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Analysis on Various Optimization Techniques used for Load Frequency Control in Power System

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Abstract: In a unified power system the Load Frequency Control (LFC) is taken for review looking at all aspects with various optimization techniques for optimizing the parameters of PI, PID and Fuzzy controllers. The power system with multi area consists of conventional, renewable and combination of both with some energy devices like SMES, battery sources is analyzed specifically in this manuscript. The controllers are designed for a deregulated environment of a power system for LFC. The Model Predictive Control (MPC) and some other control techniques are used to control LFC under various disturbances like GRC and dead band control. For the readers ease of understanding the time response comparison graph of the controller for single and multiple areas of power system is depicted.

Keywords: Automatic generation control, Area control error, Load frequency control, Optimization, Controllers.

1 Introduction

Abbreviations:

AGC – Automatic Generation Control
ACE – Area Control Error
DG – Distributed Generation
FC – Fuel Cell
LFC – Load Frequency Control
MPC – Model Predictive Control
PSO – Particle Swarm Optimization
SMES – Superconducting Magnetic Energy Storage System
TPS – Thermal Power System
TCSC – Thyristor Controlled Series Compensators

With increase in load demand of electrical power, the electrical energy is generated with various energy sources like wind, PV, geothermal and other renewable sources, which intern causes more complicated for control. The system operating with nominal frequency and voltage profile should be stable

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and reliable to supply power. To operate the power system under different disturbance conditions like imbalance between supply and demand is controlled by a supplementary control AGC [1]. Modern power system is an interconnected system in which power is transferred from one area to other depending on the loading conditions.

AGC plays a significant role in the unified power system as it controls the system with three major purposes such as (A) to maintain the system frequency to its standard value or to its limits, (B) to ensure a precise value of power exchange amongst the areas and (C) to ensure an appropriate value economically for each generating unit. With the increase in the system size there exists a complexity in control of LFC. Change in load demand in an area cause an imbalance in generation as well as the consumption which isn't acceptable [2]. Basically a power system is an inter-connected subsystems. For each subsystem the load demand and losses should be balanced with generation, this is usually known as LFC. LFC is a part of AGC system, LFC aim is to reduce the change in frequency and tie line power exchanges. The real power mismatch between loads in addition to generation will lead to ACE in a system. Both change in frequency and tie-line power is acknowledged as ACE [3]. All the generating units in a particular area are expected to be coherent group. The frequency has to be continued to be constant possible for a stable as well as reliable operation of power system. Throughout the system, the frequency is same so the change in active power at one point will affect the entire system. From literature survey it is evident that several supplementary controllers are designed and considered in LFC for AGC in single area and two areas with same type of generation units or different type of units.

In a contemporary power system, the combination of more than two generating stations in a control area with contribution factor is more natural for studying LFC. The control area may have mixture of hydro, thermal, nuclear, gas, renewable energy sources [4]. AGC is typically prescribed in three subsequent levels which are said as primary, secondary and tertiary controls. In primary control the speed governor of generating unit is controlled for change in load (frequency). The secondary control will alter the frequency to its standard value and keep the tie-line power interchange among the areas by fine-tuning the generation of the selected generators. In the third control the economic operation of different units is done and restores security levels if necessary. Deregulated environment gives an opportunity to generate power in the distributed level known as DG. In a DG level most of the non-conventional resources like wind energy and PV have gained importance due to their unlimited resource also, these are ecofriendly and rapid progress in the technology. Furthermore FC is also a different energy resource which supply both electricity and warmness to its customer [5]. The variation in wind velocity and solar radiation features pose a solemn operating problem, which leads to stability of remote DG system, which is already a weak system. It is difficult to control the isolated hybrid power system consisting of renewable energy sources for stable operation unlike those with grid connected [6]. The variation in both wind velocity and solar radiation will change in real power generation and load demand will lead to change in system frequency and voltage from the standard value. So, in order to overcome this problem these sources are connected along with some auxiliary storage devices like batteries SMES, FC and electric vehicles.

To control the power generation without any imbalance between generation and load demand a conventional controller like Proportional Integral (PI), Proportional Integral Derivative (PID) are used but due to complexity in system order and uncertainties it is not possible with it, so an intelligent controller like fuzzy, neural networks and optimizing techniques are designed with various control techniques for system dynamics. In this review a various optimizing technique are applied on interconnected power system includes various generating stations and different parameter variations are discussed. In following Fig. 1 the control classification is shown.

2 Types of Optimizing Techniques for LFC in a Multi area Power System

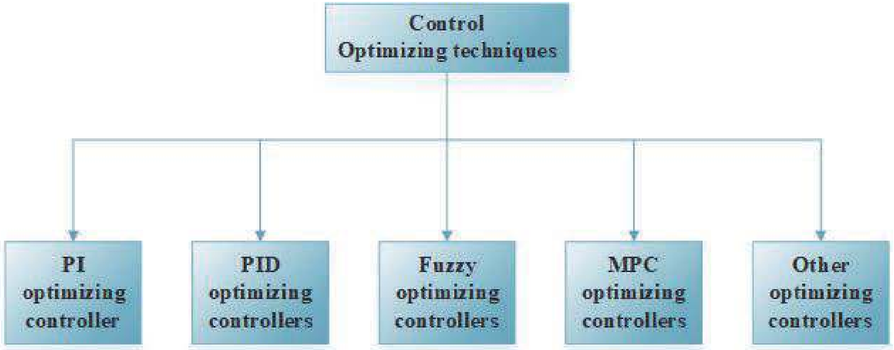

Fig. 1 – *Classification of different control optimizing techniques.*

2.1 Optimization of PI Controller for multi area power system

LFC is one of the significant control in the power system, usually PI controller is a conventional control which is tuned by trial and error approach. There are some modern control techniques like H∞ control optimization is applied to LFC problem, but there are some problems in selection of H-infinity weighting functions like the pole-zero fact linked with approach gives a closed loop poles, whose damping is directly depending on open loop system. The order of the controller will increase as the system order is increasing which leads to complex in control. To overcome this a multi objective optimization is proposed and solved using Genetic Algorithm (GA) to design well-tuned PI controllers in multi area power system [7]. To have a robust analysis on parameter variations is made [Wen Tan, and Hong Zhou][4] on local area power system using singular value method and robust analysis against the tie line power change using eigenvalue method, PI controller optimization as a decentralized LFC using Eigenvalue method and singular value method the proposed method is applied to analyze a decentralized LFC for a multi area power system. A design of PI controller with PSO optimization was proposed for a decentralized LFC of inter connected power system with AC-DC parallel lines for better transient and steady response [8].

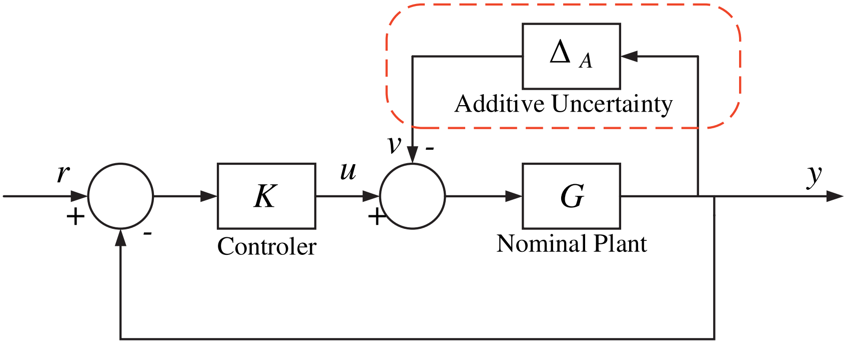

Fig. 2 – *Feedback system with inverse additive perturbation.*

An isolated hybrid diesel-wind power system was examined for several load changes by utilizing PI controller which is robust in operational point of view and is compared with design of the robust PI-based keen distributed load for the same power system for controlling the frequency variation [5]. The free uncertainties in the design of a system are signified which is applied for additive perturbation inversely used in first order PI controller. The controller robustness is improved using inverse additive perturbation as show in the Fig. 2 where G is plant to be controlled, K is the plant controller: u, v are outputs of controller and additive uncertainty respectively, r is the input reference and y is the plant output. Additionally, the real part of the dominant mode and presentation condition in the damping ratio is used for framing the problem of optimization using GA.

Another strong PI controller is designed using Kharitonov's hypothesis, the goal is to expand the robustness and transient execution at the same time based diversions are performed for making the transient conduct of the LFC framework and the ITSE is utilized for evaluating the transient execution [9]. A cost control work containing power control and transient execution is made and the GA is utilized to streamline the PI gains. The planned approach is tried on the system consisting three-areas and the outcomes are contrasted with different PI controllers.

Modern power system is an interconnected system with several sub systems. The decentralized PI is used for controlling the classical controller. The system is divided into subsystem and two-stage control is applied due to the computational complexity and reliability of the system. A central MPC control as well as a local PI control is used to control the system uncertainties [10]. The two-stage control is utilized for LFC for a power system which is interconnected. In the first stage, PI controller is used to exchange the tie-line power and control the area frequency; in the second stage, MPC is used for optimizing the local PI controller to an optimal setpoint. Delaying and coincidence point knowledge is used to highlight the computational exertion of the MPC. A various two leveled ideal control technique for the control of frequency in multi-region control frameworks is displayed. The lowest control layer comprises of the PI controllers to be decentralized which are autonomous of each other. The highest control layer comprises of supervisory prescient controller to decide set-focuses for the lowest control layer so as to acquire framework coordination as shown in the Fig. 3.

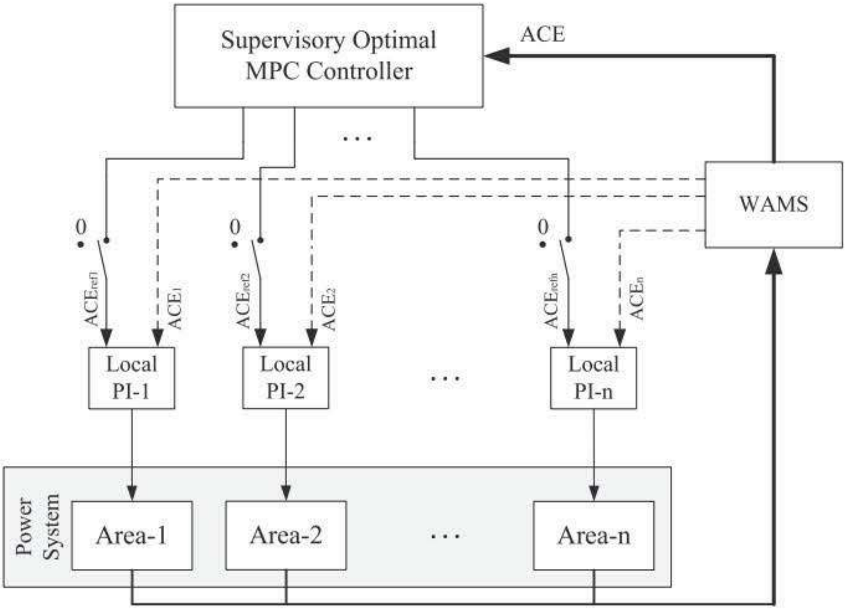

Fig. 3 – *Two-level Supervisory MPC control technique for n- area power system.*

BAT algorithm based double gain for PI controller in LFC of interconnected system is shown in the Fig. 4 [11] and applications of the controller for a two-region power system which is interconnected exhibits the viability of the anticipated controller. In addition, it has been watched that the given controller is much less touchy to framework parameter varieties. The proposed controller was contrasted and those from regular fuzzy pick up planning and PI controllers.

The influence of distribution generation and its control over the smart grid to deviate from nominal values of frequency and power at the feeder has been classified [12]. The error values at feeder is taken as difference in deviation from nominal value of power at feeder. PI controller is utilized to approximate the change in value of Distributed Energy Resource (DER) units and are set to the reference value by each PI controller. The PSO is used to reduce the error estimation control by tuning the control parameters of PI controller. The proposed control is applied on small transmission system with a feeder under balanced loading conditions for IEEE 37 bus system. The total system alongside DER units is simulated in the MATLAB with the help of Power Analysis Toolbox (PAT) to perform time area investigation.

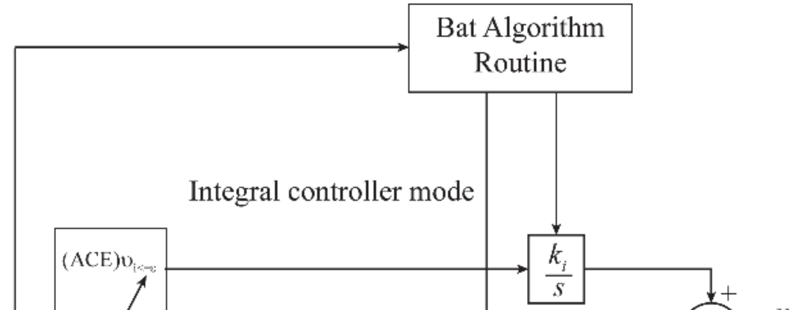

Fig. 4 – *Double mode gain scheduling for PI controller using BAT algorithm for area i.*

The different LFC management modes are analyzed in remote operation which contains different control opportunities for the steam turbine that is remotely controlled by LFC [13]. It enlightens the changes between the centralized concept of classic LFC and the decentralized concept of conventional speed control. The new thought of consolidating these two concepts is displayed and the usefulness of this thought is demonstrated on contextual analyses, utilizing dynamic model.

The delay signals inputs are given to PI controller to control the LFC for a guaranty cost. LFC for a group of unknown power systems considered with the help of Large Delay Periods (LDP's) [14]. The typical LFC for power systems with LDPs have been primarily exhibited as a switched delay system which comprises of potentially uneven subsystem due to LDPs and a stable subsystem due to Small Delay Periods (SDP's). Depending on the switching condition and under the constraint situations of the length ratio and the frequency of LPD to achieve guaranteed cost LFC, such that the closed-loop system is stable exponentially and a weighted definite cost upper limit is attained.

2.2 Optimization of PID Controller for multi area power system

Imperialistic Competitive Algorithm (ICA) for optimizing PID controller parameters of a load frequency control is used for continuous and rapid load disturbance which is problematic in LFC of power system [1]. A new method based on filtering technique is used to eliminate this problem. The frequency variations in each area and reduce in the power transfer between inter area effects the parameters of PID controller for extensive range of load variations by using ICA for better performance. A power system with three-areas is tested [15]. An multi objective optimization using GA is used to adjust the PID parameters the feedback interconnection of a plant and controller are to be designed to satisfy the requirements and is validated under different cases.

A PID controller is designed with relay based Laurent series identification method which is used to identify the power system dynamics [16]. A reheat and non-reheat of turbines have been analyzed. The parameters are approximated by using a feedback with a relay which has been tested.

A Decentralized MISO PID controller is used to tune with help of matrix eigen values and Lyaponov method [2]. A single input with multi output is considered for each control area. Each subsystem consists of a MISO PID which is to be designed.

A PID control is designed by using Sequential quadratic method for optimizing the control parameters for system when it is containing non-linearity condition [17]. The vigorous performance of the controller is related with traditional PI and also with some methods like PID-MPRS and PID-PSO which use Simulink for a two-area power system.

A decentralized PID controller is used and tuned with internal model control technique where this controller is used for a multi-area power system with and without AGC, and this is further tested in a deregulated system stability condition [18]. Simulation results are shown for the cases in order to achieve good performance results.

EA optimization based 2-DOF PID controller is designed and analyzed for degree of freedom [19]. A conventional objective function is optimized by Integral Time Squared Error (ITSE) and Integral Squared Error (ISE) to increase the effectiveness of the controller, the objective function is modified using Integral Time Absolute Error (ITAE). The output is compared with CPSO method for the above system at various non-linearity conditions and is detected that the given controller shows better response.

A population-based teaching learning-based optimization in a multi area power system for LFC is applied to inter connected multi-input power system for with and without dc link between the areas [20]. This algorithm is applied for PID controller for dynamic performance and is compared with DE algorithm which is the best feedback controller at the output for the similar power system [21, 22]. The dynamic performance of the given controller by different cost functions such as integral of time weighted squared error, integral of time multiplied absolute error and integral absolute error is studied. The controller robustness with the variation in system and load parameters towards its output is shown.

The application of fractional order PID controller technique is designed for LFC of isolated power system [23]. The parameter of the given controller using Integral Error Criterion (IEC) is optimized, and the controller robustness is tested by 50% ambiguity in each parameter and also optimal performance and robustness are evaluated on basis of IEC.

A multi objective function is optimized for LFC using Artificial Bee Colony (ABC) with PID controller [24]. The combined objective function having the objectives considered by the presentation criterions – Integral of Time Weighted Squared Error and Integral of Time Multiplied Absolute Error, for actual compensation of the system response, PID controllers of both the areas are tuned at a time and this tuning control effectiveness is compared with traditional PI, PID controllers. The algorithm robustness is tested by changing the step load perturbations and load disturbances collectively changing up to 50%.

Modified Harmony algorithm for searching is used to optimize the parameters of the PID controllers., LFC for two area hydro-thermal power system [25]. The problem cost function is proposed based on the Integral of Time-multiplied Absolute value of the error for optimizing along with the frequency bias factor so as to improve the system response to alter PID controller. The ITAE principle is selected in terms of time due to its good weight determination for error signal. This can decrease the settling time in less time and also decrease the dynamics quickly.

Modified Integral Derivative (MID) [26] controller is used for multi input multi area LFC to optimize using hybrid differential evaluation and partial swarm optimization algorithm. The boiler dynamics, generation rate constant and dead band non-linearity of power system is considered basing on the disturbance conditions, the controller is tuned with the proposed algorithm. The proposed technique is compared with Differential Evolution and Genetic Algorithm for the similar system. Further continuously system performance is tested using integral derivative and UPFC and RFB redox flow battery is used in the tie-line and in the firs area respectively for improving the system dynamics.

A mouth flame optimization is utilized for designing a PID control gains along with Thyristor Controlled Series Compensators (TCSC), SMES for multi area multi source LFC [27]. TCSC is used for compensating the power exchange between inter area by reducing the power loss, by compensating reactive power. Similarly, a battery source SMES is also used to provide an additional load disturbance in the system as when there is a disturbance of load the governor of generator cannot act quickly to change the generation, to avoid this the power is supplied from the energy storage system. TCSC and SMES controllers are controlled and designed using mouth flame optimization. The results are compared with GA based optimization with TCSC and SMES.

2.3 Fuzzy control optimization

A method using Emotional Learning based Intelligent technique with GRC for a two-area interconnected power system is used [3]. A neuro-fuzzy controller with a power change error as an input to it is taken which also uses a fuzzy critic along with ELI to tune the fuzzy controller to give better response for the system and these responses are compared with the fuzzy, PI and hybrid neuro- fuzzy controllers.

An optimal rule base fuzzy by means of c-means clustering algorithms method for LFC [28]. The rule-base for the fuzzy controller is obtained by inputs of phase plane plot in the linguistic form. It is applied to two area power system consisting GRC system with uncertain parameters and at various disturbances and finally, it is related with conventional PI and original fuzzy controller.

A type -2 fuzzy controller for a two-area power system with SMES units of a two-area reheated thermal system [29] which also considers boiler dynamics, SMES and GRC. The benefit of this controller is having more sensitivity to large disturbances. The operation of the type-2 fuzzy controller is validated with PID controller optimally and fuzzy PI controller with considering GRC, BD and SMES. The settling time and peak overshoot of the different areas vary in tie-line power in p.u. and frequency is shown in Fig. 5 and Fig. 6, respectively. Simulation analysis shows the high robustness of the planned SMES controller with less power availability against several changes and system disturbances related to SMES in the last research.

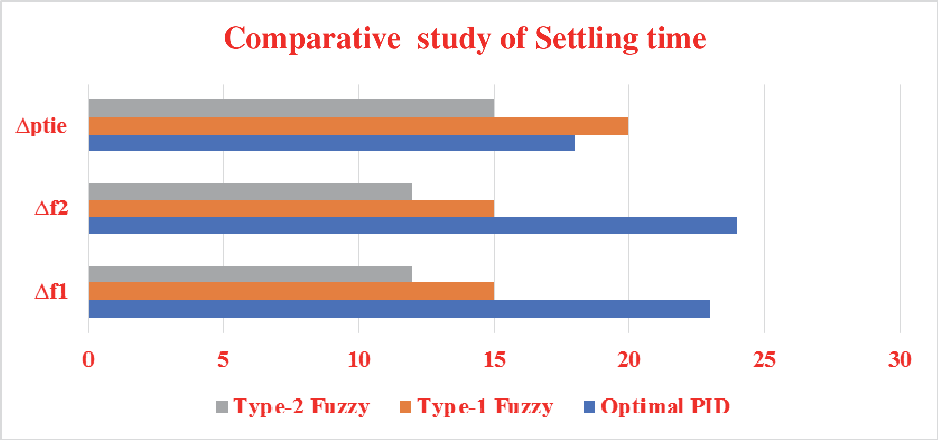

Fig. 5 – *Comparative study of settling time for different control techniques.*

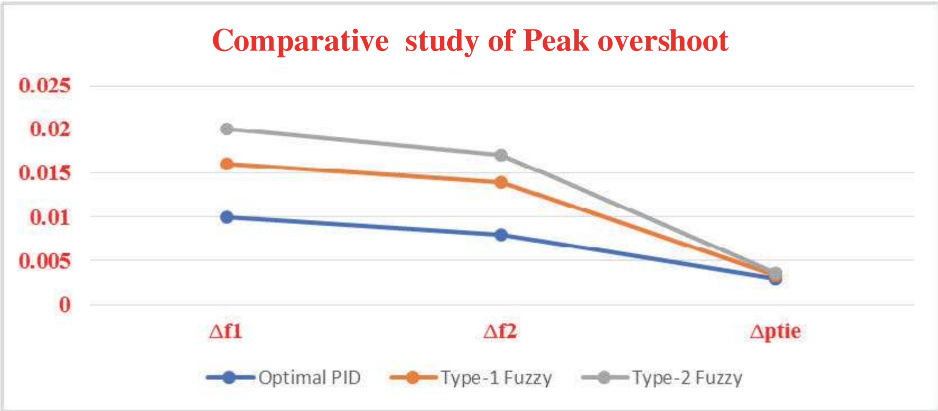

Fig. 6 – *Comparative study of peak overshoot for different control techniques.*

A fuzzy gain schedule for PI controller is used to control the frequency of the load for a multi-source multi area power system [30]. In general PI controller is used due to its various benefits, in recent trends various tuning methods are used like Ziegler Nichols method, genetic algorithm is used for PI gains, but these gain values are fixed to system conditions, but by using Fuzzy Gain Scheduling (FGS) which can tune for different system conditions. The LFC is analyzed for Z-N, GA, FGS, which gives better performance compared to all the control techniques.

An Indirect Adaptive Fuzzy Logic control for an interconnected multi area power system with unknown parameters like wear and tear of equipment and unknown parameters of interconnected like variations in synchronous power are used [31]. The control parameters of the controller are obtained from formulating by updating the procedures and also appropriating adaptive control law. The fuzzy controller will ensure the limits of all parameters in tracking error for a closed loop system. It is an auxiliary signal given to reduce the fuzzy estimate error and to reduce the trouble externally on following performance.

A operational intelligent strategy to control interconnected area frequency control using SAMBA and Fuzzy PI controller is used for optimal tune parameters [32]. A continuous Modified bat algorithm-based PI controller for fuzzy tuning is used for fuzzy controller's coefficients parameters of output and input membership functions of which are instantaneously optimized by SAMBA. Presentation of the proposed controller was assessed on a test case consisting four interconnected areas in the power system. Simulation results validate the advantage of the given controller related to optimized fuzzy PID and PID controllers. LFC for multi area power system using PSO PID controller and fuzzy PID is used for various disturbances and these responses are compared with conventional PID controller [33].

A type-2 fuzzy controller using feedback with error learning method for LFC which consists of intelligent feedforward controller like ANN along with conventional feedback control to advance the presentation of the FEL strategy, the type-2 fuzzy logic system with INFC is assumed in the place of ANN due to the capability for modelling worries, which may be present in rules and sensors measured data more efficiently [34]. This approach is related with type-1 fuzzy controller based on FEL and PID controller. The objective is to reduce the error signal to controller that is difference between the reference value r and output value y. The controlled output u_{fb} and a feed forward output of $\phi(w)$ are combined input to the plant. The FEL block structure is shown in the Fig. 7 where u_{fb} is the training error which will be driven to zero.

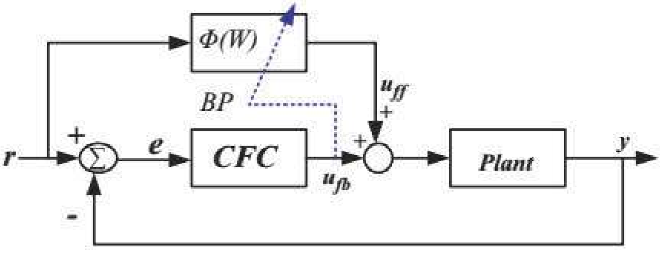

Fig. 7 – *Feedback error learning controller.*

A neuro-fuzzy control for multi area thermal power system for automatic load frequency control [35] related with the ANN, fuzzy, traditional controllers is proposed. The performance estimation based on fuzzy, ANFIS and ANN control technique for multi area interconnected hydro-thermal power plant is planned. The controller efficiency over the other methods is shown which is also applied to same power system and response of controller is verified using the simulation analysis, it shows that the above technique gives better response and also reduce the tie-line power, peak deviation in the frequency and time error. The analysis and comparison of all the control techniques of different areas overshoot and settling times are shown in the Figs. 8 and 9, respectively. It can be determined that ANFIS controller with sliding gain gives good settling time than ANN, conventional PI and PID and also fuzzy.

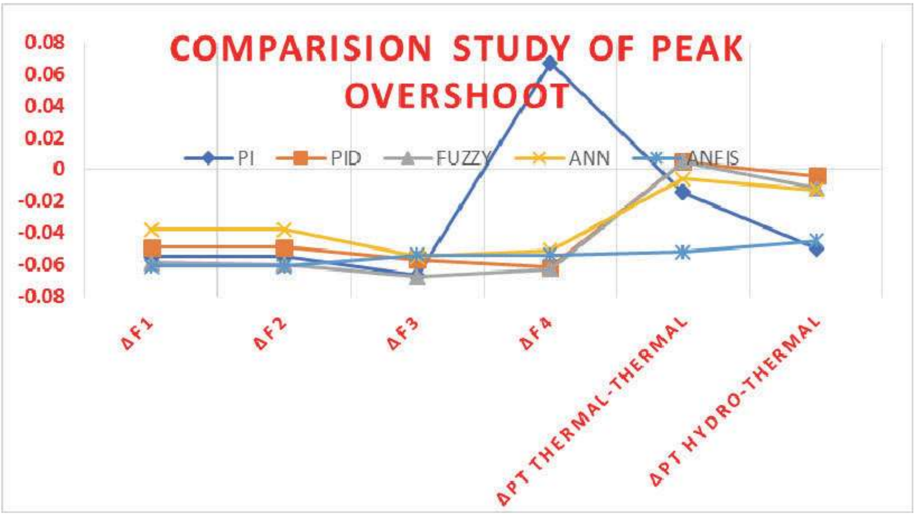

Fig. 8 – *Comparative study of peak overshoot for different control techniques.*

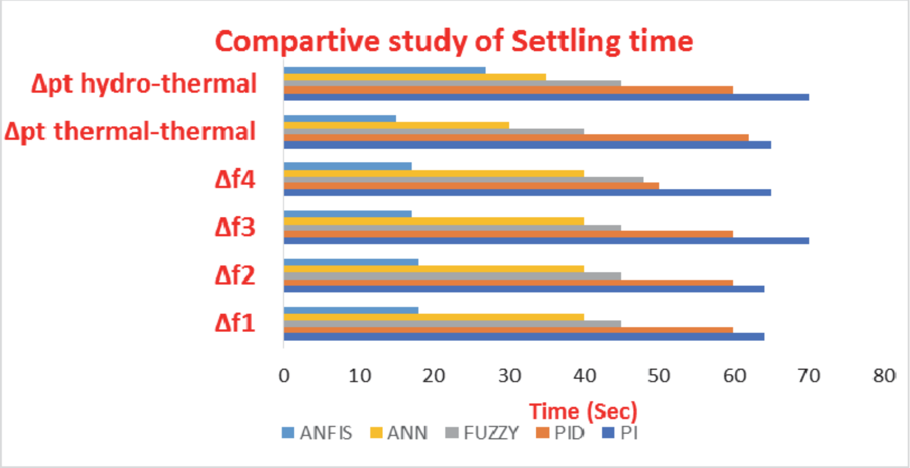

Fig. 9 – *Comparative study of settling time for different control techniques.*

3 Model Predictive Control

A MPC technique is used to a multi area power system which includes a wind generation [36] which also considers the physical restrictions of turbine and governors. A two-area power system comprising wind generation is validated with MPC. A comparison is made between the MPC and a classical controller with and without the contribution of the wind plants settling the dominance of the planned MPC technique in the presence of the contribution of the wind turbines.

A MPC technique to a multivariable of multi area power system employed for multivariable LFC and also for uncertainty in the GRC, an unnatural MPC is used to calculate optimal control input including GRC [37]. The object of MPC is further garneted an economic generation in a multi system. The robustness of the system against various parameter variation based on a Linear Matrix Inequality (LMI) approach is employed. The efficiency of MPC time-based simulation on a three-area power system are tested and the results are then analyzed with PI controller.

A DMPC technique is used for LFC to an interconnected power system [38]. The interconnected power system dynamic model is introduced with load reference setpoint constraint and GRC are considered. The system for overall is divided into several subsystems and system is controlled by MPC and these have communication with DMPC, and the system is also checked for various robust conditions and compared with cent-DMPC technique.

A model predictive control along with a SMES is used to control the LFC using a Bat Inspired Algorithm (BIA), the system includes governor dead band non-linearity GRC and time delay, to reduce the frequency deviations and power flow in an interconnected power system for load disturbance [39]. BIA algorithm is used for tuning the MPC and SMES at a time parallelly and these results are related with traditional PI controller and BIA algorithm without SMES is presented.

MPC controller for LFC is used for improving the control performance in controlling the frequency [40]. The disadvantage of using MPC is computational burden and constraint action of multi area power system which is interconnected for online optimization. Distributed MPC with Laguerre functions are used for multi area inter connected systems to overcome these difficulties. This Laguerre approach can be carried out in two ways, one is Laguerre network or its modification version is replaced in the place of MPC controller as state predictor to improve the performance, it is established on the foundation of plant with impulse response. The second one leads to follow trajectory approximation for controlling with orthonormal property by using Laguerre functions. A fractional MPC-LFC using Laguerre on the basis of methodology is confirmed centrally that it is unrealistic for large scale power systems, in order to overcome these problems, the Laguerre based MPC with augmented model which is utilized for predicting the future states of the system within the predicted horizon. a case study been conducted on distributed MPC controller on multi area system and a simulation test is conducted and compared with distributed PID results, centralized MPC and decentralized MPC. The simulation outputs had shown the improvement of the distributed MPC-LFC strategy and confirmed its importance over relative methods in characteristics of frequency fluctuations damping, as well as optimization feasibility in online.

4 Other Optimization Controllers

A multi-source generation with reheat turbine of thermal and hydro and a best feedback controller of output is used for LFC [41]. This system is tested for various cases with and without GRC and also for different %R regulation conditions and compared the results with state feedback control. The proposed control is also applied to the practical hydro power plant operational in Khozestan.

A hybrid DG for LFC with H-infinity control PSO based parameter including wind energy diesel energy UC and SMES in two area power system [42] is proposed. The controller is checked for various parameter uncertainties for different disturbances and controller robustness is observed for various wind speed variations, during which the SMES will supply the energy to make frequency stable. The results are compared with GA based $H\infty$ control, and it is observed that by using PSO based H-infinity control gives better results.

A two-level optimization method for load frequency control for controlling the complexity of system and is reduced as well as optimum control is achieved [43]. In this method, an interconnected power system is divided into different sub-systems. In first level, the optimization is solved for each area according to its local conditions and then in the next level for optimum solution of local controllers, an iterative procedure is developed by changing the interaction signals. By using this approach, the algorithm’s computational time is reduced in comparison with centralized controllers. A three-area power system is tested to show benefits and optimality of two level approach.

The LFC is done in an island mode of operation when disconnected from grid, in the microgrid a wind, solar, a diesel and SMES along with some variable load is connected, when there is a change in load the frequency deviations will occur, if it is connected to grid then the load can be compensated from grid, during islanding mode it is difficult to get compensate the load in short time, for this reason SMES is used to suppress the dynamics [44].

A novel robust control approach involving Coefficient Diagram Method (CDM) is used as a controller for LFC [45]. CDM controller design of HPs and EVs for the LFC in a remote has been presented for small area power system.

The parameters of system polynomials in CDM method have been planned depending on the model of the power system dynamically. The system with the proposed method was tested with different random parameters change, load change and unexpected controller outage situation cases. These responses were related with the responses of (PID + H2/H-infinity) control method.

The decentralized LFC for an interconnected power system is established based on Coefficient Diagram Method (CDM) [46]. The parameters of system polynomials in CDM is considered depending on dynamic model of multi area power system, the outcome of speed governor dead band and GRC are considered. The technique is applied and has been established through the effect of uncertainties due to turbine and governor parameters difference, and load changes using MATLAB simulation. An evaluation is been made among the CDM and conventional integral controller approving the advantage of the proposed technique.

The Linear Active Disturbance Rejection Control (LADRC) is designed and examined on LFC for an interconnected power system in a deregulated environment [47]. The connection between the other systems and effects for possible inter contracts are considered as disturbance due to load change disturbance. It uses an extended state observer to estimate the disturbance to compensate rapidly. The benefits of proposed method are tuning of the control parameter is easy and anti-GRC is proposed to ADRC to compensate the GRC in turbine.

The LADRC approach is used to control the LFC for multi area power system having DFIG wind farms [48]. The LFC objective is expressed as a decentralized multi-objective optimization control problem and PSO algorithm is used for optimizing the parameters of linear active disturbance rejection. Hybrid PSO is used to tune the controller and is applied to a complex power system comprising DFIG wind farms. The control parameters of the LFC issue is optimized by HPSO techniques based on ITAE. This approach is tested on different areas of power systems and the gained results are related with fuzzy PI and conventional PI controllers for robust analysis and anti-disturbance analysis.

5 Comparative Analysis of Different Control Techniques

In this review various control techniques are studied for multi area power systems where majority of systems are thermal, hydro and gas turbine plants and few number of non-conventional plants. As observed from the Figs. 10–12, the Comparative analysis for PI, PID and fuzzy optimized control techniques are considered.

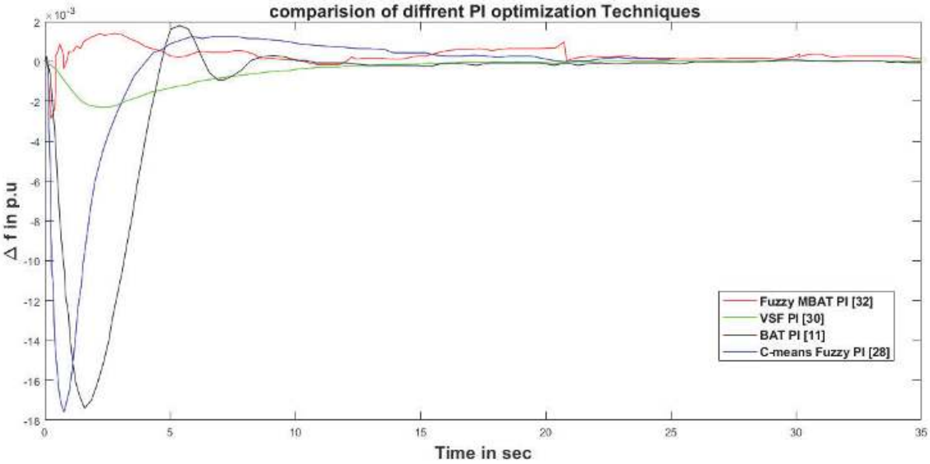

Fig. 10 – *Comparative study of settling time for different PI control techniques.*

The responses of four types of PI gain optimization techniques for LFC to a power system are shown in Fig. 10. Variable structure fuzzy (VSF) gain PI controller response is effective by means of settling time and peak overshoot with less number of damping when compared to other three techniques.

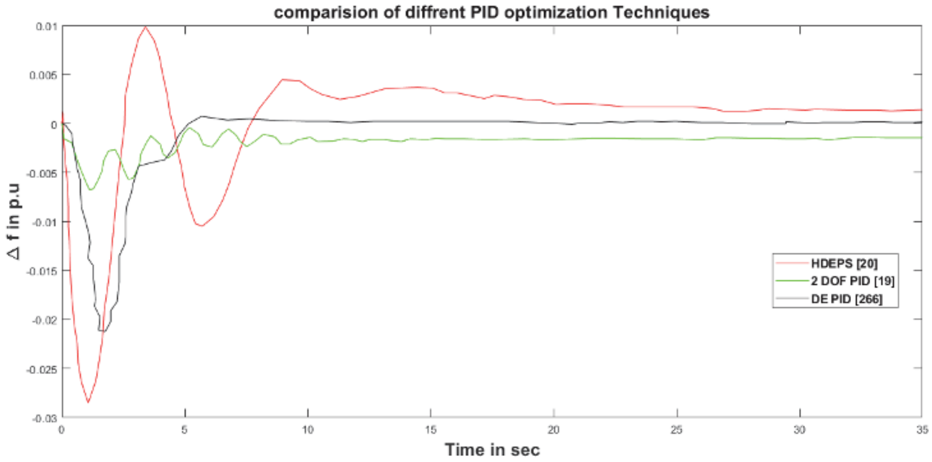

Fig. 11 – *Comparative study of settling time for different control PID techniques.*

The responses of three types of PID gain optimization techniques for LFC in a power system are shown in Fig. 11. DE optimized Two Degree of Freedom (2DOF) PID controller response is effective by means of settling time and peak overshoot with less number of damping when compared to other two techniques.

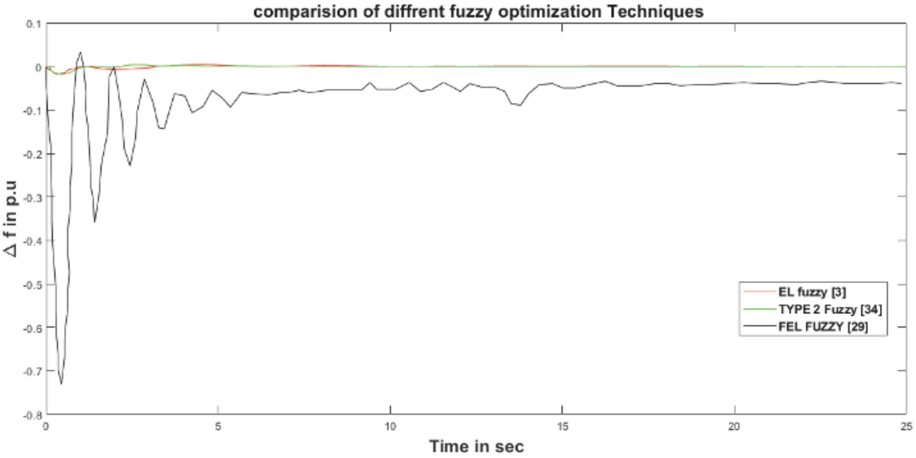

Fig. 12 – *Comparative study of settling time for different control techniques.*

The responses of three types of fuzzy optimization techniques for LFC in a power system are shown in Fig. 12. Emotional Learning based intelligent control (ELI) and type 2 fuzzy have better response when compared to Feedback error learning (FEL) approach in terms peak overshoot, settling time and damping.

At a whole, when PI, PID and fuzzy are taken into consideration, fuzzy gives an effective response when compared to PI and PID controllers with quicker settling and least number of damping. By literature survey it is observed that fuzzy optimization control techniques give less peak overshoot and settling time. It also observed that a smaller number of renewable generating stations are considered for LFC. There is a scope for researchers on renewable based power system with the help of soft computing-based control strategies.

6 Conclusion

The frequency variation control has become a challenge with increase in wind and solar electric generation and integrating to the grid as well as a stand-alone operation. The various control optimizing techniques to control the frequency disturbance under various parameter variation and integration of wind/PV system to conventional energy systems. In this paper a review is focused mainly on various control techniques and their optimizations, a comparison is also done for various system configurations which are tabulated in the below **Tables 1 – 5**. In the literature survey more, focus is done on conventional power system LFC and is discussed where less concentration is being ended on distributed generation, concentrating on distributed generation from renewable energy sources with combination of electric vehicle can also participate in frequency improvement.

Table 1

Time response analysis of three area power system under different control techniques and Avg area control error.

Ref.	System Configuration	Control Approach	Undershoot in PU			Settling Time [s]			Overshoot [PU]		
			$\Delta F1$	$\Delta F2$	$\Delta F3$	$\Delta F1$	$\Delta F2$	$\Delta F3$	$\lvert ACE_1\rvert$ Avg	$\lvert ACE_2\rvert$ Avg	$\lvert ACE_3\rvert$ Avg
[7]	Three area thermal power system	Multi object optimization using GA	--	-0.1	-0.12	--	9	7	0.0103	0.0087	0.0114
		Linear Robust PI Control using GA	--	-0.09	-0.08	--	11	8	0.0104	0.0102	0.0103
		Linear Robust PI control Using LMI	--	-0.09	-0.08	--	12	9	0.0147	0.0129	0.0113
[9]	Three area thermal power system	Robust PI control using Kharitonov's theorem	-0.06	-0.055	-0.06	52	55	56	-0.006	-0.015	-0.014

Table 2

Time response of single area power system under various control approaches for different power systems.

Ref.	System Specification	Control Approach	Undershoot [PU]	Settling Time [s]
			$\Delta F1$	$\Delta F1$
[14]	Single area power system	PI controller with Large Delay Periods	0.0125 (overshot)	12
		PI controller with Small Delay Periods	0.0126 (overshot)	23
[23]	Single area power system	FO-PID controller for Non-Reheat turbine	0.0062 (overshot)	6
		FO-PID controller for Reheat turbine	-0.0052	5
		FO-PID controller for Hydro turbine	-0.0065	30
[41]	single area multi source power system	optimal output feedback controller	-0.052	15
[42]	Single area Distributed generation with wind, Diesel, AE, FC and other storage Devices	Robust $H\infty$ control using PSO	-0.025	9
[40]	Single area multi source wind and other sources	Fuzzy Logic based	-0.11	39

Table 3

Time response of two area power system under various control approaches for different power systems.

Ref.	System Specification	Control Approach	Undershoot [PU]			Settling Time [s]		
			ΔF1	ΔF2	Δpt1	ΔF1	ΔF2	Δpt1
[17]	Two area TPS	Robust PID controller with SQP	-0.032	-0.0011	-0.0013	23	31	31
		Robust PID controller with SQP when considering GRC parameter	-0.09	-0.025	-0.0055	19	22	23
[3]	Two area Reheat TPS	Emotional learning-based neuro fuzzy controller with	-0.018	-0.005	-0.003	16	18	22
		Hybrid neuro fuzzy controller	-0.05	-0.041	-0.38	23	27	41
[28]	Two area Reheat TPS	Optimal Fuzzy controller by C-means clustering Technique	-0.015	-0.018	-0.00082	17	16	23
[36]	Two area power system with wind generation	MPC	-0.032	-0.022	-0.01	112	114	109
[29]	Two area Reheat TPS	Type-2 Fuzzy controller	0.004	0.003	0.0002	12	12	15
[19]	Two area TPS with Dead band	DE optimized 2-DOF PID controller	-0.018	-0.05	0.005	6	7	9
[30]	Two area hydro-TPS	variable structure Fuzzy controller	-0.015	-0.009	-0.03	3	5	7
[8]	Two area TPS with AC-DC Interconnected tie line	Decentralized LFC using PSO Algorithm	-0.65	-0.09	-0.33	8	7	7
[20]	Two area power system with Thermal-hydro and Gas plants in each area	TLBO based optimized PID controller with AC line	-0.014	-0.005	-0.0017	12	15	14
		TLBO based optimized PID controller with AC-DC Parallel lines	-0.008	-0.015	-0.009	7	13	12
[22]	Two area power system with Thermal-hydro and Gas plants in each area	DE based optimized PID controller with AC line	-0.026	-0.024	-0.042	19	21	28
		DE based optimized PID controller with AC-DC parallel lines	-0.013	-0.023	-0.019	15	20	19
[46]	Two area TPS	Decentralized LFC using CDM	-0.02	-0.019	0.005	42	40	38
[11]	Two area TPS with reheat turbines	BAT inspired Dual mode PI controller Optimization	-0.017	-0.016	-0.0042	8	10	8
		Fuzzy PI Optimization	-0.019	-0.02	-0.0069	11	14	13
[48]	Two area wind and thermal power system	Linear Active Disturbance Rejection	-0.0019	-0.0013	-0.0008	18	14	27
[34]	Two area TPS	Type-2 Fuzzy controller using FEL	-0.7	-0.15	-0.025	4	4.7	5
[25]	Two area Hydro-TPS	HAS-PID control by ignoring FBF	-0.02	-0.015	-0.038	8	7	10
		HAS-PID control by considering FBF	-0.015	-0.008	-0.021	5	3	9
[39]	Two area Hydro-TPS	BIA optimization for MPC controller	-0.04	-0.03	-0.009	12	10	24
[49]	Two area Hydro-TPS	Distributed MPC using Discrete -time Laguerre functions	-0.018	0.017	-0.015	22	20	23

Table 4a

Time response of three area power system under various control approaches for different Power systems.

Ref.	System Specification	Control Approach	Undershoot [PU]					
			ΔF1	ΔF2	ΔF3	Δpt1	Δpt2	Δpt3
[1]	Three area TPS	A Robust PID with ICA	-0.012	0.0052	-0.0051	0.01	-0.003	0.018
[37]	Three area TPS	LMI based MPC	-0.05	x	-0.06	0.018	x	x
[43]	Three area TPS	Two level optimal controller	-0.005	-0.007	-0.011	x	x	x
[38]	Three area TPS	Distributed MPC	-0.0011	-0.001	-0.0012	0.04	-0.12	-0.05
[31]	Three area thermal and gas power system	Adaptive Fuzzy logic controller	-0.0068	-0.0028	-0.0022	-0.0156	0.0025	0.005
[50]	Three area multi area with wind source in all the areas	PSO based Fuzzy Logic controller	-0.15	-0.16	-0.18	-0.003	-0.0018	-0.005

Table 4b

Time response of three area power system under various control approaches for different Power systems.

Ref.	System Specification	Control Approach	Settling Time [s]					
			ΔF1	ΔF2	ΔF3	Δpt1	Δpt2	Δpt3
[1]	Three area TPS	A Robust PID with ICA	63	78	97	120	25	123
[37]	Three area TPS	LMI based MPC	23	x	21	28	x	x
[43]	three area TPS	Two level optimal controller	4	5	3	X	x	x
[38]	Three area TPS	Distributed MPC	82	84	83	62	59	60
[31]	Three area thermal and gas power system	Adaptive Fuzzy logic controller	82	92	87	82	48	50
[50]	Three area multi area with wind source in all the areas	PSO based Fuzzy Logic controller	48	49	55	49	52	55

Table 5a

Time response of Four area power system under various control approaches for different power systems.

Ref.	System Specification	Control Approach	Undershoot [PU]							
			ΔF1	ΔF2	ΔF3	ΔF4	Δpt1	Δpt2	Δpt3	Δpt4
[18]	Four area reheat and non-reheat thermal power system	Decentralized PID controller with IMC	-0.012	-0.06	-0.013	-0.07	-0.02	0.021	-0.015	0.018
		Decentralized PID controller with IMC considering GRC	-0.48	-0.41	-0.51	-0.28	-0.06	0.08	-0.041	0.03
[51]	Four area reheat and non-reheat thermal power system	Decentralized PID controller with H∞ and structured single Value	-0.2	-0.12	-0.21	-0.1	-0.018	-0.01	-0.008	0.006
		Decentralized PID controller with H∞ and structured single Value considering GRC	-0.48	-0.41	-0.51	-0.28	-0.06	0.08	-0.041	0.03
[47]	Four area thermal Power system	Decentralized LFC using Eigen value method	-0.018	-0.003	-0.004	-0.008	-0.0023	0.0009	0.00083	0.00095
[32]	Four area hydro thermal power system	Online MBA fuzzy tuning PI controller	0.001	-0.003	-0.005	-0.0002	0.0003	0.0002	-0.001	-0.0017
[35]	Four area hydro thermal power system	Hybrid Neuro-Fuzzy PI controller	-0.061	-0.061	-0.054	-0.054	-0.052	-0.045	x	x

Table 5b

Time response of Four area power system under various control approaches for different power systems.

Ref.	System Specification	Control Approach	Settling Time [s]							
			ΔF1	ΔF2	ΔF3	ΔF4	Δpt1	Δpt2	Δpt3	Δpt4
[18]	Four area reheat and non-reheat thermal power system	Decentralized PID controller with IMC	7	11	9	12	9	11	13	12
		Decentralized PID controller with IMC considering GRC	11	10	9	10	13	12	14	16
[51]	Four area reheat and non-reheat thermal power system	Decentralized PID controller with H∞ and structured single Value	15	19	15	19	27	30	31	32
		Decentralized PID controller with H∞ and structured single Value considering GRC	21	20	20	22	21	19	24	34
[47]	Four area thermal Power system	Decentralized LFC using Eigen value method	25	28	22	21	29	35	26	23
[32]	Four area hydro thermal power system	Online MBA fuzzy tuning PI controller	12	10	12	17	32	26	29	38
[35]	Four area hydro thermal power system	Hybrid Neuro-Fuzzy PI controller	18	18	17	17	15	27	x	x

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