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Review

Review on Soft Computing-Based Controllers for Frequency Regulation of Diverse Traditional, Hybrid, and Future Power Systems

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Abstract: In recent decades the power system has become a complex network, to design a load frequency control (LFC) requires solving a complex equation. Optimisation techniques are essentially required to optimise the parameters of different controllers used for LFC issues in the power system. In a unified power system, the LFC is examined from all angles using different optimisation strategies to optimise the conventional PI, PID, cascaded, and fuzzy controllers as well as recently designed controllers. This manuscript specifically reviews the use of soft computing techniques in the frequency regulation of the power system with single/multiple areas that include conventional, renewable, and combinations of both, with FACTS devices and certain energy storage devices such as superconductor magnetic energy storage (SMES) and battery sources. Furthermore, deregulated power systems and microgrids are also considered for the study. To regulate LFC under various disturbances such as generation rate constraints (GRC) and dead band control, a few additional control approaches are utilised. Models of the power system are discussed and analysed. In addition, the merits and drawbacks of the studied techniques/structures that address design and implementation issues—as well as control issues that relate to the LFC problems—have been discussed.

Keywords: soft computing techniques; interconnected power systems; load frequency control; secondary frequency control; smart grids; microgrid; optimisation techniques; FACTS devices

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1. Introduction

1.1. Motivation

The infiltration of renewable energy sources (RESs), the adoption of novel ideas like the smart grid, and the computerisation of power system regulators are based on apprehensive communication technologies and contributing to increase in the complexity of power systems [1]. The aforesaid factors have an unswerving impact on the security, stability, and functioning of the power systems. The voltage and frequency are the most crucial power system indices. Frequency regulation in PS has received a lot of consideration due to its importance [2]. Primary, secondary, and tertiary control are the standard divisions of frequency regulation. The governor droop often implements the principal frequency regulation, resulting in steady stated errors. The primary frequency control loop is accountable for recording the frequency variation before the under/over frequency protection relays are activated. The secondary control for controlling frequency in power systems is called AGC, often referred to as LFC. It has two main objectives: (i) keep the frequency within a desired range; and (ii) control the exchange of power via significant tie-lines between the two control areas.

The uncertainty of active power production is greatly raised as the level of infiltration of RESs—such as wind farms and solar plants in power networks—increases, resulting in frequency variations. Along with the stochastic nature of demand, this rise in active power fluctuation would cause the power system's frequency to oscillate sharply. Therefore, more reliable and ideal LFC techniques are required for use in future power systems in order to address such issues.

In interconnected power systems, there have been numerous control strategies proposed for LFC. Four categories of strategies can be made: (i) the design of PID controllers for regulating frequency and tie-lines power flows is the primary emphasis of classical control approaches; (ii) modern controls methods comprise best control strategy, i.e., adaptive control and sliding mode control; (iii) intelligent control strategies, i.e., fuzzy and neural network based controller; and (iv) soft computing-based methods for fine-tuning the parameters of controllers, which researchers have given a lot of attention to recently.

1.2. Contributions

Power system operation and control is a broad area of study in the area of power systems that include controls for both frequency and voltage stability. These days, researchers are paying a lot of attention to the problem of frequency management because of the reasons outlined in Section 1.1. However, this topic encompasses a number of in-depth and specific subjects, power system inertia support techniques, main frequency control, secondary frequency control, and tertiary frequency control, as well as protection during frequency emergencies.

The LFC deals with regulating the frequency due to minute disruptions like load fluctuations and variations in RESs. In this study, we focus on the key details, namely LFC models, control techniques, and optimisation techniques used for controller parameter tuning. For researchers, frequency response models are crucial. Therefore, this paper introduces the most significant frequency response (FR) models and categorises them into two primary classes, namely models with emerging technologies and model structures (referred to as conventional). This study evaluates the LFC control strategies of the last ten years. The article emphasises the benefits and drawbacks of each control technique and optimisation technique in this review. Moreover, a comparison of a few techniques is shown clearly. Additionally, this study introduces the research directions and gaps, which might serve as a useful road map for researchers.

The suggested optimisation techniques for the controller parameters tuning for LFC are highlighted in this review. Furthermore, a survey of the proposed frequency response model for power systems is conducted. In addition, LFC models found in contemporary power systems, microgrids, and upcoming smart grid models are investigated. The same goes for trends and potential avenues for future research. The frequency response modeling of various power system topologies is initially discussed due to its significance in LFC investigations. Table 1 illustrates how LFC models are split into various categories—namely, traditional, hybrid, and future LFC models. Based on their configurations, the typical LFC model structures are examined.

As a result, a thorough review of dual-area, conventional three-area and multi-area PS—as well as FR models of signal control area—are conducted. Many distinct system models and formations have been published in the literature, taking into account various generating unit types as thermal, nuclear, hydro, and gas. The formations of present and future PS models for FR are then split into main categories: AGC models with high voltage direct current (HVDC) links and FACTS devices, LFC of deregulated PS, LFC models with significant penetration of distributed generation and RESs, LFC in microgrids, and LFC models appropriate for smart grids.

Table 1. Representation of power systems: conventional, hybrid, and future power systems.

	Power System Models for Optimal Frequency Regulation		
S. No.	**Conventional Power System**	**RESs Integrated Power System**	**Islanded Microgrid(IMG)/ Smart Grid**
1	Single area	Single-area	Single-area IMG
2	Multi-area (Two area, Three Area, Four area, Etc.)	Multi-area (Two area, Three Area, Four area, Etc.)	Two-area IMG
3	Deregulated PS system	Deregulated PS	Distributed energy sources (DGs)
4	PS with HVDC	PS with HVDC	—
5	PS with FACTS devices	PS with FACTS devices	–
6	PS with energy storage	PS with energy storage	–

2. Survey of Various LFC Models and Optimisation Techniques

In this section, the term conventional power systems refers to power systems where electricity is produced using fossil fuels. In fact, the most renowned power plants for these systems are thermal, hydroelectric, and nuclear generating units. PS are typically split into single-area, two-area, three-area, four-area, and multi-area power systems as per their size and interconnections. The power system models given in Table 1 are designed for conventional as well as the deregulated power systems. The primary distinction between a traditional monopolistic electricity market and the emerging competitive deregulated market is that in the former, electricity is only considered to be a component of the energy supply, whereas in the former it is viewed as a service and thus marketed similarly to other commodities. Several FR models, control strategies, and optimisation techniques for LFC models are suggested in the literature. According to no free lunch theorem, no optimisation technique can be used to solve all problems that mean a particular optimisation technique will be better suited for one kind of solution but may not be suitable for another. This means that there is always a search to find a suitable optimisation technique for a particular type of optimisation problem. A thorough assessment of the optimisation techniques used for optimizing the different controller parameters of PS models for LFC is provided in the following sections.

2.1. Single-Area Power System

Single area power system is a closely knit electrical area in which numbers of generators form a cohrent group. Figure 1 shows the representation is single area power system that consists of a governor, turbine, and generator. The proposed AGC method for SAPS and optimisation techniques are investigated in Table 2.

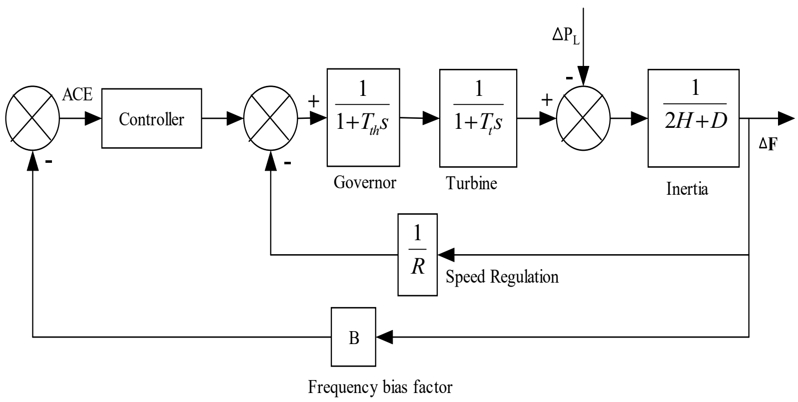

Figure 1. Generalised block diagram of single area LFC of reheat thermal based power system.

Table 2. Comparison of latest control strategy applied for LFC in the single-area power system.

Ref. No.	Power System Type	Sources	Devices	Optimisation Technique	Controller
[3]	Conventional	Thermal Unit	—	Improved Particle Swarm Optimisation (IPSO)	PID
[4]	Conventional	Thermal, Hydro, and Gas units	—	Genetic Algorithm (GA)	PI
[5]	Conventional	Thermal Unit	—	Quadratic Regulator Approach with Compensating Pole (QRAWCP)	PID
[6]	Conventional	Thermal, Hydro, and Gas units	HVDC Link	Modified PSO	PID
[7]	Conventional	Thermal Unit	—	Iterative Linear Matrix Inequality	iterative PID (IPID)
[8]	Conventional	Thermal Unit	—	Ant Colony Optimisation (ACO)	PID Controller
[9]	Conventional	Thermal Unit	—	Elephant Herding Optimisation (EHO)	PID
[10]	Hybird power plant	Thermal, wind units	—	Bat Inspired Algorithm	LADRC
[11]	Microgrid	Reheat thermal, diesel engine generation (DEG), wind	Battery energy storage (BESS), Fuel cell (FC)	Grey Wolf Optimiser (GWO)	Fuzzy PID
[12]	Microgird	DEG, PV, wind	BESS, FC	GA	MPC and PID
[13]	Microgrid	Wind turbine, BDG	Mini Pumped hydro energy storage and BESS	Coyote-Optimisation Algorithm	PI controller

The design and implementation of LFC for single-area power systems (SAPS) is the subject of the first studies on frequency control. In the literature [14–18], a number of SAPS models with LFC control techniques are examined. A dynamic mathematical model of frequency response for SAPS made up of thermal power plants is designed and a robust frequency control technique is suggested in [19]. Single-area LFC models for power networks with several energy sources—including hydro, gas, and thermal sources—is presented in [17]. A well-described frequency response LFC model of hydroelectric power systems is found in [20]. The improved PSO (IPSO) in Reference [3] is used for the AGC issues of SAPS.

2.2. Two-Area Power System

A two-area power system is constructed using two different control areas connected through a tie-line. The linearised two area power system is presented in Figure 2. A summary of AGC used in two-area power systems (TAPS) is provided in [21–38]. References [21,22] study the influence of tie-lines models on the LFC of TAPS. In [25], the LFC models for TAPS that take voltage control loop effects on the frequency response are developed. In [27–29], frequency response models for TAPS that take into account the nonlinearities of the GRC and the GDB are proposed. References [23,38] present a discussion on how to simplify the frequency response model by reducing its complexity. The multi-source, two-area LFC models that take nonlinearities into account are highlighted in [29]. LFC models of TAPS with parametric and nonparametric disturbances are discussed in references [27,29,36]. In [25], an LFC strategy is proposed for TAPS linked by HVDC/DC transmission lines. References [39,40] present TAPS frequency response models made up of reheat-thermal turbines coupled by AC/DC links. For thermal–thermal two-area power systems, load frequency control techniques that account for communication channel delay are proposed in [21–25]. Two-area power systems reheat thermal turbine frequency model with governor dead-band zone is shown in [30]. GRC non-linearity for the reheat thermal turbine-governor system in TAPS is taken into consideration in [41,42]. Considering the non-linearity of hydro power plants, the LFC strategy for hydro–hydro power systems is presented in [17,43,44]. SMES units are offered as LFC models for TAPS in [45–47]. In view of the influence of batteries and SMES, a frequency regulator for TAPS is provided in [48]. In reference [49], an LFC model of traditional two-area PS is proposed, together with the involvement of energy storage systems and electric vehicles. In [50], the LFC models take into account the electrical load's stochastic nature. In [51,52], the LFC model accounts for the uncertainty associated with RESs. The various optimisation techniques used for tuning the different controller parameters and other details for two-area PS are discussed in Table 3.

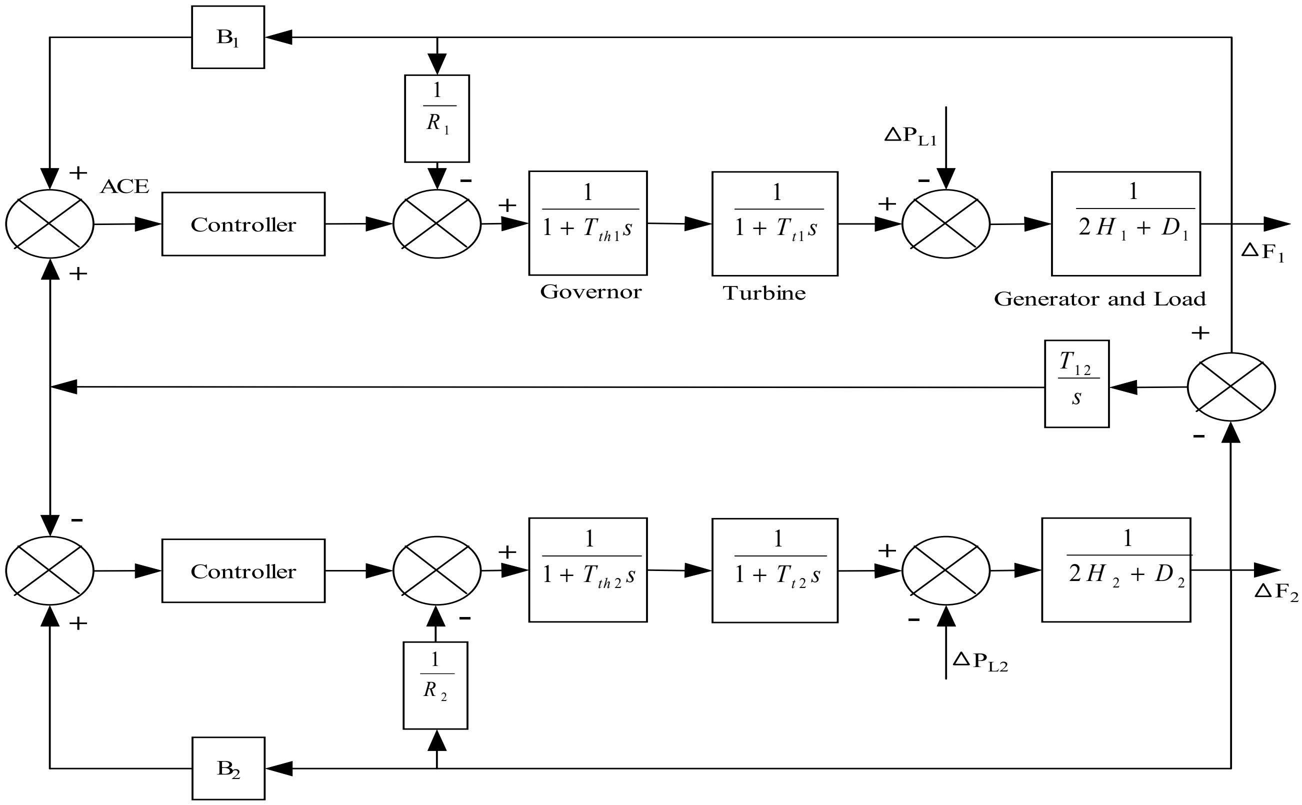

Figure 2. Generalised diagram of two area LFC of reheat thermal-based power system.

Table 3. Comparison of latest strategy applied for LFC in the different power system models.

Ref. No.	Power System Type	No. of Areas	Sources	Devices	Optimisation Technique	Controller
[53]	Conventional	1,2	Hydro-thermal gas Units	HVDC	Differential Evolution (DE) algorithm	I, PI, PID
[54]	Conventional	2	Thermal unit	—	Particle Swarm Optimisation	PID controller
[36]	Conventional	2	Thermal	—	Differential Evolution	2-DOF PID
[55]	Conventional	2	Hydro-thermal gas	—	Teaching Learning Based Optimisation (TLBO)	PID controller

Table 3. *Cont.*

Ref. No.	Power System Type	No. of Areas	Sources	Devices	Optimisation Technique	Controller
[56]	Conventional	2	Thermal	HVDC	Multi-Verse Optimiser	Fuzzy-PID controller
[26]	Conventional	2	Hydro-thermal gas	UPFC and SMES	Firefly Algorithm	Fuzzy-PID
[54]	Conventional	2	Hydro-thermal gas	(GCSC)	Sine Cosine Algorithm	Optimised fuzzy fine-tuning controller
[55]	Convetional	2	DEG and TTG	Additional inertia	Imperialist Competitive Algorithm (ICA)	FOPID controller
[56]	Conventional	2	Hydro-thermal gas units	HVDC, SMES	Bull-Lion Optimisation	PI-PDF controller
[57]	Deregulated	2,3	Thermal–hydro	–	Imperialist Competitive Algorithm (ICA).	PID Controller
[58]	Deregulated	4	Thermal–hydro	—-	Binary Coded Genetic Algorithm (BGA) and Real-Coded Genetic Algorithm (RGA)	PID controller
[59]	Deregulated	2	Thermal–thermal	TCSC	Quasi-Oppositional Harmony Search (QOHS)	PID controller
[60]	Deregulated	2	Thermal-gas power plants	TCPS, SMES	Teaching Learning Based Optimisation and Pattern Search	'TID controller
[61]	Deregulated	4	Thermal units	—-	Water Cycle Algorithm (WCA)	CC-TI-TID
[62]	Hybrid PS	2	Thermal–thermal, PV power model	—-	Genetic Algorithm (GA)	Fuzzy logic controller (FLC), PID
[63]	Hybrid PS	2	Diesel generator, photovoltaic power model	—-	Bacterial Foraging Algorithm	PI, PID, Fuzzy Logic Controller
[64]	Hybrid PS	2	Thermal, wind, photovoltaic	–	Salp Swarm Algorithm (SSA)	PID controller
[65]	Hybrid PS	2	Thermal and wind	—-	Coyote Optimisation Algorithm (COA)	Cascaded PDn-PI
[66]	Microgrid	2	Diesel generator, wind and solar	SMES, BESS	Social-Spider Optimiser (SSO)	PID controller
[67]	Microgrid	2	BDG, wind, tidal units	—-	Yellow Saddle Goatfish Algorithm (YSGA)	PIFOD-(1 + PI)
[68]	Microgrid	1,2	Thermal	—-	Electro-Search Optimisation (ESO) with Balloon Effect	Adaptive controller

For deregulated electricity networks, various control strategies have been presented as the restructuring concept is adopted. In [69–80], LFC issues for deregulated power networks are discussed. A power system is separated into sections under deregulation so that each section has its own administrator. An independent system operator (ISO) is responsible for overseeing power distribution companies (DISCOs), power transmission companies (TRANSCOs), and power generation companies (GENCOs) in this regard [70–73]. The GENCOs may or may not take part in LFC service in this new setting. In deregulated power networks, the provision of auxiliary services is based on a competitive electricity market [74,75]. For several kinds of deregulated electricity systems, frequency response models have been established in the literature [70,71,73–78]. LFC strategy for deregulated power systems with only thermal units are proposed in [75–77]. References [60,81] offer

LFC strategies for deregulated hydro power networks. An LFC framework for deregulated multi-source power system is depicted in [82]. For LFC research, a restructured TAPS with both a thermal–gas and thermal–nuclear system is depicted in [83,84].

2.3. Three Area Power System

LFC modelling for three-area interconnected power systems (TAIPS) are presented in [85–93]. An LFC model for a TAIPS is provided in [94], where steam-hydro power units are taken into account in the first and second areas, while a steam power unit is the only source of energy in the third area. In [93,95,96], a thermal power system with three control areas is examined. In three-area interconnected power systems, radial and ring networks among the various control areas are explored in [97]. In [72,98,99], a three-area power system LFC model that takes GDB and GRC nonlinearities into account is proposed. Reference [100] investigated the effects of communication latency on LFC in TAIPS. The effects of parametric uncertainty on LFC of three-area linked power systems are highlighted in References [98,101]. Three-area thermal power systems frequency control model is proposed in [102,103]. The LFC for hydropower systems with three areas is depicted in [58,104]. Three-area hydro-thermal power system load frequency controllers are presented in [101]. The LFC for multi-source power systems that take into account thermal, gas, and hydro energy sources presented in [105].

2.4. Four-Area Power System

To keep the frequency within a permitted range, large power systems are typically separated into various control regions. The LFC issues in four-area interconnected power systems (FAIPS) has been presented in [100,103,106–110]. An LFC for FAIPS with hydro power units as the first effort in this sector is presented in [73]. Furthermore, the frequency response models of FAIPS that are appropriate for LFC are presented in [111]. In [110], an LFC strategy for interconnected multi-area power systems considering nonlinearities like GRC and GDB is presented. Using a fuzzy control for an LFC model, the uncertainties of the power system characteristics are taken into account in [112]. A FAIPS with various energy sources and turbines—including hydro, gas, non-reheat thermal, and reheat thermal power plants—is presented in [95]. LFC scheme for FAIPS using various structures, such as longitudinal and ring connections is proposed in [109,110]; in this model, three area contain thermal units and one area contains a hydro unit.

2.5. Multi-Area Power System

In nature, power systems are linked together. A larger system known as the multiarea system is created by connecting various single areas together. A six area power system consisting diverse power generating sources is presented in [113–116]. AGC models are provided in [116]. For various restructured power system designs, such as five-area and multi area power systems [75,79,107,117,118]. In reference [119], a TAIPS with two GENCOs and DISCOs in each area was designed. In [120], the idea of a restructured TAIPS that is vehicle-to-grid (V2G) enabled is put forth. References [121,122] presents a discrete mode LFC method for a deregulated TAIPS. Furthermore, handling deregulation of the triple-area and four-area power systems is shown in [71,102].

2.6. Microgrid and Smart Grid

A microgrid (Figure 3) is a tiny power grid that can function on its own or in tandem with other microgrids. Energy generation that is distributed, dispersed, decentralised, or embedded refers to the use of microgrids. LFC models of fuel cell, wind, and solar-powered electric hybrid power systems is presented in [123–130]. Modelling the LFC takes into account a microgrid and hybrid system made up of PV, WTG, micro turbines, fuel cells (FC), capacitive energy storage (CES), and aqua electrolysers (AE). Active power flow and frequency stabilisation is achieved using different optimisation based PID controller [131,132]. In [133,134], they explore how electric water heaters, demand response, and electric vehicles affect the LFC of microgrids. For LFC research, nonlinear microgrid models are also proposed in [135].

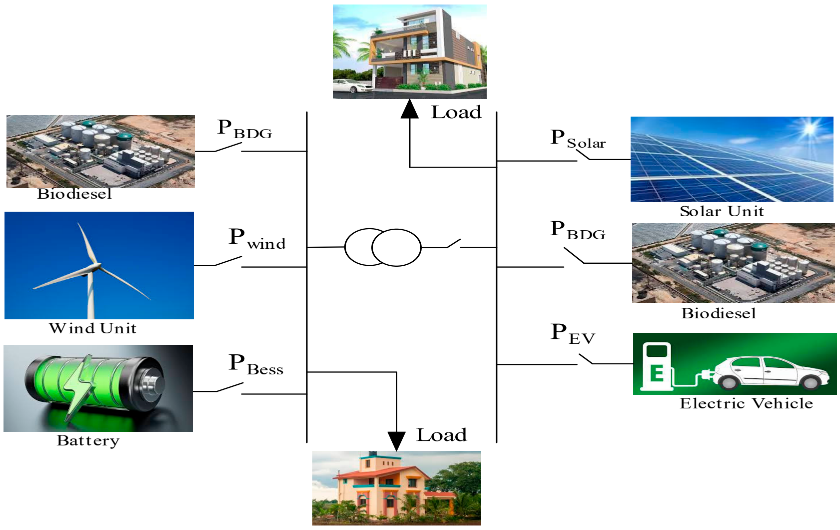

Figure 3. Schematic diagram of microgrid.

Due to its many benefits, smart grid control themes have recently attracted a lot of attention from researchers. For use in upcoming smart grid systems, several new LFC techniques have been devised in [126,136–144]. LFC models that take electric cars' (Evs') contribution into account are presented in [139]. Similarly, a coordination mechanism between heat pump water heaters and electric vehicles is recommended for LFC in upcoming smart grids [140]. Adaptive dynamic demand response, which is seen as LFC has been given significant smart grid functionality in [126,136]. Frequency response models that take into account the impact of various storage types have been proposed in [13,145,146] and evaluated. In [143,147–149], a novel plug-in EV frequency response model is put forth for the primary and secondary frequency control levels. Future smart grids may experience issues with potential cyber-attacks on LFC systems, as stated in [142,150–152].

3. Soft-Computing-Based Controller for LFC

In order to maintain a steady system frequency, a power generating module has the capacity to modify its active power output in response to a detected system frequency deviation from a setpoint. Furthermore, the LFC is classified as: (i) primary frequency control; (ii) secondary frequency control; and (iii) tertiary control.

(i) Primary frequency control: Changing a generating unit's power versus frequency in accordance with its static generation characteristic as stablished by the speed governor settings constitutes primary control. Restoring generation and demand balance within the synchronous area at a frequency other than the nominal value is the goal of primary control. This is done at the expense of the rotating masses of the producing units and associated motors' kinetic energy. After the generation and demand balance has been disturbed, the primary control action time is 0 to 30 s.

(ii) Secondary frequency control: Utilizing a central regulator, secondary control modifies the active power set points of generating sets that are subject to secondary control in order to simultaneously restore the system frequency to its set-point value and power interchanges with neighbouring control areas to their planned values. Secondary control assures that the complete reserve of primary control power activated will be made accessible once again by changing the operating points of individual producing units. A few minutes pass more slowly under secondary management than under primary control. It starts acting roughly 30 s after a disruption or event and finishes within 15 min.

(iii) Tertiary control: Tertiary controls are any automatic or manual adjustments made to the operating points of the participating generating units in order to replenish a sufficient secondary control reserve or to provide the desired (from an economic perspective) distribution of this reserve among the active generating units. Altering the set operating points of thermal power plant generation sets, around which primary and secondary control acts, connecting or disconnecting pump storage hydro power stations operating in an intervention mode, changing the power interchange programme, and controlling load are all examples of tertiary control.

Due to its great advantages, revolutionary soft-computing-based control system design has attracted a lot of attention from researchers over the past 15 years. The distinguished advantages of using soft computing techniques include their less solution costs, assurance of a solution and their viability. They can deal with difficult, nonlinear, and uncertain technical problems. In contrast to other methods, numerous researches have supported the viability of controller constructed on soft computing technique.

The LFC's parameters have been optimised using soft computing approaches in order to obtain good dynamic response. To best tune the gains of the controllers, lots of evolutionary optimisation algorithms have been applied. The classification of the various soft-computing-based controllers is presented in the Figure 4.

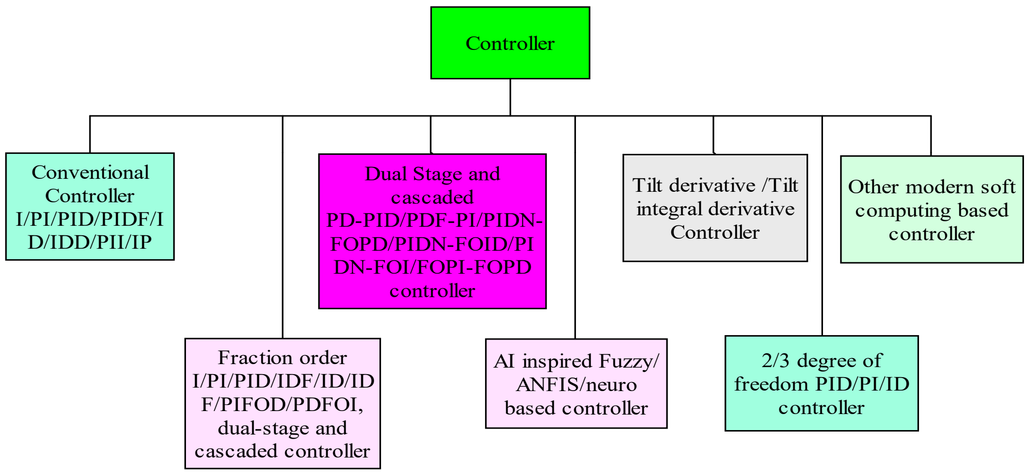

Figure 4. Classification of controller used for LFC in the different power system models.

3.1. Conventional Controller

The conventional control phenomena rely upon the traditional integer order (IO) controllers, which are frequently used to leverage the governor and minimise the ACE/µACE in the power system to improve FR. The conventional controller is designed with various combinations such as Integral (I), Proportional Integral (PI), Proportional Integral Derivative (PID), Proportional Integral Derivative with filter coefficient (PIDN). The conventional PID and PIDN controllers are presented in Figure 5a,b. Several research papers used I/PI/PID controllers in conventional, deregulated, microgrid, and smartgrid environments to deal with LFC issues. A basic integral controller tuned with Bacterial Foraging-Based Optimisation [153], iterative linear matrix inequalities techniques by the mixed H_2/H_∞ technique based decentralised proportional-integral (PI) controller [154], biogeography-based optimisation (BBO) tuned PID and fuzzy-PID four-area power system [155], conventional PID controller tuned by various optimisation techniques (i.e., hybrid genetic algorithm-simulated annealing (GA-SA), and chaotic optimisation algorithm (COA) and ant colony optimization are proposed in [156,157]; and Hosoke-Jeeve's optimisation tuned double mode PI controller [158] tuned AGC are examined for regulating the system frequency and tie-line power fluctuations. Reference [159] proposes a frequency-regulation PID regulator. In order to resolve the LFC issues in connected power systems, GA is utilised in power systems for LFC controller gains as well as controller tuning [160]. A model based on population and inspired by the cooperative behaviour of fish schooling or bird flocking—PSO—is frequently used [57]. A PSO-based PID controller is used in [3,161] to overcome the LFC problem in single-area power systems. Similar to this, a PSO-based PID controller has addressed the LFC issue in interconnected power systems with different power units, including thermal, hydro, and gas turbines in [45]. A combination of two algorithms PSO-GSA is used for tuning the parameters of PI-PD controller in multi-area hybrid power system [162]. In [163], hybrid PSO strategies combining other soft computing techniques are also suggested for LFC.

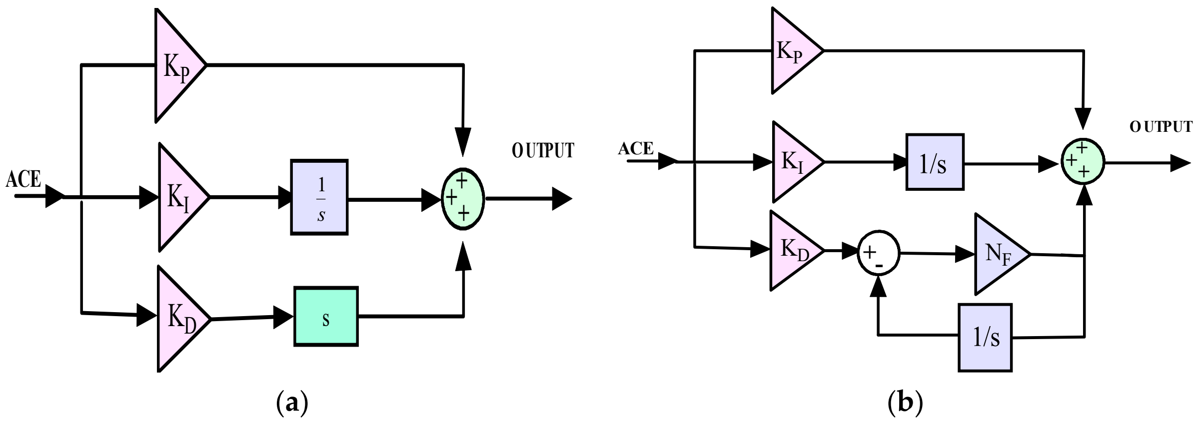

Figure 5. (**a**) Conventional PID Controller; (**b**) PID controller with filter (PIDN).

Recently, various novels proposed soft computing techniques addressing the LFC issue in both traditional and contemporary power systems have been created consider the algorithm for differential evolution (DE) [119,164,165]. The flower pollination algorithm-based PID controller is proposed in for LFC in three area power system [99]. The QOHS algorithm has been employed for FR in single-area and three-area thermal-generation-based power system [89], simlarly the QOHS algorithm has been used for hybrid diesel-tidal generation based PS [166]. A Teaching Learning Based Optimisation (TLBO) tuned PIDD controller is proposed for two-area PS in [48]. A modified bias (MB) and coefficient diagram method (CDM)-based PID regulator has been used for FR in an independent microgrid (MG) system under full unfavourable conditions and Grey Wolf Optimiser algorithm is used for tuning the controller parameters [167]. A Bat-Inspired Algorithm (BA) optimised PD controller has been deployed for single-area PS considering the high penetration of wind [10]. A GWO algorithm is considered for optimizing the PID regulator parameters for solar- thermal generation based three-area PS [168]. A bacterial foraging optimisation based integral controller is applied to a three-area power system in [169]. Mouth-Flame Optimisation (MFO) tuned PIDF controller is used for renewable based two-area hybrid power systems [170].

3.2. Fractional Order Controller

Researchers have used so many optimisation techniques-based FO controllers to handle LFC problems since they have advantages when compared with the IO-based classical controller. The FOPID controller is an improvement over the conventional PID controller that offers non-integer integro-differential order selection in addition to the traditional PID controller gains. The FOPID model is presented in Figure 6. A Lion Algorithm-based FO-based PI controller has been proposed for LFC in dual-area system made up of hydro-thermal-gas power generating units in [171]. Alomoush introduced the use of FOPID controllers in LFC problems in 2010 and established a performance comparison between the use of FOPID controllers and IOPID controllers in dual-area conventional power networks [172]. The parameters of the controller were tuned with the help of MATLAB optimisation toolbox. Furthermore, the LFC of a single-area conventional system with a non-integer BB-BC algorithm-based FOPID controller is presented in article [173].

Reference [76] provides the design of a Bacterial-Foraging-based FOPID controller for FR of a reconstructed triple-area thermal power system. The LFC of a two-area reconstructed PS utilising a decentralised BB-BC based FOPID controller is investigated in [174] with an expansion of the use of FOPID controller. How the FOPID controller compares to existing IO-based I/PI/PID controllers with respect to the dynamic performance of the system has also been examined. The paper [175] proposes a reheat, non-reheat, hydro turbine based LFC single-area PS using a FOPID controller. The proposed controller's sensitivity is established during parametric uncertainty. Furthermore, the impact of SMES on two agent restructured PS using bat optimisation tuned FOPID controller has been investigated in [176]. Grasshopper optimisation algorithm (GOA)-based FOPID has been deployed for LFC in higher-order power systems [177]. A FOPI controller is proposed for frequency regulation of a dual-area restructured power system [178].

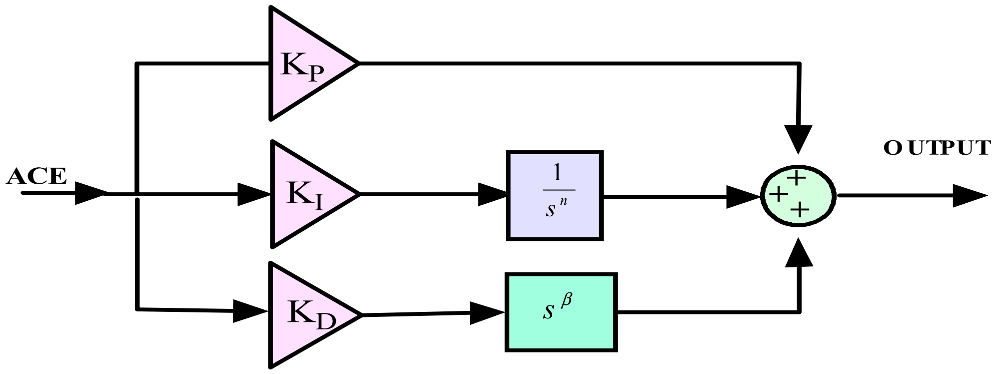

Figure 6. Fractional order PID controller.

A novel reduced order LFC technique that uses a non-integer FOPID controller is presented in [179]. Utilising a newly created fractional order IDF (FOIDF), the triple-area multi-source reconstructed power network's system frequency and tie-line power are stabilised. A tuned IO-based PIDF controller is used to compare the system dynamics [180]. Furthermore, an effective LFC of a single-area microgrid utilising a self-tuned non-integer FOPID controller [181]. The design and implementation of a MOEO-optimisation-based FOPID controller for the LFC in the isolated renewable hybrid microgrid is proposed in [182]. A modified Black Hole Optimisation algorithm based stochastic non-integer controller Fractional-Order Fuzzy proportional-integral-derivative (MOFOFPID) is built up for a hybrid microgrid in [132].

3.3. Tilt Integral Derivative (TID)/Integral-Tilt Derivative (I-TD) Controller

Tilt integral derivative (TID) as a PID-type feedback control system compensator is offered, replacing the proportional component with a tilting component with a transfer function $s^{-1/n}$. A better feedback controller is achieved because the whole compensator's transfer function comes closer to an optimal transfer function [183]. The TID controller is presented in Figure 6. An intelligent, efficient, and reliable LFC scheme is necessary in today's complex and integrated power systems using RESs to maintain frequency and tie-line power flow within a tolerable range. A novel LFC approach using a dual-stage controller designed using fractional-order tilted-integral-derivative (TID) and integer-order PD controllers is proposed [30]. Furthermore, SSA has been deployed to tune the gains of the controller. Additionally, an optimal LFC structure summarizing the idea of fractional-order based (TID) controller. The parameters of controller are optimised using same SSA algorithm in [184]. In-depth analysis has been provided to support the CC-TID controller's superiority over other widely used state-of-the-art controllers in terms of several performance indices for the LFC in hybrid energy distributed power system. Crow search algorithm is used with chaotic mapping (CCSA) for optimizing the controller gains. In [185], a combination of FOPID and TID controllers is presented for the LFC in multi-area power system. In addition, the controller and SMES unit gains are tuned through a new manta ray foraging optimisation algorithm (MRFO). In [186], a TID controller has been proposed for LFC of a two-area interconnected power system. The optimum value of gains of the TID controller is calculated using constrained nonlinear optimisation. a new integral-tilt-derivative (I-TD) controller (Figure 7), optimised by a prevailing heuristic optimisation and known as 'Water Cycle Algorithm' (WCA), is anticipated for the LFC of a two-area, thermal-hydro-nuclear power units [187].

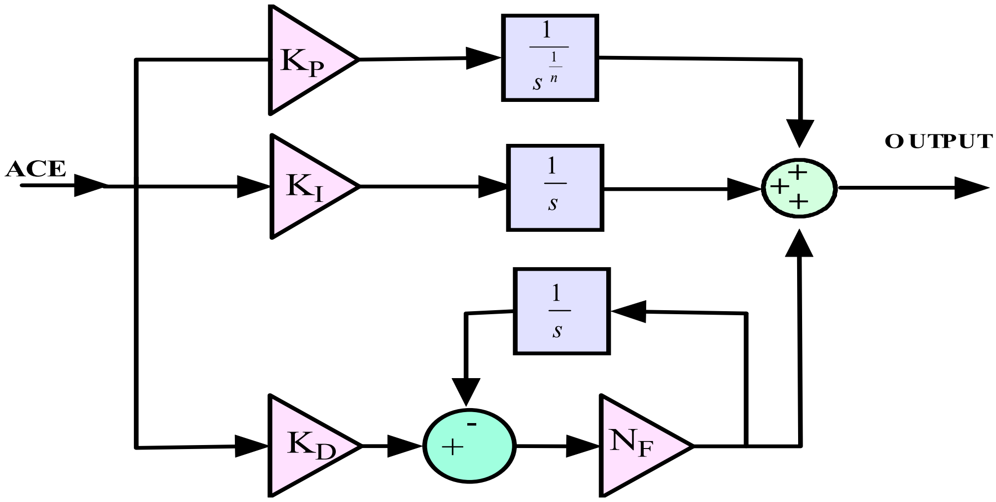

Figure 7. Tilt integral derivative controller.

3.4. Cascaded and Dual-Stage Controller

Cascaded controllers were used by numbers of researchers for minimizing the frequency tie line power deviation. In cascade control, there are two controllers, one controller located inside the feedback loop of the other. The output of the first controller serves as the set-point for the second controller. This type of controller handles the distrubances more effectively. This type of controller can respond to disturbances more efficiently. When there are multiple measurements but only one control variable is accessible, cascade control is employed. The basic configuration of cascade PI-PID and PI-PD controller is presented in Figures 8 and 9. Dash et al. present a Bat Algorithm (BA)-based PD-PID controller for the LFC system in [188]. Reference [189] used a Grey Wolf Optimisation-tuned PD-PID controller to regulate the frequency of three-area thermal reheat system. In a dual-area thermal-hydro with DG system, the use of a SCO-based PD-PID controller for the LFC issue of hybrid power system is explored in [190]. Performance of the suggested controller in comparison to a PIDF controller is also presented. Reference [191] provides an illustration of the cascaded PI-PD controller's involvement in the LFC scheme four-area thermal plant. In this context, a triple-area thermal-hydro-gas plant uses hybrid stochastic fractal search and pattern search optimisation based cascaded PI-PD controller with plug in EV proposed in [192]. A Marine Predator Algorithm (MPA)-based cascaded PIDA (Proportional-Integral-Derivative-Acceleration) controller was used to deal with LFC issues in [193]. In [135], a GOA-optimised FOPID-(1+PI) regulator is employed to regulate the frequency and tie-line power in single-area multi source microgrid.

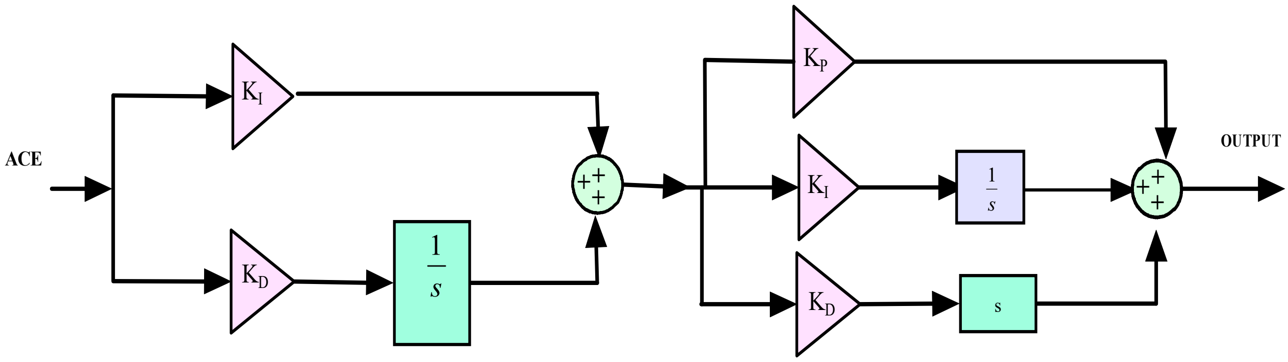

Figure 8. Cascade PI-PID controller.

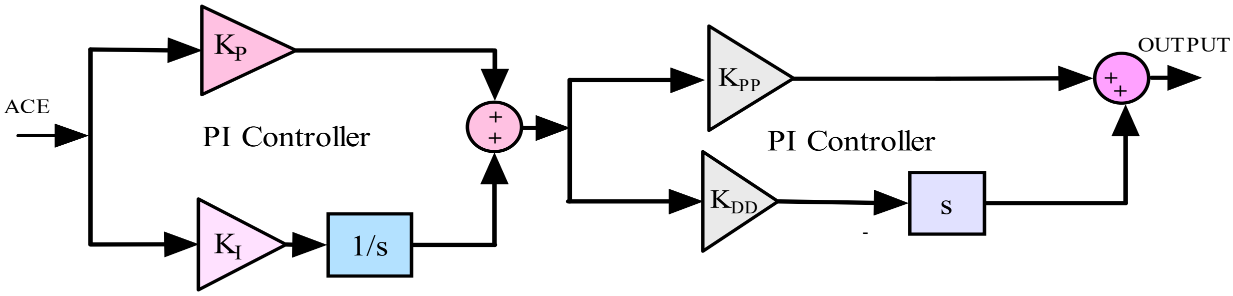

Figure 9. Cascade PI-PD controller.

A new Stochastic Fractal Search (SFS)-optimised I-PDF controller was designed in [194] to manage frequency fluctuation in triple-area (wind, thermal, and hydro) power plants. In a traditional dual-area thermal network, a Whale Optimisation Algorithm (WOA)-optimised PIDN-FOPD controller is employed for the same described problem [195]. The WOA-optimised PIDN-fractional order integral-derivative (PIDN-FOID) controller is now first equipped for LFC issue in dual-area thermal-gas system as a result of this extension. By evaluating the performance of various non-cascaded I/PI/PIDN controllers, the superiority of the controller is determined [195]. A novel multi verse optimisation (MVO to tune the combination of FOPI and FOPD controller for multi-area power system consisting hydro, thermal, and gas units in each area and the system is examined in two prospects—i.e., with and without HVDC link—to realise practical situation [196]. An Imperialist Competitive Algorithm (ICA)-tuned fuzzy PIDN-fractional order integral (FPIDN-FOI) regulator for minimizing the frequency oscillation in multi-area system is presented in [197]. The equilibrium-optimiser-based cascade FO-3DOF-PID and tilt-integral-derivative (TID) regulator for LFC in hybrid power system consisting renewable energy source integrated has been proposed in [198].

A recently designed sine-cosine algorithm optimised FOPI-FOPD regulator is used in a dual-area and triple-area reconstructed PS for AGC context by extending the FO based cascaded controller and analysis is also done on the proposed controller's superiority with regard to settling time and peak overshoot, undershoot of frequency deviation [199]. According to [82], a Volleyball Premier League (VPL)-optimisation tuned deregulated dual-area plant was accomplished using s two-degree-of-freedom proportional-integral-FO-based proportional-derivative with derivative filter (TDF-PI-FOPDN) and a fair comparison has also been demonstrated with an IO-based integral and PID controller. For triple-area LFC systems, the fundamental TDF-based cascaded (TDF-CC) controller is proposed in [200] and its performance is compared with cascaded/non-cascaded I/PI/ PID/TID/PI-PD controllers. The same Salp Swarm Algorithm (SSA)-optimised cascaded CC-TID controller is used for the same context with the increase of the control areas [201]. The Artificial Hummingbird Optimiser Algorithm (AHA)-tuned tilt fractional-order integral-derivative with fractional-filter (TFOIDFF) is proposed for renewable integrated hybrid power system in [202]. In [203], a new cascaded SSA tuned fuzzy-PI-TI controller is deployed for AGC of hybrid PS. In [204], a novel cascade fuzzy-noninteger CFPDμF-PI control strategy has been proposed to manage the frequency deviation that occurs due to the existence of RES's units in the power system. In the CFPDμF-PI controller, FPDμF as a primary and PI as a secondary controller and Slime Mold Algorithm (SMA) are used collectively as the optimiser for controller gains. A Harris' Hawks Optimisation-tuned FO3DOFTID controller is proposed for multi-area PS in [205].

3.5. AI Approaches

Artificial neural network (ANN), adaptive neuro fuzzy (ANFIS), and fuzzy logic-based controllers are commonly designed for the different LFC strategy.

3.5.1. ANN Approach

An extended control strategy for artificial neural networks (ANNs), centered on the idea of connected information processing phenomena, links the received net input neuron and output neural signal in a non-linear (connected with weighted sum) connection. In order to produce better results in complicated power networks, ANN can be used for linear and non-linear LFC problems. With appropriate controller management, the ANN technique has been used in linear and non-linear power systems to restore the system frequency as proposed in [104,206]. In [207], an application of ANN for three area PS is illustrated in [207]. A linearised reheat thermal TAPS LFC strategy with ANN support has been built in [208]. Reference [209] shows the implementation of the artificial model predictive (AMP) method for controlling the frequency of the dual-area linearised power system. In [210], they discuss the simulation of a fuzzy logic technique for reinforced learning for triple-area restructured power networks, and it is shown how to use the multi-surface perceptron neural structure (MLPNN) for the LFM problem for the dual-area restructured power network. Reference [211] takes into account poolco and bilateral transactions in traditional multi-area electric power networks when studying triple-surface feed-forward artificial neural networks for frequency stabilisation. A PSO-based ANN controller for LFC of an EV-integrated microgrid is presented in [161].

3.5.2. Neuro Fuzzy and Adaptive Neuro Fuzzy Approach

The use of the neuro-fuzzy approach for LFC has been demonstrated by a number of researchers. Studies [212,213], which concentrated on a dual-area LFC analysis under a recurring fuzzy neural network based feed-forward controller, have acknowledged the involvement of neuro-fuzzy networks in LFC issues. Dual-area thermal-hydro plant simulation results plotted under a hybrid neuro-fuzzy controller are proposed in [213]. For conventional FAIPS, Gheisarnejad et al. [111] analysed the Fractional order-fuzzy PID control technique and examined its performance for a two-area conventional power system; an intelligent neuro-fuzzy technique has also been examined. It is framed in [214] how a fuzzy-neural net tuned controller is used for the LFC issues of a dual-area reheat turbine network. In [215] an ANFIS approach with SMES-TCPS is proposed for LFC of three unequal area of power.

Similar to this, researchers have grown interested in the adaptive neuro-fuzzy interface topology (ANFIT) that is based on the conventional feed-forward technique and has no synaptic weight [122]. In [58], the functionality of an ANFIT-based controller for the AGC of a three-unequal thermal-hydro plant has been presented. The paper [216] provides an illustration of the use of an adaptive ANFIT-PID controller in a single-area electric power network. A design of an automatic power frequency regulator using an integrated four-area network of renewable resources (wind and solar PV) for frequency stabilisation is presented in [217]. In reference [218], they introduce a relative performance analysis of the ANFIT controller for the LFM problem of a six-area network consisting of super-capacitor (SC) and FACTS devices. A PSO-tuned FO-Fuzzy-PID controller is applied to a hybrid power system in [219] they present how a non-integer controller is applied to the controlled system's frequency.

3.5.3. Fuzzy Approach

Due to its sensible wide operating range and incredibly rapid response time, an efficient fuzzy logic approach for regulating system dynamics has rekindled attention among researchers. For non-linear multi-area power system frequency regulation, Chang et al.'s initial study in [220] monitored the PI controller using fuzzy logic automatic power frequency management (APFM) of linear or non-linear power system. It is discussed in [49,112,117,221] and involves monitoring various traditional as well as non-integer controllers with fuzzy logic assistance. An ideal decentralised Water Cycle Algorithm (WCA)-tuned type-II FLC for frequency stabilisation of conventional electric power systems with GRC and GDB nonlinearities is presented in [222]. A design of the online control of type-II fuzzy technique being used for the LFC of a dual-area restructured power network is illustrated in [223,224]. Reference [225] uses a relative analysis of type-I and type-II fuzzy approaches for the APFM of a four-area classical network. The Big-Bang Big-Crunch algorithm is used for tunning the membership function and controller parameters of the proposed controller. Furthermore, a multi-area electric power network's optimal LFC operation employing a neuro-fuzzy adaptive gain scheduling controller technique is examined in [58]. In [225], a type-II fuzzy system is developed for the RES's integrated microgrid. A type-2 (T2) fuzzy controller has been suggested for LFC of two-area PS with the considering the GRC. The performance of the controller is compared with PI controller and type-1 fuzzy controller [75]. To address the LFC problem, ref. [226] proposes an adaptive fractional order (FO)-fuzzy-PID controller for LFC of a renewable hybrid power system. Furthermore, the parameters of controllers have been tuned using a TLBO algorithm.

The benefits of fuzzy technique in a traditional system lead to support in green microgrid power system. The management of secondary load frequency for an island micro-power network has been the focus of the authors of [227] using the PSO tool. For the LFC problem of the dual-area solar-PV-wind based linked microgrid power system, a nominal fuzzy-PID controller has been achieved [184]. MPA algorithm is used to tune the scaling factor of the controller. In paper [228], it is explained how to determine the best adaptive neuro-fuzzy PID controller parameters by using the improved sine-cosine technique (ISCA). In [229], the frequency regulation of hybrid microgrid made up of RESs and energy storing devices has been maintained using type-II fuzzy-PID controller. The proposed controller has been tuned by Moth Swarm Algorithm.

3.6. Other Modern Controllers

In AGC and microgrid networks, a few recently developed controllers (Table 4) have proven to be reliable for LFC schemes. In order to decrease frequency oscillation in a single-area hybrid power network used sliding mode controllers in [186]. The paper [230] proposed an integral higher degree SMC controller to properly address the LFC problem for the triple-area hydro power plant in order to improve the SMC controller action. For independent renewable microgrid systems, a unique sliding mode consensus controller (SMCC) has been designed [231]. Reference [132] provides an illustration of how the H-infinity controller is set up and how it is used for LFC in a single-area distributed microgrid network powered by SMES and UCs. An iterative PID-H-infinity (IPID-H-infinity) controller for LFC of hybrid renewable microgrid system was recently proposed by Pandey et al. [232].

Table 4. Merits and demerits of controllers.

Controllers	Merits	Demerits
Conventional Controller	• These methods are well investigated in the available literature. • Smile to design.	• It delivers larger frequency deviation. • Fails to perform better under the different operating conditions.
Fractional Order Controller	• Using the FO differential equation, real-world system characterisation is simple. • Robustness, stability, and load rejection capability is more than classical IO controllers. • The higher order can be reduced to low order in FO based controller.	• Takes more time to achieve a stable state. • Numbers of control parameters need to tune optimally for better dynamics response.
Tilt Integral Derivative/Integral- Tilt Derivative Controller	• Robustness, stability, and load rejection capability is more than classical IO controllers. • It offers easier tuning, enhanced disturbance rejection capacity, and demonstrates outstanding sturdiness to parameter variability	• Takes more time to achieve a stable state. • Numbers of control parameters need to tune optimally for better dynamics response.
Cascade/Dual-Stage Controller	• Provides an additional sensor to help in disturbance reduction before the output quality is final. • Due to the larger number of tuning nubs compared to non-cascaded controllers improves the system dynamics.	• More time is required because controller has more tuning parameters. • High level of tolerance for sensor error is required. • Investigation of cyber-attack robustness required. • Selection of primary controller and secondary controller is an important factor to demonstrate superior system responses.
Fuzzy Logic Based Controller	• These controllers are cheaper to develop, they cover a wider range of operating conditions. • They are more readily customizable in natural language terms. • Adaptable, simple knowledge base design. The concepts of control and supervision are defined in the same language. • When the final user is not a control engineer, end-user interpretation is simpler. • Simple calculation toolboxes and specialised integrated circuits are widely accessible. • In rule bases, consistency, redundancy, and completeness can be verified (knowledge acquisition supervision). This might enhance user interpretability and accelerate automated learning. • Due to its capacity for universal approximation, FLC can incorporate a standard design (PID, state feedback) and fine-tune it to specific plant nonlinearities.	• Retuning takes a lot of time even if applied to a similar plant in other location. • Instinctive fuzzy PID-type design does not exactly perform better to its well-tuned conventional complement.

Table 4. *Cont.*

Controllers	Merits	Demerits
ANN Controller	• The ANFIS offers various benefits, such as the capacity for rapid learning, adaptability, and the ability to capture the nonlinear structure of a process. • Simple calculation toolboxes and specialised integrated circuits are widely accessible.	• Retuning is time consuming, even when applied to the same plant at another location.

The two-degree-of-freedom (2DOF) and three-degree-of-freedom (3DOF) PID controllers have been used in several studies. The output signal is produced by the DOF-PID controller block based on the difference between a reference signal and a measured system output. According to the given setpoint weights, the block computes a weighted difference signal for each of the proportional, integral, and derivative actions. The sum of the proportional, integral, and derivative actions on the corresponding difference signals—with each action weighted in accordance with the gain parameters—results in the block output. The derivative action is filtered by a first-order pole. Gains on controllers can be adjusted manually or automatically. The Simulink Control DesignTM programme is necessary for automatic tuning. The fundamental diagram of 2DOF-PID and 3 DOF-PID is presented in the Figures 10 and 11. A novel Seagull Optimisation Algorithm (SOA) tuned with three-degrees-of-freedom (3DOF) is suggested for multi-area (thermal, hydro, and nuclear units) power system [233].

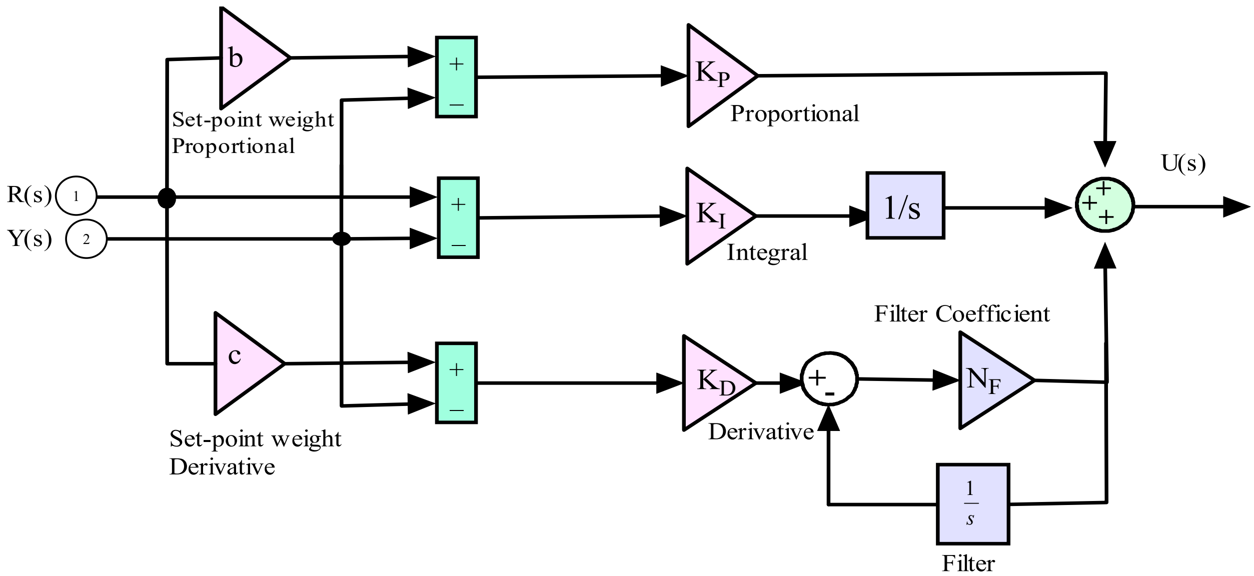

Figure 10. Two-degree-of-freedom PID controller.

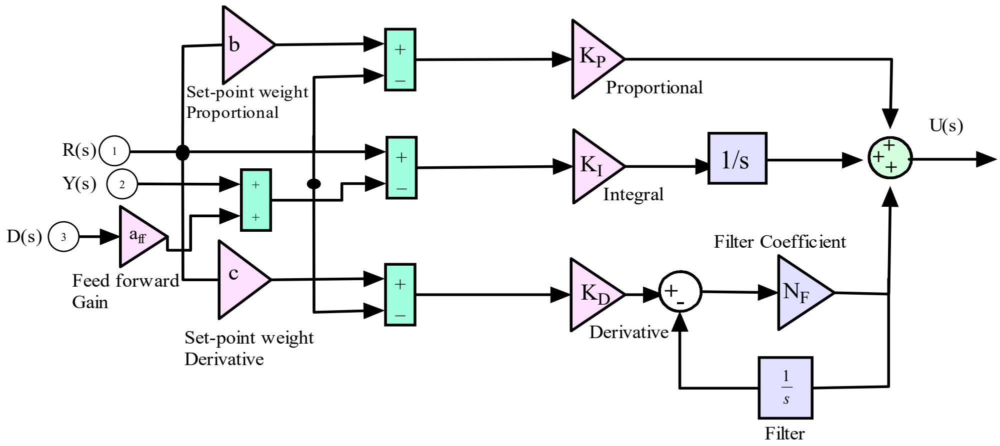

Figure 11. Three-degree-of-freedom PID controller.

A hybrid FOPID controller made by combining the FOPID and TID controller is proposed for LFC issues of multi-area PS. A Manta Ray Foraging Optimisation (MRFO) algorithm is used for optimizing the parameters of proposed controller [234]. Furthermore, in [235] a two-degree-of-freedom FO-based PID controller with AGC is discussed. The performance of the proposed controller is compared to that of the FOI, FOPI, and FOPID controllers.

4. Future Scope

The modern power system is experiencing structural modifications as a result of difficulties with environmental effects, growing industrialisation, higher demand, and supply for loads, as well as a better quality of life. India pledged to cut its carbon footprint by 33–55% from 2005 levels by 2030 as part of the Paris Climate Agreement and would work to produce 40% of its total electricity output from non-conventional sources in the same year. As a result, the system becomes oscillatory due to an increase in the penetration level of probabilistic RESs and system inertia, which causes changes in the system's frequency and interchangeable tie power. However, frequency oscillation that exceeds the rated limit causes power outages and so-called blackouts. It is abundantly obvious that the existence of renewable energy could cause frequency regulation issues for the modern electric power network of the future. Therefore, a more sophisticated control system is needed to deliver consistent electricity with better-coordinated frequency regulation while taking into account new renewable resources. Based on the observed literature survey, the following list of possible prospective studies in the area of LFC problems needs to be investigated:

- Examine some recently discovered renewable resources and how they fit into LFC.
- The LFC problem in restructured renewable microgrids needs to be further investigated.
- The existing controllers tuned with novel optimisation techniques for fine-tuning the controller gains that improve the frequency profile need to be investigated.
- Recently considered controllers that have been applied for LFC on any power system need to be investigated.

The contribution of upcoming restructured power market in microgrid LFC is an essential structure where GENCO and DISCO will be taken care of. For stable microgrid operation that takes into consideration the dynamics of restructured microgrids, additional work is needed to create improved LFC control techniques:

- Create an innovative approach to optimal-robust control that can manage system dynamics, parametric variation, and variations in power output.
- Create some cutting-edge fractional order (FO) and dual/triple-stage cascaded controllers to improve system performance.

- Future load forecasting and prediction are essential for microgrid functioning. As a result, LFC system could leverage deep learning-based encryption algorithm.
- Look into a viable control strategy to locate and isolate LFC network faults.
- Create an ideal control method for real-time LFC.
- It is necessary to investigate more communication-based LFC techniques for power networks.

To achieve LFC, various power system controllers and components exchange control signals or system frequency deviation signals. These signals are transmitted across communication infrastructure as data packets. As a result, the underlying communication is crucial for the operation of LFMC activities. A strong and trustworthy communication framework is necessary for the LFC to operate steadily and smoothly.

There have been various communication standards and protocols proposed for smart grids. Since it suggests an object-oriented modelling for all the components/domains of the power system, the IEC 61850 standard series has emerged as the front-runner among them [231]. This IEC 61850 object-oriented modelling technique is applied for power system devices in the organisation of data, the configuration of objects, and the mapping of those objects onto protocols to ensure their consistency and interoperability. IEC 61850 was initially designed for substation automation, but in more recent iterations it has been embraced for power utility automation [236].

The effects of LFC methods on single- and multi-area power systems' susceptibility to cyber-attacks have been examined. Utilizing cutting-edge information and communication technologies, single- and multi-area microgrid networks have grown dramatically in order to deliver independent operation, management, and flexibility. The need for protection for such networks from cyber-attack is increased because they are not entirely secure. The evaluation of unwanted data attack effects on tie-line power exchange is important. With the intention of diminishing cyber-attacks, the proper cyber security systems should be implemented.

Numerous factors—including environmental concerns, issues with fossil fuels, energy system security, problems with the economy, and operating costs—are changing the way the power system looks. Numerous nations have made the decision to increase the proportion of RESs such as wind and solar in their energy systems. Numerous issues arise as a result of growing the proportion of RESs in power systems, including a decrease in the system's overall inertia, an increase in the power imbalance during short-term operation, and an increase in frequency and tie-line power oscillations. The system oscillates and the frequency oscillation (highest frequency deviation) rises when the overall inertia is reduced, among other issues. The frequency oscillations directly increase when the power imbalance in instant operation increases. It is obvious that frequency control issues would arise in both present and future power systems. These systems would struggle to maintain sufficient damping and inertia. In order to control such frequency problems, appropriate control mechanisms and ancillary services such as main and secondary reserves are required. The following list of research holes in the area of LFC that require additional study is based on the literature review:

- Increasing the robustness of LFC-related control approaches.
- Optimal-robust control techniques for LFC that can manage changes in both plant parameters and power output.
- Developing new LFC objective functions that can enhance the performance of power systems, taking into account the dependability of LFC loops
- Improving the capacity of LFC models to handle cyber-attack glitches.
- Suggesting appropriate control strategies that can identify the sensor faults and isolate them from LFC loops.
- Developing new fault diagnosis techniques that work with LFC.
- Recommending appropriate control techniques to identify and isolate sensor defects in LFC loops.

- Developing new control strategies that utilise wide variation in the plant paramters and load demand.
- Developing control strategies for power systems modelled without assumptions.

The potential for demand-side participation to provide some ancillary services for independent system operators, such as primary and secondary storage and LFC services, is now being investigated in great detail. Realistic participation strategies are needed to minimise the oscillatory increase in frequency. For contemporary power systems, a suitable coordination between demand-side and generation-side participation in LFC can be suggested as a promising area of study. To support demand-side participation in LFCs, further research into the infrastructure of contemporary power systems is also needed. Where extensive market research is required for infrastructure and supporting services, electric vehicles and other demand side factors can contribute to Smart Load LFC. Therefore, new strategies are needed to reduce the oscillatory increase in frequency.

5. Conclusions

The most recent advances in LFM approaches for various traditional and renewable energy-based power systems and renewable integrated microgrid/smart girds are surveyed in this article. Single- and multi-area power systems are covered. An effort has been made to obtain a critical remark on precise single/multi-area power system frequency response models, LFC for RESs-based power systems, and their relative analysis in conventional, deregulated, and microgrid power domains due to the significant frequency stabilisation feature in modern power systems. There has been some discussion of the mathematical modelling related to changes in frequency deviation, tie-line power deviation, tie-line error, and control error of conventional/microgrid power networks under the LFC scenario. Additionally, the detailed applications of classical controllers, FO controllers, tilt derivative, tilt integral controllers, recently invented cascaded controllers, as well as other recently developed and used controllers for the LFC are examined. Different controllers' merits and demerits have also been examined. Additionally, various current soft computing strategy are examined for the LFC problem, including optimisation algorithms, fuzzy logic method, artificial neural network, and other recent approaches. Finally, the future scope and research gaps of this domain have been identified.

The research makes it clear that LFC is essential for future power systems that include renewable energy resources. The recent trend involves using various computing techniques to boost LFC performance and accuracy. Finally, a few areas for further research in the field of contemporary LFC systems are discussed. To enable large-scale application, integrated modelling and application studies that pair these LFC approaches with feasible communication technologies are needed.

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Abbreviations

Follwing abbreviations has been used in this menuscript

PS	Power System
FR	Frequency Response
DG	Distributed Generation
FC	Fuel Cell
PID	Propotional Integral Derivative
PIDD	Proportional-Integral Plus Double Derivative
PSO	Particle Swarm Optimisation
SMES	Superconducting Magnetic Energy Storage System
TID	Tilt Integral Derivative
IDD	Integral Plus Double Derivative
BESS	Battery Energy Storage System
MPC	Model Productive Control
LADRC	Linear Active Disturbance Rejection Control
GCSC	Gate Controlled Series Capacitors
TTG	Tidal Turbine Genereation
CC-TI-TID	Fractional Order Calculus-Based Cascade Tilt-Integral–Tilt-Integral-Derivative
ID	Integral Derivative
SCO	Sine-Cosine Optimisation
ABC	Artificial Bee Colony
AE	Aqua Electrolyser
BFO	Bacterial Foraging Optimisation
BB-BC	Big-Bang Big-Crunch
MOEO	Multi-Objective Extremal Optimisation
CSA	Cuckoo Search Algorithm
DG	Distributed Generation
DISCOs	Distribution Companies
EVs	Electric Vehicles
GDB	Governor Dead Band
GENCOs	Generation Companies
GRC	Generation Rate Constraint
PDn	Proportional Derivative with Filter
ID	Integral Derivative

References

1. Sharma, D. Load Frequency Control: A Literature Review. *Int. J. Sci. Technol. Res.* **2020**, *9*, 6421–6437.
2. Umrao, R.; Kumar, S.; Mohan, M.; Chaturvedi, D.K. Load Frequency Control methodologies for power system. In Proceedings of the ICPCES 2012—2012 2nd International Conference on Power, Control and Embedded Systems, Allahabad, India, 17–19 December 2012; pp. 1–10.
3. Tungadio, D.H.; Sun, Y. Load frequency controllers considering renewable energy integration in power system. *Energy Rep.* **2019**, *5*, 436–453. [CrossRef]
4. Ibraheem, A.; Kumar, P.; Kothari, D.P. Recent philosophies of automatic generation control strategies in power systems. *IEEE Trans. Power Syst.* **2005**, *20*, 346–357. [CrossRef]
5. Pandey, S.K.; Mohanty, S.R.; Kishor, N. A literature survey on load—frequency control for conventional and distribution generation power systems. *Renew. Sustain. Energy Rev.* **2013**, *25*, 318–334. [CrossRef]
6. Fernández-Muñoz, D.; Pérez-Díaz, J.I.; Guisández, I.; Chazarra, M.; Fernández-Espina, Á. Fast frequency control ancillary services: An international review. *Renew. Sustain. Energy Rev.* **2020**, *120*, 109662. [CrossRef]
7. Tzoneva, E.R.; Krishnamurthy, S.; Krishnamurthy, S. Review of Automatic Generation Control in Deregulated Environment Review of Automatic Control in Deregulated Environment. *IFAC-Pap.* **2017**, *50*, 88–93.
8. Gautam, S.K.; Goyal, N. Improved particle swarm optimization based load frequency control in a single area power system. In Proceedings of the 2010 Annual IEEE India Conference (INDICON), Kolkata, India, 17–19 December 2010; pp. 1–4.
9. Ramakrishna, K.S.S.; Bhatti, T.S. Sampled-data automatic load frequency control of a single area power system with multi-source power generation. *Electr. Power Compon. Syst.* **2007**, *35*, 955–980. [CrossRef]

10. Hanwate, S.D.; Hote, Y.V. Optimal PID design for Load frequency control using QRAWCP approach. *IFAC-Pap.* **2018**, *51*, 651–656. [CrossRef]
11. Singh, K.; Shankar, G. PID parameters tuning using modified particle swarm optimization and its application in load frequency control. In Proceedings of the 2016 IEEE 6th International Conference on Power Systems (ICPS), New Delhi, India, 4–6 March 2016; pp. 1–5.
12. Bensenouci, A.; Ghany, A.M.A. Performance analysis and comparative study of LMI-based iterative PID load-frequency controllers of a single-area power system. *WSEAS Trans. Power Syst.* **2010**, *5*, 85–97.
13. Omar, M.; Soliman, M.; Ghany, A.M.A.; Bendary, F. Ant Colony Optimization based PID for single area load frequency control. In Proceedings of the 2013 5th International Conference on Modelling, Identification and Control (ICMIC), Cairo, Egypt, 31 August–2 September 2013; pp. 119–123.
14. Sambariya, D.K.; Fagna, R. A novel Elephant Herding Optimization based PID controller design for Load frequency control in power system. In Proceedings of the 2017 International Conference on Computer, Communications and Electronics (Comptelix), Jaipur, India, 1–2 July 2017; pp. 595–600.
15. Ali, S.; Yang, G.; Huang, C. Performance optimization of linear active disturbance rejection control approach by modified bat inspired algorithm for single area load frequency control concerning high wind power penetration. *ISA Trans.* **2018**, *81*, 163–176. [CrossRef]
16. Lal, D.K.; Barisal, A.K. Load Frequency Control of AC Microgrid Interconnected Thermal Power System. *IOP Conf. Ser. Mater. Sci. Eng.* **2017**, *225*, 012090. [CrossRef]
17. Mishra, S.; Nayak, P.C.; Prusty, U.C.; Prusty, R.C. Model predictive controller based load frequency control of isolated microgrid system integrated to plugged-in electric vehicle. In Proceedings of the 2021 1st Odisha International Conference on Electrical Power Engineering, Communication and Computing Technology (ODICON), Jaipur, India, 1–2 July 2017; pp. 1–5.
18. Dhundhara, S.; Verma, Y.P. Application of micro pump hydro energy storage for reliable operation of microgrid system. *IET Renew. Power Gener.* **2020**, *14*, 1368–1378. [CrossRef]
19. Yildirim, B. Gain and phase margins based stability region analysis of time-delayed shipboard microgrid with sea wave energy. *IET Electr. Power Appl.* **2020**, *14*, 1347–1359. [CrossRef]
20. Wang, Y.; Zhou, R.; Wen, C. New robust adaptive load-frequency control with system parametric uncertainties. *IEE Proc. Gener. Transm. Distrib.* **1994**, *141*, 184–190. [CrossRef]
21. Jiang, L.; Yao, W.; Wu, Q.H.; Wen, J.Y.; Cheng, S.J. Delay-dependent stability for load frequency control with constant and time-varying delays. *IEEE Trans. Power Syst.* **2012**, *27*, 932–941. [CrossRef]
22. Parmar, K.P.S.; Majhi, S.; Kothari, D.P. Load frequency control of a realistic power system with multi-source power generation. *Int. J. Electr. Power Energy Syst.* **2012**, *42*, 426–433. [CrossRef]
23. Wang, Y.; Zhou, R.; Wen, C. Robust load-frequency controller design for power systems. *IEE Proc. C Gener. Transm. Distrib.* **1993**, *140*, 11–16. [CrossRef]
24. Doolla, S.; Bhatti, T.S. Load Frequency Control of an Isolated Small-Hydro Power Plant With Reduced Dump Load. *IEEE Trans. Power Syst.* **2006**, *21*, 1912–1919. [CrossRef]
25. Concordia, C.; Kirchmayer, L.K. Tie-Line Power and Frequency Control of Electric Power Systems—Part II. *Trans. Am. Inst. Electr. Eng. Part III Power Appar. Syst.* **1954**, *73*, 133–146.
26. Moorthi, V.R.; Aggarwal, R.P. Damping Effects of Excitation Control in Load-Frequency Control System. *Proc. Inst. Electr. Eng.* **1974**, *121*, 1409–1416. [CrossRef]
27. Kumar, D.M.V. Intelligent controllers for automatic generation control. In Proceedings of the roceedings of IEEE TENCON '98. IEEE Region 10 International Conference on Global Connectivity in Energy, Computer, Communication and Control (Cat. No.98CH36229), New Delhi, India, 17–19 December 1998; Volume 2, pp. 557–574.
28. Gozde, H.; Taplamacioglu, M.C. Automatic generation control application with craziness based particle swarm optimization in a thermal power system. *Int. J. Electr. Power Energy Syst.* **2011**, *33*, 8–16. [CrossRef]
29. Chen, D.; Kumar, S.; York, M.; Wang, L. Smart automatic generation control. In Proceedings of the 2012 IEEE Power and Energy Society General Meeting, San Diego, CA, USA, 22–26 July 2012; pp. 1–7.
30. Bose, A.; Atiyyah, I. Regulation error in load frequency control. *IEEE Trans. Power Appar. Syst.* **1980**, *PAS-99*, 650–657. [CrossRef]
31. El Yakine Kouba, N.; Menaa, M.; Hasni, M.; Tehrani, K.; Boudour, M. A novel optimized fuzzy-PID controller in two-area power system with HVDC link connection. In Proceedings of the 2016 International Conference on Control, Decision and Information Technologies (CoDIT), Saint Julian's, Malta, 6–8 April 2016; pp. 204–209.
32. Kothari, M.L.; Nanda, J.; Kothari, D.P.; Das, D. Discrete-mode automatic generation control of a two-area reheat thermal system with new area control error. *IEEE Trans. Power Syst.* **1989**, *4*, 730–738. [CrossRef]
33. Hsu, Y.Y.; Chan, W.C. Coordinated Frequency and Voltage Control of Synchronous Generators. *IEEE Trans. Aerosp. Electron. Syst.* **1987**, *AES-23*, 2–10. [CrossRef]
34. Kocaarslan, I.; Çam, E. Fuzzy logic controller in interconnected electrical power systems for load-frequency control. *Int. J. Electr. Power Energy Syst.* **2005**, *27*, 542–549. [CrossRef]
35. Çam, E.; Kocaarslan, I. Load frequency control in two-area power systems using fuzzy logic controller. *Energy Convers. Manag.* **2005**, *46*, 233–243. [CrossRef]

36. Khodabakhshian, A.; Hooshmand, R. A new PID controller design for automatic generation control of hydro power systems. *Int. J. Electr. Power Energy Syst.* **2010**, *32*, 375–382. [CrossRef]
37. Saikia, L.C.; Bharali, A.; Dixit, O.; Malakar, T.; Sharma, B.; Kouli, S. Automatic generation control of multi-area hydro system using classical controllers. In Proceedings of the 2012 1st International Conference on Power and Energy in NERIST (ICPEN), Nirjuli, India, 28–29 December 2012; pp. 1–5.
38. Ibraheem; Nizamuddin; Bhatti, T.S. AGC of two-area power system interconnected by AC/DC links with diverse sources in each area. *Int. J. Electr. Power Energy Syst.* **2014**, *55*, 297–304. [CrossRef]
39. Verma, R.; Pal, S.; Sathan, S. Intelligent automatic generation control of two-area hydrothermal power system using ANN and fuzzy logic. In Proceedings of the 2013 International Conference on Communication Systems and Network Technologies, Gwalior, India, 6–8 April 2013; pp. 552–556.
40. Kumar, P.; Varshana, P.; Das, J.K. Two-area LFC model reduction. In Proceedings of the IEEE TENCON '98. IEEE Region 10 International Conference on Global Connectivity in Energy, Computer, Communication and Control (Cat. No.98CH36229), New Delhi, India, 17–19 December 1998; Volume 1, pp. 186–188.
41. Sharma, M.; Prakash, S.; Saxena, S. Robust Load Frequency Control Using Fractional-order TID-PD Approach Via Salp Swarm Algorithm. *IETE J. Res.* **2021**, 1–17. [CrossRef]
42. Tavakoli, M.; Pouresmaeil, E.; Adabi, J.; Godina, R.; Catalão, J.P.S. Load-frequency control in a multi-source power system connected to wind farms through multi terminal HVDC systems. *Comput. Oper. Res.* **2018**, *96*, 305–315. [CrossRef]
43. Sharma, G.; Narayanan, K.; Davidson, I.E.; Akindeji, K.T. Integration and enhancement of load frequency control design for diverse sources power system via DFIG based wind power generation and interonnected via parallel HVDC/EHVAC tie-lines. *Int. J. Eng. Res. Africa* **2020**, *46*, 106–124.
44. Sahu, R.K.; Gorripotu, T.S.; Panda, S. Automatic generation control of multi-area power systems with diverse energy sources using Teaching Learning Based Optimization algorithm. *Eng. Sci. Technol. Int. J.* **2016**, *19*, 113–134. [CrossRef]
45. Biswas, S.; Roy, P.K.; Chatterjee, K. FACTS-based 3DOF-PID Controller for LFC of Renewable Power System Under Deregulation Using GOA. *IETE J. Res.* **2021**, 1–14. [CrossRef]
46. Selvaraju, R.K.; Somaskandan, G. Impact of energy storage units on load frequency control of deregulated power systems. *Energy* **2016**, *97*, 214–228. [CrossRef]
47. Padhan, S.; Sahu, R.K.; Panda, S. Automatic generation control with thyristor controlled series compensator including superconducting magnetic energy storage units. *Ain Shams Eng. J.* **2014**, *5*, 759–774. [CrossRef]
48. Choudhary, K.; Singh, B. Load Frequency Control in Two-area Power Systems Integrated with SMES Combination using Fuzzy-PID and ANFIS Controller. *Int. Res. J. Eng. Technol.* **2019**, *6*, 2335–2341.
49. Dhandapani, L.; Abdulkareem, P.; Muthu, R. Two-area load frequency control with redox ow battery using intelligent algorithms in a restructured scenario. *Turkish J. Electr. Eng. Comput. Sci.* **2018**, *26*, 330–346. [CrossRef]
50. Aryan, P.; Raja, G.L. Design and Analysis of Novel QOEO Optimized Parallel Fuzzy FOPI-PIDN Controller for Restructured AGC with HVDC and PEV. *Iran. J. Sci. Technol.-Trans. Electr. Eng.* **2022**, *46*, 565–587. [CrossRef]
51. Ramesh, M.; Yadav, A.K.; Pathak, P.K. An extensive review on load frequency control of solar-wind based hybrid renewable energy systems. *Energy Sources Part A Recover. Util. Environ. Eff.* **2021**, 1–25. [CrossRef]
52. Sanki, P.; Basu, M.; Pal, P.S. Study of AGC as two-area thermal interconnected power system consisting WPG and SPG. In Proceedings of the 2018 Emerging Trends in Electronic Devices and Computational Techniques (EDCT), Kolkata, India, 8–9 March 2018; pp. 1–6.
53. Latif, A.; Hussain, S.M.S.; Das, D.C.; Ustun, T.S. Double stage controller optimization for load frequency stabilization in hybrid wind-ocean wave energy based maritime microgrid system. *Appl. Energy* **2021**, *282*, 116171. [CrossRef]
54. Khuntia, S.R.; Panda, S. Simulation study for automatic generation control of a multi-area power system by ANFIS approach. *Appl. Soft Comput. J.* **2012**, *12*, 333–341. [CrossRef]
55. Sahu, R.K.; Panda, S.; Rout, U.K. DE optimized parallel 2-DOF PID controller for load frequency control of power system with governor dead-band nonlinearity. *Int. J. Electr. Power Energy Syst.* **2013**, *49*, 19–33. [CrossRef]
56. Barisal, A.K. Comparative performance analysis of teaching learning based optimization for automatic load frequency control of multi-source power systems. *Int. J. Electr. Power Energy Syst.* **2015**, *66*, 67–77. [CrossRef]
57. Pradhan, P.C.; Sahu, R.K.; Panda, S. Firefly algorithm optimized fuzzy PID controller for AGC of multi-area multi-source power systems with UPFC and SMES. *Eng. Sci. Technol. Int. J.* **2016**, *19*, 338–354. [CrossRef]
58. Illias, H. Optimisation of PID controller for load frequency control in two-area power system using evolutionary particle swarm optimisation. *J. Electr. Syst.* **2016**, *12*, 315–324.
59. Khezri, R.; Oshnoei, A.; Oshnoei, S.; Bevrani, H.; Muyeen, S.M. An intelligent coordinator design for GCSC and AGC in a two-area hybrid power system. *Appl. Soft Comput. J.* **2019**, *76*, 491–504. [CrossRef]
60. Zaheeruddin; Singh, K. Primary frequency regulation of a microgrid by deloaded tidal turbines. *Soft Comput.* **2020**, *24*, 14667–14685. [CrossRef]
61. Singh, B.; Slowik, A.; Bishnoi, S.K. A Dual-Stage Controller for Frequency Regulation in a Two-Area Realistic Diverse Hybrid Power System Using Bull–Lion Optimization. *Energies* **2022**, *15*, 8063. [CrossRef]
62. Kumar, N.; Kumar, V.; Tyagi, B. Multi area AGC scheme using imperialist competition algorithm in restructured power system. *Appl. Soft Comput.* **2016**, *48*, 160–168. [CrossRef]

63. Bhatt, P.; Roy, R.; Ghoshal, S.P. Optimized multi area AGC simulation in restructured power systems. *Int. J. Electr. Power Energy Syst.* **2010**, *32*, 311–322. [CrossRef]
64. Nandi, M.; Shiva, C.K.; Mukherjee, V. TCSC based automatic generation control of deregulated power system using quasi-oppositional harmony search algorithm. *Eng. Sci. Technol. Int. J.* **2017**, *20*, 1380–1395. [CrossRef]
65. Khamari, D.; Sahu, R.K.; Gorripotu, T.S.; Panda, S. Automatic generation control of power system in deregulated environment using hybrid TLBO and pattern search technique. *Ain Shams Eng. J.* **2020**, *11*, 553–573. [CrossRef]
66. Kumari, S.; Shankar, G. Maiden application of cascade tilt-integral-derivative controller in load frequency control of deregulated power system. *Int. Trans. Electr. Energy Syst.* **2020**, *30*, e12257. [CrossRef]
67. El-Ela, A.A.A.; El-Sehiemy, R.A.; Shaheen, A.M.; Diab, A.E.G. Design of cascaded controller based on coyote optimizer for load frequency control in multi-area power systems with renewable sources. *Control Eng. Pract.* **2022**, *121*, 105058. [CrossRef]
68. Sharma, J.; Hote, Y.V.; Prasad, R. PID controller design for interval load frequency control system with communication time delay. *Control Eng. Pract.* **2019**, *89*, 154–168. [CrossRef]
69. Civelek, Z.; Gorel, G.; Luy, M.; Barısci, N.; Cam, E. Effects on load-frequency control of a solar power system with a two-area interconnected thermal power plant and its control with a new BFA algorithm. *Elektron. Ir Elektrotechnika* **2018**, *24*, 3–10. [CrossRef]
70. Cam, E.; Gorel, G.; Mamur, H. Use of the genetic algorithm-based fuzzy logic controller for load-frequency control in a two-area interconnected power system. *Appl. Sci.* **2017**, *7*, 308. [CrossRef]
71. El-Fergany, A.A.; El-Hameed, M.A. Efficient frequency controllers for autonomous two-area hybrid microgrid system using social-spider optimiser. *IET Gener. Transm. Distrib.* **2017**, *11*, 637–648. [CrossRef]
72. Latif, A.; Das, D.C.; Barik, A.K.; Ranjan, S. Illustration of demand response supported co-ordinated system performance evaluation of YSGA optimized dual stage PIFOD-(1 + PI) controller employed with wind-tidal-biodiesel based independent two-area interconnected microgrid system. *IET Renew. Power Gener.* **2020**, *14*, 1074–1086. [CrossRef]
73. Dahab, Y.A. Adaptive Load Frequency Control of Power Systems Using Electro-Search Optimization Supported by the Balloon Effect. *IEEE Access* **2020**, *8*, 7408–7422. [CrossRef]
74. Sekhar, G.T.C.; Kumar, R.; Baliarsingh, A.K.; Panda, S. Electrical Power and Energy Systems Load frequency control of power system under deregulated environment using optimal firefly algorithm. *Int. J. Electr. Power Energy Syst.* **2016**, *74*, 195–211. [CrossRef]
75. Rosaline, A.D.; Somarajan, U. Structured H-Infinity controller for an uncertain deregulated power system. *IEEE Trans. Ind. Appl.* **2019**, *55*, 892–906. [CrossRef]
76. Alhelou, H.H.; Hamedani-Golshan, M.E.; Heydarian-Forushani, E.; Al-Sumaiti, A.S.; Siano, P. Decentralized Fractional Order Control Scheme for LFC of Deregulated Nonlinear Power Systems in Presence of EVs and RER. In Proceedings of the 2018 International Conference on Smart Energy Systems and Technologies (SEST), Seville, Spain, 10–12 September 2018; pp. 1–6.
77. Shayeghi, H.; Jalili, A.; Shayanfar, H.A. A robust mixed H2/H∞ based LFC of a deregulated power system including SMES. *Energy Convers. Manag.* **2008**, *49*, 2656–2668. [CrossRef]
78. Morattab, A.; Shafiee, Q.; Bevrani, H. Decentralized Model Predictive load-frequency control for deregulated power systems in a tough situation. In Proceedings of the 2011 IEEE Trondheim PowerTech, Trondheim, Norway, 19–23 June 2011; pp. 1–5.
79. Sudha, K.R.; Santhi, R.V. Robust decentralized load frequency control of interconnected power system with Generation Rate Constraint using Type-2 fuzzy approach. *Int. J. Electr. Power Energy Syst.* **2011**, *33*, 699–707. [CrossRef]
80. Debbarma, S.; Saikia, L.C.; Sinha, N. AGC of a multi-area thermal system under deregulated environment using a non-integer controller. *Electr. Power Syst. Res.* **2013**, *95*, 175–183. [CrossRef]
81. Tan, W.; Zhang, H.; Yu, M. Decentralized load frequency control in deregulated environments. *Int. J. Electr. Power Energy Syst.* **2012**, *41*, 16–26. [CrossRef]
82. Villena, J.; Vigueras-Rodríguez, A.; Gómez-Lázaro, E.; Fuentes-Moreno, J.Á.; Muñoz-Benavente, I.; Molina-García, Á. An analysis of decentralized demand response as frequency control support under critical wind power oscillations. *Energies* **2015**, *8*, 12881–12897. [CrossRef]
83. Yang, T.; Zhang, Y.; Li, W.; Zomaya, A.Y. Decentralized Networked Load Frequency Control in Interconnected Power Systems Based on Stochastic Jump System Theory. *IEEE Trans. Smart Grid* **2020**, *11*, 4427–4439. [CrossRef]
84. Mi, Y.; Yang, Y.; Zhang, H.; Yu, A.; Wang, L.; Ren, L. Sliding mode based load frequency control for multi-area interconnected power system containing renewable energy. In Proceedings of the 2014 IEEE Conference and Expo Transportation Electrification Asia-Pacific (ITEC Asia-Pacific), Beijing, China, 31 August–3 September 2014; pp. 1–6.
85. Shahalami, S.H.; Farsi, D. Analysis of Load Frequency Control in a restructured multi-area power system with the Kalman filter and the LQR controller. *AEU-Int. J. Electron. Commun.* **2018**, *86*, 25–46. [CrossRef]
86. Lakshmi, D.; Fathima, A.P.; Muthu, R. Simulation of the Two-Area Deregulated Power System using Particle Swarm Optimization. *Int. J. Electr. Eng. Inform.* **2016**, *8*, 93–107. [CrossRef]
87. Prakash, A.; Murali, S.; Shankar, R.; Bhushan, R. HVDC tie-link modeling for restructured AGC using a novel fractional order cascade controller. *Electr. Power Syst. Res.* **2019**, *170*, 244–258. [CrossRef]
88. Arya, Y.; Kumar, N. 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.* **2016**, *75*, 127–138. [CrossRef]
89. Mohanty, B.; Hota, P.K. Comparative performance analysis of fruit fly optimisation algorithm for multi-area multisource automatic generation control under deregulated environment. *IET Gener. Transm. Distrib.* **2015**, *9*, 1845–1855. [CrossRef]

90. Davison, E.J.; Tripathi, N.K. The Optimal Decentralized Control of a Large Power System: Load and Frequency Control. *IEEE Trans. Automat. Contr.* **1978**, *23*, 312–325. [CrossRef]
91. Bevrani, H.; Daneshfar, F.; Daneshmand, P.R. Intelligent automatic generation control: Multi-agent Bayesian networks approach. In Proceedings of the 2010 IEEE International Symposium on Intelligent Control, Yokohama, Japan, 8–10 September 2010; pp. 773–778.
92. Yousef, H.A.; Al-Kharusi, K.; Albadi, M.H.; Hosseinzadeh, N. Load frequency control of a multi-area power system: An adaptive fuzzy logic approach. *IEEE Trans. Power Syst.* **2014**, *29*, 1822–1830. [CrossRef]
93. Saikia, L.C.; Paul, A.; Dash, P.; Choudhury, N.B.D. AGC of an interconnected multi-area hydrothermal system using a neuro-fuzzy controller. In Proceedings of the 2014 International Conference on Control, Instrumentation, Energy and Communication (CIEC), Calcutta, India, 31 January–2 February 2014; pp. 407–411.
94. Shiva, C.K.; Mukherjee, V. A novel quasi-oppositional harmony search algorithm for automatic generation control of power system. *Appl. Soft Comput. J.* **2015**, *35*, 749–765. [CrossRef]
95. Rahmani, M.; Sadati, N. Hierarchical optimal robust load-frequency control for power systems. *IET Gener. Transm. Distrib.* **2012**, *6*, 303–312. [CrossRef]
96. Shiroei, M.; Toulabi, M.R.; Ranjbar, A.M. Robust multivariable predictive based load frequency control considering generation rate constraint. *Int. J. Electr. Power Energy Syst.* **2013**, *46*, 405–413. [CrossRef]
97. Dong, L. A Robust Decentralized Load Frequency Controller for Interconnected Power Systems. *Electr. Eng. Comput. Sci. Fac. Publ.* **2012**, *51*, 410–419. [CrossRef]
98. Bengiamin, N.N.; Chan, W.C. Multilevel load-frequency control of interconnected power systems. *Proc. Inst. Electr. Eng.* **1978**, *125*, 521. [CrossRef]
99. Omar, M.; Soliman, M.; Ghany, A.M.A.; Bendary, F. Optimal tuning of PID controllers for hydrothermal load frequency control using Ant Colony Optimization. *Int. J. Electr. Eng. Informatics* **2013**, *5*, 348–360. [CrossRef]
100. Kouba, N.E.Y.; Menaa, M.; Hasni, M.; Boudour, M. Load Frequency Control in multi-area power system based on Fuzzy Logic-PID Controller. In Proceedings of the 2015 IEEE International Conference on Smart Energy Grid Engineering (SEGE), Oshawa, ON, Canada, 17–19 August 2015.
101. Acharyulu, B.V.S.; Mohanty, B.; Hota, P.K. Performance analysis of a cascade controller for conventional and deregulated power systems. *Int. J. Model. Simul.* **2020**, *40*, 260–278. [CrossRef]
102. Bevrani, H.; Habibi, F.; Babahajyani, P.; Watanabe, M.; Mitani, Y. Intelligent Frequency Control in an AC Microgrid: Online PSO-Based Fuzzy Tuning Approach. *IEEE Trans. Smart Grid* **2012**, *3*, 1935–1944. [CrossRef]
103. Bevrani, H.; Mitani, Y.; Tsuji, K. Robust decentralised load-frequency control using an iterative linear matrix inequalities algorithm. *IEE Proc.-Gener. Transm. Distrib.* **2004**, *151*, 347. [CrossRef]
104. Yu, X.; Tomsovic, K. Application of Linear Matrix Inequalities for Load Frequency Control With Communication Delays. *IEEE Trans. Power Syst.* **2004**, *19*, 1508–1515. [CrossRef]
105. Jagatheesan, K.; Anand, B.; Dey, N. Evolutionary algorithm based LFC of single area thermal power system with different steam configurations and non-linearity. *Adv. Intell. Syst. Comput.* **2016**, *435*, 185–194.
106. Jagatheesan, K.; Anand, B.; Samanta, S.; Dey, N.; Santhi, V.; Ashour, A.S.; Balas, V.E. Application of flower pollination algorithm in load frequency control of multi-area interconnected power system with nonlinearity. *Neural Comput. Appl.* **2017**, *28*, 475–488. [CrossRef]
107. Davison, E.; Tripathi, N. Decentralized tuning regulators: An application to solve the load and frequency control problem for a large power system. In Proceedings of the 1979 18th IEEE Conference on Decision and Control including the Symposium on Adaptive Processes, Fort Lauderdale, FL, USA, 12–14 December 1979; pp. 879–885.
108. Tan, W. Decentralized load frequency controller analysis and tuning for multi-area power systems. *Energy Convers. Manag.* **2011**, *52*, 2015–2023. [CrossRef]
109. Mohammadikia, R.; Aliasghary, M. A fractional order fuzzy PID for load frequency control of four-area interconnected power system using biogeography-based optimization. *Int. Trans. Electr. Energy Syst.* **2019**, *29*, e2735. [CrossRef]
110. Prakash, S.; Sinha, S.K. Simulation based neuro-fuzzy hybrid intelligent PI control approach in four-area load frequency control of interconnected power system. *Appl. Soft Comput. J.* **2014**, *23*, 152–164. [CrossRef]
111. Tan, W.; Zhou, H. Robust analysis of decentralized load frequency control for multi-area power systems. *Int. J. Electr. Power Energy Syst.* **2012**, *43*, 996–1005. [CrossRef]
112. Padhan, D.G.; Majhi, S. A new control scheme for PID load frequency controller of single-area and multi-area power systems. *ISA Trans.* **2013**, *52*, 242–251. [CrossRef] [PubMed]
113. Vrdoljak, K.; Perić, N.; Petrović, I. Sliding mode based load-frequency control in power systems. *Electr. Power Syst. Res.* **2010**, *80*, 514–527. [CrossRef]
114. Malik, O.P.; Kumar, A.; Hope, G.S. A load frequency control algorithm based on a generalized approach. *IEEE Trans. Power Syst.* **1988**, *3*, 375–382. [CrossRef]
115. Kumar, A.; Malik, O.P.; Hope, G.S. Discrete Variable Structure Controller for Load Frequency Control of Multiarea Interconnected Power Systems. *IEE Proc. C Gener. Transm. Distrib.* **1987**, *134*, 116–122. [CrossRef]

116. Prakash, S.; Bhardwaj, A.K.; Sinha, S.K. Neuro fuzzy hybrid intelligent approach for four-area load frequency control of interconnected power system. In Proceedings of the ICPCES 2012—2012 2nd International Conference on Power, Control and Embedded Systems, Allahabad, India, 17–19 December 2012.
117. Tan, W. Unified tuning of PID load frequency controller for power systems via IMC. *IEEE Trans. Power Syst.* **2010**, *25*, 341–350. [CrossRef]
118. Du, X.; Li, P. Fuzzy Logic Control Optimal Realization Using GA for Multi-Area AGC Systems. *J. Inf. Technol.* **2006**, *12*, 63–72.
119. Sharma, M.; Bansal, R.K.; Prakash, S.; Asefi, S. MVO Algorithm Based LFC Design of a Six-Area Hybrid Diverse Power System Integrating IPFC and RFB. *IETE J. Res.* **2021**, *67*, 394–407. [CrossRef]
120. Prakash, S.; Sinha, S.K. Automatic Load Frequency Control of Six Areas' Hybrid Multi-Generation Power Systems Using Neuro-Fuzzy Intelligent Controller. *IETE J. Res.* **2018**, *64*, 471–481. [CrossRef]
121. Dutta, A.; Prakash, S. Utilizing Electric Vehicles and Renewable Energy Sources for Load Frequency Control in Deregulated Power System Using Emotional Controller. *IETE J. Res.* **2022**, *68*, 1500–1511. [CrossRef]
122. Alhelou, H.H.; Zamani, R. Challenges and Opportunities of Load Frequency Control in Conventional, Modern and Future Smart Power Systems: A Comprehensive Review. *Energies* **2018**, *11*, 2497. [CrossRef]
123. Alhelou, H.H.; Golshan, M.E.H.; Fini, M.H. Wind Driven Optimization Algorithm Application to Load Frequency Control in Interconnected Power Systems Considering GRC and GDB Nonlinearities. *Electr. Power Components Syst.* **2018**, *46*, 1223–1238. [CrossRef]
124. Demiroren, A.; Zeynelgil, H.L. GA application to optimization of AGC in three-area power system after deregulation. *Int. J. Electr. Power Energy Syst.* **2007**, *29*, 230–240. [CrossRef]
125. Falahati, S.; Taher, S.A.; Shahidehpour, M. Grid frequency control with electric vehicles by using of an optimized fuzzy controller. *Appl. Energy* **2016**, *178*, 918–928. [CrossRef]
126. Shayeghi, H.; Shayanfar, H.A.; Jalili, A. Multi stage fuzzy PID load frequency controller in a restructured power system. *J. Electr. Eng.* **2007**, *58*, 61–70.
127. Shree, S.B.; Kamaraj, N. Hybrid Neuro Fuzzy approach for automatic generation control in restructured power system. *Int. J. Electr. Power Energy Syst.* **2016**, *74*, 274–285. [CrossRef]
128. Dhanalakshmi, R. ANFIS based Neuro-Fuzzy Controller in LFC of Wind- Micro Hydro-Diesel Hybrid Power System. *Int. J. Comput. Appl.* **2012**, *42*, 28–35.
129. Bhatti, T.S.; Al-Ademi, A.A.F.; Bansal, N.K. Load-frequency control of isolated wind-diesel-microhydro hybrid power systems (WDMHPS). *Energy* **1997**, *22*, 461–470. [CrossRef]
130. Piagi, P.; Lasseter, R.H. Autonomous Control of Microgrids. In Proceedings of the 2006 IEEE Power Engineering Society General Meeting, Montreal, QC, Canada, 18–22 June 2006; pp. 1–8.
131. Guerrero, J.M.; Member, S.; Vasquez, J.C.; Matas, J.; De Vicuña, L.G.; Castilla, M. Hierarchical Control of Droop-Controlled AC and DC Microgrids—A General Approach Toward Standardization. *IEEE Trans. Ind. Electron.* **2011**, *58*, 158–172. [CrossRef]
132. Lopes, J.A.P.; Moreira, C.L.; Madureira, A.G. Defining Control Strategies for MicroGrids Islanded Operation. *IEEE Trans. Power Syst.* **2006**, *21*, 916–924. [CrossRef]
133. Singh, K.; Amir, M.; Ahmad, F.; Khan, M.A. An Integral Tilt Derivative Control Strategy for Frequency Control in Multimicrogrid System. *IEEE Syst. J.* **2021**, *15*, 1477–1488. [CrossRef]
134. Yammani, C.; Maheswarapu, S. Load Frequency Control of Multi-microgrid System considering Renewable Energy Sources Using Grey Wolf Optimization. *Smart Sci.* **2019**, *7*, 198–217.
135. Barik, A.K.; Das, D.C. Active power management of isolated renewable microgrid generating power from Rooftop solar arrays, sewage waters and solid urban wastes of a smart city using Salp swarm algorithm. In Proceedings of the 2018 Technologies for Smart-City Energy Security and Power (ICSESP), Bhubaneswar, India, 28–30 March 2018; Volume 2018, pp. 1–6.
136. Singh, V.P.; Mohanty, S.R.; Kishor, N.; Ray, P.K. Robust H-infinity load frequency control in hybrid distributed generation system. *Int. J. Electr. Power Energy Syst.* **2013**, *46*, 294–305. [CrossRef]
137. Khooban, M.-H.; Niknam, T.; Shasadeghi, M.; Dragicevic, T.; Blaabjerg, F. Load Frequency Control in Microgrids Based on a Stochastic Noninteger Controller. *IEEE Trans. Sustain. Energy* **2018**, *9*, 853–861. [CrossRef]
138. Pahasa, J.; Ngamroo, I. Coordinated Control of Wind Turbine Blade Pitch Angle and PHEVs Using MPCs for Load Frequency Control of Microgrid. *IEEE Syst. J.* **2016**, *10*, 97–105. [CrossRef]
139. Zaheeruddin; Singh, K. Intelligent Fractional-Order-Based Centralized Frequency Controller for Microgrid. *IETE J. Res.* **2022**, *68*, 2848–2862. [CrossRef]
140. Shimizu, K.; Masuta, T.; Ota, Y.; Yokoyama, A. Load Frequency Control in Power System Using Vehicle-to-Grid System Considering the Customer Convenience of Electric Vehicles. In Proceedings of the International Conference on Power System Technology, Zhejiang, China, 24–28 October 2010; pp. 1–8.
141. Samarakoon, K.; Ekanayake, J.; Jenkins, N. Investigation of Domestic Load Control to Provide Primary Frequency Response Using Smart Meters. *IEEE Trans. Smart Grid* **2012**, *3*, 282–292. [CrossRef]
142. Palensky, P.; Dietrich, D. Demand side management: Demand response, intelligent energy systems, and smart loads. *IEEE Trans. Ind. Inform.* **2011**, *7*, 381–388. [CrossRef]
143. Vachirasricirikul, S.; Ngamroo, I. Robust LFC in a smart grid with wind power penetration by coordinated V2G control and frequency controller. *IEEE Trans. Smart Grid* **2014**, *5*, 371–380. [CrossRef]

144. Masuta, T.; Yokoyama, A. Supplementary load frequency control by use of a number of both electric vehicles and heat pump water heaters. *IEEE Trans. Smart Grid* **2012**, *3*, 1253–1262. [CrossRef]
145. Kanchev, H.; Lu, D.; Colas, F.; Lazarov, V.; Francois, B. Energy management and operational planning of a microgrid with a PV-based active generator for smart grid applications. *IEEE Trans. Ind. Electron.* **2011**, *58*, 4583–4592. [CrossRef]
146. Sargolzaei, A.; Yen, K.; Abdelghani, M. Delayed inputs attack on load frequency control in smart grid. In Proceedings of the ISGT 2014, Washington, DC, USA, 19–22 February 2014; pp. 1–5.
147. Alhelou, H.H.; Golshan, M.E.H. Hierarchical plug-in EV control based on primary frequency response in interconnected smart grid. In Proceedings of the 2016 24th Iranian Conference on Electrical Engineering, ICEE 2016, Shiraz, Iran, 10–12 May 2016; pp. 561–566.
148. Makdisie, C.; Haidar, B.; Alhelou, H.H. An optimal photovoltaic conversion system for future smart grids. In *Handbook of Research on Power and Energy System Optimization*; IGI Global: Hershey, PA, USA, 2018; pp. 601–657.
149. Izadkhast, S.; Garcia-Gonzalez, P.; Frias, P.; Ramirez-Elizondo, L.; Bauer, P. Aggregation of plug-in electric vehicles in distribution networks for primary frequency control. In Proceedings of the 2014 IEEE International Electric Vehicle Conference, IEVC 2014, Florence, Italy, 17–19 December 2014.
150. Liu, S.; Liu, X.P.; El Saddik, A. Denial-of-Service (dos) attacks on load frequency control in smart grids. In Proceedings of the 2013 IEEE PES Innovative Smart Grid Technologies Conference, ISGT 2013, Washington, DC, USA, 24–27 February 2013; pp. 1–6.
151. Nanda, J.; Mishra, S.; Saikia, L.C. Maiden application of bacterial foraging-based optimization technique in multiarea automatic generation control. *IEEE Trans. Power Syst.* **2009**, *24*, 602–609. [CrossRef]
152. Bevrani, H.; Hiyama, T. On Load–Frequency Regulation With Time Delays: Design and Real-Time Implementation. *IEEE Trans. Energy Convers.* **2009**, *24*, 292–300. [CrossRef]
153. Ghoshal, S.P. Application of GA/GA-SA based fuzzy automatic generation control of a multi-area thermal generating system. *Electr. Power Syst. Res.* **2004**, *70*, 115–127. [CrossRef]
154. Farahani, M.; Ganjefar, S.; Alizadeh, M. PID controller adjustment using chaotic optimisation algorithm for multi-area load frequency control. *IET Control Theory Appl.* **2012**, *6*, 1984–1992. [CrossRef]
155. Chatterjee, K. Design of Dual Mode PI Controller for Load Frequency Control. *Int. J. Emerg. Electr. Power Syst.* **2010**, *11*. [CrossRef]
156. Anwar, M.N.; Pan, S. A new PID load frequency controller design method in frequency domain through direct synthesis approach. *Int. J. Electr. Power Energy Syst.* **2015**, *67*, 567–569. [CrossRef]
157. Safari, A.; Babaei, F.; Farrokhifar, M. A Load Frequency Control Using a PSO-based ANN for Micro-Grids in the Presence of Electric Vehicles A Load Frequency Control Using a PSO-based ANN for Micro-Grids in the Presence of Electric Vehicles. *Int. J. Ambient Energy* **2021**, *42*, 688–700. [CrossRef]
158. Pahlavanzadeh, H.; Nooriasl, P. Entropy generation in liquid desiccant dehumidification system. *Energy Procedia* **2012**, *14*, 1855–1860. [CrossRef]
159. Ahuja, A.; Narayan, S.; Kumar, J. Robust FOPID controller for load frequency control using Particle Swarm Optimization. In Proceedings of the 2014 6th IEEE Power India International Conference (PIICON), Delhi, India, 5–7 December 2014; pp. 1–6.
160. Veerasamy, V.; Wahab, N.I.A.; Ramachandran, R.; Othman, M.L.; Hizam, H.; Irudayaraj, A.X.R.; Guerrero, J.M.; Kumar, J.S. A Hankel Matrix Based Reduced Order Model for Stability Analysis of Hybrid Power System Using PSO-GSA Optimized Cascade PI-PD Controller for Automatic Load Frequency Control. *IEEE Access* **2020**, *8*, 71422–71446. [CrossRef]
161. Shayeghi, H.; Shayanfar, H.A.; Jalili, A. LFC Design of a Deregulated Power System with TCPS Using PSO. *Int. J. Electr. Comput. Eng.* **2009**, *3*, 632–640.
162. Fathy, A.; Kassem, A.M.; Abdelaziz, A.Y. Optimal design of fuzzy PID controller for deregulated LFC of multi-area power system via mine blast algorithm. *Neural Comput. Appl.* **2020**, *32*, 4531–4551. [CrossRef]
163. Mohanty, B.; Panda, S.; Hota, P.K. Controller parameters tuning of differential evolution algorithm and its application to load frequency control of multi-source power system. *Int. J. Electr. Power Energy Syst.* **2014**, *54*, 77–85. [CrossRef]
164. Sahu, R.K.; Sekhar, G.T.C.; Panda, S. DE optimized fuzzy PID controller with derivative filter for LFC of multi source power system in deregulated environme nt. *Ain Shams Eng. J.* **2015**, *6*, 511–530. [CrossRef]
165. Kumar, A.; Shankar, G. Quasi-oppositional harmony search algorithm based optimal dynamic load frequency control of a hybrid tidal-diesel power generation system. *IET Gener. Transm. Distrib.* **2018**, *12*, 1099–1108. [CrossRef]
166. Kumar, B.; Adhikari, S.; Datta, S.; Sinha, N. Real Time Simulation for Load Frequency Control of Multisource Microgrid System Using Grey Wolf Optimization Based Modified Bias Coefficient Diagram Method (GWO-MBCDM) Controller. *J. Electr. Eng. Technol.* **2021**, *16*, 205–221. [CrossRef]
167. Sharma, Y.; Saikia, L.C. Automatic generation control of a multi-area ST—Thermal power system using Grey Wolf Optimizer algorithm based classical controllers. *Int. J. Electr. Power Energy Syst.* **2015**, *73*, 853–862. [CrossRef]
168. Dhillon, S.S.; Lather, J.S.; Marwaha, S. Multi objective load frequency control using hybrid bacterial foraging and particle swarm optimized PI controller. *Int. J. Electr. Power Energy Syst.* **2016**, *79*, 196–209. [CrossRef]
169. Sharma, M.; Bansal, R.K.; Prakash, S.; Dhundhara, S. Frequency regulation in PV integrated Power System using MFO tuned PIDF controller. In Proceedings of the 2018 IEEE 8th Power India International Conference (PIICON), Kurukshetra, India, 10–12 December 2018; pp. 1–6.
170. Sharma, D.; Yadav, N.K. Lion Algorithm with Levy Update: Load frequency controlling scheme for two-area interconnected multi-source power system. *Trans. Inst. Meas. Control* **2019**, *41*, 4084–4099. [CrossRef]

171. Alomoush, M.I. Load frequency control and automatic generation control using fractional-order controllers. *Electr. Eng.* **2010**, *91*, 357–368. [CrossRef]
172. Jain, S.; Hote, Y. Design of fractional PID for Load frequency control via Internal model control and Big bang Big crunch optimization. *IFAC-Pap.* **2018**, *51*, 610–615. [CrossRef]
173. Kumar, N.; Tyagi, B.; Kumar, V. Application of fractional order PID controller for AGC under deregulated environment. *Int. J. Autom. Comput.* **2018**, *15*, 84–93. [CrossRef]
174. Mishra, D.K.; Panigrahi, T.K.; Mohanty, A.; Ray, P.K. ScienceDirect Effect of Superconducting Magnetic Energy Storage on Two Agent Deregulated Power System Under Open Market. *Mater. Today Proc.* **2020**, *21*, 1919–1929. [CrossRef]
175. Guha, D.; Roy, P.K.; Banerjee, S. Grasshopper optimization algorithm scaled fractional order PI-D controller applied to reduced order model of load frequency control system. *Int. J. Model. Simul.* **2020**, *40*, 217–242. [CrossRef]
176. Kumar, K.V.; Ganesh, V. Design of fractional order proportional integral controller for load frequency control of multi-area power system under deregulated environment. *Int. J. Power Energy Convers.* **2020**, *11*, 223–247. [CrossRef]
177. Saxena, S. Load frequency control strategy via fractional-order controller and reduced-order modeling. *Int. J. Electr. Power Energy Syst.* **2019**, *104*, 603–614. [CrossRef]
178. Debbarma, S.; Dutta, A. Utilizing Electric Vehicles for LFC in Restructured Power Systems Using Fractional Order Controller. *IEEE Trans. Smart Grid* **2017**, *8*, 2554–2564. [CrossRef]
179. Nithilasaravanan, K.; Thakwani, N.; Mishra, P.; Kumar, V.; Rana, K.P.S. Efficient control of integrated power system using self-tuned fractional-order fuzzy PID controller. *Neural Comput. Appl.* **2019**, *31*, 4137–4155. [CrossRef]
180. Wang, H.; Zeng, G.; Dai, Y.; Bi, D.; Sun, J.; Xie, X. Design of a Fractional Order Frequency PID Controller for an Islanded Microgrid: A Multi-Objective Extremal Optimization Method. *Energies* **2017**, *10*, 1502. [CrossRef]
181. Dash, P.; Saikia, L.C.; Sinha, N. Automatic generation control of multi-area thermal system using Bat algorithm optimized PD–PID cascade controller. *Int. J. Electr. Power Energy Syst.* **2015**, *68*, 364–372. [CrossRef]
182. Debnath, M.K.; Jena, T.; Mallick, R.K. Novel PD-PID cascaded controller for automatic generation control of a multi-area interconnected power system optimized by grey wolf optimization (GWO). In Proceedings of the 2016 IEEE 1st International Conference on Power Electronics, Intelligent Control and Energy Systems (ICPEICES), Delhi, India, 4–6 July 2016; pp. 1–6.
183. Gorripotu, T.S.; Ramana, P.; Sahu, R.K.; Panda, S. Sine Cosine Optimization Based Proportional Derivative-Proportional Integral Derivative Controller for Frequency Control of Hybrid Power System. In *Computational Intelligence in Data Mining, Proceedings of the International Conference on ICCIDM 2018*; Springer: Singapore, 2020; pp. 789–797.
184. Dash, P.; Saikia, L.C.; Sinha, N. Flower Pollination Algorithm Optimized PI-PD Cascade Controller in Automatic Generation Control of a Multi-area Power System. *Int. J. Electr. Power Energy Syst.* **2016**, *82*, 19–28. [CrossRef]
185. Padhy, S.; Panda, S. A hybrid stochastic fractal search and pattern search technique based cascade PI-PD controller for automatic generation control of multi-source power systems in presence of plug in electric vehicles. *CAAI Trans. Intell. Technol.* **2017**, *2*, 12–25. [CrossRef]
186. Yakout, A.H.; Attia, M.A.; Kotb, H. Marine Predator Algorithm based Cascaded PIDA Load Frequency Controller for Electric Power Systems with Wave Energy Conversion Systems. *Alexandria Eng. J.* **2021**, *60*, 4213–4222. [CrossRef]
187. Saha, D.; Saikia, L.C. Performance of FACTS and energy storage devices in a multi-area wind-hydro-thermal system employed with SFS optimized I-PDF controller. *J. Renew. Sustain. Energy* **2017**, *9*, 024103. [CrossRef]
188. Saha, A.; Saikia, L.C. Utilisation of ultra-capacitor in load frequency control under restructured STPP-thermal power systems using WOA optimised PIDN- FOPD controller. *IET Gener. Transm. Distrib.* **2017**, *11*, 3318–3331. [CrossRef]
189. Saha, A.; Saikia, L.C. Combined application of redox flow battery and DC link in restructured AGC system in the presence of WTS and DSTS in distributed generation unit. *IET Gener. Transm. Distrib.* **2018**, *12*, 2072–2085. [CrossRef]
190. Sahoo, P.K.; Mohapatra, S.; Gupta, D.K.; Panda, S. Multi Verse Optimized Fractional Order PDPI Controller for Load Frequency Control. *IETE J. Res.* **2022**, *68*, 3302–3315. [CrossRef]
191. Arya, Y. Improvement in automatic generation control of two-area electric power systems via a new fuzzy aided optimal PIDN-FOI controller. *ISA Trans.* **2018**, *80*, 475–490. [CrossRef] [PubMed]
192. Guha, D.; Roy, P.K.; Banerjee, S. Equilibrium optimizer-tuned cascade fractional-order 3DOF-PID controller in load frequency control of power system having renewable energy resource integrated. *Int. Trans. Electr. Energy Syst.* **2021**, *31*, e12702. [CrossRef]
193. Tasnin, W.; Saikia, L.C. Performance comparison of several energy storage devices in deregulated AGC of a multi-area system incorporating geothermal power plant. *IET Renew. Power Gener.* **2018**, *12*, 761–772. [CrossRef]
194. Raju, M.; Saikia, L.C.; Sinha, N. Maiden application of two degree of freedom cascade controller for multi-area automatic generation control. *Int. Trans. Electr. Energy Syst.* **2018**, *28*, e2586. [CrossRef]
195. Guha, D.; Roy, P.K.; Banerjee, S. Maiden application of SSA-optimised CC-TID controller for load frequency control of power systems. *IET Gener. Transm. Distrib.* **2019**, *13*, 1110–1120. [CrossRef]
196. Mohamed, E.A.; Aly, M.; Watanabe, M. New Tilt Fractional-Order Integral Derivative with Fractional Filter (TFOIDFF) Controller with Artificial Hummingbird Optimizer for LFC in Renewable Energy Power Grids. *Mathematics* **2022**, *10*, 3006. [CrossRef]
197. Çelik, E.; Öztürk, N. Novel fuzzy 1PD-TI controller for AGC of interconnected electric power systems with renewable power generation and energy storage devices. *Eng. Sci. Technol. Int. J.* **2022**, *35*, 101166. [CrossRef]

198. Sharma, M.; Saxena, S.; Prakash, S.; Dhundhara, S.; Arya, Y. Frequency stabilization in sustainable energy sources integrated power systems using novel cascade noninteger fuzzy controller. *Energy Sources Part A Recover. Util. Environ. Eff.* **2022**, *44*, 6213–6235. [CrossRef]
199. Saikia, L.C.; Mishra, S.; Sinha, N.; Nanda, J. Automatic generation control of a multi-area hydrothermal system using reinforced learning neural network controller. *Int. J. Electr. Power Energy Syst.* **2011**, *33*, 1101–1108. [CrossRef]
200. Qian, D.; Tong, S.; Liu, H.; Liu, X. Load frequency control by neural-network-based integral sliding mode for nonlinear power systems with wind turbines. *Neurocomputing* **2016**, *173*, 875–885. [CrossRef]
201. Shayeghi, H.; Shayanfar, H.A. Application of ANN technique based on μ-synthesis to load frequency control of interconnected power system. *Int. J. Electr. Power Energy Syst.* **2006**, *28*, 503–511. [CrossRef]
202. Demiroren, A.; Zeynelgil, H.L.; Sengor, N.S. The application of ANN technique to load-frequency control for three-area power system. In Proceedings of the 2001 IEEE Porto Power Tech Proceedings (Cat. No.01EX502), Porto, Portugal, 10–13 September 2001; Volume 2, p. 5.
203. Kassem, A.M. Neural predictive controller of a two-area load frequency control for interconnected power system. *Ain Shams Eng. J.* **2010**, *1*, 49–58. [CrossRef]
204. Pal, A.K.; Bera, P.; Chakraborty, K. AGC in two-area deregulated power system using reinforced learning neural network controller. In Proceedings of the 2014 First International Conference on Automation, Control, Energy and Systems (ACES), Adisaptagram, India, 1–2 February 2014.
205. Bhongade, S.; Gupta, H.O.; Tyagi, B. Artificial neural network based automatic generation control scheme for deregulated electricity market. In Proceedings of the 2010 Conference Proceedings IPEC, Singapore, 27–29 October 2010; pp. 1158–1163.
206. Qu, Z.; Xu, C.; Ma, K.; Jiao, Z. Fuzzy neural network control of thermostatically controlled loads for demand-side frequency regulation. *Energies* **2019**, *12*, 2463. [CrossRef]
207. Prakash, S.; Sinha, S.K. Neuro-Fuzzy Computational Technique to Control Load Frequency in Hydro-Thermal Interconnected Power System. *J. Inst. Eng. Ser. B* **2015**, *96*, 273–282. [CrossRef]
208. Chidambaram, I.A.; Francis, R. Automatic generation control of a two-area reheat interconnected power system based on CPS using fuzzy neural network. In Proceedings of the 2011 International Conference on Emerging Trends in Electrical and Computer Technology, Nagercoil, India, 23–24 March 2011; pp. 200–205.
209. Mosaad, M.I.; Salem, F. LFC based adaptive PID controller using ANN and ANFIS techniques. *J. Electr. Syst. Inf. Technol.* **2014**, *1*, 212–222. [CrossRef]
210. Fathy, A.; Kassem, A.M. Antlion optimizer-ANFIS load frequency control for multi-interconnected plants comprising photovoltaic and wind turbine. *ISA Trans.* **2019**, *87*, 282–296. [CrossRef] [PubMed]
211. Prakash, S.; Sinha, S.K. ALFC of hybrid multi-generation power system using UC and TCPS by ANFIS control technique. *Int. J. Electron.* **2019**, *106*, 174–211. [CrossRef]
212. Pan, I.; Das, S. Fractional order fuzzy control of hybrid power system with renewable generation using chaotic PSO. *ISA Trans.* **2016**, *62*, 19–29. [CrossRef] [PubMed]
213. Chang, C.S.; Fu, W.; Wen, F. Load frequency control using genetic-algorithm based fuzzy gain scheduling of pi controllers. *Electr. Mach. Power Syst.* **1998**, *26*, 39–52. [CrossRef]
214. Khooban, M.H.; Niknam, T. A new intelligent online fuzzy tuning approach for multi-area load frequency control: Self Adaptive Modified Bat Algorithm. *Int. J. Electr. Power Energy Syst.* **2015**, *71*, 254–261. [CrossRef]
215. Arya, Y. Automatic generation control of two-area electrical power systems via optimal fuzzy classical controller. *J. Franklin Inst.* **2018**, *355*, 2662–2688. [CrossRef]
216. Rajesh, K.S.; Dash, S.S.; Rajagopal, R. Hybrid improved firefly-pattern search optimized fuzzy aided PID controller for automatic generation control of power systems with multi-type generations. *Swarm Evol. Comput.* **2019**, *44*, 200–211. [CrossRef]
217. Kalyan, C.N.S.; Goud, B.S.; Reddy, C.R.; Ramadan, H.S.; Bajaj, M.; Ali, Z.M. Water cycle algorithm optimized type ii fuzzy controller for load frequency control of a multi-area, multi-fuel system with communication time delays. *Energies* **2021**, *14*, 5387. [CrossRef]
218. Sabahi, K.; Ghaemi, S.; Pezeshki, S. Application of type-2 fuzzy logic system for load frequency control using feedback error learning approaches. *Appl. Soft Comput. J.* **2014**, *21*, 1–11. [CrossRef]
219. Yesil, E. Interval type-2 fuzzy PID load frequency controller using Big Bang-Big Crunch optimization. *Appl. Soft Comput. J.* **2014**, *15*, 100–112. [CrossRef]
220. Khooban, M.H.; Gheisarnejad, M. A Novel Deep Reinforcement Learning Controller Based Type-II Fuzzy System: Frequency Regulation in Microgrids. *IEEE Trans. Emerg. Top. Comput. Intell.* **2021**, *5*, 689–699. [CrossRef]
221. Annamraju, A.; Nandiraju, S. Robust frequency control in a renewable penetrated power system: An adaptive fractional order-fuzzy approach. *Prot. Control Modn Power Syst.* **2019**, *4*, 16. [CrossRef]
222. Yakout, A.H.; Kotb, H.; Hasanien, H.M.; Aboras, K.M. Optimal Fuzzy PIDF Load Frequency Controller for Hybrid Microgrid System Using Marine Predator Algorithm. *IEEE Access* **2021**, *9*, 54220–54232. [CrossRef]
223. Rajesh, K.S.; Dash, S.S. Load frequency control of autonomous power system using adaptive fuzzy based PID controller optimized on improved sine cosine algorithm. *J. Ambient Intell. Humaniz. Comput.* **2019**, *10*, 2361–2373. [CrossRef]
224. Prusty, U.C.; Nayak, P.C.; Prusty, R.C.; Panda, S. An improved moth swarm algorithm based fractional order type-2 fuzzy PID controller for frequency regulation of microgrid system. *Energy Sources Part A Recover. Util. Environ. Eff.* **2022**, 1–23. [CrossRef]

225. Sharma, M.; Prakash, S.; Saxena, S.; Dhundhara, S. Optimal Fractional-Order Tilted-Integral-Derivative Controller for Frequency Stabilization in Hybrid Power System Using Salp Swarm Algorithm. *Electr. Power Compon. Syst.* **2021**, *48*, 1912–1931. [CrossRef]
226. Guha, D.; Roy, P.K.; Banerjee, S. Performance evolution of different controllers for frequency regulation of a hybrid energy power system employing chaotic crow search algorithm. *ISA Trans.* **2022**, *120*, 128–146. [CrossRef]
227. Mohamed, E.A.; Ahmed, E.M.; Elmelegi, A.; Aly, M.; Elbaksawi, O.; Mohamed, A.-A.A. An Optimized Hybrid Fractional Order Controller for Frequency Regulation in Multi-Area Power Systems. *IEEE Access* **2020**, *8*, 213899–213915. [CrossRef]
228. Topno, P.N.; Chanana, S. Load frequency control of a two-area multi-source power system using a tilt integral derivative controller. *JVC/Journal Vib. Control* **2018**, *24*, 110–125. [CrossRef]
229. Kumari, S.; Shankar, G. Novel application of integral-tilt-derivative controller for performance evaluation of load frequency control of interconnected power system. *IET Gener. Transm. Distrib.* **2018**, *12*, 3550–3560. [CrossRef]
230. Guha, D.; Roy, P.K.; Banerjee, S. Disturbance observer aided optimised fractional-order three-degree-of-freedom tilt-integral-derivative controller for load frequency control of power systems. *IET Gener. Transm. Distrib.* **2021**, *15*, 716–736. [CrossRef]
231. Mi, Y.; Fu, Y.; Li, D.; Wang, C.; Loh, P.C.; Wang, P. The sliding mode load frequency control for hybrid power system based on disturbance observer. *Int. J. Electr. Power Energy Syst.* **2016**, *74*, 446–452. [CrossRef]
232. Sarkar, M.K.; Dev, A.; Asthana, P.; Narzary, D. Chattering free robust adaptive integral higher order sliding mode control for load frequency problems in multi-area power systems. *IET Control Theory Appl.* **2018**, *12*, 1216–1227. [CrossRef]
233. Kalyan, C.N.S.; Suresh, C. Higher Order Degree of Freedom Controller for Load Frequency Control of Multi-area Interconnected Power System with Time Delays. *Glob. Transitions Proc.* **2022**, *3*, 332–337. [CrossRef]
234. Debbarma, S.; Saikia, L.C.; Sinha, N. Automatic generation control using two degree of freedom fractional order PID controller. *Int. J. Electr. Power Energy Syst.* **2014**, *58*, 120–129. [CrossRef]
235. Ustun, T.S.; Aftab, M.A.; Ali, I.; Hussain, S.M.S. A novel scheme for performance evaluation of an iec 61850-based active distribution system substation. *IEEE Access* **2019**, *7*, 123893–123902. [CrossRef]
236. Ali, I.; Hussain, S.M.S.; Tak, A.; Ustun, T.S. Communication Modeling for Differential Protection in IEC-61850-Based Substations. *IEEE Trans. Ind. Appl.* **2018**, *54*, 135–142. [CrossRef]