STUDIES ON AUTOMATIC GENERATION CONTROL OF INTERCONNECTED POWER SYSTEM

A DISSERTATION

SUBMITTED IN PARTIAL FULFILLMENT OF THE REQUIREMENTS
FOR THE AWARD OF THE DEGREE OF

MASTER OF TECHNOLOGY
IN
POWER SYSTEM

Submitted by:

KIRTIMAN GODARA

2K19/PSY/09

Under the supervision of

PROF. NARENDRA KUMAR

DEPARTMENT OF ELECTRICAL ENGINEERING
DELHI TECHNOLOGICAL UNIVERSITY
(Formerly Delhi College of Engineering)
Bawana Road, Delhi-110042

JULY, 2021

DELHI TECHNOLOGICAL UNIVERSITY

(Formerly Delhi College of Engineering)

Bawana Road, Delhi-110042

CANDIDATE'S DECLARATION

I, Kirtiman Godara, Roll No. 2K19/PSY/09 student of M.Tech. (Power System), hereby declare that the Dissertation titled "**Studies On Automatic Generation Control of interconnected power system**" which is submitted by me to the Department of Electrical Engineering, Delhi Technological University, Delhi in partial fulfillment 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 other similar title or recognition.

Place: Delhi **KIRTIMAN GODARA**

Date: 16 -09-2021

DEPARTMENT OF ELECTRICAL ENGINEERING

DELHI TECHNOLOGICAL UNIVERSITY

(Formerly Delhi College of Engineering)

Bawana Road, Delhi-110042

CERTIFICATE

I hereby certify that the Dissertation titled "**Studies On Automatic Generation Control of interconnected power system**" which is submitted by Mr.Kirtiman Godara, Roll No 2K19/PSY/09 Electrical Engineering Department, Delhi Technological University, Delhi in partial fulfillment of the requirement for the award of the degree of Master of Technology, is a record of the project work carried out by the students under my supervision. To the best of my knowledge this work has not been submitted in part or full for any Degree or Diploma to this University or elsewhere.

Place: Delhi

Date: 16-09-2021

PROF. NARENDRA KUMAR

SUPERVISOR

Professor

ACKNOWLEDGEMENT

First and foremost, I express my deep sense of gratitude to my supervisor, counselor and advisor **Prof. Narendra Kumar**, Professor, department of Electrical Engineering for his constant guidance, support, motivation and encouragement throughout the period this work was carried out. His readiness for consultation at all times, his educative comments, his concern and assistance has been invaluable.

I want to thank **Prof. Uma Nangia,** Head of Electrical Department for building this platform and creating such an energetic environment for research work.

Finally, I wish to thank my parents for their moral support and confidence showed in me to pursue M. Tech at an advanced stage of my academic career.

KIRTIMAN GODARA

ABSTRACT

Automatic generation control (AGC) and Load frequency control (LFC) are very important part of the power systems in order to provide reliable and quality power supply to the end users. Load variations can lead to the deviation generated power frequency which ultimately can destabilize the entire power system. Here comes the LFC for rescue by maintain the power frequency at desired value. In LFC, area controllers are used to perform this task. To avoid this kind of problem AGC and load frequency control method is used for balancing the power system frequency.

For tuning purpose objective function have been used. In this work three area interconnected LFC system has been used for simulation purpose. Fractional order proportional integral (FOPI) controllers and proportional controller (PI) were used as an area controller in order to mitigate the effect of load variation in power system.

In order to optimize the parameters of controllers, three optimization algorithms namely genetic algorithm (GA), Particle swarm optimization (PSO) and Water cycle algorithm (WCA) have been used. Performance comparison between optimized controllers using these algorithms has also been performed.

For further work multisource single area has been simulated in the thesis to understand the process of automatic generation. Comparative analysis shows that the WCA optimization performed better than the other two GA and PSO algorithms. LFC system was simulated on MATLAB with the load disturbance of 0.01 p.u. in all areas at the same time.

Table of Contents

CONDIDATE'S DECLARATION.. **i**

CERTIFICATE ii

ACKNOWLEDGEMENT iii

ABSTRACT.. iv

TABLE OF CONTENTS……………………………………………………………….v

LIST OF TABLE………………………………………………………………….vii

LIST OF FIGURE……………………………………………………………….viii

LIST OF SYMBOL…………………………………………………………...ix

CHAPTER 1 INRODUCTION **1**

1.1 INTRODUCTION 2

1.2 CHARACTERISTICS OF A PROPERLY DESIGNED POWER SYSTEM ... 3

1.3 REASONS OF LIMITING FREQUENCY DEVIATIONS 3

1.4 CONCEPT OF CONTROL AREA.. 4

1.5 OBJECTIVE RELATING TO POWER SYSTEM 4

1.6 MAJOR OBJECT OF LFC IN POWER SYSTEM... 5

1.7 ADVANTAGES OF LFC IN POWER SYSTEM 5

1.8 TYPES OF CONTROL.. 5

1.9 NEED OF INTERCONNECTION OF AREAS.. 6

1.9.1ADVANTAGE OF INTERCONNECTED POWER SYSTEM 6

1.9.2 DISADVANTAGE OF INTERCONNECTED POWER SYSTEM........... 7

1.10TYPES OF CONTROL... 7

CHAPTER 2 LITERATURE SURVEY **8**

2.1 LITERATURE REVIEW ……………………………………………………8

2.2 MOTIVATION……………………………………………………………..10

2.3 OUTLINES OF THESIS……………………………………………………11

CHAPTER 3 POWER SYSTEM.. **12**

3.1 DYNAMICS OF POWER SYSTEM.. 12

3.2 TURBINE 13

3.3 GOVERNOR.. 13

3.4 GENERATOR.. 14

3.5 LOAD 15

3.6 TIE - LINE 16

3.7 AREA CONTROL ERROR 16

3.8 PARALLEL OPERATION OF GENERATORS 17
3.9 MODELLING OF ALFC…………………………………………………… 18
3.9.1 MODELLING OF CHANGING IN FREQUENCY 18
3.9.2 MODELLING OF TIE LINE…………………………………………..…20
3.10 CONCLUSION ……………………………………………………….22
CHAPTER 4 OPTIMIATION ALGORITHM **23**
4.1 INTRODUCTION 23
4.2 GENETIC ALGORITHM 24
4.2.1 GA OPERATORS 25
4.2.2 THE OBJECTIVE FUNCTION CONTROL TUNING………………… 27
4.3 PARTICLE SWARM OPTIMIATION 28
4.4 WATER CYCLE ALGORITHM 32
4.4.1 HOW DOES A STREAM FLOW TO RIVER OR SEA…………………..34
4.4.2 EVAPORATION PROCESS 35
4.4.3 RAINING PROCESS 36
4.5 CONCLUSION ……………………………………………………...…37
CHAPTER 5 PERFORMANCE COMPARISION OF THREE AREA 3**8**
5.1 INTRODUCTION 38
5.2 FOPI CONTROLLER 39
5.3 PLANT DESCRIPTION 39
5.3.1 PLANT MODEL 40
5.3.2 OBJECTIVE FUNCTION 43
5.4 RESULT AND DISCUSSION 43
5.4.1 OPTIMIATION ALGORITHM RESULT 43
5.4.2 LFC RESULT OF EACH AREA 46
5.5 CONCLUSION 48
CHAPTER 6 FREQUENCY ANALYSIS OF MULTISOURCE SINGLE AREA POWER SYSTEM **49**
6.1 INTRODUCTION 49
6.2 PI CONTROLLER 50
6.3 PLANT DESCRIPTION 51

6.3.1 PLANT MODEL…………………………………………………… 51
6.3.2 OBJECTIVE FUNCTION…………………………………………… 53
6.3.3 OPTIMIATION ALGORITHM……………………………………… 54
6.4 RESULT AND DISSCUSSION……………………………………………54
6.5 CONCLUSION……………………………………………………………..58
CHAPTER 7 CONCLUSION AND FUTURE SCOPE **59**
7.1 CONCLUSION…………………………………………………59
7.2 FUTURE SCOPE……………………………………………….60
REFERENCE **51**
LIST OF PUBLICATIONS ……………………………………………………**67**

LIST OF FIGURES

Fig. 1.1 Control Loops in AGC system 5

Fig.3.1 Block Diagram of Load Frequency Control 10

Fig.3.2 Automatic Generation loop 14

Fig.3.3 Parallel Operation of Generators 17

Fig 3.4 Power transfer through tie line 17

Fig.3.1. flow chart of GA 22

Fig.3.2 Single point crossover 23

Fig.3.3 binary mutation 24

Fig.3.4 flow chart of PSO 28

Fig.3.5 water cycle process 29

Fig.3.6 process of WCA 31

Fig. 3.7 flow chart of WCA 33

Fig.4.1 SIMULINK model of three area 42

Fig.4.2 optimization convergence curve for GA, PSO, WCA 42

Fig.4.3 Frequency Deviation for area 1 44

Fig.4.4 Frequency Deviation of Area 2 47

Fig.4.5 Frequency Deviation of Area 3 47

Fig.5.1 WCA based PI controller 51

Fig.5.2 SIMULINK Model of multi-source single area power system 53

Fig.5.3 Frequency Deviation of Area 57

Fig.5.4 Frequency Deviation of Area 57

LIST OF TABLES

Table.4.1. Notations Used In the Table 37

Table.4.2. Optimization Parameters Vale 42

Table.4.3. FOPI Controller Parameter Value 45

Table.5.1. Optimization Parameter Vale 54

Table.5.2. Statistical Analysis Value 55

Table.5.3. PI controller parameters value 56

LIST OF SYMBOLS, ABBREVIATION

P_M = Mechanical Power

T_e = Electrical power

P_L = Load power

P_e = Electrical power

S = Laplace operator

ΔW_r = Rotor Speed Deviation

ΔP_L = non frequency load change

B = frequency bias parameter

T_G = time constant of governor

T_T = time constant of turbine

T_P = time constant of power system

ΔP_G = incremental change in governor input

R = speed regulation

GA = genetic algorithm

PSO = particle swarm optimization

WCA = water cycle algorithm

ACE = area control error

p.u. = per unit

CHAPTER 1

INTRODUCTION

1.1 INTRODUCTION

As the development migrates throughout the society is executed where electricity is considered a basic need of humanity. Due to wide application and easy convertibility. Earlier Sources of energy fossil fuels. But due to greenhouse gas emission and its associated negative impact leads to a shift in non –conventional energy sources. Where are solar, hydro and wind, etc. Whereas the availability of non-conventional sources is limited in geographical expense. Such as solar is limited to between both of the subtropics, whereas other areas are not able to produce as compare to these. Due to the distance of geographical constraints sources are spare less distributed. By the means of transmission line and power cable are interconnected. The interconnection of sources and loads and various fascillating apparatus is called a power system[1].

In this emergent power scenario, it is absolutely a challenge for electric suppliers to deliver safe and sound electric power to meet the demands of consumers. In the enormous generating stations exchange of bulk amount of power has been done by the help of tie-lines. It is a very hard-hitting job of power system to stay within stability by balancing between whole produced and demanded power simultaneously.

Automatic generation control is answerable for supporting the basic constraints in the accepted scope by following the active power and reactive power stability mechanism. Conventional technologies alone are not enough to react rapidly against the intolerable power fluctuations. Area controller error (ACE) conveys to zero by appraising net variation in the required generation to protect and restore the equilibrium state of the system with an economical manner[2].

The limiting of generating stations/sources leads to the coupling of several generators. Sources are being connected to load centers through a mesh of transmission lines. Whereas these generators have economically restraints. Due to which generators are coupled through tie –lines. Tie–lines provide support between the area for energy exchange and during the abnormal condition. Tie–lines are used for contractual energy exchange between different areas. The active and reactive power varying with respect to load (rising and falling trend).The active and reactive power must be varying continuously to match the load. Because whenever there is a mismatch between demand and generation power its cause's system frequency deviation. System frequency is affected by active power of system .but load varies through the day so maintain the system frequency to its nominal value by the governor it's a very difficult task.

With the help of a suitable control strategy that automatically regulates the governor valve which controls the real power output of the alternator. Supplementary control action requires to restore the system frequency at rated value. So primary function of load frequency control (LFC) is to maintain frequency at a nominal value. And also the maintain interchange power between the areas by adjusting the output of generators. Basically, load frequency control deals with regulation of real power output of the generator and its frequency incessant progress of AGC strategies over for more than five decades. Apart From the conventional approach recently new methods are implementing in the design and analysis of AGC schemes.

Flywheel governor used earlier to control the frequency of the power system but later on a supplementary control was incorporated with the help of signal directly proportional to frequency plus it's integral or integral of summation of deviation in frequency plus tie-line known as area control error (ACE).In a large power system, it's very important to address the system frequency[3]. Power system frequency is a very important parameter of power system. Power system is not feasible without stable frequency.

So for a stable power system frequency should be stable within the permissible limit. Frequency can be controlled by various techniques. Active power of a system is dependent on a system. In a complex power system, there is one or more generators to feed power to the system. If any of the generators is misbalance by means of frequency mismatch its effects in whole complex power system[4]. So frequency mismatch is controlled by the primary and secondary control system. Using flywheel governor steam can be controlled. In primary control action, the governor input changes according to the output. If the output power is decreased then the input valve increases the steam (or hydro) and vice-versa. Primary control action acts fast as compare to secondary control action. Secondary control action acts more accurate as compare to primary[5].

1.2 CHARACTERISTICS OF A PROPERLY DESIGNED POWER SYSTEM

1) Power should be available at every possible customer.
2) Continuous supply of power.
3) Supply should not be affected by changing of load.
4) Safety of equipment should be necessary.
5) Flexibility in power supply is good for power system.

The power delivered must meet certain minimum requirements in terms of supply quality.

Healthy power system can be determined as follows –

1) System frequency should be kept at around 50 Hz.
2) Voltage value of bus should be maintained within the limits (nominal value).

1.3 REASONS OF LIMITING FREQUENCY DEVIATIONS

There are some reasons why frequency fluctuations can be strictly limited and the system frequency should be kept constant. The following are the details:

The frequency is exactly related to the running speed of three phase a.c. motors. As a result, changes in system frequency will have a direct impact on motor performance. The alternator steam and water turbine blades are operates on specific frequency. If any disturbances occur in system its affects speed of turbine and frequency also. So due to this vibration occurs in system and system become unstable.

1.4 CONCEPT OF CONTROL AREA

A control is inferred as where common control techniques is applied for automatic generation control. Concept of control area is important when power system become complex rather than simple network. In complex power system network where area of generation is more than single area so instead of using control technique for each area which is not feasible a common technique for all control area should be implemented. It’s basically control mechanism which deals with every area in a common way. More than two area is connected through the tie line power. When power purchase agreement made between two companies for power sharing. Due to disturbance in power system or load demand mismatch there is need of a power in affected area so with the help of tie line objective of healthy power can be achieved. But there is need of common control. Technique rather than individual. When there is a disturbance occur due to load demand there is a mismatch of frequency at affected area[6].

If due to load demand its affects the system frequency or respective area and earlier discussed if frequency value is different from their nominal value system become unstable and their nominal value and parts of the system could be damaged. so to avoid this states in power system a control mechanism is necessity of power system. so for smooth process of power system a common control mechanism should be implemented. So when this states occurs, system should be responded as much as quickly to counter the effect of fault. If disturbance occurs in area so according to power agreement power can be share in affected area to become system stable as much as fast.

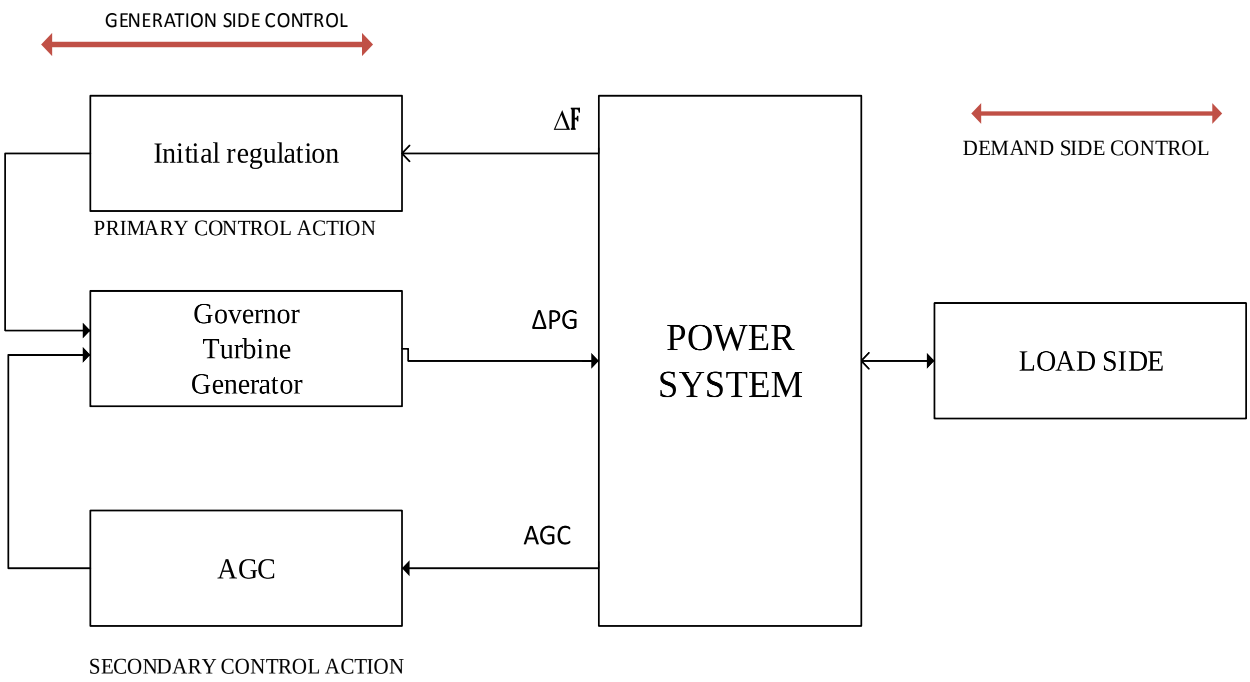

Fig. 1.1 Control loops in AGC system

1.5 OBJECTIVE RELATING TO POWER SYSTEM

1) Each area should be completed its load demand if any disturbance occur and with the help power sharing with other areas.
2) System response on disturbance as much as quickly so system so system become stable in less time.

1.6 MAJOR OBJECT OF LFC IN POWER SYSTEM

1) Objective of LFC in power system is to take care of load demand of alternator. When load demand increasing or decreasing input power of alternator varying accordingly.
2) If area are connected through the tie line than with the help of LFC power sharing between areas is done properly.
3) With the varying of load demand there is mechanism which is automatically regulate the input power according to load power demand until the input power equal to output power.

1.7 ADVANTAGES OF LFC IN POWER SYSTEM

Main objective of LFC is to keep the system frequency at prescribed value.

1) With the addition of frequency with LFC generation control of alternator should be achieved.
2) So to control the frequency and generation control of alternator, LFC have major role in power sharing between the areas according to agreement.

1.8 TYPES OF CONTROL

Primary Control: Primary control is to keep the system balance so steady state error becomes zero. Due to change in load demand system steady state frequency will be changes accordingly to droop characteristics and frequency sensitivity of load.

In primary control action all generating unit contribute to the affected unit or load demand change area according to their droop characteristics.

Secondary Control Action: In primary control action steady state frequency is not up to the nominal value so keep the system frequency at nominal value after disturbance secondary control action should be used. In secondary control action there is changing in generation in only load demand change unit.

Secondary control action response is slower compare to primary control action.

Secondary control action takes action after primary control action.

1.9 NEED OF INTER-CONNECTION OF AREAS

As earlier power system are operated as single unit bus. There was no such interconnected area. Because earlier there was not such high demand and fault so no need of fault protection and reliable operation.

But in today scenario where power demand is increasing day by day so to keep the system balance or keep the system reliable area interconnected are necessity part of the power system.

In an inter connected of area power supply is reliable because if one area is not respond at any time so there is second area that is interconnected to first area is to keep fed power supply.

In an interconnected power system load demand balance could be achieve easily.

1.9.1 ADVANTAGE OF INTERCONNECTED POWER SYSTEM

1) Due ti interconnected power system reliability of system is increased.

2) In a large system some machines are required to use for reserve capacity no need of use all machines at every time of operation without to take care of sudden change of load.

3) It would be economically sound system if interconnected system has been used in power system.

4) There is a less burden in an interconnected power system because of power sharing of each alternator.

1.9.2 DISADVANTAGES OF INTERCONNECTED POWER SYSTEM

1) Proper protection is required in interconnected power system.

2) Fast response required of every single equipment.

3) Power share management is required for larger system.

4) Rating of several equipment is increased.

CHAPTER 2

LITERATURE SURVEY

2.1 LITERATURE REVIEW

Many researchers gives emphasis towards AGC due to its regulation against the instability regarding nonlinearities of unified power system. Mechanism of AGC in closed loop determines the generations to fulfil the prescheduled system constraints in order to keep secure the system from abnormalities related governor wind-up. In ref. [7], [8] suitable modelling of AGC is presented to achieve the stimulating tasks concerning fluctuations regarding faults, load demand etc. Recently researchers improve many relevant researches about AGC that described in below section. In present research to obtain the fruitful operation of load frequency control (LFC) a multiple combination of reheat based thermal, hydro and gas sources are deliberated to keep an eye on LFC complications[6]. In [9] an effort has been done along with hybrid optimization technique named hybrid firefly algorithm and pattern search over a multi area system with Proportional integral derivative (PID) controller mechanism. Dated back proportional integral (PI) controller caught the eye of researches to keep on progress on AGC problems. A modified objective function integral time absolute error (ITAE) along with suitable weight coefficients of settling time of frequency and interline power alternations are further developed to acquire the minimal values of differential evolution (DE) tuned PI controller [10]. Release of carbon and rapidly lack of conventional energy resources paid attention towards renewable energy sources. To fulfil the energy demands solar and wind energy sources employed as alternate sources and implemented over a hybrid system. Addition of fossil fuel which has a great impact on global warming along with solar, wind and diesel has been imposed for research work [11]13]. Wind energy considered as the utmost promising resources not only for quickly reduction in the cost of wind generators but also it is eco-friendly and eye-catching for wind provinces. In 2015 Lu Chia-Liang gave emphasis to solve the problem of wind thermal coordination dispatch tuned for AGC [13]. The controllers are implemented to find out the appropriate instructions to acquire the desired state with less fluctuations. Dated back proportional-integral-derivative controller is introduced to make a control over stability and dynamic responses of a hydro- power system [14]. A population based artificial bee colony algorithm is imposed for optimization process of PI, PID controller for AGC [15]. Fuzzy logic has quickly become the utmost methodology for the designing of classy control system. It resembles the human thinking with the capability of producing exactness solutions. Multi-stage fuzzy proportional integral derivative controller [16], proportional with integral controller with crazy PSO[17] has employed to meet the challenges of AGC. Later on in [18][19] the multi area power system is verified with the presence of generation rate constraint and thyristor control phase shifter (TCPS) along with fuzzy logic based PI and PID controller. From the above discussion, it can be conferred that LFC for multi-area system is a challenging task and lot to be done in order to improve the overall quality of the power systems. Keeping this in mind, in this work a three area interconnected thermal power system has been designed. In order to mitigate the effect of load variations in any area on the generated power frequency, fractional order proportional integral (FOPI) controllers have been used in each area as an area controller.

. In present research to obtain the results of load frequency operation (LFC) a multiple combination of reheat based thermal, hydro and gas sources are deliberated to keep an eye on LFC complications. Modern control theory and its application by Fosha and Elgerd[20] in power system. In this paper a unified technique dependent for LFC of power system is discused.

The design of linear PI regulator for two and three area power system was presented by calovic[21]. Two area multi source system was proposed by Kothari[22]. To improve the performance of automatic generation control system under changeable system parameters and operating conditions, various controllers have offered remarkable work over the last decades intelligent technique has emerged in a big way to deal with system design and implementation of control techniques in large power system. various techniques like genetic algorithm (GA)[23], particle swarm optimization (PSO), artificial bee colony (ABC)algorithm[24], bacterial foraging algorithm (BFOA)[25], the controllers are implemented to find out the appropriate instructions to acquire the state with less fluctuations. In this paper multi source multi area hydrothermal system has been simulated using pi controller. Selection based on different different techniques based. To check the stability of system with open loop and close loop has been investigated[26].with extent in this[27] paper another controller name fuzzy gain scheduling are considered for automatic generation control and compare with other optimal controller with some algorithm and conclude that fuzzy gain controller is superior to other.in tis[28] paper FOFPID controller is proposed for automatic generation control. Its compares with other controller by proposed algorithms and at last it concludes that it effectiveness is more than any other controller either same power system.[29] In this research work PID controller with GSA algorithm with two area thermal power system is proposed.in this application of gravitational search algorithm is presented with PI controller for automatic generation control[30].in this paper design of LFC using GSA is considered and also GRC and governor dead band is also considered[31].

In this paper PID controller is used for multisource power system using foraging optimization technique[32]. Many authors give their contribution to understand the automatic generation control in a better way with different algorithms have been used for tuning the function, some optimization are pattern search algorithm[33],firefly algorithm[34] , in this (hFA –PS) optimization is implemented using generation rate constant[35].in the paper hybrid PSO and fuzzy PI controller is used for automatic generation control[36],grey wolf optimization (GWO) in inter connected power system[37] , BIA based design model predictive controller(MPC) is considered[38].using TLBO[39] comparative analysis has been done of power system.

2.2 MOTIVATION

In the literature review a no. of article have been published that described the method of automatic generation control. Paper have been published in the domain of AGC and their strategies.in power system stability of the system is key factor. Day by day demand is increasing so to keep the system stable automatic generation control is must for the system. So studies was done on automatic generation control. In power system major problem is load balance. As in rural areas load varies continuously or at industries level its affects the all over the system. Due to disturbances in system there is mismatch in frequency and its Leeds to instability of system. Automatic generation control technique is the control technique that helps to keep system frequency at their nominal level. So there is a lot scope of improvement in this field.

2.3 OUTLINE OF THESIS

This thesis is completed in six chapter.

First chapter deals with introduction of automatic generation control. After that literature review presented to as previous work.

In the second chapter it describes about introduction of power system and their components and dynamics of the system. In this working of turbine, governor, generator, tie line have been explained.

Third chapter describes the algorithm that have been implemented in the work. For this work three algorithm have been implemented name as genetic algorithm, particle swarm optimization, water cycle algorithm their proposed work in the AGC is discussed.

Fourth and fifth chapter includes the performance of three area connected thermal power system with different algorithm and at last compare the algorithm with their time response. In fifth chapter frequency analysis has been done with multi source single area system.

In last chapter it deals with conclusion and future scope.

CHAPTER 3

DYNAMICS OF POWER SYSTEM

3.1 DYNAMICS OF POWER SYSYEM

In simple power system there is no need of controlling the generation automatically to control the load demand. But in complex power system to operate the generation device automatically rather than manually for controlling the frequency at their nominal value. In automatic load frequency control there is controlling technique which helps the power system network to control the frequency parameter. Its helps the tie line power sharing between the power areas. So when disturbance occurs in any area due to load demand so with the help of LFC controlling technique frequency can be controlled. Some components can be help in for frequency control in LFC loop.

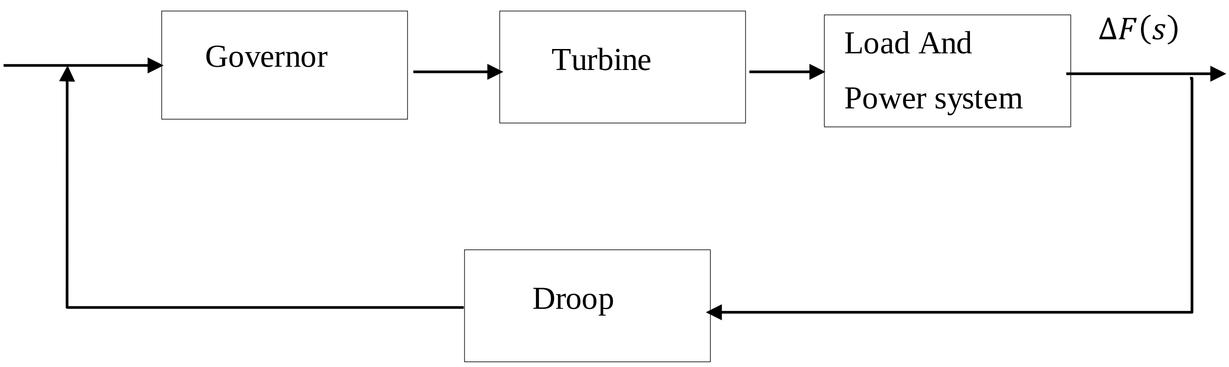

Fig 3.1 Block Diagram of Load Frequency Control

3.2 TURBINE

It initially only one type of steam engine available which was a reciprocating or piston engine. Principle of piston engine operated was the potential energy. Use of potential energy to drive a piston in cylinder. Charle parson is the inventor of steam turbine. For steam turbine to use the kinetic energy of steam (from high pressure source) to drive an engine. Steam is used in turbine to move the wheel by moving the blade is mounting on a wheel.

Steam turbine for large coal station are generally divided into three sets, first is high pressure, intermediate pressure, low pressure turbine[40]. Gas turbine is machine delivering mechanical power.in this work three types of turbines model are considered for study. For initial non reheat turbine model and reheat turbine model, gas turbine model and hydro based turbine model are used. For here transfer function of non-reheat turbine model are presented its does this using a gaseous working fuel.

$$G_T(s) = \frac{\Delta P_T(S)}{\Delta P_V(S} = \frac{K_T}{1 + ST_T} \qquad 2.1$$

For reheat turbine transfer function model is presented by Eq. 2.2

$$G_T(s) = \frac{\Delta P_T(S)}{\Delta P_V(S} = \frac{K_T}{1+ST_T} + \frac{T_T(s).c+1}{T_T(s)+1} \qquad 2.2$$

For gas turbine transfer function model is presented by Eq. 2.3

Where $\Delta P_T(S)$ = the output of the turbine.

$\Delta P_V(S)$ = the input of the turbine.

3.3 GOVERNOR

When there is load changes by means of electrical load so due to this electrical power is greater than mechanical input. This required power is supplied by kinetic energy stored in the system. But due to mismatch between electrical and mechanical power its affects the speed of turbine. And speed of turbine and frequency is directly related with each other. To avoid this situation governor comes into the picture. Governor sensed the speed deviation that occurs due to load demand and its acts the input valve of the turbine to change the input steam to change the mechanical output according the power demand output and set the new steady state value of frequency.in earlier governor was used is watt governor which sensed the speed by rotating balls and provides mechanical response accordingly speed changes.in this work different different governor is taken for more study of LFC. In this work steam governor hydro governor and gas plant governor is taken. Mathematically equation is given by this and transfer function of governor output is given by this-

$$\Delta P_G = \Delta P_{ref}(s) - \frac{1}{R}\Delta F(s) \tag{2.3}$$

ΔP_G = the governor output

$\Delta P_{ref}(s)$ = the reference signal

R = droop

$\Delta F(s)$ = frequency deviation due to speed

3.4 GENERATOR

Main work of generator its convert mechanical power energy into electrical form of energy. Here our main aim is to regulate the speed accordingly the load so system keeps stable. Where there is load varying its effect on the speed of the rotor. So turbine mechanical output should be countered the demand of demand. So with the help of sensing device power balance should be balance for stable operation of power system. Electromagnetic generator uses a magnet that produced by current. A generator consists of stator and rotor in its structure. Whereas stator is a static part of any generator. Winding are mounting on stator on and rotor parts also kept running winding which helps to generate electricity. An input fluid like steam, water gas are drives on rotor blades which are mounted on rotor. These rotor blades starts to rotate with the help of fluid. In this work different type of turbine generator is used like steam turbine generator and hydro turbine generator is used for study.

The transfer function of generator is presented by Eq. (4)

$$G_G(s) = \frac{\Delta P_V(s)}{\Delta P_G(s)} = \frac{1}{1 + T_G(s)} \quad (4)$$

$\Delta P_V(s)$ = the output of generator

$\Delta P_G(s)$ = the input parameter of generator

$T_G(s)$ = time constant of generator

3.5 LOAD

The load on power system be made up of different type of load. Like resistive loads are lighting and rods for heating purpose and for frequency sensitive load are motors and fans are frequency dependent load. Like motors dependent loads are very sensitive to frequency. How it's sensitive to frequency this depend on speed load charactertics by driven devices. Varity od loads affects the control mechanism of power system. If it's only resistive load that means it load are free from frequency less load so it easy to control that type of load. Composite load are described by this equation -

$$\Delta P_E = \Delta P_L + D\Delta W \quad (2.4)$$

ΔP_L = non frequency responsive change load

$D\Delta W$ = Frequency response load change

D = % Change in load / %change in frequency

3.6 TIE LINES

In today's scenario where load demand increase day by day areas should be feasible for any power demand and fault condition. So single or isolated areas may not be good for today's scenario where load demand increase or decrease instantly. Areas must be connected together with each other through tie line. Tie line is a transmission line which connect two generation areas or two transmission line for power sharing with one another one. In isolated areas when demand varying then its make complicated for system to meet demand in short of time. So it's better to make system interconnected for better performance of system. Tie line is interconnected line between the areas and areas can make agreement for power sharing as per need. So in single areas load disturbances occurs then its leads to instability of system. So avoid these situation areas should be connected with each other through tie lines. When there is load disturbances occurs then other areas can also share the power accordingly their droop characteristics and power purchase agreement. So it's so helpful for healthy system and it's also increase the system stability. The main objective of tie lines is to trade power between the areas in economical way. So when areas want the power on urgent basis so it can be share with the help of tie line.so here for understanding purpose two area is to be considered.

So Let there be two areas and power is to exchange from area 1 to area 2

$$P_{12} = \frac{|V_1||V_2|}{X_{12}} Sin(\delta_1 - \delta_2) \tag{2.5}$$

Where 1 denotes for control area 1 and 2 denotes for control area 2

P_{12} = active power flow from area 1 to are 2

X_{12}= reactance of tie line

$|V_1|$ = voltage of area 1

$|V_2|$ = voltage of area 2

.

3.7 AREA CONTROL ERROR

When there is two area are connected with each other than which area share how much power to other area without disturbing own stable condition. So when there is disturbing occurs in any area then all the area contribute their own power to the demand area as per requirement. So in primary control action all the unit takes place for power sharing accordingly their sped droop characteristics. But primary action does not counter fully but its acts fast as compare to secondary control action. So after primary control action steady state frequency is not their nominal value. So to bring the frequency at their nominal value secondary control can be used in power system. Secondary control action is slow compare with primary control action. In secondary control action only demand area will adjust their demand value only. Other area cannot be share their power. So load demand area should countered the unbalance based on own parameter. The supplementary control in given area should ideally correct, only for changes in that are i.e. if there is change in area 1 load there should be increase of generation in area 1 only not in area 2 as same if there is change in area 2 load then there should be increase of generation in area 2 only not in area 1. A control signal made of the tie line power flow deviation (ΔP_{12}) added to the frequency deviation (ΔF) weighted by a bias factor, full fills the objective. This control signal is known as area control error.

Area control error for area 1 is –

$$(ACE)_1 = (\Delta P_{12}) - \beta_1 \Delta F \quad (2.6)$$

Area control error for control area 2 is –

$$(ACE)_2 = (\Delta P_{21}) - \beta_2 \Delta F \quad (2.8)$$

Where ΔP_{12} = power flow from area 1 to area 2

β_1 = composite frequency response characteristics of area 1

β_1 = composite frequency response characteristics of area 2

ΔF = frequency deviation of area 1 and area 2

3.8 PARALLEL OPERATION OF GENERATORS

In automatic generation control for feasible operation generators works in parallel operation.in parallel operation the work or burden on generator may be less. And due to this stability of power system is increase. Combine parameter like inertia constant (M_{eq}) and damping constant (D_{eq}), characteristics for frequency response (B_{eq}) is presented. Parallel operation is combined more than one generation unit. Unit parameter determined as a combined parameter.

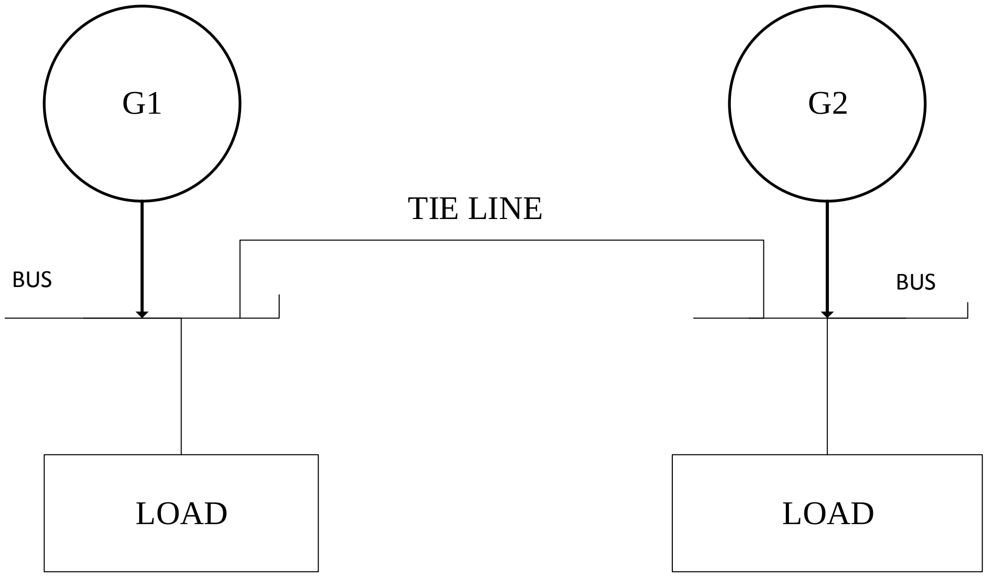

Fig. 3.2 Block Diagram Of Parallel Operation of generators

3.9 MODELLING OF ALFC

Modelling of load frequency control is for frequency and tie line power in this work. In frequency analysis to check the behavior of power system parameter when there is load disturbances occurs. How the tie line power share the power through the neighbor area.

3.9.1 MODELLING OF CHANGE IN FREQUENCY

To check the behavior of frequency in power system a small change in load and with respect to load how the governor is change the input valve of turbine. Due to change in load demand to check the value of frequency in steady state and dynamic response.

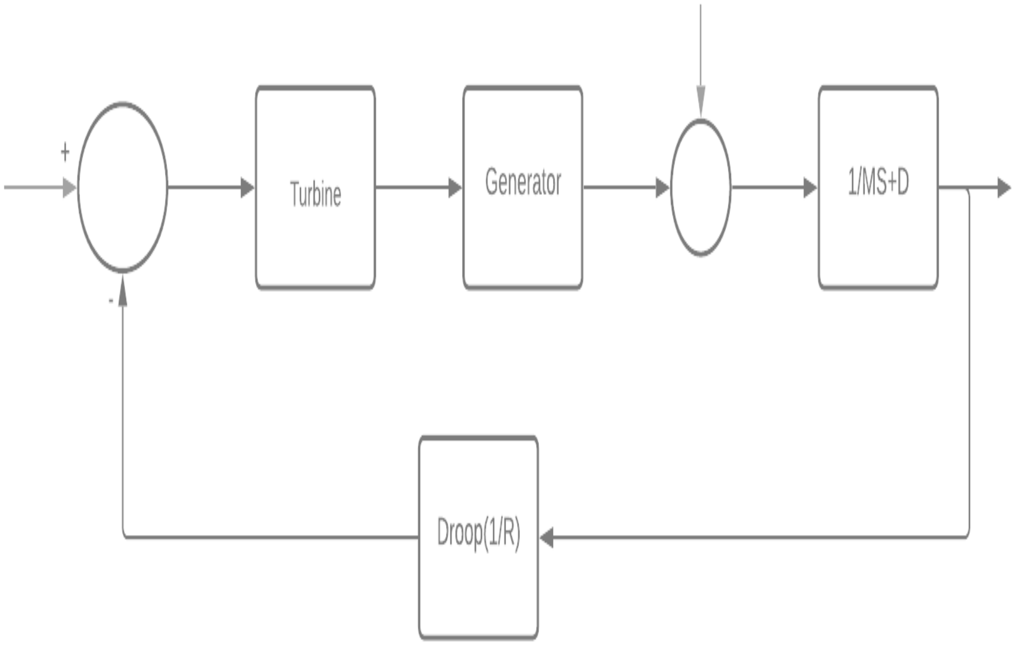

Fig 3.3 Automatic Load Frequency Control Loop

Transfer function of turbine = $\frac{1}{1+ST_{CH}}$

Transfer function of governor = $\frac{1}{1+ST_G}$

MI Of Turbine and Governor = $\frac{1}{MS+D}$

$$\text{Output} = \frac{\Delta W_r(S)}{\Delta P_L(S)} = \frac{-\frac{1}{MS+D}}{1+\frac{1}{MS+D}\times\frac{1}{R}\times\frac{1}{1+ST_{CH}}\times\frac{1}{1+ST_G}} \qquad (2.9)$$

For step Change in Load

$$\Delta W_r(S) = -\frac{\Delta P_{L'}}{S}\left\{\frac{\frac{1}{MS+D}}{1+\frac{1}{MS+D}\times\frac{1}{1+ST_{CH}}\times\frac{1}{1+ST_G}}\right\} \qquad (2.10)$$

$$\Delta W_r(S) = s \xrightarrow{lim} 0\ S\Delta W_r(S) = \frac{-\Delta P_L}{D+\frac{1}{R}} \qquad (2.11)$$

3.9.2 MODELLING OF TIE LINE

For modelling of tie line in power system let us consider that power flow from area 1 to area 2 through tie line.

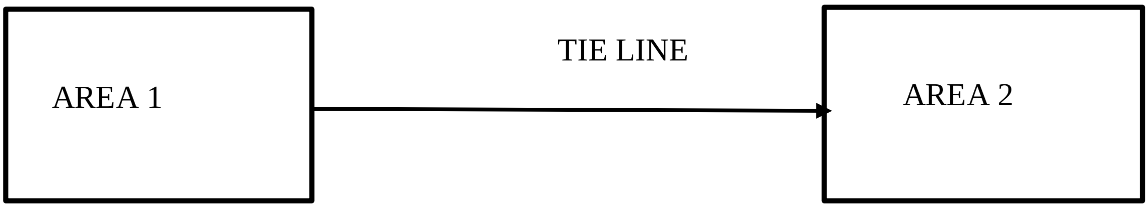

Fig 3.4 Power Transfer through Tie –Line

In this modelling, power flow from area1 to area 2 so for area power is P_1 AND power of area is P_2 and power flow from control area 1 to 2 so power is P_{12}

So power flow

$$P_{12} = \frac{\varepsilon_1 \varepsilon_2}{X_T} \sin(\delta_1 - \delta_2) \tag{2.12}$$

ε_1 = magnitude of voltage of area 1

ε_2 = magnitude of voltage of area 2

X_T = reactance of tie line

Let us assume that system is in steady state with voltage –

$$\overline{\varepsilon_1} = \varepsilon_1 \angle \delta_{10} \text{ And } \overline{\varepsilon_2} = \varepsilon_2 \angle \delta_{20} \tag{2.13}$$

$$\text{So } P_{120} = \frac{\varepsilon_1 \varepsilon_2}{X_T} \sin(\delta_{10} - \delta_{20}) \tag{2.14}$$

Now following change in load

$$P_{120}+\Delta P_{12} = \frac{\varepsilon_1\varepsilon_2}{X_T}\sin[(\delta_{10}+\Delta\delta_1)-(\delta_{20}+\Delta\delta_2)] \quad (2.15)$$

After solving this equation

$$\Delta P_{12} = \frac{\varepsilon_1\varepsilon_2}{X_T}\cos(\delta_{10}-\delta_{20})\,\Delta\delta_{12} \quad (2.16)$$

Where T = $\frac{\varepsilon_1\varepsilon_2}{X_T}\cos(\delta_{10}-\delta_{20})$ = synchronizing torque coefficient

$$\Delta P_{12} = \text{T}.\,\Delta\delta_{12} = \frac{W_0 T}{S}[\Delta W_{r1}(s)-\Delta W_{r2}(s)] \quad (2.17)$$

For area 1 -

$$\Delta F_{SS} = \frac{-\Delta P_{L1}}{D_1+\frac{1}{R}} = \Delta F_1 \quad (2.18)$$

$$\Delta P_{L1} = -\frac{\Delta F_1}{R_1} - D_1 - \Delta P_{12} \quad (2.19)$$

As for area 2 –

$$\Delta F_{SS} = \frac{-\Delta P_{L2}}{D_2+\frac{1}{R}} = \Delta F_2 \quad (2.20)$$

$$\Delta P_{L2} = -\frac{\Delta F_2}{R_2} - D_2 + \Delta P_{12} \quad (2.21)$$

So there is an incremental power increase due to change in load demand followed by rise in frequency.

If two isolated area connected through the tie-line so its help the in power sharing when disturbances occurs. And in secondary control action control other control area do not share their power to demand area. So area control error value should be zero of concerned area.

Let

ACE_1 = Area Control Error of Area 1

ACE_2 = Area Control Error of Area 2

For area 1 = $\Delta P_{L1} = -\frac{\Delta F_1}{R_1} - D_1\Delta F - \Delta P_{12}$ (2.21)

As same as for area 2 = $\Delta P_{L2} = -\frac{\Delta F_2}{R_2} - D_2\Delta F + \Delta P_{12}$ (2.22)

Suppose that there is change n load only in area 2

ΔP_{12} = -$\left(\frac{1}{R_1} + D_1\right)\Delta F$ = -$\beta_1.\Delta F$ (2.23)

ΔP_{L2}= -$(\beta_1 + \beta_2)\Delta F$ (2.24)

AND $\Delta F = -\frac{\Delta P_{L2}}{(\beta_1+\beta_2)}$ (2.25)

To ensure the above requirement AGC uses a control signal called area control error-

$ACE_1 = -\Delta P_{12} - \beta_1\Delta F$ (2.26)

$ACE_2 = -\Delta P_{21} - \beta_2\Delta F$ (2.27)

These signal are implemented in governor control of both areas.

3.10 CONCLUSION

A comprehensive study has been done in this chapter. In this chapter a part of power system has been described. In the dynamics of power system generator work and turbine work has been studied. For better understanding of AGC in this chapter use of tie line and parallel operation has been studied. Modelling of tie line and LFC has been done in this chapter. In the modelling of tie line working of tie line how the tie line works in the context of automatic generation control has been described. In the modelling of area control error working of ACE has been explained.

CHAPTER 4

OPTIMIATION ALGORITHMS

4.1 INTRODUCTION

Optimization algorithms can play a crucial role in order to make right solution for optimization problem. And also due to diversity of optimization the choice of optimization is very important and also it is defined by low and high bounds. Objective function can be linear or nonlinear. Variables can be discrete and continuous in nature. These nonlinear equation cannot be solved properly without technique. It became more difficult to solve problem. Optimization techniques are mainly classified mainly as local optimization problem or global optimization problem. Local optimization algorithms are based on gradient information.to find the solution of objective function these type of algorithms used gradient information for solving the problem.

After local optimization algorithm to find the more accurate result of objective function have been used in optimization problem. Global optimization algorithms given much better result or solution to find the minimum value of objective function. Although optimization technique doesn't give certainty to find the exact minimum value of the problem but it gave more and more accurate point nearer the minimum value of any problem.

Global optimization algorithm can be classified as evolutionary or deterministic algorithms. In evolutionary optimization algorithms have been used more frequently for last decays. In evolutionary algorithms to find the best solution of any objective function make use of set of population or group of data rather than gradient information used in local optimization algorithms. Evolutionary algorithms have been used in this work. Evolutionary algorithms like genetic algorithms (GA)], particle swarm optimization algorithm (PSO), water cycle algorithms (WCA) have been used for optimize the objective function used in load frequency control[41].

4.2 GENETIC ALGORITHM

For many problems we are not able to construct an algorithm for searching a solution step by step and choosing the best one, but very often we can specify the set of potential solutions. Goal of strategy is searching and analyze elements of set in order to fix the best one. It is easy for small sets but if set increases it becomes more and more complicated or impossible. One of the most advanced and very modern searching methods are genetic algorithms.

Genetic algorithms are stochastic global methods based on the mechanics of natural genetics and natural selection. They are basically iterative methods that are widely used in several branches of science and technologies for optimization problems.

In genetic algorithm methodology, for each iteration (generation), not only one point in the search space is taken into account but a set of solutions defining a population of individuals is considered. The individuals are ranked according to the solution that each one can lead to.

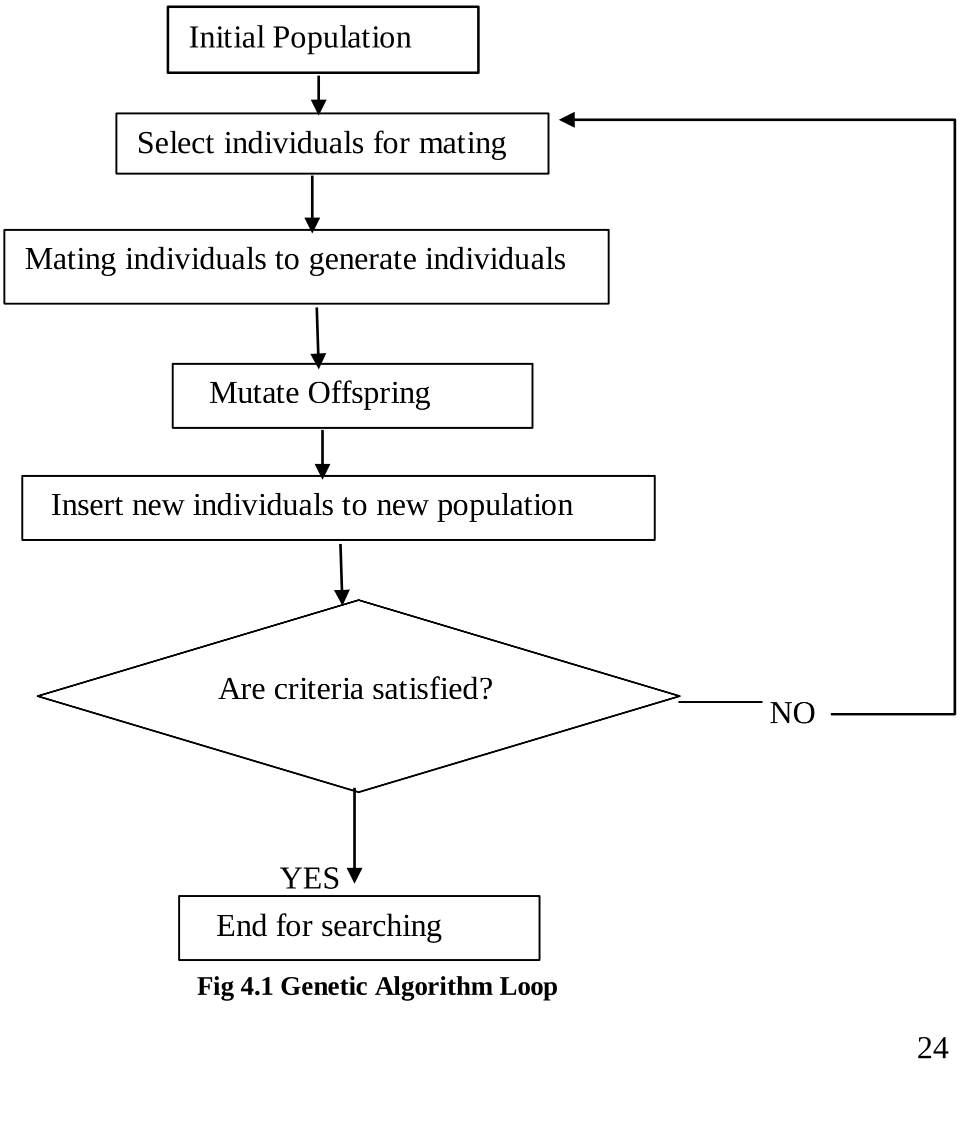

Fig 4.1 Genetic Algorithm Loop

From Fig.4.1 the loop is closed. Replication for choosing the best individual start at the base point. The selection of chromosomes is random; however it is strongly directed for choosing the best individual for reproduction. In usual practice it is required to terminate the GA after number of generations and then test for quality of best number of population against the problem definition. GA may be restarted again if no acceptable solution is found.

4.2.1 Genetic Algorithm Operations

A) Selection

The purpose of the parent selection in GA is to give more reproductive changes to those individuals that are fit.

The commonly used technique to do this process is RWS (roulette wheel parent selection) which includes the following steps:

i) Creating the net total fitness by summing the fitness of all population members.

ii) Generating a random number n, between 0 and total fitness.

iii) Returning the first population members whose fitness added to the fitness of the preceding population members is greater or equal to n.

The effect of roulette wheel parent selection is to return a randomly selected parent. Using this selection algorithm, each parent's selection chance is directly proportional to the fitness.

B) Crossover

The basic operator for producing new chromosomes in GA is crossover. Crossover produces new individuals which has some traits of both parents as exist happens in nature. There are various types of crossover for example: single point, dual-point, multipoint, uniform, shuffle, asexual crossover and single child crossover. Fig.4.3 shows the single-point crossover which is the simplest form of crossover.

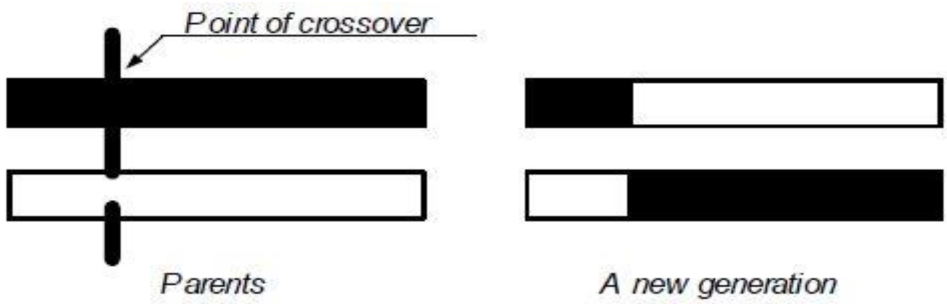

Fig 3.2 Single point Crossover

C) Mutation

Mutation causes the change in the genetic representation according to probabilistic rule. In the binary string representation, mutation causes the random bit to change its state (i.e from 0 to 1 or 1 to 0). In natural evolution, mutation is applied with very low probability, typically in the range 0.001 and 0.01 and modifies the elements in the chromosomes. It is possible that a given binary string may be mutated at more than one point if it is given that mutation is generally applied uniformly to an entire string.

PLACE OF MUTATION

ORIGINAL STRING: 0 1 0 1 0 1 1 0

MUTATED STRING: 0 1 1 1 0 1 1 0

Fig 3.3 Binary Mutation

D) Reinsertion

Once the selection and recombination of the individuals from the old population have produced a new population, the fitness of the population individuals in the new population may be determinate. If fewer individuals are produced by recombination as compared to the size of the original population, the fractional difference between the new and old population size is called or termed as generation gap.

In order to maintain the size of the original population, the reinsertion of the individuals into the old population is done. Similarly if the size of the offspring is large as compared to original population then a reinsertion scheme must be used to determine which individuals are to exist in the new population. During selection of which member of the old population is relocated, the most apparent strategy is to replace the least fit member of the old population deterministically. The replacement should select and replace the oldest members of the population.

4.2.2 The Objective Function Of Controller Tuning

The most crucial step in application of GA is to choose the objective functions that will be used to evaluate the fitness of each chromosome. To optimize the performance of PID, the PID gains must be adjusted to minimize or maximize the certain performance index. The performance index is calculated in the region 0 < T < t, where 'T' is time interval of performance index calculation and 't' is settling time of the system.

The performance indexes are:

1) ITAE (Integral of Time multiply Absolute Error)

$$\int t|e(t)|dt$$

2) IAE (Integral of Absolute Error)

$$\int |e(t)|dt$$

3) ISE (Integral of Squared Error)

$$\int e^2(t)dt$$

4) ITSE (Integral of Time multiply Squared Error)

$$\int te^2(t)dt$$

4.3 PARTICLE SWORM OPTIMIATION

The proposed PSO algorithm is a new method discussed in the project work. Taking the flaws of basic PSO into consideration, Proposed PSO is developed and implemented on mathematical test functions as well as on economic load dispatch. Though basic PSO is efficient and can be implemented to optimize any objective function. But the BPSO algorithm has a small probability to get stuck at the local minimum point in place of the global minimum point. Also, it has been seen that particles converge faster and reaches an optimum point but have higher velocity even when it is about to reach the optimum point. It leads the algorithm to perform more number of iterations than required to reach the optimum point. Also, the time consumed will be more[42].

Therefore, a retardation factor has been introduced which is to be multiplied with the velocity after a certain number of iterations. Concept of NFEV is introduced in our thesis work, which gives us information about how many times a function is evaluated. This process includes the evaluation of function for each particle's every iteration, personal best, and global best position. It has played a significant role in proving how the proposed PSO algorithm is better than the basic PSO algorithm. The proposed PSO algorithm is implemented on mathematical test functions to check the convergence and accuracy of the algorithm. After getting better results than the BPSO, it is implemented on the economic load dispatch problem. In the case of economic load dispatch, the main objective is to optimize the fuel cost function. Therefore using the proposed PSO algorithm we have optimized the fuel cost function.

Optimization is the simple action t make the best utilization of any resources. Thus optimization should be done for each entities in power system to increase efficiency. Particle swarm optimization is nature based swarm based algorithm is based on a model of interaction between agents and swarm intelligence to get maximum and minima of a fitness function. In particle swarm optimization algorithm no. of particle or entities are placed in a space of as cost function. During first iteration all of particles are evaluate by cost function[43]. After evaluate the each particle P_{Best} and G_{Best} are to be find out. If current fitness value is better than previous value then current value of is the new $P_{Best..}$

Chooose the particle with the best fitness value of all particle as the $G_{best.}$ For each particle calculate particle velocity and particle position.

1. The objective function to be minimized is defined.
2. Input the maximum number of iterations, swarm size, social acceleration coefficients C_1 & C_2, r_1& r_2, tolerance value and retardation factor.
3. Initialize the variables like position, the velocity of particles as well as the NFEV.
4. Define the search space for the variables. Random initial values are selected using unifrnd and rand. These two functions generate uniformly distributed and randomly distributed numbers respectively.
5. The function value for each particle in swarm using the objective function is calculated.
6. After calculating the value of the objective function for each particle, P_{best} and G_{best} of particles are found out.
7. Best position of a particle for which the value of the objective function is optimized, known as the personal best position.
8. The best value among all the personal best positions is known as the global best position.
9. The position and velocity of each particle are updated using the position and velocity update equations.

$$V_j(i)=w * V_j(i-1)+C_1r_1\left[(P_{best})j - x_j(i-1)\right] + C_2r_2[G_{best}(i-1)]$$
$$x_j(i) = x_j(i-1) + V_j(i)$$

10. A retardation factor is multiplied with the velocity of the particle for the next iteration. It will reduce the velocity of each variable's particle and reduce the number of iterations to reach the optimum point.
11. $V_j(i)$ = retardation factor * $V_j(i-1)$.
12. This process is repeated for several iterations until the stopping criteria are met.
13. If the personal best position at present iteration is better than the personal best position at the previous iteration then the present value will be set as a new P_{best} position.

14. Similarly, if the global best position at present iteration is better than the global best at present iteration then the present value will be set as a new G_{best} position.
15. The New G_{best} position of the particle will give the optimum point of the objective function.
16. If stopping criteria is satisfied, display the value of the number of function evaluations, the minimum value of the function at the global optimum point.
17. Display the time consumed to optimize the function and number of iterations performed.
18. The plot of each particle is traced in search of a global optimum point.
19. The plot between the function value of the objective function and the number of iterations is also traced.

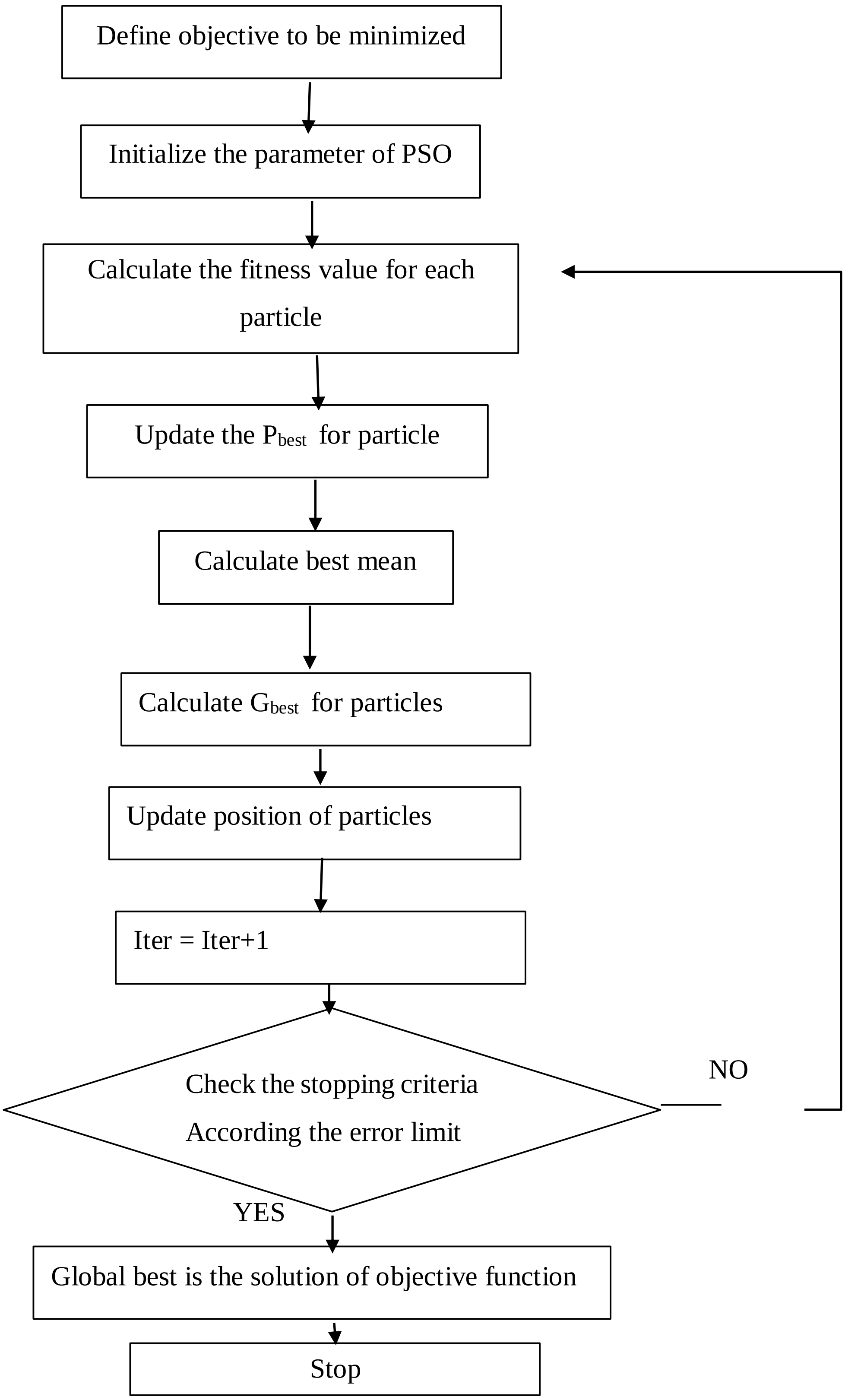

Fig 3.4 flow chart of PSO

4.4 WATER CYCLE ALGORITHM

WCA algorithm is a novel met heuristic algorithm for optimizing the any problem. Water cycle algorithm is based on a real life water cycle process that means how river or stream is created and hoe they flow after created to sea. WCA is based on natural process based algorithm how river and stream flow to sea to get optimize solution or optimize point. And to avoid local minima how the evaporation process work from the river and sea[44]. After evaporation of water its form clouds in atmosphere. They get condenses in colder region of atmosphere and coming back to earth in the form of raindrops as shown in fig 3.4.

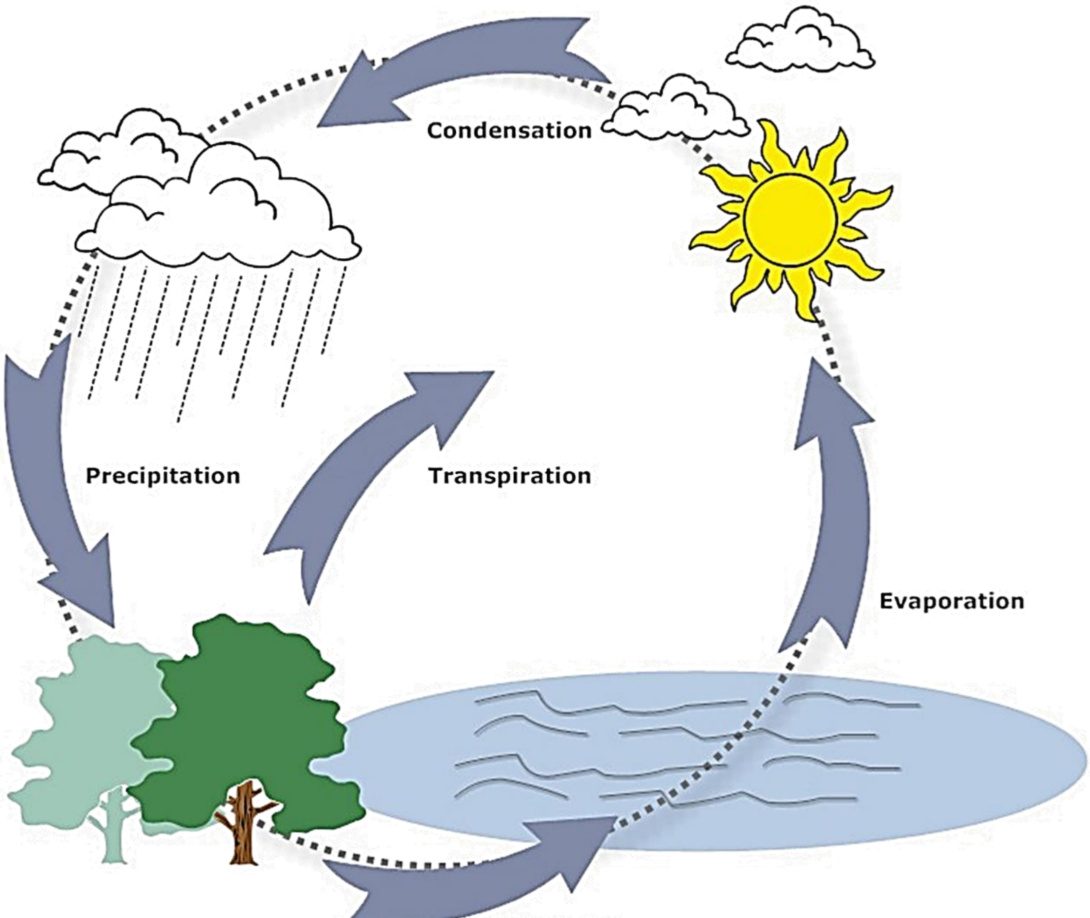

Fig 3.5 Water Cycle Process

.

WCA is also a nature based algorithm. In the proposed WCA as its starts with initializing the parameter of algorithm as population. In WCA population is defined by the raindrops. So from raindrops population best raindrops is selected as sea. After this another best category is selected as river. After all this part the remaining drops is selected as stream. Depending upon the value of drops flow of river to sea and stream to river has been decided. How the stream flow to river and river flow to into the sea is explained further[45].

To provide a solution of optimization problem like other algorithm WCA have defined problem variables and this is formed as an array. In water cycle algorithm problem variables chosen raindrop. And it's formed as an array. This array is defined as

$$\text{Raindrop} = [X_1\ X_2\ X_3\ X_4\ X_5 \ldots\ldots..X_N\ ] \tag{3.1}$$

The cost value is determined each raindrop by objective function.

$$C_i = Cost_i = f(X_1^i\ X_1^i\ X_1^i \ldots .X_{Nvar}^i)\quad i = 1, 2, 3, \ldots..N_{pop} \tag{3.2}$$

Where

N_{pop} = population of raindrops

N_{var}= problem variables

After evaluating the cost value of each raindrop the minimum value of cost function selected as sea and river. The minimum value of among the all raindrop considered as sea.

N_{sr} = No. of rivers +1(sea)

to calculate the

Define the raindrop as a river or as a sea is depending on the intensity of flow.

$$NS_n = round\{\left|\frac{C_n}{\sum_{i=1}^{N_{SR}} Cost_i}\right| \times N_{Streams}\} \quad , \quad n = 1, 2, \ldots, N_{SR} \tag{3.3}$$

4.4.1 HOW DOES A STREAM FLOW TO THE RIVER OR SEA

As discussed earlier streams created from raindrops and more than one streams join each other to form a river and some of the drops are join the sea to get a best optimal solution. Steam and river is connecting through a line between them as a random chosen distance[46].

$$X \in (0, C \times d), C > 1 \quad (3.4)$$

Where C is value between 1and 2. The best value of C is near 2. d is the current distance between river and sea. To flow of stream in to river value of c must be greater than 1. This equation is valid same for river and sea. So new position of river and sea is given as

$$X_{stream}^{i+1} = X_{stream}^{i} + rand \times C \times (X_{river}^{i} - X_{stream}^{i}) \quad (3.5)$$

$$X_{river}^{i+1} = X_{river}^{i} + rand \times C \times (X_{sea}^{i} - X_{river}^{i}) \quad (3.6)$$

Where

Rand = uniformly distributed number (0< rand > 1)

If the solution of stream is better than the river than stream can Convert River and river become stream and this process can also be happen in river and sea as shown in fig.

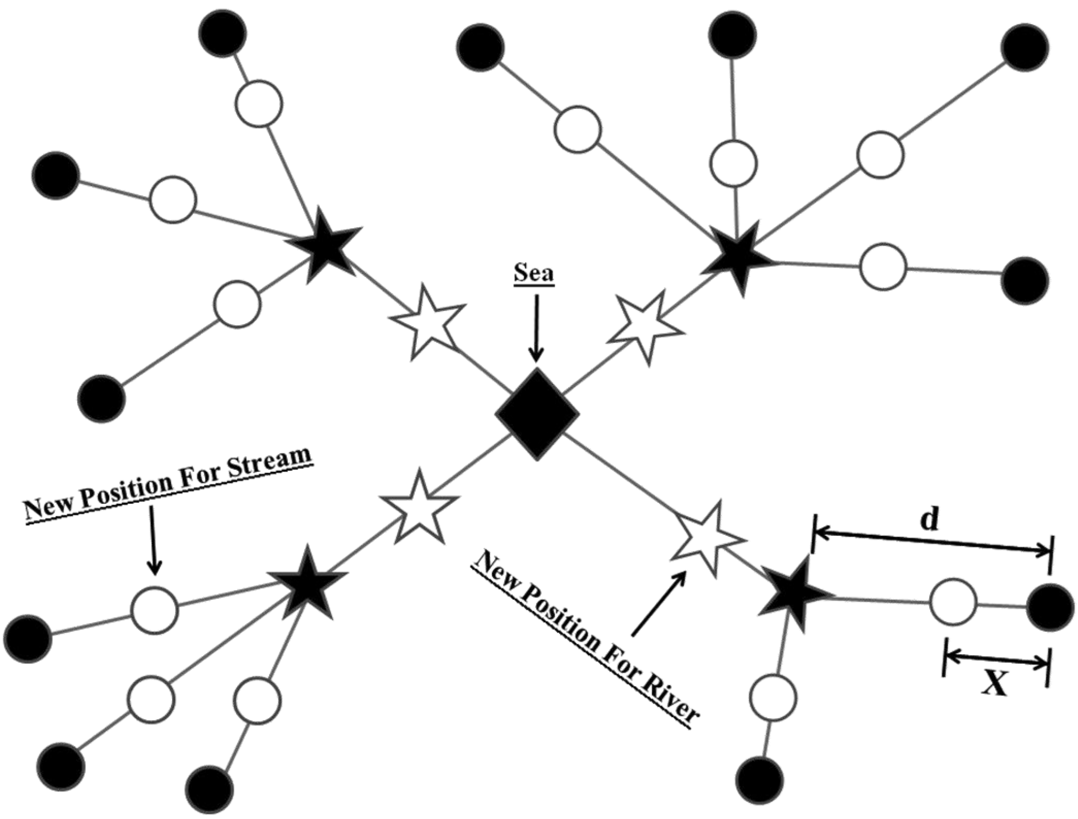

Fig 4.6 Process of WCA

4.4.2 EVAPORATON CONDITION

Convergence problem occurred in optimization algorithm while solving the optimize problem. In WCA to avoid this kind of problem evaporation is main factor. Water evaporates through the river and stream and then ita convert into clouds and condenses in atmosphere of cold.

And return back to earth in form of rain. To avoid to get local minimum the assumption has made that sea water evaporates.these equation can be given idea whether river flow to seaor not.

If $X_{sea}^{i} - X_{river}^{i} < d_{max}$ i = 1, 2, 3 …….$N_{sr} - 1$ then evaporation and raining process end. In this equation d_{max} is least value number. So

If the distance between river and sea is less than d_{max} the after some time evaporation process starts.

And if the value of d_{max} is grater then it's decrease the possible solution nearer the optimum point. So d_{max} is deciding factor for solution and evaporation process. The value of d_{max} should be minimum as much possible.

$$d_{max}^{i+1} = d_{max}^{i} - \frac{d_{max}^{i}}{\max iter} \tag{3.7}$$

4.4.3 RAINING PROCESS

After the completion this process due to evaporation newly raindrop has been formed. This cycle repeats as previous as stream convert the river and river convert the sea. So to identifying newly raindrop the equation has been used –

$$X_{Stream}^{New} = LB + rand \times (UB - LB) \tag{3.8}$$

Flow chart of proposed WCA has been presented in the in fig. 3.5.

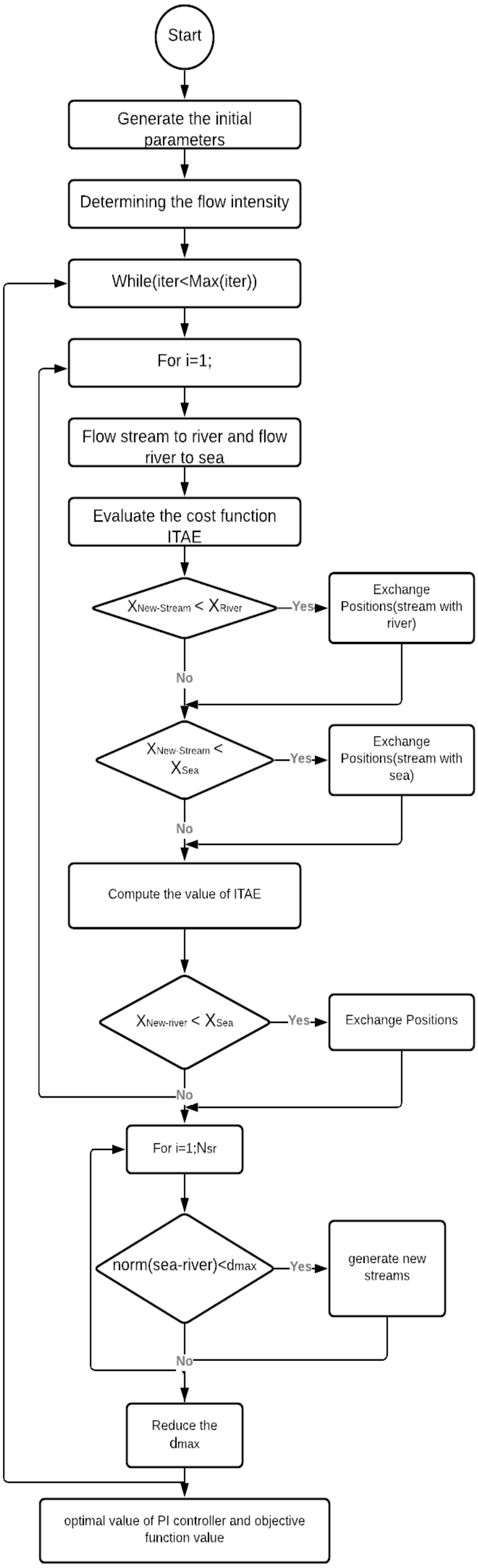

Fig 3.7 Water Cycle Process

4.5 CONCLUSION

In this chapter three different algorithm have been discussed. Firstly algorithm genetic algorithm (GA) has been used to for optimization. Second algorithm particle swarm optimization (PSO) and water cycle algorithm have been discussed. In this unit basic brief about algorithm have been discussed. Procedure of optimization algorithm have been discussed through flow chart for each optimization. With the help of these algorithms LFC has been analyzed. In next chapter comparison of all three algorithm have been published. From the results it clearly shows that WCA algorithm is better performance compare to others.

CHAPTER 5

PERFORMANCE COMPARISON OF GA, PSO AND WCA FOR THREE AREA INTERCONNECTED LOAD FREQUENCY CONTROL SYSTEM

5.1 INTRODUCTION

In this emergent power scenario, it is absolutely a challenge for electric suppliers to deliver safe and sound electric power to meet the demands of consumers. In the enormous generating stations exchange of bulk amount of power has been done by the help of tie-lines. It is a very hard-hitting job of power system to stay within stability by balancing between whole produced and demanded power simultaneously. Automatic generation control is answerable for upholding the basic constraints within the accepted range by following the active power and reactive power stability mechanism. Conventional technologies alone are not enough to react rapidly against the intolerable power fluctuations. Area controller error (ACE) conveys to zero by appraising net variation in the required generation to protect and restore the equilibrium state of the system with an economical manner. In this chapter three non reheat thermal power is presented. In this three area is interconnected through the tie line. Advantage of tie line has been discussed previously. To see the effect of frequency deviation if three area connected has been observed. To control the area FOPI controller has been used as an area controller.

Further, organization of rest of the paper is as follows: Section II describes the FOPI controller structure, Section III presents the description of three area interconnected LFC system, Section IV presents the results obtained in this study and Section V concludes the paper with possible direction for future work.

5.2 FOPI CONTROLLER

In recent years, fractional order calculus has gained lot of attention due to its improved performance over integer powered calculus. Based on this motivation a new kind of controllers have been developed named as fractional order controllers. In this section a brief about FOPI controller has been presented.

At first researcher Podunk introduced the methodologies of the robust FOPID controller into the research work. The integral part and derivative part of the FOPID controller does not belongs to the integer, which makes this subjected controller very efficient and dynamic as compare to PID controller. Presence of additional optimization algorithms enhances the beauty of FOPI controller. Therefore, traditional proportional, integral gains are tuned along with the integral order {λ}. In the fractional order control system, researchers mostly preferred the Caputo's fractional differentiation expression. The explanation of fractional order derivative controller is usually employed to find out transfer function models of fractional calculus out of fractional order usual differential equations having zero initial situations.

Mathematical equation of the FOPI controller can be given by –

$$G_C(s) = K_p + \frac{K_i}{S^{\lambda}} \quad (4.1)$$

Depending upon the value of the λ, the FOPI controller can also work as a PI controller. To obtain PI controller, the value of λ must be 1. In this work, FOMCON toolbox has been used in order to implement the FOPI controller in SIMULINK.

5.3 PLANT DESCRIPTION

A multi-area network comprises of more than one interconnected area. A basic three equal areas non-reheat based power system with its transfer functions are modelled for investigation. In this section, description of various components of the plant has been provided.

5.3.1 PLANT MODEL

Each area involves of a governor, a generator, a turbine and speed governing system., we have to find out the ratio of the output of Laplace transform to the inputs of Laplace transform in order to find out the transfer function.

The Laplace transfer function of governor output response ΔP_G is defined as

$$\Delta P_G = \Delta P_{ref}(s) - \frac{1}{R}\Delta F(s) \tag{4.2}$$

The Laplace transfer function for governer is given by Eq. (3) as follows:

$$G_G(s) = \frac{\Delta P_V(s)}{\Delta P_G(s)} = \frac{1}{1+T_G(s)} \tag{4.3}$$

Transfer function of the non-reheated turbine is given by Eq. (4)

$$G_T(s) = \frac{\Delta P_T(s)}{\Delta P_V(s)} = \frac{1}{1+T_T(s)} \tag{4.4}$$

In generator, variation within the increments in power demand and generated turbine power assists as input and the output signal is formed by using the following transfer function

$$\mathrm{G_p}(s) = \frac{\mathrm{K_{ps}}}{\mathrm{T_p}\, s+1} \tag{4.5}$$

A non-reheat three multi area interconnected networks is modelled to investigate the load frequency control. The appropriate parameters with their corresponding values of all the components are presented in Table 1.

TABLE NO. -4.1 NOTATION USED IN THE TABLE

Parameter Symbol	Parameter Name	Value
B	Frequency bias parameter	0.425
K_{pm}	Gain of electric power system (p.u, MW)	120
T_G	Time constant of governor (s)	0.08
T_T	Time constant of non-reheat turbine(s)	0.3
T_p	Time constant of electric power system(s)	20
R	Speed regulation	2.4
ΔP_L	Disturbance in load	
ΔP_g	Incremental variation in governor input	
ΔF	Incremental fluctuations in system frequency (Hz)	
ΔP_v	Incremental variation in governor valve location	
ΔP_m	Incremental variation in turbine output (p.u, MW)	

Figure 1 shows the SIMULINK model of three area interconnected thermal power system with non-reheated turbines. Step load disturbance (ΔP_L) has been added into each area. For the simulation purpose, load disturbance was provided at the same time in each area.

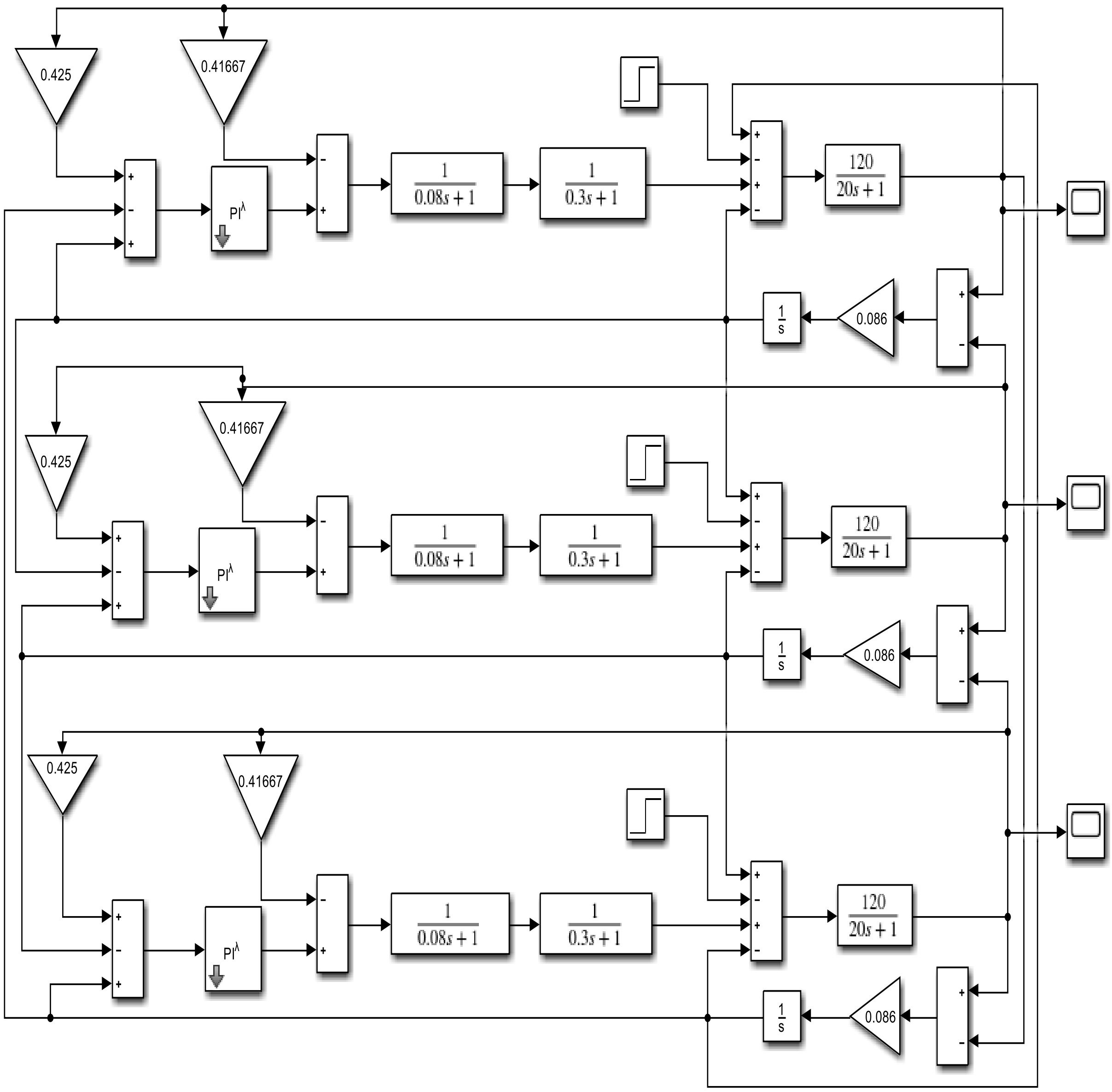

Fig 4.1 SIMULINK Model Of Three Area Inter Connected Thermal Power System

5.3.2 OBJECTIVE FUNCTION

Optimization algorithms use objective or cost function in order to tune the parameters of the underline controller. They tried to minimize the value of objective function and then in return response of the system become better. In this work ITAE objective function is used which incorporate controller error, area frequency deviation and tie power. Mathematical equation of the objective function is given by Eq. (6)

$$ITAE = \int_0^t \left(\sum_{i=1}^{n} \left(|e_i| + |\Delta F_i| + |\Delta P_{tie_i}| \right) \right) . t . dt \qquad (6)$$

Where, n is the no. of areas, e_i is the error input to the controller, ΔF_i is the area frequency deviation and ΔP_{tie_i} is the change in tie power for each area.

5.4 RESULT AND DISUSSION

In this section, results obtained from simulation study of three area interconnected LFC system has been presented. For this study MATLAB/SIMULINK© was used. ODE 45 solver was used in SIMULINK for the simulation purpose. Further, personal computer with 8GB RAM, WINDOWS 10, INTEL i3 processor was used.

5.4.1 OPTIMIATION ALGORITHM RESULT

GA, PSO and WCA algorithms were run with same parameters in order to do comparison among them. Details of the various optimization parameters used in this study are given in Table II. All optimization algorithms were run with the population size of 50 and for 50 iterations. As discussed in earlier section there are three FOPI controllers for each area and hence there are total 6 gain parameters named as $K_{p1}, K_{i1}, K_{p2}, K_{i2}, K_{p3}, K_{i3}$ and 3 integrator order parameters named as $\lambda_1, \lambda_2, \lambda_3$. Lower bound (LB) and upper bound (UB) for the gain parameters were chosen as -2 and + 2 respectively. LB and UB for integrator order were chosen as 0 and 2 respectively.

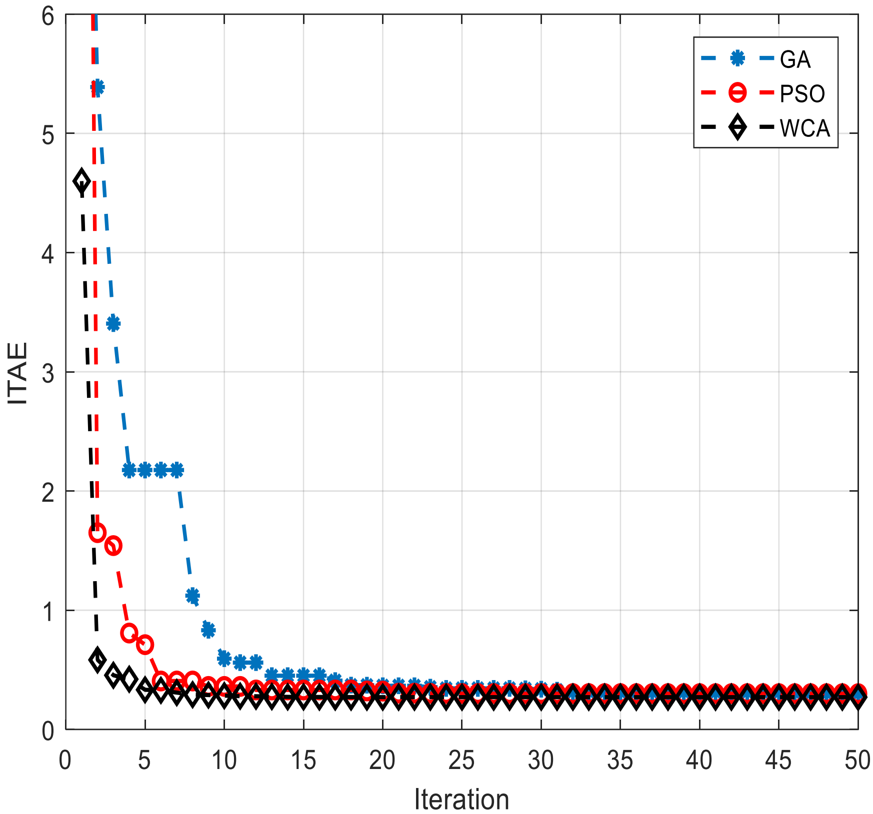

Fig 4.2 Optimization convergence curve for GA, PSO and WCA

TABLE NO. -4.2 OPTIMIATION PARAMETER

Sr. No.	Optimization Parameter	Value
1	Population Size	50
2	Iterations	50
3	Lower bound	-2 for Gain Values 0 for integrator order
4	Upper bound	2 for Gain Values 2 for integrator order

Fig. 2. shows the optimization convergence curve for all three GA, PSO and WCA optimization algorithms. From the Fig. 2, it is very much clear that WCA outperforms GA and PSO in terms of convergence. WCA took around 5 iterations only to get minimum ITAE value while GA took around 25 iterations to reach upto that level. PSO performed in between GA and WCA as it took around 15 iterations to converge at minimum value of ITAE objective function. Table III presents the optimized values of three FOPI controller parameters along with minimum ITAE obtained using optimization algorithms. From the Table III it is clear that WCA algorithm gives minimum ITAE value as 0.2706.

TABLE NO.-4.3 FOPI CONTROLLER PARAMETER VALUE

Parameter Name	GA	PSO	WCA
K_{p1}	-1.595	-1.684	-1.231
K_{i1}	-1.862	-2.000	-2.000
K_{p2}	-1.443	-1.681	-1.009
K_{i2}	-1.308	-1.995	-1.297
K_{p3}	-1.533	-1.683	-1.231
K_{i3}	-1.898	-2.000	-2.000
λ_1	1.457	1.420	1.388
λ_2	1.007	1.421	0.982
λ_3	1.416	1.420	1.388
ITAE	0.3046	0.3003	0.2706

5.4.2 LFC RESULTS FOR EACH AREA

The three area LFC system was simulated with step load disturbance of 0.01p.u. in each area at the same time. By this, performance of the proposed FOPI controller can be judged effectively. Optimized FOPI controller parameters were used to obtain the frequency deviation result for each area. Fig. 3 – Fig. 5 shows the frequency deviation curve for area 1, area 2 and area 3 respectively. All graphs have been color coded in order to distinguish between the responses between optimization algorithms. From these figures, it is clear that WCA optimized parameters performs better that GA and PSO.

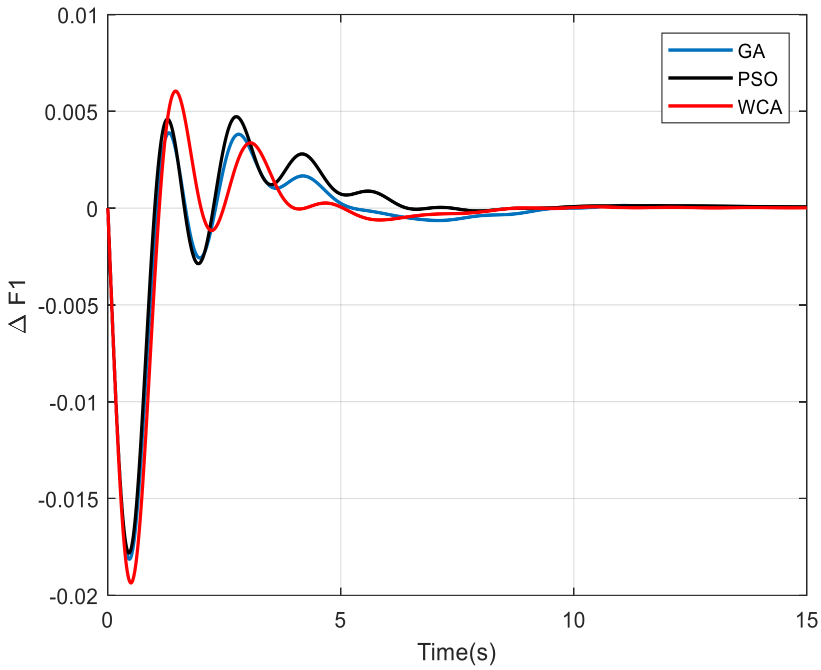

Fig 4.3 Frequency Deviation for Area 1

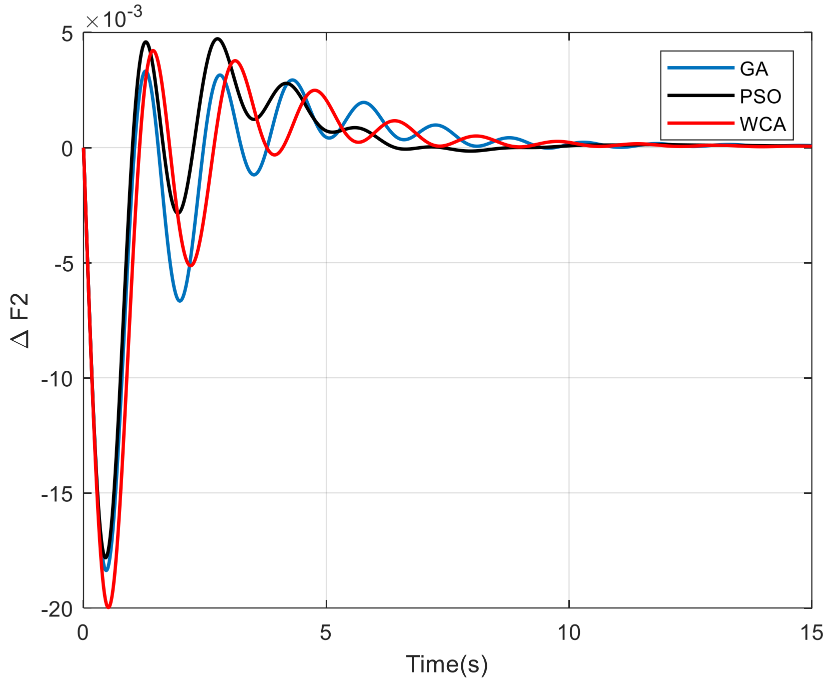

Fig 4.4 Frequency Deviation for Area 2

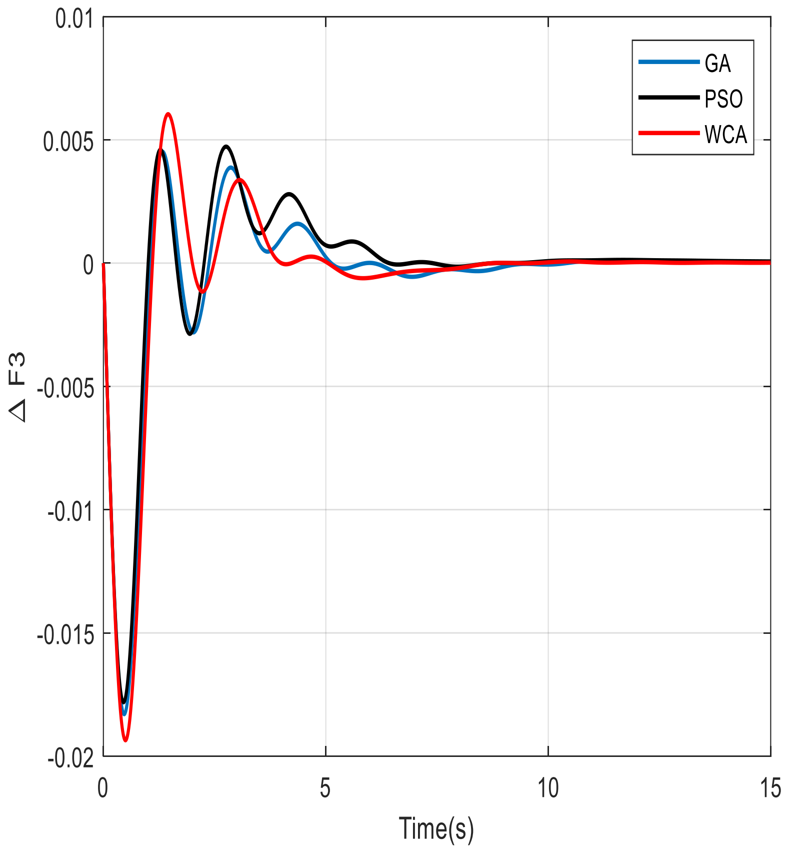

Fig 4.5 Frequency Deviation for Area 3

5.5 CONCLUSION

In this paper, three area interconnected thermal power system has been simulated with non-reheated turbine. Fractional order PI (FOPI) controllers were used as an area controller in order to minimize the effect of load variation in any area on the generated power frequency. Three optimization algorithms namely GA, PSO and WCA were used in order to optimize the parameters of FOPI controllers.

Further performance comparison between these three algorithms shows that WCA gives better optimized parameters and that too in lesser no. of iterations. In future work authors will try to do the similar comparison between optimization algorithms for power system with different kind of energy generation systems.

CHAPTER 6

FREQUENCY ANALYSIS OF MULTI –SOURCE SINGLE AREA POWER SYSYTEM USING WCA ALGORITM

6.1 INTRODUCTION

The interconnection of sources and loads and various facilitating apparatus is called as power system. The limiting of generating stations/sources leads to coupling of several of generators. Sources are being connected to load centers through as mesh of transmission line. As these generators have economically restraints because of which generators are coupled through tie –lines. Tie –lines provide support between the areas for energy exchange during abnormal condition. Tie –lines are used for contractual energy exchange between different areas.

In this chapter three single different different power system has been taken for study purpose. One is non reheat thermal power system has been taken rather than non reheat to see the effect of this to gain value of system. Second is hydro thermal is taken and third is gas power plant has been taken. Motive of taken three different power system is that to see the effect of frequency deviation when any disturbances occurs.

In previous chapter three same non reheat power system have been taken to study the behavior of frequency when load demand increases simultaneously at all area. From the figure its clearly see the difference of algorithm that applied on same power system. so in this chapter WCA algorithm has been applied for optimize the parameter the objective function. PI controller has been used as an area controller I all three power system. Unit step used as load demand increase. Transfer function of all three power system has been presented. Algorithm used in this chapter has been described earlier in previous chapter.

6.2 PI CONTROLLER

Proportional integral controllers are widely used in industries because of their easy design, low cost and simple structure. It eliminates the forced oscillations and steady state error. Proportional controller does not have the means to predict what will happen in near future, so proportional integral controller will not increase the speed of the response. Introducing derivative mode in existing proportional integral controller configuration the problem of fast response is solved since proportional integral controller now gets the ability to predict error in near future and accordingly decreases the reaction time. In industries where speed of the response is not a major problem the PI controller finds its wide use[47].

The output produced by this type of controller is the actuating signal that is input to the plant, which regulates the output of the system depending upon the error signal input to the proportional integral controller. Error signal is “set point – measured value” where set point is reference value that is needed at the output and measured value is instantaneous output value of the plant.

In PI controller term P is proportional to the current value of the error signal. If the error signal is large and positive, the control output will be proportionately large and positive depending upon the gain factor K_p. Proportional control alone requires an error to generate the proportional response. If there is no error there will be no corrective response. Term I accounts for the past values of the error and integrate them over period of time to produce integral term. For example if there is residual error after the application of the proportional control, the integral control will try to eliminate the residual error by adding he control effect due to historic cumulative value of the error. The integral term will cease to grow when the error is eliminated, this will result in diminishing the proportional effect as the error decreases.

Mathematical equation of the PI controller can be given by (1).

$$G_C(s) = K_p + \frac{K_i}{s} \quad (5.1)$$

From the figure it's clearly see that how a controller work in automatic generation control.

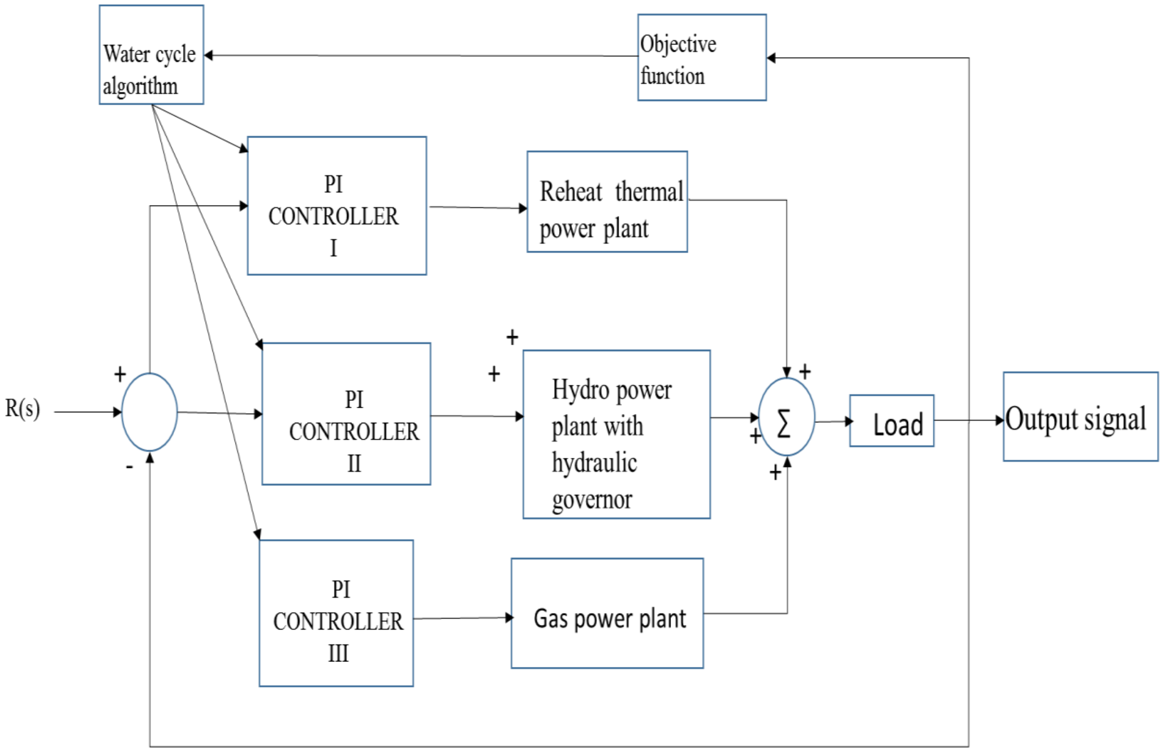

Fig 5.1 WCA Based PI Controller

6.3 PLANT DESCRIPTION

In this paper a multi-source single area power system is considered for load frequency control. In this work a LFC model with three multi-Source name as reheat thermal plant, hydro plant and gas turbine with mechanical hydraulic governor have been used. Basically multi-source single area with its different transfer function are modelled.

6.3.1 PLANT MODEL

Multi-source single area consists of governor, reheat turbine, generator, and speed governing system. Transfer function is found with the help of ratio of Laplace transform.

The Laplace transfer function of governor output is defined as

$$\Delta P_G = \Delta P_{ref}(s) - \frac{1}{R}\Delta F(s) \tag{5.2}$$

The Laplace transfer function of governor is as follows –

$$G_G(s) = \frac{\Delta P_V(s)}{\Delta P_G(s)} = \frac{1}{1+T_G(s)} \tag{5.3}$$

Laplace function of the reheated turbine is given by Eq. (5.4)

$$G_T(s) = \frac{\Delta \mathrm{P_T(S)}}{\Delta \mathrm{P_V(S}} = \frac{\mathrm{K_T}}{1+\mathrm{ST_T}} \times \frac{T_T(s).c+1}{T_T(s)+1} \tag{5.4}$$

The Laplace transfer function of hydro governor power system is given by Eq. (5.5)

$$G_{GH}(s) = \frac{\Delta \mathrm{P_T(S)}}{\Delta \mathrm{P_V(S}} = \frac{\mathrm{K_T}}{1+\mathrm{ST_T}} + \frac{T_T(s).c+1}{T_T(s)+1} \tag{5.5}$$

The Laplace transfer function of hydro turbine power system is giver by Eq. (5.6)

$$G_T(s) = \frac{\Delta \mathrm{P_T(S)}}{\Delta \mathrm{P_V(S}} = \frac{-T_T(s).+1}{T_T(s)(0.5)+1} \tag{5.6}$$

In generator, variation within the increments in power demand and generated turbine power assists as input and the output signal is formed by using the following transfer function

$$\mathrm{G_p}(s) = \frac{\mathrm{K_{ps}}}{\mathrm{T_p}(s)+1} \tag{5.7}$$

SIMULINK model of single area multi source network is designed and is shown in figure 1

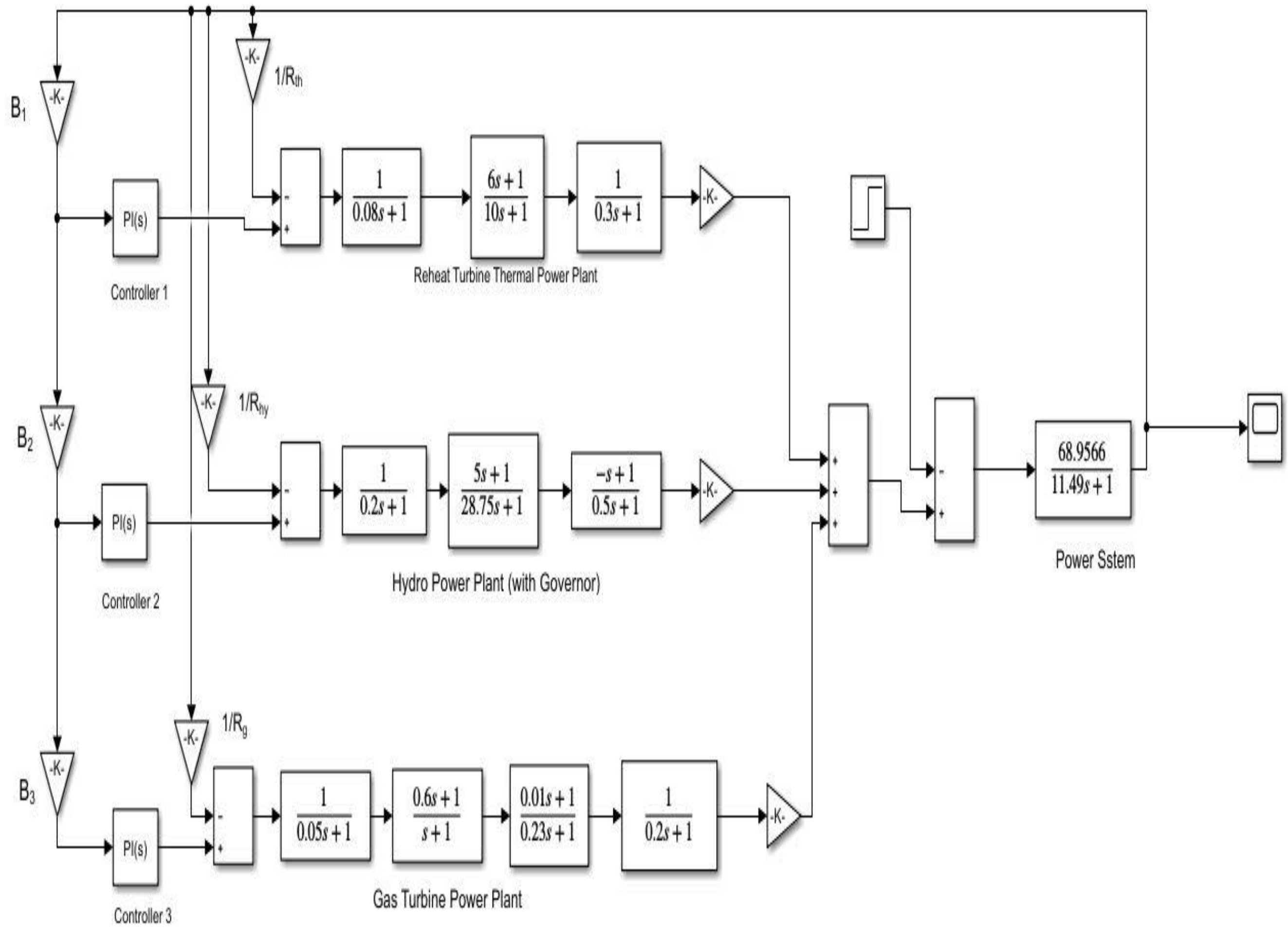

Fig 5.2 SIMULINK Model of Multisource Single Area System[48]

6.3.2 OBJECTIVE FUNCTION

In this chapter objective function is ITAE has been chosen. Objective function is chosen as its tune the parameter value in efficient way. As a area controller PI controller has been chosen. WCA algorithm use the objective function in oreder to adjust the parameter of PI controller. Algorithm is tried to minimize the value of objective function. In this paper integral time absolute error objective function has been considered for optimization.

$$ITAE = \int_0^t (|e_i| + \Delta F).t.dt$$

Where, n is the no. of areas, e_i is the error input to the controller, ΔF_i is the area frequency deviation and ΔP_{tie_i} is the change in tie power for each area.

6.3.3 OPTIMIATION TECHNIQUE

In this chapter for tuning the controller WCA optimization algorithm has been used. Brief about this algorithm has explained earlier in this work.

6.4 RESULT AND DISUSSION

In this section of paper results obtained from simulation of multi-source single area (reheat thermal, hydro and gas power plant with mechanical hydraulic governor) has been presented. The parameter and their value has been taken for WCA and algorithm. Table I shows the parameters value.

TABLE NO. -5.1 OPTIMIATION PARAMETER

Sr. No.	Optimization Parameter	Value
1	Population Size	50
2	Iterations	50
3	Lower bound	-2 for Gain Values 0 for integrator order
4	Upper bound	2 for Gain Values 2 for integrator order

Population size and iteration is taken same for both the algorithms is 50. The objective function is used to optimize the value of PI controller parameter $K_{p1}, K_{i1}, K_{p2}, K_{i2}, K_{p3}, K_{i3}$ for load frequency system. The upper bound and lower bound values were taken +2 to -2 for gain parameters. The results of WCA is presented to show the effectiveness of WCA algorithm. Table II shows the statistical analysis of WCA algorithm with PI controller. Which shows the WCA gives better performance.

TABLE NO. -5.2 STASTSTICAL ANALYSIS

S. No.	**Statistical analysis**	**GA**	**WCA**
1.	Max value	6.817×10^{-4}	6.850×10^{-4}
2	Min value	-3.418×10^{-2}	-3.405×10^{-2}
3	Peak to peak value	3.48×10^{-1}	3.474×10^{-2}
4	Mean	-1.22×10^{-3}	-1.212×10^{-3}
5	RMS	5.492×10^{-3}	5.456×10^{-3}

Table III represents the optimal value of PI controller using WCA algorithms along with minimize value of ITAE function using algorithm. From the table its clearly shows that WCA performance is better.

TABLE NO. -5.3 PI CONTROLLER PARAMETERS VALUE

S.NO.	Parameter Name	WCA	GA
1	K_{p1}	-1	-0.998
2	K_{i1}	-1	-0.9985
3	K_{p2}	-0.2799	-0.1566
4	K_{i2}	0.8064	0.8069
5	K_{p3}	-1	- 0.9910
6	K_{i3}	-1	-0.9831
7	ITAE	0.3863	-0.3872

In the multi-source single area power system PI has been used for tuning purpose. Step load of 1% has been implemented for each area at the same time. And due to this how the frequency behaves accordingly. How this controller affect frequency deviation is observed. In fig. 5.3 has shown the frequency deviation in single area multi source power system.

From the fig. it's clearly seen that effect of time response is reduce if wca algorithm has been implemented. So main objective of automatic generation control is to bring the steady state frequency at their nominal value. So for this problem or to solve this problem different different algorithm has been used earlier bur WCA algorithm gives better result so for this chapter only WCA algorithm has been used.

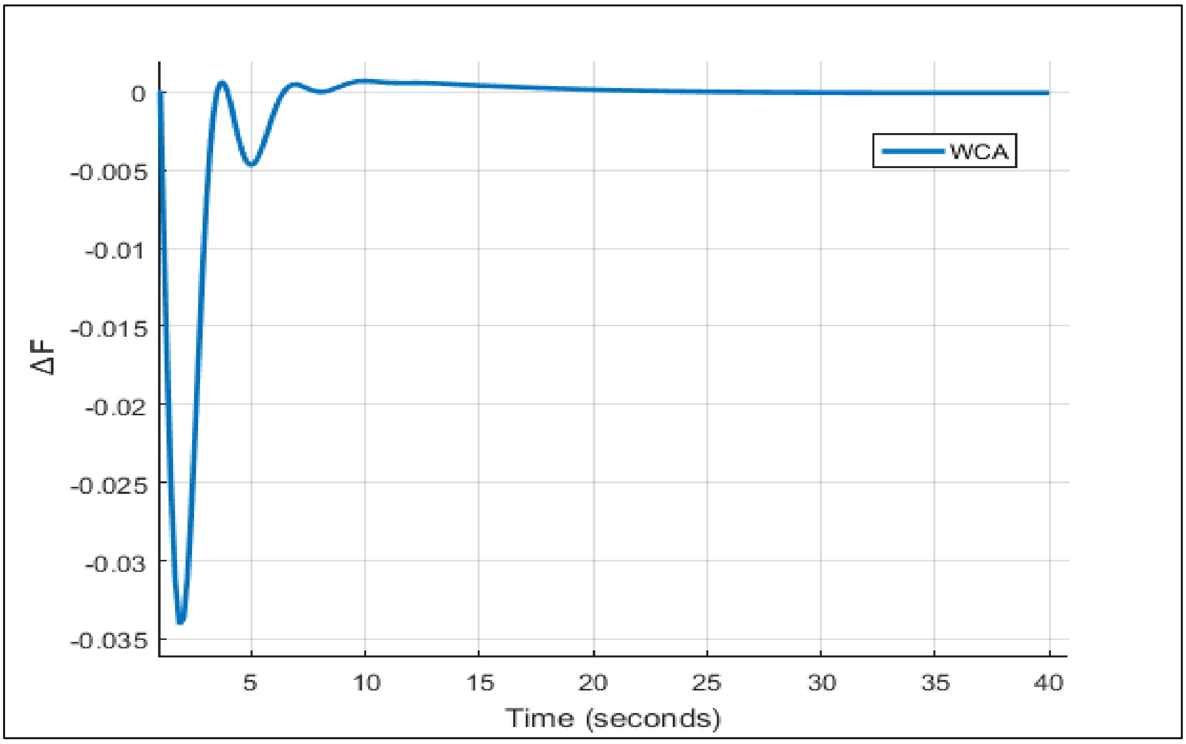

Fig5.3 Frequency deviation In Area

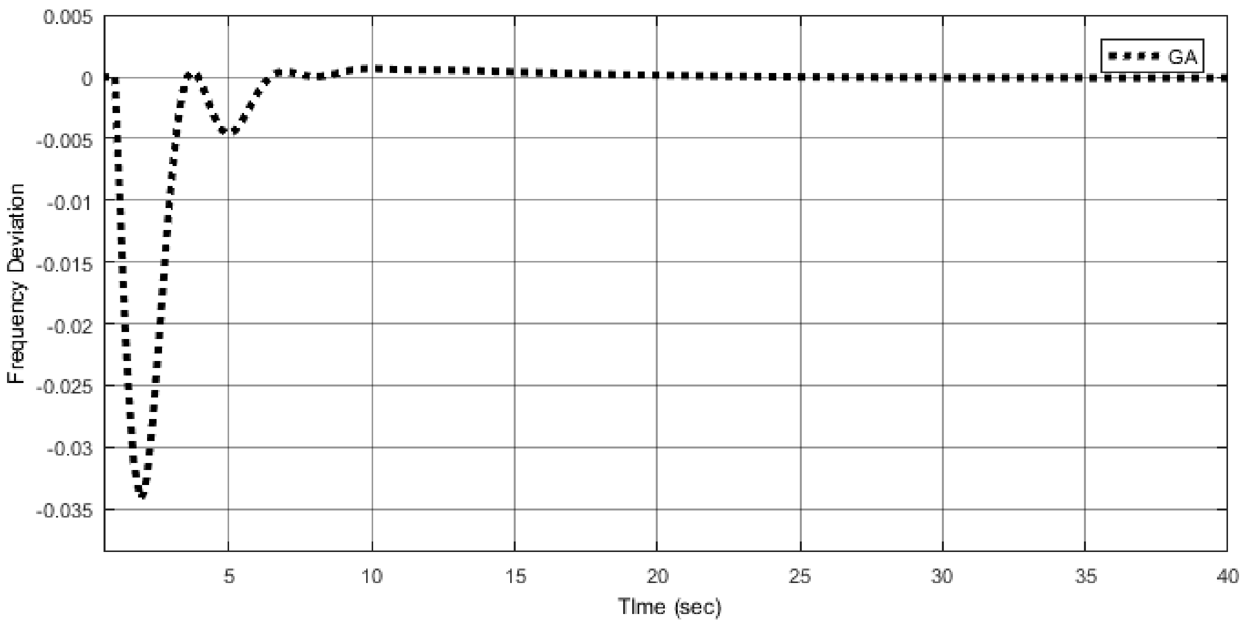

Fig5.4 Frequency deviation In Area

6.5 CONCLUSION

Multi source (reheat thermal power plant, hydro power plant and gas power plant) single area has been simulated. In this work PI controller is used as area controller. WCA has been used to tune the parameter of controller. Statistical analysis of PI controller using WCA algorithm for optimization has been done. Some parameters like maximum value, minimum value, peak to peak value mean value, RMS values have been calculated and the frequency behaviour of system when load disturbance happen has also been observed.

CHAPTER 7

CONCLUSION AND FUTURE SCOPE

7.1 OVERVIEW OF THE WORK

In this unit presents an overall work made done in entire thesis. In the thesis presents various technique and method on automatic generation control of three area interconnected thermal power system and multisource single area. Optimization algorithm have been applied to minimize the error. To avoid the deviation of frequency control mechanism have been applied in power system.

First chapter describes the introduction of automatic generation control And some previous work that have been done by many authors. Some concepts presented related to load frequency control like objective of power system and concepts of load frequency control.

In the second chapter dynamics of power system have been described. In this chapter work process of turbine, governor, generator, concepts of tie line have been presented and their role in automatic generation control in power system.

In third chapter optimization algorithm used in AGC have been described. For this work three algorithm have been used to tuning the parameter of controller. In algorithms their introduction and what was the process for optimization have been described. Three algorithms namely GA (genetic algorithm), PSO (particle swarm optimization), WCA (water cycle algorithm) have been used.

In fourth chaper performance comparison of three area interconnected thermal power system with non reheat turbine have been done precisely. In this chapter FOPI controller has been used as area controller. All three algorithm have been used for optimization and at the last compare the algorithms in terms of time response.

In the fifth chapter multi source single area has been used for frequency analysis. In last as proves that WCA algorithm is beteer in terms of time response so in current chapter only water cycle algorithm has been used for optimization and some parameters like peak to peak value RMS value have been calculated.

7.2 FUTURE SCOPE

In this present work it has been made good effort to design a proper automatic generation controller to make power system stable in interconnected power system. in this thesis performance comparison has been done for only parameter but it can be done for many parameters. In this work focus was only at frequency control. For future work it can be done for voltage control. Some other optimization technique can be used for comparison. Controllers plays major role so different different controller can be used in AGC for tuning purpose. In today's scenario where renewable energy sources produce more energy so to take different different sources in order to check their stability and synchronism. In the future automatic generation control can be used in power purchase agreement. In this work model of LFC is limited to two or three area in future this can be extend to four / five areas. In this work controllers have been used FOPI and PI but in future different controllers can be used for tuning purpose. In this model design of controllers are continuous but it can be discrete mode.

REFRENCES

[1] "Hadi Saadat - Power Systems Analysis. 3nd Edition-PSA (2011).pdf." .

[2] K. Prabha, "[Prabha Kundur] Power System Stability and Control.Pdf." p. 1176, 1994.

[3] V. Jeyalakshmi and P. Subburaj, "PSO-scaled fuzzy logic to load frequency control in hydrothermal power system," *Soft Comput.*, vol. 20, no. 7, pp. 2577–2594, 2016, doi: 10.1007/s00500-015-1659-8.

[4] Y. Xu, C. Huang, X. Li, and F. Li, "A Novel Automatic Generation Control for Thermal and Gas Power Plants," *2018 IEEE Power Energy Soc. Gen. Meet.*, pp. 1–5, 2018.

[5] A. Daraz, S. A. Malik, and A. Haq, "Review of Automatic Generation Control For Multi- Source Interconnected Power System Under Deregulated Environment," *2018 Int. Conf. Power Gener. Syst. Renew. Energy Technol.*, no. September, pp. 1–5, 2018.

[6] K. P. S. Parmar, S. Majhi, and D. P. Kothari, "Load frequency control of a realistic power system with multi-source power generation," *Int. J. Electr. Power Energy Syst.*, vol. 42, no. 1, pp. 426–433, 2012, doi: 10.1016/j.ijepes.2012.04.040.

[7] M. R. Patel, *Wind and Solar Power Systems*. .

[8] H. Glavitsch and J. Stoffel, "Automatic generation control," vol. 2, no. i, 1980.

[9] R. K. Sahu, S. Panda, and S. Padhan, "A hybrid firefly algorithm and pattern search technique for automatic generation control of multi area power systems," *Int. J. Electr. Power Energy Syst.*, vol. 64, pp. 9–23, 2015, doi: 10.1016/j.ijepes.2014.07.013.

[10] U. K. Rout, R. K. Sahu, and S. Panda, “Design and analysis of differential evolution algorithm based automatic generation control for interconnected power system,” *Ain Shams Eng. J.*, vol. 4, no. 3, pp. 409–421, 2013, doi: 10.1016/j.asej.2012.10.010.

[11] A. Rahman, L. C. Saikia, and N. Sinha, “Automatic generation control of an interconnected two-area hybrid thermal system considering dish-stirling solar thermal and wind turbine system,” *Renew. Energy*, vol. 105, pp. 41–54, 2017, doi: 10.1016/j.renene.2016.12.048.

[12] D. C. Das, A. K. Roy, and N. Sinha, “GA based frequency controller for solar thermal-diesel-wind hybrid energy generation/energy storage system,” *Int. J. Electr. Power Energy Syst.*, vol. 43, no. 1, pp. 262–279, 2012, doi: 10.1016/j.ijepes.2012.05.025.

[13] C. L. Lu, C. L. Chen, D. S. Hwang, and Y. T. Cheng, “Effects of wind energy supplied by independent power producers on the generation dispatch of electric power utilities,” *Int. J. Electr. Power Energy Syst.*, vol. 30, no. 9, pp. 553–561, 2008, doi: 10.1016/j.ijepes.2008.08.002.

[14] A. Khodabakhshian and R. Hooshmand, “A new PID controller design for automatic generation control of hydro power systems,” *Int. J. Electr. Power Energy Syst.*, vol. 32, no. 5, pp. 375–382, 2010, doi: 10.1016/j.ijepes.2009.11.006.

[15] H. Gozde, M. Cengiz Taplamacioglu, and I. Kocaarslan, “Comparative performance analysis of Artificial Bee Colony algorithm in automatic generation control for interconnected reheat thermal power system,” *Int. J. Electr. Power Energy Syst.*, vol. 42, no. 1, pp. 167–178, 2012, doi: 10.1016/j.ijepes.2012.03.039.

[16] H. Shayeghi, H. A. Shayanfar, and A. Jalili, “Multi-stage fuzzy PID power system automatic generation controller in deregulated environments,” *Energy Convers. Manag.*, vol. 47, no. 18–19, pp. 2829–2845, 2006, doi: 10.1016/j.enconman.2006.03.031.

[17] H. Gozde and M. C. Taplamacioglu, “Automatic generation control application with craziness based particle swarm optimization in a thermal power system,” *Int. J. Electr. Power Energy Syst.*, vol. 33, no. 1, pp. 8–16, 2011, doi: 10.1016/j.ijepes.2010.08.010.

[18] A. Behera, T. K. Panigrahi, A. K. Sahoo, and P. K. Ray, "Hybrid ITLBO-DE optimized fuzzy PI controller for multi-area automatic generation control with generation rate constraint," *Smart Innov. Syst. Technol.*, vol. 77, pp. 713–722, 2018, doi: 10.1007/978-981-10-5544-7_70.

[19] D. K. Lal, A. K. Barisal, and M. Tripathy, "Grey Wolf Optimizer Algorithm Based Fuzzy PID Controller for AGC of Multi-area Power System with TCPS," *Procedia Comput. Sci.*, vol. 92, pp. 99–105, 2016, doi: 10.1016/j.procs.2016.07.329.

[20] C. E. Fosha and O. I. Elgerd, "The Megawatt-Frequency Control Problem: A New Approach Via Optimal Control Theory," *IEEE Trans. Power Appar. Syst.*, vol. PAS-89, no. 4, pp. 563–577, 1970, doi: 10.1109/TPAS.1970.292603.

[21] M. Ćalović, "Linear regulator design for a load and frequency control," *IEEE Trans. Power Appar. Syst.*, vol. PAS-91, no. 6, pp. 2271–2285, 1972, doi: 10.1109/TPAS.1972.293383.

[22] M. L. Kothari and J. Nanda, "Application of Optimal Control Strategy To Automatic Generation Control of a Hydrothermal System.," *IEE Proc. D Control Theory Appl.*, vol. 135-D, no. 4, pp. 268–274, 1988, doi: 10.1049/ip-d.1988.0037.

[23] K. R. M. Vijaya Chandrakala, S. Balamurugan, and K. Sankaranarayanan, "Variable structure fuzzy gain scheduling based load frequency controller for multi source multi area hydro thermal system," *Int. J. Electr. Power Energy Syst.*, vol. 53, no. 1, pp. 375–381, 2013, doi: 10.1016/j.ijepes.2013.05.009.

[24] V. Shanmugasundaram, "Artificial bee colony algorithm based automatic generation control in two-area non-reheat thermal power system using SMES," *IEEE Int. Conf. Power, Control. Signals Instrum. Eng. ICPCSI 2017*, pp. 2126–2130, 2018, doi: 10.1109/ICPCSI.2017.8392092.

[25] L. C. Saikia, N. Sinha, and J. Nanda, "Maiden application of bacterial foraging based fuzzy IDD controller in AGC of a multi-area hydrothermal system," *Int. J. Electr. Power Energy Syst.*, vol. 45, no. 1, pp. 98–106, 2013, doi: 10.1016/j.ijepes.2012.08.052.

[26] Y. Arya and N. Kumar, "Electrical Power and Energy Systems AGC of a multi-area multi-source hydrothermal power system interconnected via AC / DC parallel links under deregulated environment," *Int. J. Electr. POWER ENERGY*

Syst., vol. 75, pp. 127–138, 2016, doi: 10.1016/j.ijepes.2015.08.015.

[27] Y. Arya and N. Kumar, “Fuzzy Gain Scheduling Controllers for Automatic Generation Control of Two-area Interconnected Electrical Power Systems,” *Electr. Power Components Syst.*, vol. 44, no. 7, pp. 737–751, 2016, doi: 10.1080/15325008.2015.1131765.

[28] Y. Arya and N. Kumar, “BFOA-scaled fractional order fuzzy PID controller applied to AGC of multi-area multi-source electric power generating systems,” *Swarm Evol. Comput.*, vol. 32, pp. 202–218, 2017, doi: 10.1016/j.swevo.2016.08.002.

[29] S. Duman and N. Yörükeren, “Automatic generation control of the two area non-reheat thermal power system using gravitational search algorithm,” *Prz. Elektrotechniczny*, vol. 88, no. 10 A, pp. 254–259, 2012.

[30] “citation-272273225 (2).” .

[31] M. Elsisi, M. Soliman, M. A. S. Aboelela, and W. Mansour, “GSA-Based Design of Dual Proportional Integral Load Frequency Controllers for Nonlinear Hydrothermal Power System,” *Int. J. Electr. Comput. Eng.*, vol. 9, no. 8, pp. 928–934, 2015, doi: 10.5281/zenodo.1108983.

[32] I. Nasiruddin, T. S. Bhatti, and N. Hakimuddin, “Automatic generation control in an interconnected power system incorporating diverse source power plants using bacteria foraging optimization technique,” *Electr. Power Components Syst.*, vol. 43, no. 2, pp. 189–199, 2015, doi: 10.1080/15325008.2014.975871.

[33] L. V. Suresh Kumar, G. V. Nagesh Kumar, and S. Madichetty, “Pattern search algorithm based automatic online parameter estimation for AGC with effects of wind power,” *Int. J. Electr. Power Energy Syst.*, vol. 84, pp. 135–142, 2017, doi: 10.1016/j.ijepes.2016.05.009.

[34] S. Padhan, R. K. Sahu, and S. Panda, “Application of firefly algorithm for load frequency control of multi-area interconnected power system,” *Electr. Power Components Syst.*, vol. 42, no. 13, pp. 1419–1430, 2014, doi: 10.1080/15325008.2014.933372.

[35] S. Debbarma, L. C. Saikia, and N. Sinha, “Automatic generation control using two degree of freedom fractional order PID controller,” *Int. J. Electr. Power Energy Syst.*, vol. 58, pp. 120–129, 2014, doi: 10.1016/j.ijepes.2014.01.011.

[36] R. K. Sahu, S. Panda, and G. T. Chandra Sekhar, “A novel hybrid PSO-PS

optimized fuzzy PI controller for AGC in multi area interconnected power systems," *Int. J. Electr. Power Energy Syst.*, vol. 64, pp. 880–893, 2015, doi: 10.1016/j.ijepes.2014.08.021.

[37] D. Guha, P. K. Roy, and S. Banerjee, "Load frequency control of interconnected power system using grey Wolf optimization," *Swarm Evol. Comput.*, vol. 27, pp. 97–115, 2016, doi: 10.1016/j.swevo.2015.10.004.

[38] M. Elsisi, M. Soliman, M. A. S. Aboelela, and W. Mansour, "Bat inspired algorithm based optimal design of model predictive load frequency control," *Int. J. Electr. Power Energy Syst.*, vol. 83, pp. 426–433, 2016, doi: 10.1016/j.ijepes.2016.04.036.

[39] A. K. Barisal, "Comparative performance analysis of teaching learning based optimization for automatic load frequency control of multi-source power systems," *Int. J. Electr. Power Energy Syst.*, vol. 66, pp. 67–77, 2015, doi: 10.1016/j.ijepes.2014.10.019.

[40] S. Turbines, "CHAPTER 4 Steam Turbines and Generators," 2015, doi: 10.1016/B978-0-12-804006-5.00010-1.

[41] G. Venter, "Review of Optimization Techniques," *Encycl. Aerosp. Eng.*, pp. 1–10, 2010, doi: 10.1002/9780470686652.eae495.

[42] N. Gupta and N. Kumar, "Particle Swarm Optimization based Automatic Generation Control of Interconnected Power System incorporating Battery Energy Storage System," *Procedia Comput. Sci.*, vol. 132, pp. 1562–1569, 2018, doi: 10.1016/j.procs.2018.05.120.

[43] R. Poli, J. Kennedy, and T. Blackwell, "Particle swarm optimization An overview," pp. 33–57, 2007, doi: 10.1007/s11721-007-0002-0.

[44] A. Sadollah, H. Eskandar, H. M. Lee, D. G. Yoo, and J. H. Kim, "Water cycle algorithm: A detailed standard code," *SoftwareX*, vol. 5, pp. 37–43, 2015, doi: 10.1016/j.softx.2016.03.001.

[45] H. Eskandar, A. Sadollah, A. Bahreininejad, and M. Hamdi, "Water cycle algorithm – A novel metaheuristic optimization method for solving constrained engineering optimization problems," *Comput. Struct.*, vol. 110–111, pp. 151–166, 2012, doi: 10.1016/j.compstruc.2012.07.010.

[46] M. A. El-Hameed and A. A. El-Fergany, "Water cycle algorithm-based load frequency controller for interconnected power systems comprising non-

linearity,” *IET Gener. Transm. Distrib.*, vol. 10, no. 15, pp. 3950–3961, 2016, doi: 10.1049/iet-gtd.2016.0699.

[47] Y. Arya and N. Kumar, “Design and analysis of BFOA-optimized fuzzy PI/PID controller for AGC of multi-area traditional/restructured electrical power systems,” *Soft Comput.*, vol. 21, no. 21, pp. 6435–6452, 2017, doi: 10.1007/s00500-016-2202-2.

[48] N. Paliwal, L. Srivastava, and M. Pandit, “Application of grey wolf optimization algorithm for load frequency control in multi-source single area power system,” *Evol. Intell.*, no. 0123456789, 2020, doi: 10.1007/s12065-020-00530-5.

LIST OF PUBLICATIONS

[1] Kirtiman Godara, Narendra Kumar, Karni Pratap Palawat. "Performance Comparison of GA, PSO and WCA for Three Area Interconnected Load Frequency Control System." International online Conference on Smart Grid energy system and controls (SGESC-2021).

[2] Kirtiman Godara, Narendra Kumar. "Performance Analysis of Multi Source Single Area Power System Using WCA Algorithm." International Conference on Recent Developments in Control, Automation and Power Engineering (RDCAPE-2021).