research fields [23,66]. Intelligent technique controller is consisting of plant, feedback system and a controller. In this the error is attained from the difference of achieved and required data that is obtained from the Intelligent technique controller in the given power system. It is required to enhance the parameters of various controllers by tuning the parameters of the controller to get the frequency and tie-line power within limits. However, it's a challenging task for many researchers to optimize the controller parameters by using the enhanced AI techniques. These techniques provide a better solution for the controllers by optimizing their parameters within definite limits. These limits are set according to the various optimization techniques for enhancing the parameters of required controller.

In this research work Fractional Order Proportional-Integral-Derivative (FOPID) controller is used as a controller for achieving the required result within set parameters and limits. This generalization of the PID offers a much wider selection of tuning parameters and thereby more flexibility in the controller design, which leads to more accurate control of plants or process. The well description and information about this controller is defined in the next section of the current chapter.

## 5.2. FOPID Controller

The flexibility of FOPID in comparison to PID controller is more so FOPID controller is receiving more research and interest. It was first suggested by Alomoush [67] in the year 2010 in AGC and application of this controller can be seen widely in the literature. This controller is very flexible because it gives liberty to optimize five parameters and those are $K_P$ (proportional), $K_I$ (integral) and $K_D$ (derivative) gain as well as the order of fractional integral and that of derivative i.e., $\lambda$ and $\mu$. In present study FOPID controller is used in each area and structure of FOPID is given in the Fig. 5.1. The use of FOPID controller in AGC can be seen available in various research papers [20,68]. Differential equations are deal with the FOC (Fractional Order Controller) theory via FC (Fractional Calculus) and this the generalized form in ordinary calculus.

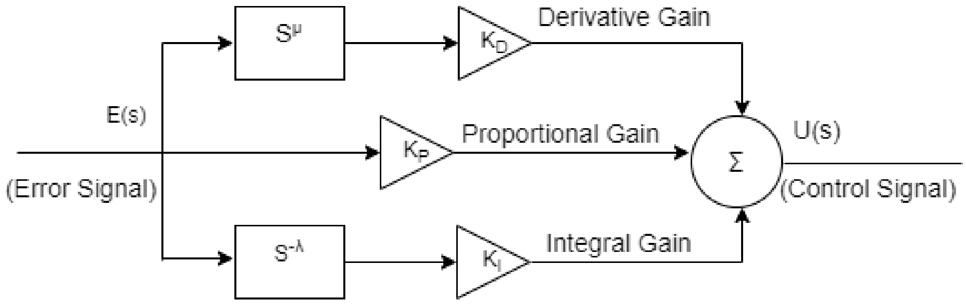


**Fig. 5.1.** Block diagram of FOPID controller

The equation of the proposed controller is given by:

$$G_C(s) = K_P + \frac{K_I}{s^{\lambda}} + K_D s^{\mu} \tag{5.1}$$

Design of $K_P, K_I, K_D$ and λ, μ is done to make the FOPID controller and the orders here are the real numbers rather than integers. If λ, μ is equal to 1 then the proposed controller will form a conventional PID controller. In addition to this if λ=1, μ=0 then it's a PI controller, λ=0, μ=1 it will be PD controller. If λ=0, μ=0 then it's only P. The controllers integral order is characterised in λ-μ plane as shown in the Fig. 5.2. The generalization of PID controller in λ-μ plane is done by FOPID and increases from a point to entire plane.

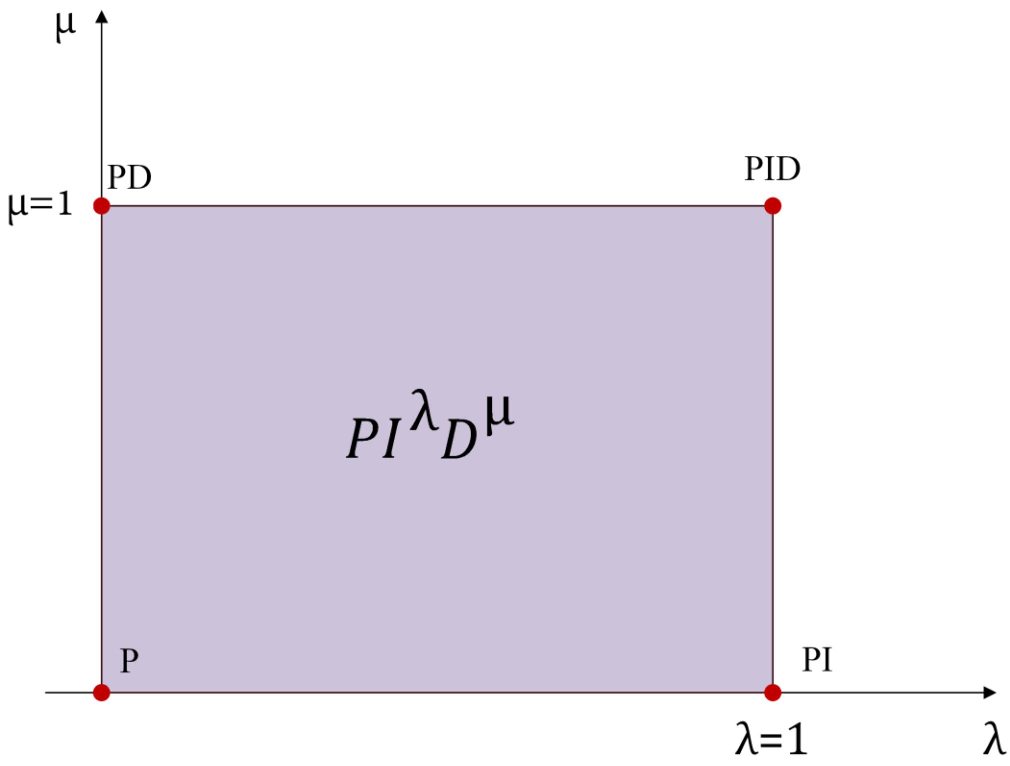


**Fig. 5.2.** FOPID structure-based controller

This way of generalizing PID controller provides a broad choice for optimizing the parameters and also much more resilience for the design of controller. This will lead to exact control of plant. For approximating a fractional order transfer function, a normal transfer function would work on zeros and poles that are infinite.

## 5.3. Optimization Problem

In past few decades researchers across the world are working on the various optimization techniques that are showing distinct behaviour for the multiple systems. The working of the optimization techniques is to discover the best attainable solution for linear or non-linear system, constraint or unconstrained system, single or multi problems and discrete or continuous variable. Among multiple feasible solutions that are variable and used to find the best solution is defined as optimization. Here, feasible solutions are those that elates all the constraints of the given optimization problem. The performance of non-linear or linear dynamic systems can be enhanced by using appropriate optimization technique. The optimization techniques have two methods one is deterministic, this method is the mathematical programming which gives the precise solution for the given problem [69]. The other method in optimization technique is non-deterministic that is also known as stochastic algorithm. The stochastic method is divided into meta-heuristic and heuristic algorithm [70,71]. These algorithms help in solving various complex problems and provides global search.

The Meta-Heuristic algorithms are further divided into population and trajectory based [15]. Various optimization technique such as: SOS algorithm [47], grasshopper optimization algorithm [51], big bang-big crunch optimization (BB-BCO) [14,48], genetic algorithm (GA) [28], Mine Blast Algorithm (MBA) [52], particle swarm optimization (PSO) algorithm [32], bacterial foraging optimization algorithm (BFOA) [33], bat algorithm (BA) [37,56], teaching-learning based optimization (TLBO) algorithm [17], Hybrid stochastic fractal search and pattern search technique [53], Quasi-oppositional atom search optimization algorithm [54], JAYA [55], Seagull Optimization Algorithm (SOA) [58], Artificial electric field algorithm [60] etc. The population-based algorithms depend upon the population and the TLBO (Teaching-learning based optimization) algorithm used in this paper is a population based meta-heuristic technique that depends upon two phases one is teacher and another is learner [17]. In this the population is examined as the learners class and the population is considered by the proceeding of the global solution. The teacher will be considered as the best solution gained up to now. After applying all the constraints, the defined optimization technique runs for the given population size and iterations that are set to get the desired value of all the parameters. As in AGC the main focus is to optimize the parameters of the given controller to achieve less deviation in frequency as well as tie-line power interchange.

## 5.4. Objective Function

In this to lesser the objective function of the given power system by considering the relevant performance index is main purpose of objective function. The performance of the optimization method depends on the selection of the performance index. The controller's performance is analysed on the basis of various performance indices these are stated as follows:

- Integral of Square Error (ISE),
- Integral of Time Multiplied Squared Error (ITSE),
- Integral of Absolute Error (IAE) and
- Integral of Time Multiplied Absolute Error (ITAE).

In this study ITAE (Integral Time Absolute Error) is used as the performance index for designing the proposed controller. While constructing a FOPID controller selection of objective function is also very important. The objective function is being used for tuning the criterion of the controller depending upon the performance criteria of the controller.

ITAE is used as an objective function. Mathematical equation is given by:

$$\text{ITAE} = \int_0^T \{ |\Delta F| + |\Delta ptie_{12}| \} dt \qquad (5.2)$$

The optimized problem can depict to minimize "ITAE" in subject to the below limitations:

- $K_{P,I,D}$ (minimum) $\leq K_{P,I,D} \leq K_{P,I,D}$ (maximum),
- $\lambda_{(minimum)} \leq \lambda \leq \lambda_{(maximum)}$,
- $\mu_{(minimum)} \leq \mu \leq \mu_{(maximum)}$.

Here, $\lambda_{(minimum)}$, $\mu_{(minimum)}$, $K_{P,I,D}$(minimum) are the min and $\lambda_{(maximum)}$, $\mu_{(maximum)}$, $K_{P,I,D}$(maximum) are the max constraints of FOPID controller [33]

# CHAPTER 6

# RESULTS AND DISCUSSION

## 6.1. Simulink Model

In this the SIMULINK model of MSMA hydrothermal system is designed with 1% of step load perturbation as shown in Fig. 6.1 and the record of symbols that are applied in equations are given in Appendix. The complete specification of the investigated system is given by Kundur (1994) and Kothari and Nagrath (2012). Table 6.1 shows the optimized values of FOPID controller using TLBO algorithm, minimized value of ITAE and better dynamic performance for both frequency as well as tie-line power deviation in terms of settling time, peak undershoots, peak overshoot is given in Table 6.2.

**Table 6.1** Optimize TLBO-FOPID Parameter

| **Parameter Name** | **TLBO-FOPID** |
|---|---|
| $K_{P1}$ | 0.1989 |
| $K_{I1}$ | -0.4557 |
| $K_{D1}$ | 0.0320 |
| $\lambda_1$ | 0.8105 |
| $\mu_1$ | 0.6492 |
| $K_{P2}$ | 0.1622 |
| $K_{I2}$ | -0.3778 |

| | |
|---|---|
| $K_{D2}$ | 0.0265 |
| $\lambda_2$ | 0.7265 |
| $\mu_2$ | 0.7718 |

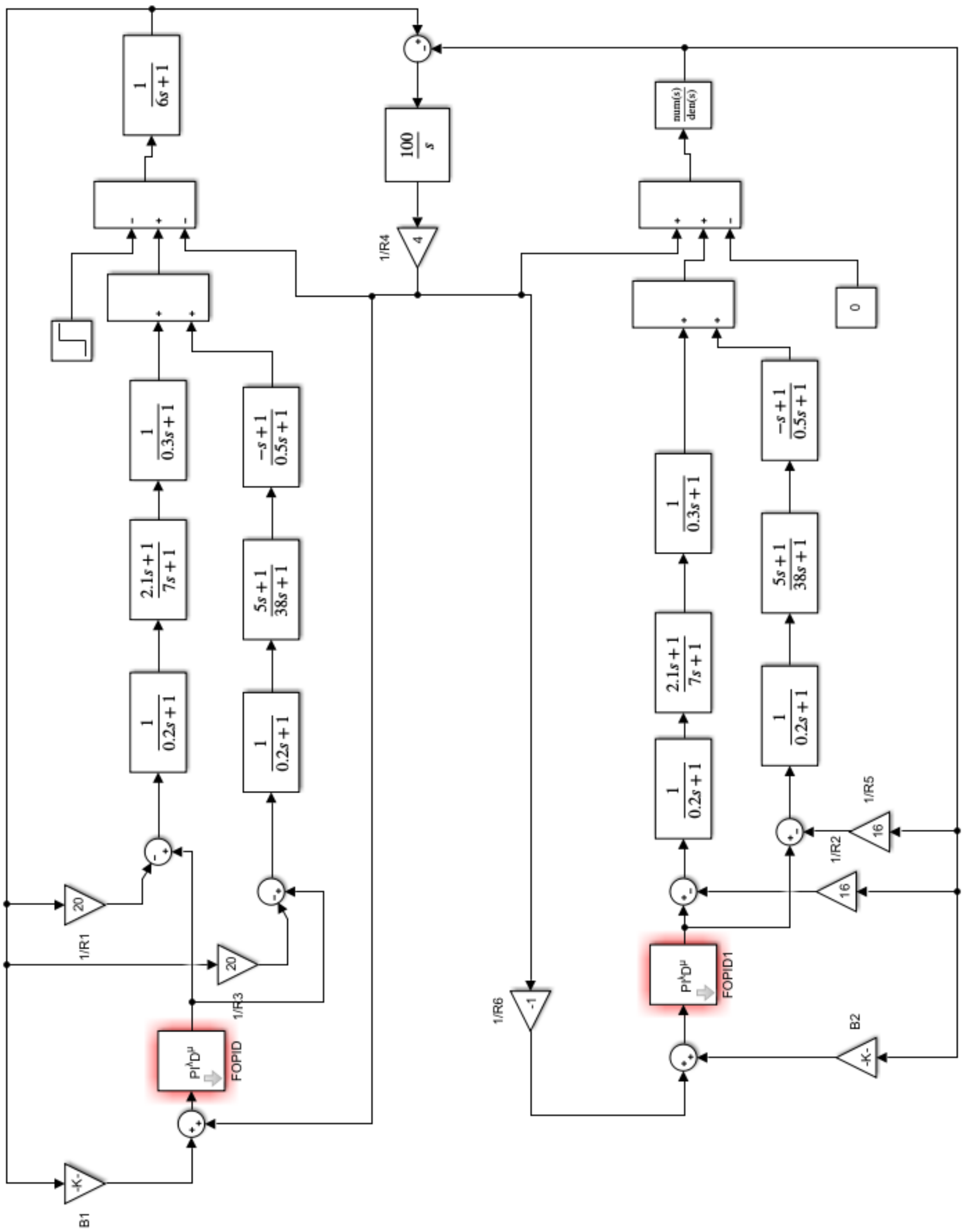


**Fig. 6.1.** SIMULINK model of multisource multiarea power system

**Table 6.2** Comparative performance parameters (A) settling time (B) peak overshoot (C) peak undershoot (D) Performance Indices

| ALGORITHM | SETTLING TIME | |
|---|---|---|
| | ΔF | ΔP |
| **TLBO: FOPID** | 23.29 | 24.66 |
| **FOPID** | 29.68 | 28.77 |
| **PID** | 38.28 | 29.66 |

**(A)**

| ALGORITHM | PEAK OVERSHOOT | |
|---|---|---|
| | ΔF | ΔP |
| **TLBO: FOPID** | 0.002849 | 0.009547 |
| **FOPID** | 0.00665 | 0.01079 |
| **PID** | 0.008845 | 0.01106 |

**(B)**

| **ALGORITHM** | **PEAK UNDERSHOOT** | |
|---|---|---|
| | **ΔF** | **ΔP** |
| **TLBO: FOPID** | 0.01042 | 0.09116 |
| **FOPID** | 0.01057 | 0.09462 |
| **PID** | 0.01089 | 0.09657 |

**(C)**

| **ALGORITHM** | **PERFORMANCE INDICES** |
|---|---|
| | **ITAE**<br>**(INTEGRAL TIME ABSOLUTE ERROR)** |
| **TLBO: FOPID** | $6.6638\ e^{-04}$ |
| **FOPID** | $4.839\ e^{-03}$ |
| **PID** | 0.7842 |

**(D)**

## 6.2. Simulation Results

In this paper, SLP of 1% is executed to the given MSMA system. The implementation of metaheuristic TLBO algorithm is required to tune the gains and to find the optimum values of FOPID controller that will help in minimizing the objective function stated by equation (5.2). Population size is taken to be 50 for 100 iterations. The TLBO will optimize for 100 iterations to obtain the tuned parameters of FOPID controller. Table I shows the optimized parameters of the given controller (FOPID) using TLBO algorithm and also the minimized value of ITAE. Tie-line power (ΔPtie) and frequency(ΔF) deviation with TLBO optimized FOPID, PID and FOPID in MSMA hydrothermal power system are shown in Figure [6.2 - 6.7]. It is seen from the obtained Fig. [6.2 - 6.7] that TLBO tuned FOPID controller offers dynamic execution for both tie-line interchange and deviation in frequency

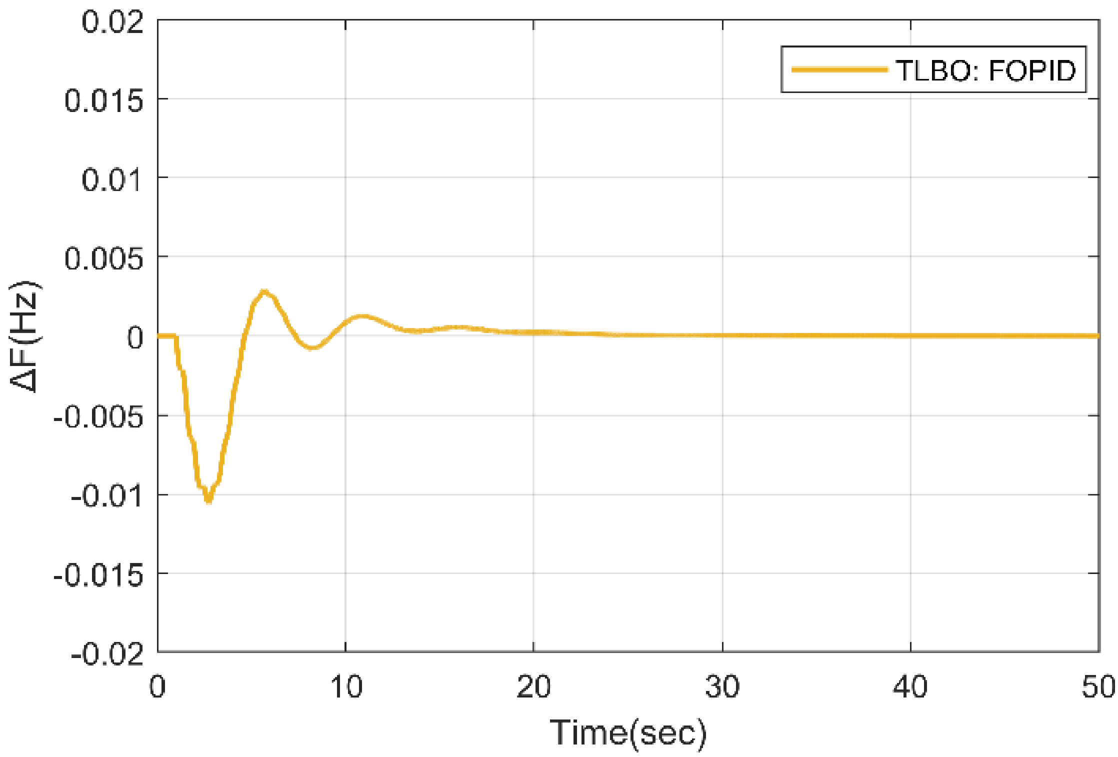


**Fig. 6.2.** Frequency deviation of areas for TLBO optimized FOPID Controller

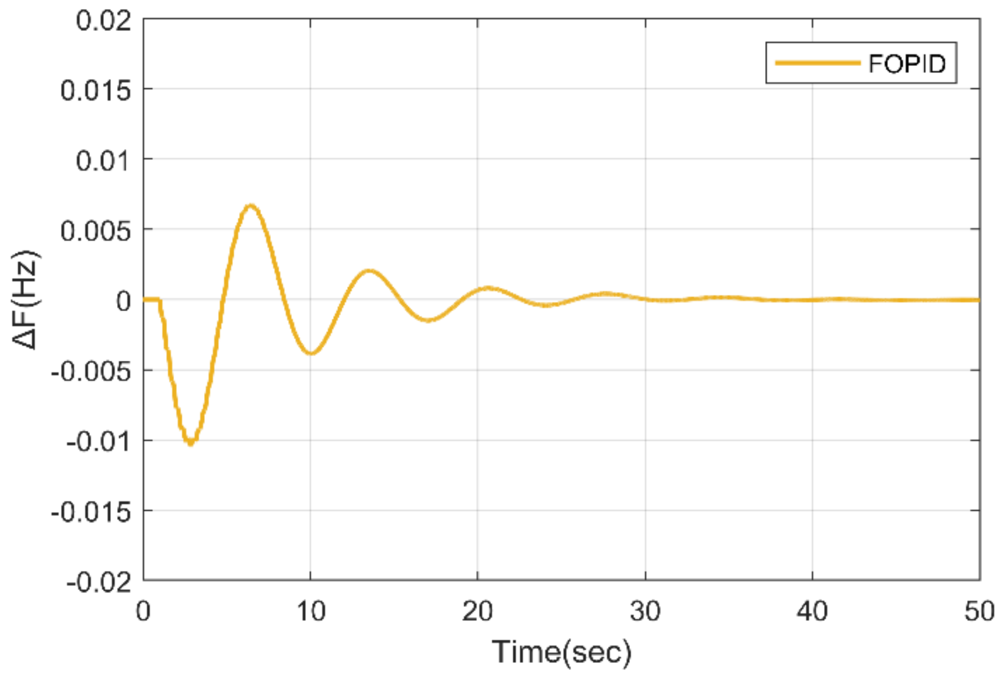


**Fig. 6.3.** Frequency deviation of areas with FOPID Controller

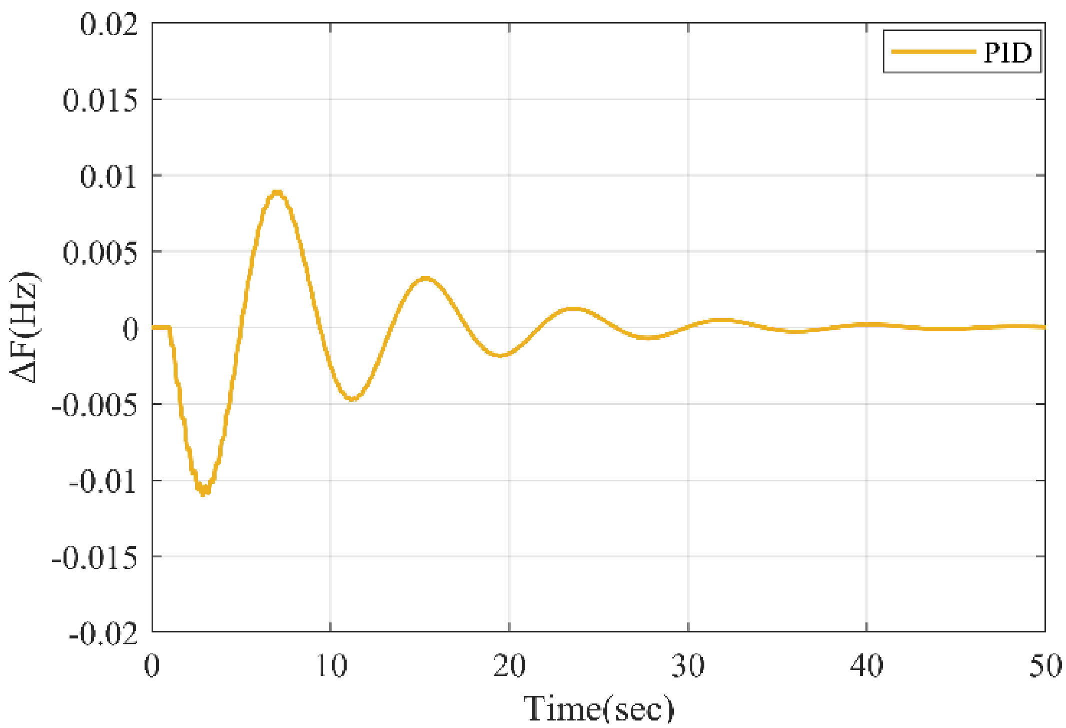


**Fig. 6.4.** Frequency deviation of areas with PID Controller

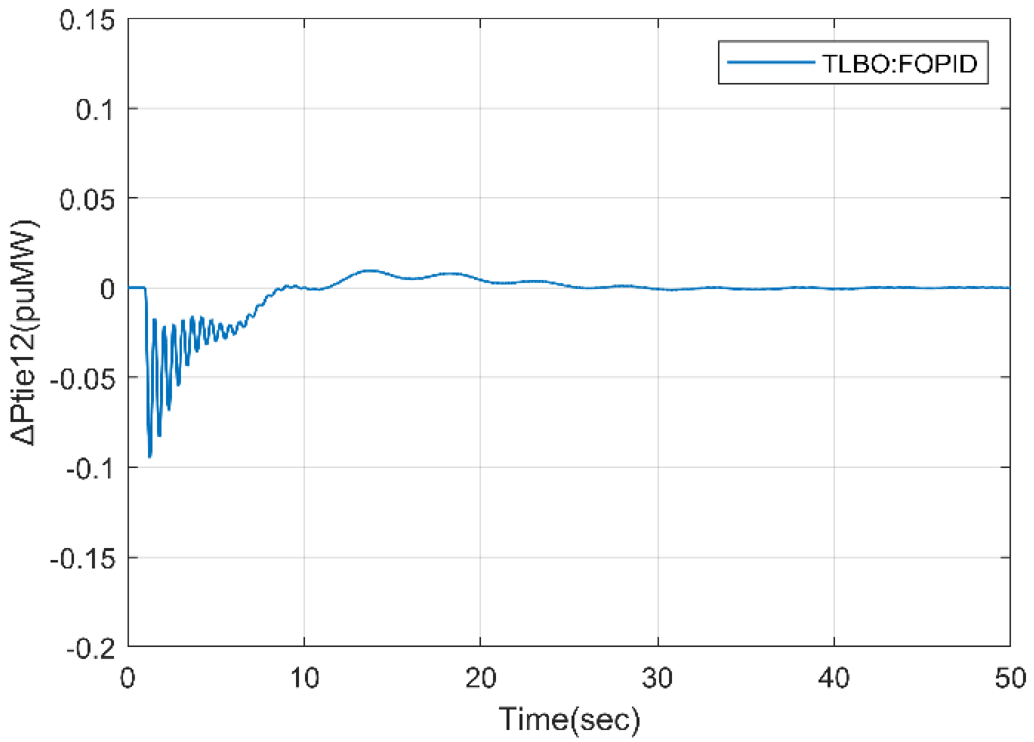


**Fig. 6.5.** Tie-line power deviation using TLBO optimized FOPID Controller

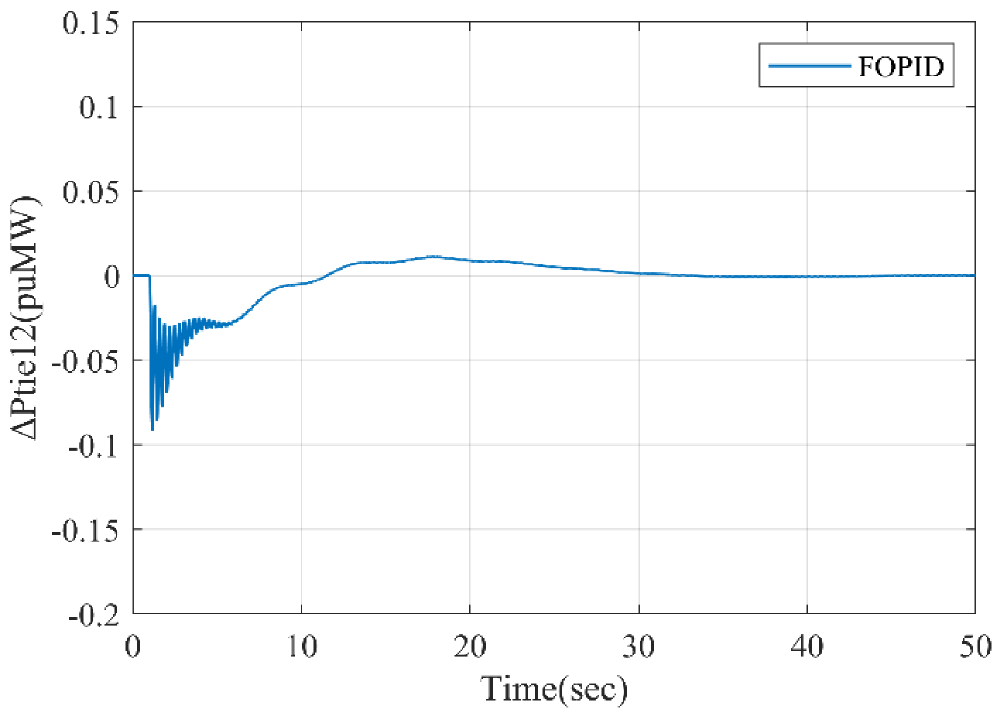


**Fig. 6.6.** Tie-line power deviation using FOPID Controller

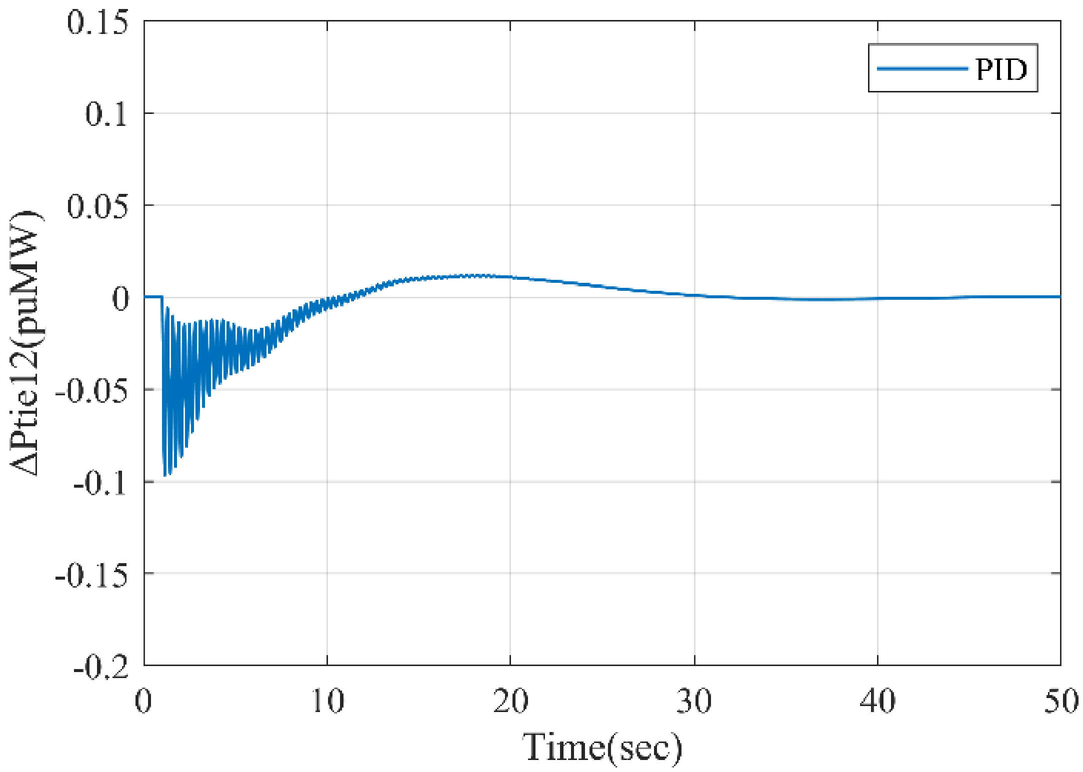


**Fig. 6.7.** Tie-line power deviation using PID Controller

# CHAPTER 7

## CONCLUSION & FUTURE SCOPE

### 7.1. Overview Of The Work

This chapter gives an overview about the contributions made in the current research work and also few suggestions for extending the research work in future. In this work an effort is made to present various approaches on AGC of an interconnected multisource multi area power system. To work upon the issues related to AGC various controllers are proposed in this work. In the literature survey the comparison with various other conventional controllers is done. The comparison of the proposed controller with the conventional PID controller is done in the given work. The main aim of the work is done in various chapters of the thesis and are stated as follows:

The chapter 1 proposes a brief about the various problems and solutions associated with the interconnected power system. The best solution is to use an AGC with an optimized controller for controlling the active power. The introduction to various controllers and optimization techniques with their usage in the given power system.

Chapter 2 provides an idea about the literature survey for the available research on AGC.

In chapter 3 it explains about the various transfer function models of turbines, speed governor system and that of associated with hydro-thermal power plant.

The chapter 4 presents a brief idea about the proposed optimization algorithm that is Teaching Learning Based Optimization algorithm (TLBO).

The chapter 3 explains the block diagram and working of fractional order proportional-integral-derivative (FOPID) controller and its comparison with other controllers. The optimization problem that is considered is also described.

The chapter 6 presents the Simulink model of a multisource multiarea (MSMA) interconnected power system. The results shown are obtained by using FOPID controller and TLBO algorithm.

Chapter 7 concludes the thesis after the evaluative and investigative study of the Automatic Generation Control with Teaching Learning Based Optimization algorithm. The future scope in the area of AGC of multisource multiarea power systems is also provided.

The conclusion of the work done in the present thesis work is expressed below:

**TLBO based AGC of multisource multiarea hydro-thermal power system with FOPID controller:**

TLBO optimized FOPID controller for AGC of multisource multiarea power system with 1% of step load perturbation and some load disturbances or transients. The MSMA consist of various sources such as hydro and thermal that are interconnected via tie-lines. From, the results its concluded that Fractional order Proportional-Integral-Derivative (FOPID) based Teaching Learning Based Optimization algorithm (TLBO) shows better responses in terms of settling time, peak undershoot, peak overshoot and performance indices. TLBO based FOPID controller gives better results then the various other intelligent control approaches. The combination of sources used that are hydro and thermal helps in increasing the dynamic response of the given system. It is observed from the system outcomes on MATLAB platform that TLBO tuned FOPID outperforms over FOPID and PID controller available in the most recent literatures.

The investigation carried out reveal that optimal AGC regulator based on structures of control and state cost weighting matrices with scaling method offer remarkable improvement in dynamic stability as compared to other designed regulators based on minimum performance index and by giving equal importance to each variable. Comparative analysis portrays potential benefits of proposed approach when compared with different other techniques for tuning of AGC of an interconnected hydro-thermal power system. In this work, the optimum gains of different confines for the proposed controller are attained by considering TLBO. For investigating the transient response of system on the basis of peak overshoot, settling time and peak undershoot the SLP of 1% is performed on the given system. For tunning the parameters of FOPID controller TLBO is used. Results for all the controllers (TLBO optimized FOPID, PID and FOPID) that are used in AGC is compared and it is noticed that TLBO tunned FOPID controller produces desirable performance resulting in lesser peak overshoot, settling time and peak undershoot with respect to PID and not optimized FOPID controller.

## 7.2. Scope For The Future Research

The present work has been carried out to put forward the few good ideas for the designing of the controllers in Automatic Generation Control (AGC) for the proposed interconnected multisource multiarea power system. The proposed controllers are tending to give better results in terms of each criterion. However, there are various areas which need further research to provide some other better AGC controller designs for various types of power system structures. These areas are as stated as follows:

1. The current study is only limited to two area multisource interconnected power system. So, this work can be extended further to three/four/five area power systems.
2. In this present study, the design of FOPID controller is carried out using TLBO technique but more fruitful results may be obtained by using some other new intelligent optimization techniques. Hybrid of some AI techniques may be implemented in future studies on multi source power systems with renewable sources.
3. In the present study, the given power system has the combinations of multi-sources of power generations like thermal and hydro in each area. However, further studies may be done by considering diverse sources like gas, nuclear, wind, diesel, bio diesel, PV etc. in each control area of multiarea power system.

4. Some other supplementary controllers such as neural, neural-fuzzy, two degree of freedom PID, 2-DOF-FOPID etc., in relation with some newer optimization techniques may be implemented in future studies on multisource multiarea power system.
5. In present study, only AC tie lines are considered between multi areas. DC tie line or both AC/DC tie lines can be implemented in power systems.

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# APPENDIX-I

Typical values of multisource multiarea interconnected power system with reheat thermal, non-reheat thermal source and hydro source are stated as follows:

**Non-reheat thermal system [33-36, 40]:**

$P_{ri}$ = 2000 MW, $\Delta P_{Di}$ = 1000 MW, $\alpha_{12}$ = –1, F = 60 Hz, D = 0.00833 puMW/Hz, H = 5 s, R = 2.4 Hz/puMW, β = 0.425 puMW/Hz, $K_{PSi}$ = 120, $T_{PSi}$ = 20 s, $\delta_i$ = 300, $P_{tiemax}$ = 0.1Pri MW, $2\pi T_{12}$ = 0.545 pu MW/Hz, $T_{Gi}$ = 0.08 s, $T_{Ti}$ = 0.3 s.

**Reheat thermal system [23, 28-31]:**

$P_{ri}$ = 2000 MW, 0 $\Delta P_{Di}$ = 1000 MW, $\alpha_{12}$ = –1, F = 60 Hz, D = 0.00833 puMW/Hz, H = 5 s, R = 2.4 Hz/puMW, β = 0.425 puMW/Hz, $K_{PSi}$ = 120, $T_{PSi}$ = 20 s, $\delta_i$ = 300, $P_{tiemax}$ = 0.1Pri MW, $T_{12}$ = 0.086 puMW/rad, $T_{Gi}$ = 0.08 s, $T_{Ti}$ = 0.3 s, $K_{ri}$ = 0.5, $T_{ri}$ = 10 s.

**Multi-source hydrothermal power system [33, 41]:**

$P_{ri}$ = 2000 MW, 0 $\Delta P_{Di}$ = 1000 MW, $\alpha_{12}$ = –1, F = 60 Hz, D = 0.00833 puMW/Hz, $R_1$ = 2 Hz/puMW, $R_2$ = 2.4 Hz/puMW, β = 0.425 puMW/Hz, $K_{PSi}$ = 100, $T_{PSi}$ = 20 s, δ = 450, $P_{tiemax}$ = 0.1Pri MW, $T_{12}$ = 0.0707 puMW/rad, $T_{Gi}$ = 0.08 s, $T_{Ti}$ = 0.3 s, $T_{RHi}$ = 48.7 s, $T_{Ri}$ = 5 s, $T_{GHi}$ = 0.513 s, $T_{Wi}$ = 1 s.

# LIST OF PUBLICATIONS

1. Akanksha Sayogi, Narendra Kumar. "Performance analysis of TLBO tuned FOPID controller for AGC of a multi area power system". International Conference on Data Analytics and Computing (ICDAC) - 2022. **(ACCEPTED)**

2. Deepesh Sangwan, Akanksha Sayogi, Narendra Kumar, Saket Gupta. "Sine-Cosine Acceleration Coefficient Based JAYA Optimized Generation Control Strategy for a Multi-Source Multi-Area Power System". Arabian Journal For Science and Engineering- 2022. **(COMMUNICATED)**