A Recent Comprehensive Review of The Research Challenges and Opportunities of Automatic Generation

Getaneh Mesfin Meseret† and **Lalit Chandra Saikia**, Non-members

ABSTRACT

The main goal of modern power systems is to balance the power generated at the end of the generation with the demand for power on the consumer side. However, the consumer's development needs are constantly shifting load demand. Therefore, it is necessary to monitor and meet the load demand continuously. Customers gain from receiving cheaper electricity, more alternatives, and better services as the power system problem approaches the deregulation paradigm. Automatic Generation Control is presented in this thorough literature review (AGC). The current AGC designs for power systems are analyzed and categorized in this study for present-day and foreseeable intelligent power systems. Then, various control techniques- including classic control, optimal control, artificial intelligence control, adaptive and self-tuning control, and other optimization techniques, are discussed for the modeling of AGC in regulated and deregulated environment contexts. Multiple control groups are also created from the proposed AGC control mechanisms and examined. The paper's conclusion lists numerous new AGC research directions and gaps.

Keywords: AGC, Deregulated Power Systems, Interconnected Power Systems, Smart Grids, Microgrids

1. INTRODUCTION

A modern power system is intelligent and complex, with multiple areas and various power generation sources. Controlling electrical energy within predetermined bounds while maintaining nominal system frequency and tie-line power interchange is essential [1], [2]. The load frequency control is crucial to the power pool because it keeps the scheduled system frequency and tie-line power during regular operation and minor disturbances [3], [4]. Any random load perturbations in the power system can deviate from tie-line power exchanges and create frequency oscillations [5, 6]. To offer enough and consistently reliable electricity with high-quality power, automatic load frequency control (ALFC) is a crucial issue in the operation and management of power systems. The main objective of autonomous generation regulation of a power system is to maintain the frequency of each area and tie-line power flow within a set tolerance [7, 8]. The thermal power plants are facing a severe issue with the delayed response of AGC load demand, which negatively affects the control performance of the AGC power system [9]. Electrical power is a real-time good that is created and used right away. In the 20^{th} century, consumers had no choice but to purchase electricity. Vertically integrated utilities were required to sell it to them [9] [10]. In deregulated electricity structures, distribution companies (DISCOs), transmission companies (TRANSCOs), and generation companies (GENCOs) are independent legal entities. The transmission firms, or TRANSCOs, move the energy between GENCOs and DISCOs. The GENCOs, TRANSCOs, and DISCOs connected to the executed contracts are enclosed in a control area [11], [12]. Any frequency deviation with a sudden load disturbance directly impacts the efficiency and dependability of the power system in the real-time power market. Vibrations from low system frequencies can harm steam turbines. To reduce frequency variations and control tie-line power, AGC is essential to design and operate the deregulated electricity system. Area control error (ACE) is the foundation of the AGC [13] and [14]. The DISCOs have agreements with GENCOs in the same control region, known as "pool-co transactions." Bilateral transactions are the agreements that DISCOs have with any GENCOs in their own or other areas [15]. DISCOs may break a contract if more power is needed. The uncontract demand or contract violation refers to this surplus power. [16]. All transactions must be cleared through an ISO. AGC/LFC schemes differ depending on the market structure used in most developed nations [17], [18].

1.1 Survey Methodology

A systematic and realistic examination of the state of the arts is conducted using a variety of approaches. The techniques utilized to complete this AGC state-of-the-art review are fully described in this section. This extensive study searches the most prominent and well-known databases, including IEEE Discover, Scopus, Science Direct, IEEE Transaction, and Springer, for publications published in AGC/ALFC/ using the relevant keywords. It is important to remember that the study only considered

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The authors are with Department of Electrical Engineering, National Institute of Technology Silchar, Assam, India.

†Corresponding author: getanehmesfin469@gmail.com

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research published online, including guidelines, research articles, conference papers, review papers, and scientific books. The authors that come after me go into great depth about the techniques used in this study. The databases searched to complete this review included Scopus, Science Direct, Springer, IEEE Explore, Taylor & Francis, and Wiley Publishers. Keywords like "load rate control," "automatic generation control," and "frequency control" were utilized in this study by the authors. After eliminating duplicates, 413 articles remained from the 648 papers that the first search using the above methods had produced. Then, 192 papers were eliminated after their contributions, abstracts, and titles were scrutinized following the criteria and goals of this work. The authors reviewed the final paper lists on LFC/AGC in great detail. It's also important to note that before being submitted to the Journal, this review study underwent a thorough literature review procedure conducted by two colleagues who are authorities on AGC/LFC. This essay examines literature that was released between 1956 and 2022. The linked literature survey also compiles 65 years of illustrious research on the LFC issue. Although the paper's topic is broad, this paper might be helpful for beginners and first-year students to show the direction and research trend over time. Review articles on the "LFC problem" published in reputable publications in earlier years may be located [19].

2. CONVENTIONAL POWER INDUSTRY

The conventional electric power industry has historically been governed by vertical integration, a government monopoly that controls the assets for generation, transmission, and distribution [20], [21]. It also had a trust in the region. Every customer in the regulated power system area receives services and electricity from the same company or government entity [22], [23]. The government or a government agency frequently imposes the rules. The government has put these regulations in place to maintain order and discipline across the system, to the benefit of any one entity at the expense of the final consumer. The government governed all-natural power plants and initial implementations [24].

2.1 Characteristics of Traditional Power Industry

(i) Due to the fact that only local and national electric utilities were allowed to generate, transmit, distribute, and sell commercial electric power within their service areas, this power system is considered to be traditional.

(ii) Duty to serve: The energy provider must meet the demands of all customers within its service region, not simply those who were lucrative.

(iii) Regulatory Oversight: Utility operations and company operations must adhere to regulations by governmental regulatory organizations.

(iv) Regulated rates: Government rules and regulations either set or regulated the electric service tariffs.

(v) The guaranteed rate of return: The government ensured that the electric utility would receive a fair profit margin above its cost thanks to regulated laws.

(vi) The least cost operation: The electric services were necessary to minimize overall revenue requirements. However, vertically integrated monopolies cannot deliver services as effectively as rivals airline, telephone, and natural and gas firms. The electric power industry plans to improve its efficiency by restructuring by providing more reliable energy at the least cost to customers. Computation activities are guaranteed by establishing a restructured environment where customers can buy from different suppliers and change suppliers to pay market-based rates.

3. OVERVIEW OF DEREGULATION

Vertical Integrated Utility has been how the electric power industry has operated (VIU). End users are supplied with electricity by VIU's generation-transmission-distribution system. As the owner of all three tiers of the power supply circle, generation, transmission, and distribution, VIU can regulate the pricing and sale of electricity. Thus, VIU is the sole monopolistic utility operating in the electric power sector [25], [26]. Additionally, this connector offers very high reliability. Its drawbacks include ineffective production, significant losses, aging infrastructure, and poor management. Deregulation of the electric power business is therefore required, and generation, transmission, and distribution must be established as separate independent entities [27]. Several players have emerged, including distribution companies (DISCOs), generation companies (GENCOs), transmission companies (TRANSCOs), and independent system operators (ISO). The AGC is one of the auxiliary services offered by ISO. A region's DISCO (or buyer) is free to select from GENCOs (or sellers) operating in the same or other control areas for electricity contracts in the open market scenario, which ISO oversees.

3.1 Benefits of Deregulation

Customers and private companies stand to gain from the competitive market in several ways. According to [28], the following are just a few of the critical advantages of the power industry's deregulation:

(i) *The cost of electricity will decrease*: It is well known that prices in a free market are lower than those under a monopoly. The price of power charged to consumers and small companies is dramatically reduced. By driving higher prices through market forces and more competition, energy production costs will decrease.

(ii) *The customer choice*: The customer will choose its retailer. Resellers will compete on the additional benefits that they offer to customers in addition to the price that is supplied. These can include

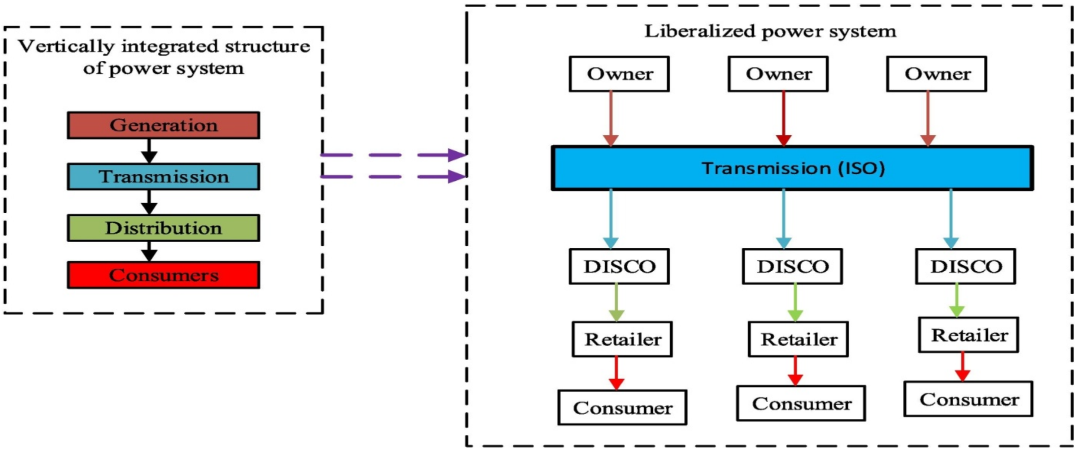

Fig. 1: *Block diagram of restructured power system.*

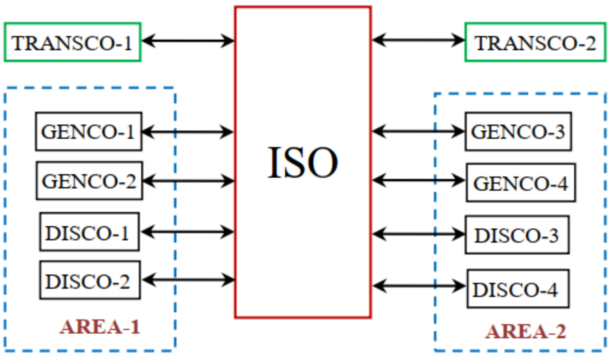

Fig. 2: *Interconnection of GENCOs, DISCOs, and TRANSCOs.*

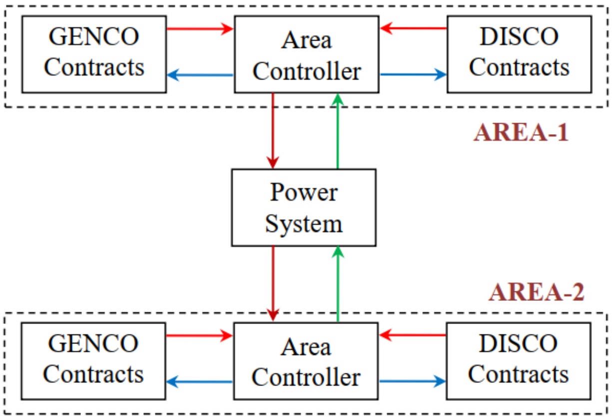

Fig. 3: *Schematic diagram of an interconnected restructured power system model.*

more effective plans, dependability, quality, sustainability, etc. This will deliver more significant incentives for short and long-term efficiencies than economic regulation.

(iii) *Customer-focused service*: Retailers go above and beyond what a monopolist would do regarding customer service.

(iv) *Innovation*: Electric utilities had no motivation to innovate or take chances on new ideas that would boost customer value because of the regulatory procedure and lack of competition.

(v) In a deregulated market, the electric utility will always endeavor to alter and innovate to enhance customer service, ultimately resulting in cost savings and increased profit.

(vi) New companies selling novel goods and services will emerge due to the restructuring of the power sector, and consumers will have additional options besides purchasing electrical services.

3.2 Disadvantages of Deregulation

(i) Unusually high wholesale market prices could result from improper or hurried restructuring implementation. As a result, California experienced an electricity crisis in 2000–2001 that threatened to destroy the state's economy and had unintended consequences for the rest of the West.

(ii) Employee Uncertainty: When a company is restructuring its power structure, its employees get anxious and worry about the future stability of their jobs. While the news spreads, the business is undergoing a restructuring, and some employees may start seeking other jobs [29], [30].

(iii) Sometimes the tension of the restructuring system prevents the workers from concentrating on their actual work.

3.3 Structural Elements of Restructured System

The structural elements, which include generation companies (GENCOS), power exchanges (PX), independent system operators (ISO), ancillary services (AS), retail service providers (R), schedule coordinators (SC), and distribution firms, represent various electrical market segments (DISCOS) [31], [32].

(i) *GENCOS (Generating Company) and Power Marketers*: The primary and secondary generation industries are GENCOS and Power Marketers, respectively. GENCOS, the owner-operators of one or more generators, maintain them and sell the electricity on the open market. Thanks to unfettered access to transmission, GENCOS can use the transmission network without limitations or competition.

(ii) *A power marketer* is a facility's representative. It markets electricity on behalf of the generations, may set up auxiliary services like transmission as needed, is viewed as a middleman between the buyer and the seller, and is anticipated to lower consumer prices.

(iii) *TRANSCO (Transmission Company)*: A Transco delivers electricity from GENCOS to DISCOS or retailers. To ensure the overall dependability of the electric power system, the Transco operates and maintains the transmission system in some geographic regions.

(iv) *DISCO (Distribution Company)* is the local power distribution network's proprietor and the operator provides electricity to particular businesses, centers, and households. In some locations, regional distribution and retail operations are merged. Purchasing wholesale power on the spot market or through direct agreements with GENCOS, and then delivering it to end-users. However, discos frequently do not sell their clients power. However, it merely owns and manages the local utility distribution system, and it makes money by transporting electricity via its network.

(v) *RESCO (Retail Energy Service Company)*: An electric power retailer is a RESCO. The RESCO purchases electricity from GENCOS and distributes it straight to end consumers.

(vi) *Customer*: in the client have several options in a deregulated power system, including placing a bid on the spot market or buying energy directly from a GENCO or a DISCO.

(vii) *ISO (Independent Service Operator)* An ISO is a separate entity that doesn't participate in market trading. It is responsible for ensuring the electrical system is secure and reliable. The ISO promotes several auxiliary services, including reactive power from other system participants, emergency reserve supply, and frequency control.

(viii) By ancillary services, We refer to "services linked to activities on the released electrical networks required for the support power transmission by guaranteeing the requisite level of quality power and safety on the systems" Twelve supplementary services have been suggested by NERC (North American Electric Reliability Corporation). These support services carry out the following tasks:
- To maintain equilibrium between generation and load (frequency control).
- To maintain support for both reactive power and voltage.
- To keep transmission and generation reserves.
- To be ready in case of an emergency (system restart and stability control).

3.4 Different restructure power system models

Deregulated power systems typically have a complicated dynamic structure and a vast scale. They have numerous interconnections, load centers, and producing stations. Only conventional varieties are the main energy generators. However, in the 21st century, traditional power sources must deal with significant issues such as environmental contamination, depletion of fossil resources, and high power generation costs. As a result, many researchers are increasingly concentrating on distributed generation (DG)-based renewable energy sources [33], [34].

3.4.1 Deregulated power system with renewable energy sources

Central power producers use traditional energy sources such as hydro, thermal, diesel, natural gas, and nuclear power. The primary goal of a power supply system is to balance the real and reactive power generation to load demand while considering loss. The system frequency deviation is an issue when attempting to control the real power of each group. A load frequency control is the tie-line power exchange within set parameters (LFC). Excitation control is the primary issue with reactive power balance control in an electrical system. The flywheel regulator of the synchronous machine was the primary method of frequency regulation, although it was ineffective. The regulator used a signal that is proportional to the frequency variation and is integral to add more control. The proportional control strategy is more integrally used in the conventional approach to autonomous generation control of electrical systems. Most utilities use integral, proportional, and proportional-integral-derivative (PID) controllers to match power and frequency to the appropriate scheduled levels. Conventional control methods must be revised to govern rapid changes in these electrical systems in complicated and deregulated structures. Among the fast-acting controllers that focus in the study are the Flexible AC transmission system, alternative energy sources, energy-storing technologies, and other auxiliary devices. According to researchers, the LFC issue in deregulated power networks is complicated [35].

3.4.2 A non-regulatory electric grid that uses renewable energy sources

Non-conventional energy is a natural energy source that is both clean and sustainable. Non-conventional energy is much less expensive and more economical than other generated power sources. As a result, more academics are concentrating on producing electricity from renewable sources. A restructured power system model that incorporates wind turbine generators and Flexible AC Transmission System devices is described in [36], [37] to address the LFC challenges. Verma.et. al [38] have analyzed focuses on a two-area restructure power system using doubly fed induction generators in both control zones [39].

3.4.3 Deregulated electrical system with distributed generation (DG) and smart gird

The term "distributed generation" (DG) often refers to a small (1 kW to 50 MW). DGs are seen as hybrid power system models (HPSM) that combine conventional combustion-based power generating units (PGUs), like micro-turbine generators (MTG) and diesel engine generators (DEG), with unconventional power generators, like fuel cells (FC) with aqua-electrolyze (AE). Solar photovoltaic (PV), wind turbine generators (WTG), solar thermal power, and energy storage units (ESUs) such as batteries, flywheels, ultra-capacitors, and superconducting magnetic energy storage devices are a few examples of renewable energy generators. Research on HPSM is presented in depth in [40], [41], and [42]. Kamwa et al. [43] suggested dynamic system modeling and the development of sturdy regulators for load frequency control in the no-storage wind-diesel-based HPSM.

3.5 Deregulated power system and market models

Following deregulation, a traditional power systems vertically integrated utility paradigm is replaced with a competitive, deregulated market. Three distinct market models make up the mainly deregulated electricity grid. The following sections show how these market models were developed based on a legal agreement with various organizations in a restructured power system [44], 45], [46], [47], and [48].

3.5.1 Pool market charge structure

The customer and the provider are the two primary participants in the deregulated market under a charged structure. Examining the electricity proposals (quantity and price) from these two parties, the independent network operator (ISO) distributes the demand economically based on the price and MW biddings. Thanks to the ISO, customers and suppliers only have indirect contact with one another in Poolco-based markets. Runs the control algorithm, calculates the ACE, including frequency and net exchange deviation, and delivers control signals to GENCOs prepared to provide a high/low generation shift for demand-responsive pricing. The charged structure can offer services to both load regulation and load following. The design and analysis of load frequency control problems in a charged system for the pool market are discussed in [49]. Stacke Fabio et al. conducted and presented the initial stage of the Poolco-based market in [50].

3.5.2 Bilateral structure

The two key actors are customers and suppliers who enter into contracts in a bilateral market. It simply provides load-following services. In this market, the customers set the cost of delivering the load following service, not the independent system operator (ISO). When the trade has been completed, the ISO must be notified since ISO makes sure that the benefits don't jeopardize the security of the system. This kind of market has no centralized control [51], [52]. The primary problem with this arrangement is contract violations made by market participants, whether they do it consciously or not [53].

3.5.3 Charged bilateral structure

Charged cum Bilateral Structure is a hybrid model that includes elements from the earlier models. It gives the players more freedom and is likely to be adopted in many nations. Communicate with their various GENCOs; the discos chose bilateral contracts. ISO is responsible for all other discos that choose pool structures [54], [55], [56].

3.6 Types contracts for deregulated power system

The components are the contributions. After restructuring, a traditional electricity system's vertical integration utility paradigm is replaced with a competitive, deregulated market structure. The entities include independent system operators, generation firms, transmission companies, and distribution companies (ISO). Numerous GENCOs and DISCOs could be found inside the deregulated framework. Every DISCO has an agreement with their region's generation companies (GENCOs). These transactions can be divided into three categories, each described below. These transactions need to be approved by an impartial organization known as an Independent System Operator (ISO) [57], [58]. Pay et al. [59] described the DISCO Participation Matrix (DPM) details, representing these various contracts in a matrix form. A DISCO Participation matrix's rows and columns reflect the number of GENCOs and DISCOs. The DPM displays each entry as a factor for contract participation (cpf). It is the ratio of GENCO's contribution to the total amount of DISCO's demand. The diagonal components in a DISCO Participation matrix stand in for local needs, while the off-diagonal parts represent input from other regions.

3.6.1 Unilateral contract

In a unilateral contract, the electricity contract can only be joined by GENCOs and DISCOs in the same region. A Poolco-based contract is another name for this. LFC concerns in a unilaterally contracted power system based on the DISCO Participation matrix (DPM) [60], [61], and AGPM [63], [64] are thoroughly explained in an AGPM [65], respectively. The effects of a unilateral contract scenario's generator rate constraint on a thermal power system-based GENCO with and without an artificial neural network-based controller were proposed by Bhongade and colleagues. Under [66], [67], applications for reheating steam turbines in a unilateral contract for load frequency control issues are described. Ref. [68] represents local controllers for reducing LFC problems in a one-sided load frequency control market. The unilateral agreements the thermal and reheat thermal unit GENCOs entered into are described in [69], [70].

3.6.2 Bilateral contract

A DISCO in one control area can enter into agreements or conduct business with any other GENCOs in another control region under this contract. In [71], a thorough description of load frequency control difficulties in a bilateral agreements power system based on DPM [72], [73], [74], and AGPM is discussed. The usage of local controllers for load frequency control difficulties is discussed in [75], [76].

3.6.3 Contract violation

In this situation, DISCOs across the globe need excess uncontract power demand, which the GENCOs in the same region typically meet. Although it is not a part of the contracted demand, the extra power provided should be shown as a local area load. Ref. [77], [78], and [79], deliberate analyses of situations involving contract violations are presented, along with an explanation of how the surplus power is acquired from other DISCOs with load frequency control.

4. DIFFERENT AGC TOPOLOGIES AND STRUCTURES SURVEY

The term "conventional power systems" in this part refers to an electrical power system that generates electricity using fossil fuels. Thermal, hydroelectric, and nuclear-generating units commonly power these systems. Based on their sizes, power systems can be divided into isolating, two-area, three-area, and four-area categories. The literature has many system frequency response models for AGC/LFC. The following subsections review the literature on power system models for AGC/LFC [80].

4.1 Single-Area Power Systems

The design and implementation of automatic generation control for single-area power systems is the subject of the first studies on frequency control. The literature [81] studies models of single-zone electrical systems, including LFC control techniques. In [82], [83], an autonomous generation control system for hydropower plants considering non-linearity is proposed. It provides examples of how reactive and active power regulation interactions affect LFC models of single-area power systems.

4.2 Two-Area interconnected Power Systems

An assessment of the load frequency control and automatic generation control systems in a two-area power system is given [84, [85]. [86] Investigates tie-line models' effects on a two-area power system's load frequency control. The impact of voltage control loops on the frequency response is considered by the load frequency control (LFC) models for two-area power systems [87]. An AGC approach is advised for two-area power systems connected by HVDC transmission lines [88]. Reheat-thermal turbines coupled with HVDC links have been the subject of documented two-area power system frequency response models.

4.3 Three-Area interconnected Power Systems

In [89], [90], an evaluation of LFC modeling for three interconnected areas is offered. Steam hydropower is regarded as an AGC model in the first and second categories. The AGC for multi-source power systems considering thermal, gas, and hydropower sources is suggested in [91].

4.4 Four-Area interconnected Power Systems

Massive power systems are frequently separated into control regions to keep the frequency within a suitable range. Malik et al. [92] load frequency control for four-area interconnected hydropower systems was the first attempt on this subject. The pioneering work in this field is a load frequency control for four-region interconnected hydropower systems investigated by Malik et al. [93].

Malik et al. [94] have investigated the models of four-area connected power systems desirable for load frequency control have developed, maintaining load frequency in frequency response.

4.5 Survey on AGC emerging technologies

The transfer function gain represents the penetration of the introduced renewable energy in this system. Wind turbines, solar PV systems, gas turbines, fuel cells, and battery energy systems are examples of renewable energy sources studied. In addition, novel ideas like micro-grid, smart grids, and deregulated power systems have impacted current power system control and stability. Several innovative control strategies are suggested to counteract the effects of future power systems' growing complexity and uncertainty. This section thoroughly examines current and upcoming power systems [95].

4.6 AGC with the HVDC Link

Modern electric power networks frequently use HVDC transmission lines. To better understand their effects, AGC studies have also considered HVDC dynamic models [96]. In this context, the analysis of power systems with a single area, two areas, and three areas connected by AC/DC tie-lines. Two-area and three-area interconnected power systems integration of parallel AC/DC tie-lines links are studied by [97]. As shown in [98], [99], two control-area power systems are interconnected via HVDC/DC connections and AC transmission lines. The four-area integrated power systems' HVDC transmission links connect the control regions [100].

On the other hand, DC transmission links are connected to the five-area power system [101]. The impacts of combining high voltage direct current (HVDC) and

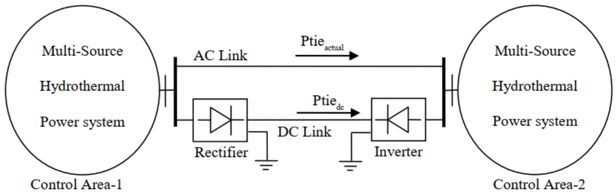

Fig. 4: The AC/DC parallel links connect with a two-area multi-source power system.

alternative current (AC) tie-lines on system response are also studied. It is found that parallel AC-HVDC tie-lines provide better dynamics than AC tie-lines alone.

4.7 Electric Power Systems with Deregulation environment

Novel control mechanisms have been developed for the deregulated power systems moving toward the restructuring paradigm. The AGC modeling issues for deregulated power systems were discussed in [102], [103]. A power system is divided into power generation companies (GENCOs), power transmission companies (TRANSCOs), and power distribution companies (DISCOs) businesses in a deregulated environment [104, [105]. An independent system operator (ISO) oversees each of these companies. GENCO might not participate in load frequency control service in this new environment. A competitive energy market provides the foundation for auxiliary services in deregulated power systems [106]. For several deregulated electricity systems, frequency response models were established in the literature. According to [107], frequency response models suitable for load frequency control research should be used in deregulated power systems with only thermal units. Deregulation is a multi-area, multi-source power system frequency response model [108]. AGC modeling is recommended for various restructured power system designs considering multi-area multi-sources and hybrid multi-area power systems [109].

4.8 AGC with the Renewable Energy Generation Systems

Distributed generation (DG) and renewable energy resources (RERs) have received a lot of attention in the last ten years due to their benefits in reducing emissions and greenhouse gas concerns [110], [111]. LFC/AGC/ problems with contributions from DGs and RERs were addressed in [112]. The Power system model for LFC research, which accounts for solar (PV), wind turbine generator (WTG), and flexible alternating current transmission systems (FACTS), have presented in [113], [114]. High DG contributing energy system LFC issues are covered in [115]. In [116], [117], the system frequency response of a double induction generator powered by a wind turbine is present in [118], [119], and [122]; frequency response models appropriate for electrical networks with significant renewable energy penetration

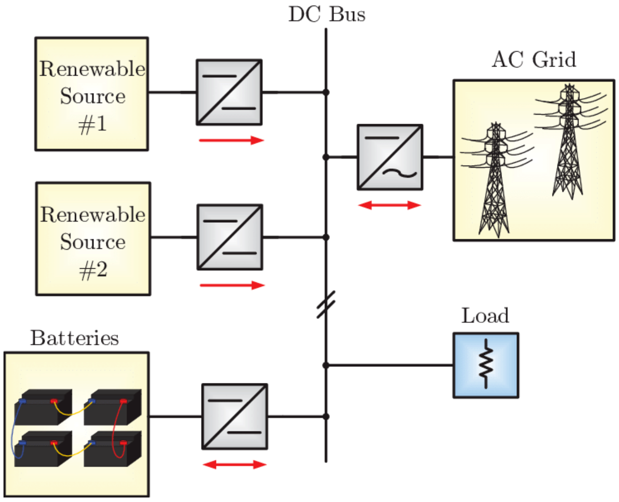

Fig. 5: Schematic diagram of micro-grid [120].

are also proposed.

4.9 AGC with Microgrids

AGC hybrid fuel cell, wind, and solar system models are provided. Modeling the LFC takes into account a Microgrids and a hybrid power system made up of accounts for solar (PV), wind turbine generator (WTG), micro-turbines, and fuel cells (FC) [123]. In [124], [125], it is explored how electric water heaters, electric cars, and dynamic demand response affect the CFL of microgrids. Additionally, [126], [127], and [128] propose nonlinear microgrids models for LFC research.

4.10 AGC with Smart Grid

Due to their immense importance, smart grid control concerns have recently received much attention from academics [130]. In [131] LFC models that account for the contribution of electric vehicles (EV) are proposed. Similarly, a coordination mechanism between heat pump water heaters and electric cars is proposed for CFL in upcoming smart grids [132]. A vital component of smart grids, dynamic demand response, has been created for LFC [133]. The contributions of various types of energy storage are considered using frequency response models presented and reviewed in [134]. A novel system frequency response model has been developed for primary and secondary frequency control levels for EV plug-ins. Future smart grids' vulnerability to cyber attacks on LFC systems is described in [135].

4.11 AGC with the IEEE 39-Bus System

The frequency's relationship to the active power balance is well established. Additionally, the dynamic power affects the net exchange power as well. The kinetic energy of the spinning mass of the generators and motors is initially used to offset the power demand in the case of a change in load. Dynamic frequency deviation is the term for this. The active power is then balanced at

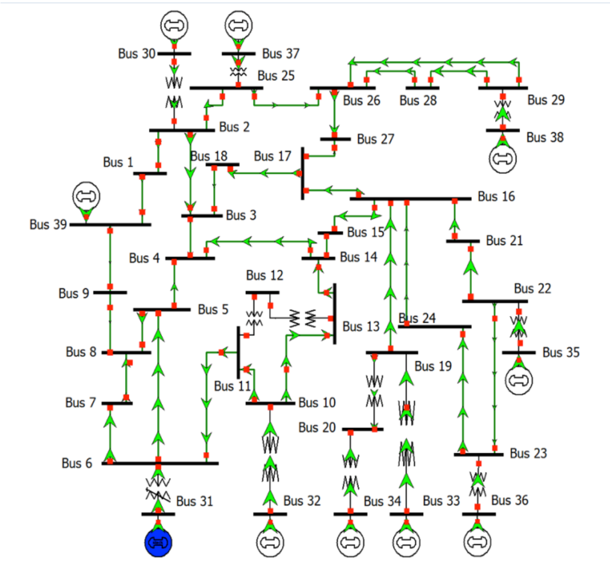

***Fig. 6**: IEEE 39 bus system.*

a deviation frequency, referred to as main control, as a result of the dynamic properties of the governors and loads [136]. After that, the secondary control determines the frequency and power correction. However, the frequency and interchange power discrepancy can be corrected using the AGC. For interconnected power systems (IPS) to operate reliably and to balance the total generation and the load demand with associated losses in real-time, automatic generation control is crucial. The modeling of AGC, the governing system, and the analysis of three different scenarios are all covered in this paper. An AGC system has been developed and examined using the IEEE 39-Bus test bench. One synchronous generator, known as an interconnected power system, is included. The remaining generators are located in the other region. Each interconnected power system has its control module. Demand growth causes increased operational stress, which highlights the need for AGC and further develops the controlling system. Within a few seconds of a disturbance, the main control begins to operate. The steady-state will thereafter experience frequency deviations due to any changes in load demand, while the primary control is still operating in this case, secondary control aids in restoring the frequency [137].

By modifying the corresponding machine generation through the governor, AGC aids in not only restoring the nominal frequency but also maintaining the exchange of scheduled power between the interconnected areas. Load frequency control (LFC) is the name of this technique [138].

$$P_{net} = \sum_{k=1-3}^{P} Pf_{low_k}, \tag{1}$$

where Pf_{low_k} denotes the tie line interchanges power via individual line.

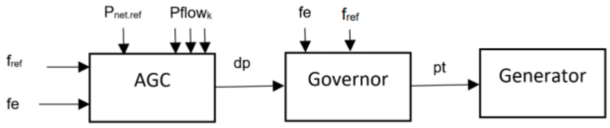

***Fig. 7**: The basic structure of an AGC controller.*

The basic mechanism of the AGC is depicted here:

$$\Delta f = f_{e-}f_{ref}, \tag{2}$$

$$\Delta p_{net} = p_{net-}p_{net.ref}, \tag{3}$$

where f_e denotes the measured frequency form generator, f_{ref} the reference frequency set point, and $p_{net.ref}$ the reference set point of net interchange power.

Every area has a unique additional control signal that exclusively affects that area. To achieve that control, an area control error (ACE) signal must be produced.

$$ACE = \Delta p_{net} + k_{bias}\Delta f, \tag{4}$$

where K_{bias} denotes the frequency bus.

5. TAXONOMY OF CONTROL TECHNIQUE

Different AGC methods have been developed in the past for power systems. The techniques include classical control approaches, reliable control strategies, digital control variable structures, adaptive control plans, and intelligent designs. The recommended control strategies for AGC in power systems are thoroughly reviewed in this section.

5.1 Classical Control Methods

The foundation of the conventional control method design is the consistent application of classical controllers to the governor model. It improves the power systems' area control error (ACE) to enhance system frequency response. For CFL in power systems, specific traditional control approaches have been put forth [139], [140]. Using the methods of Nyquist and Bode, gain and phase margin analysis is applied in conventional control processes. Using the relevant area control center, the proposed approach regulates frequency deviation brought on by load variation. Frequency and tie-line power don't interact at all. Proportional-integral (PI) control for hydropower systems and dual-mode PI controllers have been introduced. Using the relevant area control center, the proposed approach regulates frequency deviation brought on by load variation. Frequency and tie-line power don't interact at all. PI control for hydropower systems and a dual-mode proportional-integral (PI) controller have been introduced. Different degrees of freedom PID controllers are also revised, such as the first degree of freedom (1-DOF), the second degree of freedom (2-DOF), and three degrees of freedom (3-DOF).

Advantages and Disadvantages: Power systems have extensively explored LFC's classical control methodologies. Several electric power systems use these techniques for LFC. For modern power systems of the future, a number of challenges and downsides must be resolved. The following are the key drawbacks and issues:

(i) More realistic techniques are required to address the problem of load frequency controllers setting the parameters optimally.
(ii) It is essential to distinguish between robustness to parametric and non-parametric uncertainty.
(iii) Establishing control strategies for sensors that do not rely on actuator tolerance or failure is essential.
(iv) They require more research to determine how resilient they are to potential cyber-attack problems.

5.2 Optimal Control Methods

For multivariate control systems, most optimum control techniques have provided answers. These techniques consider the minimization of an objective function and the analysis model of state variables. The best control strategies are thus possible if all state variables are accessible to characterize and generate response control signals. These requirements complicate large-scale power systems and make an optimal control method unappealing. Using the regulator optimum control approach and a state-space variable model, a unique feedback control rule is developed for two-area interconnected power systems with re-reheat hydro-thermal power systems. A theory of modern optimum control has been used to design load frequency controllers that efficiently manage both the frequency responses and the power variations of the connecting line. Modern, robust control theory is the foundation for some LFC methods [141], [142]. The concept is applied to create the best linear regulator, which regulates the load frequency in power systems. Modern optimal control theory is the foundation for some LFC methods. The concept is applied to create the best linear regulator, which regulates the load frequency in power systems.

Merit and *Demerit*: Optimal control methods have many merits, including optimal control of the systems and regulation of all dynamic states of the controlled systems. Future intelligent power systems will be largely dependent on these techniques. Some drawbacks are given below.

(i) Real-time monitoring of dynamic state power system reactions is required.
(ii) The dynamic estimators of the model must take cyber-attack issues into account.
(iii) It is necessary to consider the intended system's parametric uncertainties.
(iv) Dynamic observers eliminate the necessity to build the unknown input effects of the power system model.

5.3 Adaptive Schemes

If the system's operating point changes, the performance of the frequency controller might not be at its best. Therefore, adjusting the settings based on the operating point would be desirable for good control efficiency. Model reference and self-tuning control (STC) schemes are two categories within the adaptive control technique. Since this strategy does not consider factors and dynamics, the sub-control mechanism is less susceptible to them. Many adaptive control schemes [143], [144] have been proposed for load frequency control in connected power systems. Self-tuning control strategies for CFLs in energy systems have been presented by specific authors [145], [146]. The design criteria for adaptive controls and the practical challenges LFC faces to meet these goals are proposed in [147], [148]. Check the hyper-stability conditions and consider changing plant characteristics; [149] provides an adaptive controller with a proportional-integral control method. Ref. [150] presents the automatic regulator for LFC/AGC, considering the interplay between frequency and voltage control circuits. A multi-area adaptive load frequency control approach is created, and a reduced-order adaptive controller for load frequency control is proposed [152]. [153] describes a few other problems with hydrothermal systems. [154] presents a self-tuning approach to the load frequency management issue in linked power networks.

To improve performance for various operating points, LFC is provided based on an adaptive fuzzy technique [155]. A self-tuning system is demonstrated to enhance the effectiveness of automatic generation control as a stabilizer for the AGC primary circuit and SMEs. Ref. [156] discusses self-tuning controllers for minimizing a multivariate optimization function, cost function, and control effort limits. In [157], a novel adaptive load frequency control with robust control and adaptive management is proposed. It takes parameter uncertainties into account. A load frequency management study is carried out for a two-area hydrothermal system using the Adaptive Neuro-Fuzzy Interference System (ANFIS). Ref. [158] describes an adaptive Neuro-Fuzzy gain scheduling technique using a proportional-integral and optimal Load frequency control. The primary application for knowledge-based adaptive governors' control has been demonstrated in [159]. It has been suggested to use automated steam turbine control.

Benefits and Drawbacks Adaptive controllers are complex and require an ideal model following conditions and an online explicit parameters identification, notwithstanding the significant advantages of these control schemes. These techniques, nevertheless, can occasionally be implausible and challenging to use.

5.4 Robust Control Techniques

An essential consideration in the design of the AGC is robustness. The primary goal is to maintain reliable performance and stability in the face of system parameter fluctuations, unpredictability, and perturbations in extremely competitive power markets. The bounds of system parameter uncertainties are also considered for robustness. Bevrani [160] has used the singular values theorem to develop a reduced-order robust LFC for a deregulated power system. Additionally, Bevrani et al. [161] have suggested a robust decentralized AGC in a deregulated power system based on bilateral contracts utilizing a hybrid $H_2/H\infty$ control method. The outcomes are contrasted with controllers that only use $H\infty$. Bevrani et al. [162] suggested a reliable decentralized AGC using a hybrid H2/H∞ control technique in a reorganized power system based on bilateral agreements. In another investigation, the outcomes are contrasted with those from pure H∞ regulators. Tyagi et al. [163] have investigated a decentralized AGC scheme for a multi-area power system in a competitive energy market by adequately allocating the proper structure of each isolated subsystem through status feedback. Lim et al. [164] showed how the decentralized robust load frequency controller (DRLFC) and auxiliary frequency controllers (AFCs) might work together in harmony for a three-area system. Shayeghi et al. [165] created a new decentralized mixed H2/ H∞ control technique to address load frequency control challenges in deregulated power systems. This combines the features of H2/ H∞ control synthesizes to reach the appropriate level of resilience. A novel strategy is presented in Reference [166] based on the structured singular value (μ-synthesis) of DPS in the robust decentralized AGC design. Fathima et al. [166] investigated the design of a new reliable controller for the deregulated power system's ancillary frequency regulation services. A decentralized model predictive controller for LFC in deregulated power systems under challenging conditions has been suggested in Reference [167]. Robust control technology and adaptive control are two different things. Thanks to sophisticated control technology, control rules for parameter fluctuations cannot alter a specific boundary [168].

Advantages and Drawbacks: Effective controllers that can manage parametric uncertainty are the advanced control approaches. But, these techniques have several shortcomings when used for frequency management in electrical networks.

(i) They required expertise in system dynamics modeling, which is lacking in most power systems.
(ii) They are often built to withstand a wide range of uncertainty.
(iii) They are often built to withstand a wide range of uncertainty.
(iv) Their suitability for use in power systems under challenging circumstances like cyber attacks and unidentified inputs is not examined.

5.5 Soft Computing Techniques

The traditional PID and PI controllers handle system non-linearity slowly and ineffectively. Fuzzy controllers are thus implemented for LFC [169], [170], and [171] to solve these issues. Due to its benefits, evolutionary computing-based control system design has attracted a lot of attention from scholars across the globe in the past ten years. The Soft computing techniques' well-known benefits include a solution's certainty, minimal solution costs, and viability [172]. Due to its benefits, evolution computing-based controller systems modeling have attracted a lot of attention from scholars across the globe in the past ten years. The load frequency controllers' parameters have been optimized using gentle computing approaches to obtain adequate control and dynamic system performances. As the first study, a genetic algorithm (GA) has been presented as a viable approach for tackling load frequency and other power system challenges [173]. In hydro-thermal power systems, GA has been proposed for AGC, and it is also used for power system controller tuning and fuzzy controller gains for LFC [174], [175], [176]. Some writers have offered soft computing techniques for LFC issues in classical and contemporary power systems [177-185]. The examination and performance comparison of the results of the created simulation show that the recently built skill optimization algorithm (SOA) performs better than the taken-into-account account methods and generates noticeably more competitive results.

5.6 Advantages and Disadvantages of Control Techniques

The design and application of traditional control systems are straightforward but require more time. As a result, different operating circumstances are incompatible with specific control systems. They have a significant frequency deviation and are ineffective at coping with system non-linearity. Additionally, multivariate control systems have found solutions thanks to optimum control techniques. A complete understanding of the dynamic system is necessary for the ideal controller model. These controllers are challenging to realize. Therefore, it is frequently impossible to apply optimal control. Update parameters based on changes in the system's operating point; adaptive control approaches are preferred. These controllers require a flawless model that follows the given conditions, but they are difficult. As a result, their implementation can be difficult and unrealistic [186-191].

6. AGC DESIGN STRUCTURES

Designing and implementing controllers for load frequency control (LFC) or automatic generation control (AGC) of large-scale power systems is challenging. Various control design solutions have been reported in the literature to address these issues, including centralized, decentralized, and distributed control. Because of the complexity, essential stability, resilience, inherent computer sophistication, and communication bandwidth, centralized LFC is rarely considered for deregulated power systems [192], [193]. However, interaction effects between neighboring subsystems are not taken into consideration. In that case, the system's performance could suffer given that some effective strategies, including the deregulated environment, have advocated a decentralized control structure.

AGC's key objectives are to keep the scheduled system frequency constant; tie-line power flows with nearby control areas at acceptable tolerance values, and adjusts active power generation in response to fluctuating power demands. Improved power system stability is attained with the right design of a supplementary controller used in an AGC system. However, the AGC work has become difficult due to ongoing size and complexity expansion, stochastically increasing power demands, model errors, changes in the structure of the electric power system, and changes in system characteristics throughout time. Consequently, conventional control strategies may need to be more competent to handle such unpredictable variations in an AGC system. To adequately address the AGC problem of power systems, researchers worldwide attempt to present several unique control solutions that combine knowledge, techniques, and methodologies from different sources.

6.1 Control loops in the AGC system

Automatic generation control (AGC) schemes must perform various control operations. The primary and supplemental AGC loops, as depicted in Fig. 8, carry out these control functions. The primary AGC loop is in charge of controlling the generator's real power output and speed. It consists of the prime mover's mounted speed governor [195].

The key objectives of AGC are to keep the scheduled system frequency constant, tie-line power flows with surrounding control areas at acceptable tolerance values and adjust active power generation in response to fluctuating power demands. An integrated power system connects each generator to its Automatic load-frequency control (ALFC) and Automatic Voltage Regulator (AVR) systems. In actuality, neither loop interacts with the other. The cross-coupling between ALFC and AVR is minimal. Both controllers are set up for a specific working environment and can handle modest fluctuations in load demand while keeping the frequency and voltage magnitude within limits [196].

6.2 Load Frequency Control (LFC)

LFC is the primary mechanism for controlling the operation of the electrical system. Whenever there is a change in load demand on generating unit, there is an imbalance between real power input and output. The load frequency also controls the power transfer through the interconnected transmission lines by detecting the change in power flow through the connecting lines. When the load increases, the frequency decreases in LFC, and our primary objective is to keep the frequency constant [197-200].

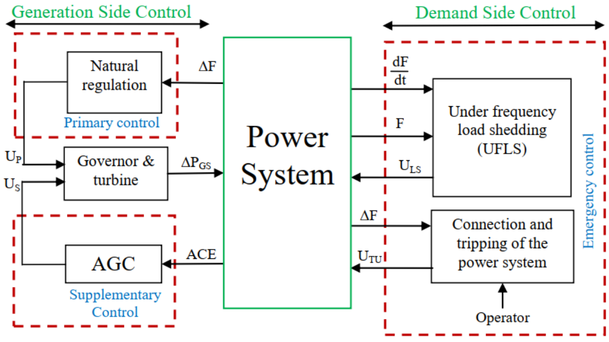

Fig. 8: Control loops in the AGC system.

7. DYNAMIC PERFORMANCE COMPARISONS CONSIDERING VARIOUS ASPECTS OF AREAS AND AUXILIARIES IN AN AGC/LFC/ SYSTEM WITH VARIOUS SECONDARY CONTROLLERS

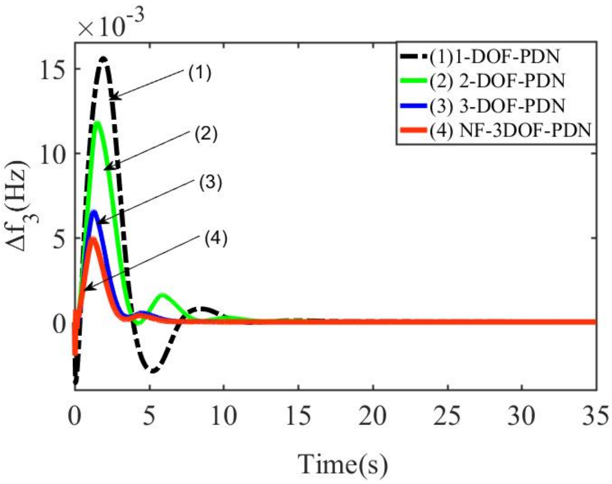

Fig. 9: Dynamic performance comparison of three-area hydrothermal system with various secondary controllers' 1-DOF-PDN, 2-DOF-PDN, 3-DOF-PDN and NF-3DOF-PDN.

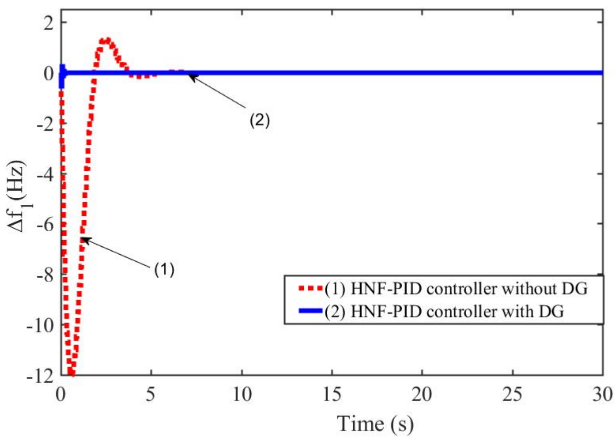

Fig. 10: Comparison of dynamic responses vs. time, two area thermal system with hybrid Neuro-Fuzzy-PID considering distribution generation (DG).

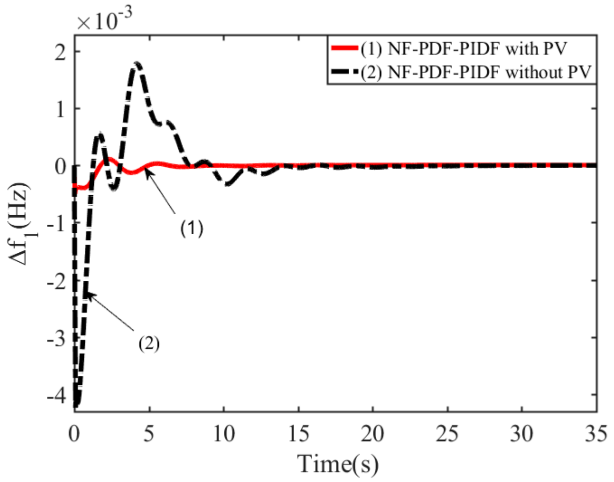

***Fig. 11**: Comparison of dynamic responses vs. time, three-area hydrothermal system with hybrid NF-PDF-PIDF with/without considering solar PV.*

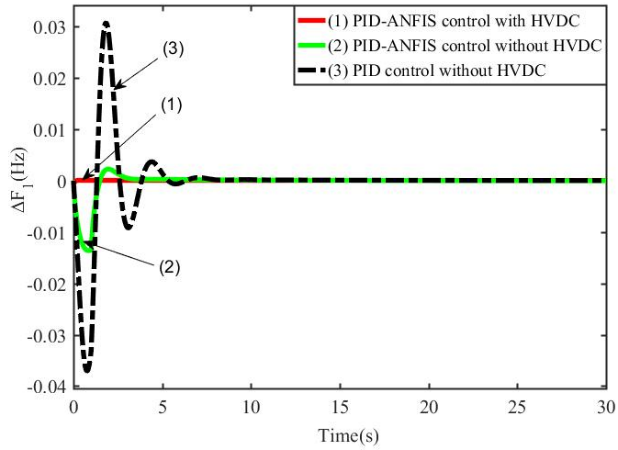

***Fig. 13**: Comparison of dynamic responses vs. time, three area hydrothermal system with Neuro-Fuzzy-PIDN, Neuro-Fuzzy and PIDN considering impacts of HVDC on dynamic performance.*

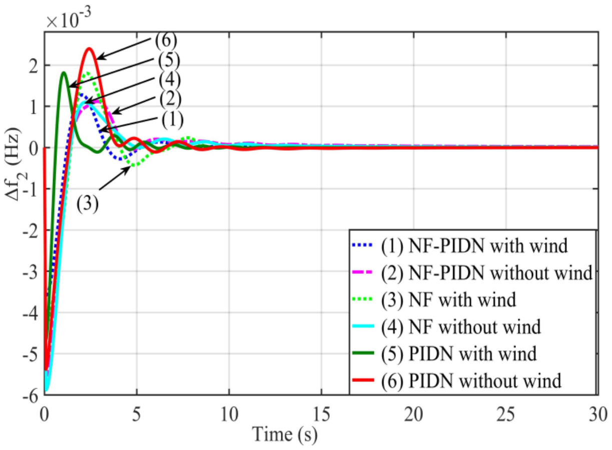

***Fig. 12**: Comparison of dynamic responses vs. time, three area hydrothermal system with Neuro-Fuzzy-PIDN, Neuro-Fuzzy and PIDN considering Wind power plant (WPP).*

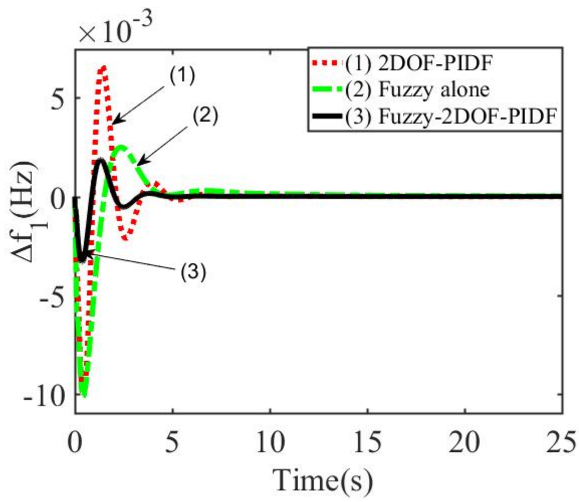

***Fig. 14**: Comparison of dynamic responses vs. time, three area hydrothermal system with Fuzzy-2DOF-PIDF, Fuzzy and 2DOF-PIDF.*

8. RESEARCH GAPS AND DIRECTIONS

Numerous factors, including environmental concerns, issues with fossil fuels, energy system security, and problems with economics and operating costs, are changing how the power system looks. The penetration of non-conventional energy sources like solar and wind energy resources in a country's energy system has increased. Still, as renewable energy sources become more prevalent in power systems, various issues arise, including a growing power imbalance in the functioning of short-term power plants. The increasing frequency and tie-line power oscillations while decreasing system overall inertia in plants. Numerous ISO issues, including a rising frequency nadir and system oscillation, are brought on by reducing the total inertia in electrical systems [201-208]. Additionally, a short-term operation with a more significant power imbalance causes frequency oscillations to rise directly. Frequency control issues would arise in both current and upcoming power facilities. These systems might encounter problems with insufficient damping and system inertia. For online control methods like system frequency problems, proper ancillary services are required as primary and secondary reserves. AGC is a crucial control factor when developing and using an electrical system panel with interconnected components. Because of the expanding size of the power system, structural changes, the massive influx of environmentally friendly power sources, parametric weaknesses and variety, many specialized and ecological constraints, and other power system difficulties. Different analog and computational control strategies are created and tested for particular /different areas and conventional/ deregulated power systems. Future AGC models must be intelligent enough to handle multi-objective optimization issues, have a wide range of

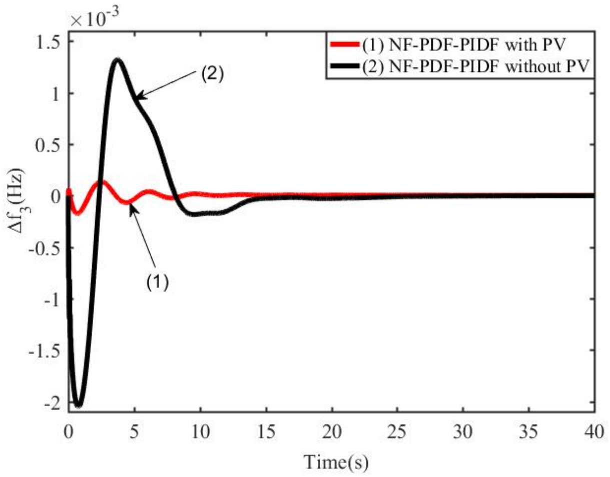

***Fig. 15**: Comparison of dynamic responses vs. time, three area hydrothermal system with Neuro-Fuzzy-PDF-PIDF, with/without PV.*

control approaches and policies, and manage various load and generation profiles. Advanced information technology, adaptable algorithms, and reliable network architecture should make up this intelligence [209-211]. The AGC domain occasionally gains valuable scientific advancements due to this conflict [212]. The AGC design has been dramatically improved to handle uncertainties, non-linearity, parametric fluctuations, and integration of various systems, such as energy storage systems, HVDC links, wind and PV sources, and other unconventional fuel sources [213-222]. Different analog and computational control strategies are created and tested for particular /different areas and conventional/deregulated power systems. Developing intelligent control methods, including fuzzy logic, neural networks, and evolutionary and heuristic optimization techniques, is one of the most advanced control strategies in the AGC configuration for responding to a non-linear power system. The future of AGC is presented below to be further studied in light of a thoroughly considered literature:

(i) Investigate AI strategies to program the AGC algorithm to turn on the best reserves possible to ensure the smooth operation of the power system with widespread RES integration.
(ii) To improve the system's performance in the real-world environment, investigate and incorporate new constraint coefficients, like transmission line congestions, in the goal functions.
(iii) Investigate resilient and adaptive control techniques for AGC to handle parametric system changes efficiently.
(iv) Accurately estimate load and weather conditions in large- and small-scale renewable energy-based power systems and investigate various AGC control strategies.
(v) Most survey studies by researchers exclusively address load frequency control (LFC). However, the authors have also integrated using renewable energy sources and LFC (RES). The book summarizes and illustrates the benefits and challenges of renewable energy sources coupled with LFC.
(vi) A comparative table shows the benefits and drawbacks of the various controllers suggested by AGC for related research projects.
(vii) For the current era of the modern energy system, the Explanation Review Study contains all the most recent fundamental technical trends of LFC mechanisms.
(viii) The optimal-robust control techniques for LFC/AGC proposed by robust control methods used LFC/AGC can handle both the parameters and changes in power generation.
(ix) Recommending new LFC /AGC objective functions that could enhance the performance of the power system.
(x) Look into how reliable LFC loops are.
(xi) Increasing the LFC system's capacity to manage problems with cyber attacks.
(xii) Recommending appropriate control techniques for locating and isolating sensor problems in LFC loops.
(xiii) New fault detection techniques that are suitable for LFC/AGC are needed.
(xiv) Considering how LFC, AVR, and other control loops interact.

Researchers may bridge the gap between research, development, and implementation with this thorough literature review. There is now a lot of research on demand-side management capabilities or engagement in providing several additional services for independent system operators (ISO), such as the primary and secondary reserves and load frequency control services. To improve frequency oscillation growth as a fruitful study direction for the researcher, adequate, realistic interactive methodologies are required. In power systems, it is feasible to coordinate the generation-side and demand-side engagement in load frequency control. Similarly, more research is necessary to secure demand-side load frequency control participation in modern energy infrastructure. According to a literature review, multiple researchers have put forth various controller types that have been tuned using different traditional and intelligent soft computing strategies to address the LFC problem in conventional and restructured systems. The literature review also reveals that the controller's structure and the intelligent technique significantly impact the LFC system's performance.

9. CONCLUSIONS

This article presents a critical analysis of current ideologies in the AGC area. Recent developments include creating accurate RES models, contemporary, sophisticated, and cascade controller designs, including HVDC systems, and the growing importance of SOA-ISE and ESD integration for AGC concerns. Particular emphasis has been made on categorizing various

Table 1*: Lists the benefits and drawbacks of AGC-based control strategies.*

Control strategies	**Merits**	**Demerits**
Conventional control		
PI, PI2, PIDD, PID, ID and IDD	Design and execution are very straightforward.	These controllers respond slowly because the governor reacts slowly and handles system non-linearity inefficiently. It requires more time and produces significant frequency variation.
Optimal control		
The minimization of an objective function and the state variable model.	It provides a optimal solution for multi-variable systems	It is frequently impossible to implement the ideal control. In other words, the design of an optimal controller necessitates a thorough grasp of the system's dynamics, making it challenging to implement such a controller.
Gradient Newton Algorithm	Provides the best integral control gain solely for simulation studies.	Real-time power systems have not been tested.
Adaptive control	Updating the parameters in accordance with the operating point.	Unreasonable and challenging to implement
Artificial intelligence control		
Optimization algorithms PSO, GA, HCPSODE, BFO, HPSO, FFO and CABBBC-based PID controller	Enhancement of the systems' dynamic performance	These methods are not evaluated in deregulated real-time power systems, taking into account the effects of time delay, dead governor band, and GRC.
Big bang big crunch (BBBC) -based PID controller	Have an inexpensive computational cost and a quick convergence rate.	The number of iterations is limited
Quasi-oppositional harmony search (QOHS)-PID controller	When physical constraints are taken into account, this optimization strategy for complicated deregulated nonlinear power systems seems promising.	In the study, communication delays are not taken into account.
Biogeography-based optimization based 3DOF-PID controller	Controller excellent dynamic performance resilient to load changes.	A few parameters (B and R) are chosen by a process of trial and error.
Particle swarm optimization (PSO) -based Adaptive Neuro-fuzzy inference system (ANFIS) controller	Gives a good dynamic reaction to tie-line power error and frequency variations. Real-time updates to adaptive control improvements are possible.	PSO's lengthy computation of the optimal gains makes it unsuitable for real-time applications.
Artificial neural network -based ANFIS controller	Application is simple. High resilience capabilities	Less adaptable for real-time applications, uncomfortable
Robust control techniques		
H∞ control	Resilient to disruptions in massive power systems	Gives a higher-order control
μ-Synthesis	Effective for perturbations rejection	In the presence of disturbance, it has a low frequency regulation
Additional control techniques		
Variable structure control/ sliding mode control	It performs well for model-based approaches and has low computing costs. Unaffected by changes in parameter values, nonlinearities, and physical limitations.	For complex power systems, it is not practically implement
Distributed model predictive control (DMPC)	Outlines the AGC issue and enhances closed-loop system performance when there are constraints and outside disturbances.	It uses a model-based methodology. An expensive computing resource is required for online optimization.

AGC/LFC tactics, highlighting their key features. AGC is one of the essential auxiliary services for supplying high-quality, reliable electricity in a restructured power system. In a restructured power system with both traditional and renewable energy sources, the various AGC/LFC control techniques are examined. The latest automatic generation control investigation is the main topic of this paper. With a critical analysis of the current application of different market models, agreements, control techniques, intelligent controllers, and various types of energy storage in the automatic generation control problem, it aims to be a helpful reference and search tool. The contemporary control perspectives like optimum control theory, robust control, and soft computing-based control techniques have been discussed for automatic generation control. Moreover, the role of renewable energy power plants in deregulated power systems is growing. A recent study concentrated on the interaction between energy storage devices and FACTS units in traditional and restructuring automatic generation control systems. It is widely granted to apply various conventional and modern control approaches, including intelligent controllers, DOF controllers, and cascade controllers, controllers. Additionally, Table 1 briefly discusses the advantages and disadvantages of the aforementioned secondary controllers. The studies perform better than those conducted in a traditional or restructured environment. As part of a literature discussion, real-world RES, UPFC, and HVDC models are considered in conventional and deregulated scenarios. Additionally, the AGC/LFC evaluation of SOA-based secondary controllers, conventional and non-conventional, is briefly discussed. The SOA-ISE AGC system has notably improved dynamics performances in Fig. 8–13. The use of AGC in deregulated power systems is thoroughly discussed, along with its difficulties.

The following are the primary contributions of this review article:

- The evolution of the AGC system under conventional and unregulated thermal PSs combined with RES is investigated, considering nonlinearities such as GDB, GRC, parametric fluctuations, time delay issues, inertial response, and state variable observability.
- The concept of a multi-area AGC system with distinct performance indices based on objective functions is introduced from the literature and is utilized to lower the ACE.
- Modern AGC schemes are described for existing and future intelligent power systems, focusing on classical and contemporary control methodologies. Techniques for AGC using fuzzy, neural networks, Neuro-fuzzy, and soft computing are also demonstrated. Furthermore, the advantages and disadvantages of different control approaches are tabulated.
- A comprehensive literature review of AGC approaches was conducted, including various RESs, ESD, HVDC interconnections, and FACTS devices.
- Dynamic performance comparisons have been presented considering various areas (area-2, area-3, and area-4 in an AGC/LFC/ system with different secondary controllers.

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Getaneh Mesfin Meseret was born in Ethiopia, Amhara Region Dangila. He got B.Sc. Degree in Electrical and Computer Engineering in 2014 from Mekelle Institute of Technology; he received M.Sc. Degree in Power System Engineering in 2018 from Barhir Dar institute of technology (BIT), Bahirdar, Ethiopia. He is currently studying for a full-time Ph.D. Degree in Power and Energy system engineering from NIT Silchar, Assam. Some of his research interests include automatic Generation Control, Soft Computing Applications in Power Systems, Power System Control and Operation, Hybrid Energy Systems, and Renewable Energy Systems.

Lalit Chandra Saikia was born in the Indian state of Assam. In 1993, he received a B.Tech Degree in Electrical Engineering from Dibrugarh University in Assam, India, and in 2007, he received an M. Tech in Power Systems Engineering from IIT Delhi. In April 2012, he obtained his Ph.D., in Electrical Engineering from NIT Silchar in Assam. He is currently employed as an Associate Professor in the Electrical Engineering Department at the National Institute of Technology in Silchar, Assam, India. He specializes in power systems control and operation, engineering applications of soft computing, distributed generation, power quality, demand-side management, and smart grids.