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Investigation of AGC System for the Two area Load Frequency Control for Power Systems Under Load Imbalance

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ABSTRACT –

This study examines how delay control and automatic gain control (AGC) affect a two-area hybrid energy system's load frequency control (LFC). Reducing the LFC curves' overshoot and settling time is the main goal of the study. First, the work opens the door for more research by validating earlier findings and offering fresh perspectives on the development of the LFC issue. By raising the delay of the first generator and the load systems block, the effect of increasing an imbalance in area 1 of the suggested two-area system is examined. In order to reduce the imbalanced method's response and overshoot, the impact of optimum control gaining is finally investigated. Simulation is used for validating the proposed approach, and the results show that it performs better than the current system. The LFC system's response to steps curve in Area 1 exhibits oscillation after an initial undershoot, with a peak overshoot of roughly 0.05 p.u. in the reverse direction, a rise time of two to three seconds, and a settling period of fifteen to twenty seconds. Following AGC control, the corresponding response for both regions shows improved stability and less oscillations. According to the results, the suggested AGC-based method offers a potential strategy for preserving system efficiency and reliability in contemporary power grids by greatly boosting the LFC of two-area interconnected networks under imbalanced load conditions.

Key Words: Load Frequency Control, Hybrid Power system, Two area interconnected Network, AGC, Overshoot, Response Time,

INTRODUCTION

Maintaining stability and dependability in linked power grids requires the design of an effective multi-area Automatic fain control (AGC) based load frequency control (LFC) for power systems. With this strategy, the power system is divided into several control areas, each of which is in charge of balancing its own load and controlling its own generation while coordinating with other regions. The major goals are to control tie-line power transfers between regions and keep the system frequency within reasonable bounds.

To guarantee smooth coordination between various control areas, the multi-area AGC-based LFC solution for PS uses complex control algorithms and communication networks. The frequency and tie-line power flows are continuously monitored by the AGC system that is installed in each region. The AGC system modifies the output of participating generators within its region to restore balance when deviations arise as a result of variations in load or generation. This localized control lessens the strain on a centralized control system and contributes to system stability. The precision of load forecasting, the responsiveness of generating units, and the resilience of the communication infrastructure are some of the variables that affect how effective two-area AGC-based LFC is. To improve these systems' performance, sophisticated methods like machine learning, fuzzy logic, and adaptive control are being used more and more. Furthermore, LFC has new potential and problems as a result of the integration of energy storage systems and renewable energy sources.

To handle the intermittency and unpredictability of these resources, more adaptable and dynamic control mechanisms are needed.

The creation of precise mathematical models for every control region, the application of reliable control algorithms, and the incorporation of cutting-edge communication technologies for real-time data interchange are some of the essential elements of the design process. When building the AGC system, engineers need to take into account elements such the system dynamics, load characteristics, and the generation mix. Furthermore, the management strategy becomes more complex with the addition of energy storage devices and renewable energy sources, necessitating the use of predictive and adaptive control techniques to manage the inherent uncertainty and fluctuation of these resources. In the end, an effective multi-area AGC system should be able to minimize frequency deviations, react swiftly to load variations, and maximize overall system performance while maintaining grid stability and cost-effective operation.

2 Challenges of two area LFC design

The design of a two-area load frequency control (LFC) system presents several significant challenges. One primary difficulty lies in managing the interconnected nature of power systems, where changes in one area can have cascading effects on the other. This interconnectedness requires careful consideration of the dynamic interactions between areas, including power flow, frequency deviations, and tie-line power exchanges. Engineers must develop robust control strategies that can maintain system stability and performance across both areas simultaneously, accounting for potential disturbances and load variations in each region. Another challenge in designing two-area LFC systems is the need to address time delays and uncertainties inherent in power systems. Communication delays between control centres, measurement inaccuracies, and varying system parameters can all impact the effectiveness of the control scheme. Additionally, the integration of renewable energy sources, which often have intermittent and unpredictable output, further complicates the design process. Designers must incorporate adaptive and resilient control algorithms that can handle these uncertainties while ensuring optimal performance and minimizing frequency deviations and area control errors across both interconnected regions.

Another significant challenge in two-area LFC design is the integration of renewable energy sources, which introduce intermittency and variability into the power system. The fluctuating nature of renewable generation can lead to more frequent and severe frequency deviations, requiring faster and more sophisticated control actions. Additionally, the increasing penetration of power electronic devices and smart grid technologies necessitates the development of advanced control strategies that can leverage these new capabilities while ensuring compatibility with existing infrastructure. Balancing the conflicting objectives of system stability, economic operation, and environmental sustainability further complicates the design process, requiring multi-objective optimization techniques and careful trade-off analysis.

Automatic Gain Control (AGC) plays a crucial role in maintaining system frequency and tie-line power deviations in interconnected power systems. For a two-area power system, various control strategies and optimization techniques have been proposed to enhance AGC performance. Fuzzy logic controllers have been applied to design AGC systems, demonstrating improved responses for frequency and tie-line power deviations compared to classical integral controllers (Indulkar & Raj, 1995). Recent advancements include the development of a Fractional Order Integral-Tilt Derivative (FOI-TD) controller, optimized using the Improved-Fitness Dependent Optimizer (I-FDO) algorithm. This approach incorporates realistic constraints such as Boiler Dynamics, Time Delay, Generation Rate Constraint, and Governor Dead Zone, showing superior performance and robustness compared to other controllers (Daraz et al., 2021). Additionally, distributed model predictive control (DMPC) has been proposed for four-area interconnected power systems with wind turbines, effectively addressing generation rate constraints and wind speed variability (Zhang et al., 2017). In conclusion, designing an efficient AGC system for two-area load frequency control requires considering both performance and economic aspects. The integration of economic load dispatch (ELD) with AGC, known as eco-AGC, has been proposed to improve economic efficiency (Sahu & Prusty, 2020., and Li et al., 2016). Advanced optimization techniques, such as the Salp Swarm Optimization (SSO) algorithm and Pelican Optimization Algorithm (POA), have shown promising results in tuning controllers for improved stability and reduced oscillations (Sagor et al., 2024; Sahu & Prusty, 2020). These approaches, combined with the incorporation of renewable energy sources and energy storage systems, offer promising solutions for designing efficient and robust AGC systems in modern power grids.

Thus, overall LFC is a mechanism that balances power generation and demand to maintain frequency deviations within acceptable limits. An AGC ia a comprehensive control system encompasses LFC and keeps track of system frequency, making adjustments to power plant outputs as needed. Usually, the control system using feedback mechanism consisting of Proportional, Integral, and Derivative components.

Contribution of Work

Paper has investigated the impact of AGC gain and delay control in two area hybrid power system using LFC. The study is focused on reducing the settling time and overshot of the LFC curves. This paper has three major contributions.

- Initially, paper haze validated that these studies not only confirmed the initial findings but also revealed new insights into problem formulation phenomenon, paving the way for further investigation in LFC field.
- Secondly it has investigated the impact of increasing the imbalance in area 1 of proposed two area system. the delay of Generator 1 and load system block are increased for misbalancing the system response.
- Finally, the impact of optimal gain control is in investigated for minimizing the response and overshoot of the imbalanced system.

Overall paper hah significant contribution to provide AGC based solution for LFC od two are connected systems under imbalance load.

3. Advantage of using Two-area FLC based PS:

The main power control is the prime requirement of the any FLC system. the other advantages of using FLC for any two area PS are shown in the Figure 1. Two-area power systems offer significant advantages for studying and implementing LFC strategies, providing valuable insights for larger, more complex power networks. The two-area power system LFC provides enhanced stability, improved reliability, better frequency regulation, flexibility in implementing control strategies, a more realistic representation of interconnected power grids, and efficient power sharing.

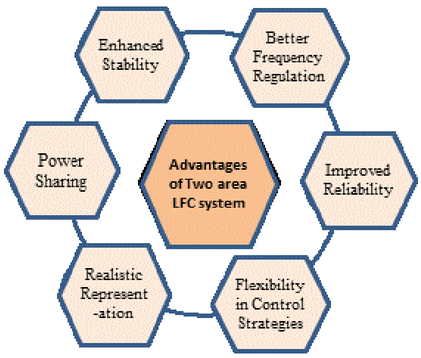


Figure 1 advantages of the Two area LFC systems

4. Review of Two area LFC Systems

Load frequency control (LFC) is crucial for maintaining stable operation in interconnected power systems. In a two-area system, LFC aims to regulate generator output in response to changes in network frequency and tie-line power, ensuring scheduled frequency and power exchange between areas are maintained within prescribed limits Table 1 describes the summary of the LFC for two area PS.

Table.1 Summary of basic LFC using AGC based control for two area PS

Reference	Methodology	Limitations	Performance Analysis
[1] Daraz et al. (2021)	Implemented a Fractional Order Integral-Tuned Derivative (FOI-TD) controller for automatic generation control (AGC) in multi-source interconnected power systems.	Limited to specific system configurations; may not generalize to all types of power systems.	Demonstrated improved performance in frequency regulation compared to conventional controllers, with simulation results showing reduced settling time and overshoot.
[2] Indulkar & Raj (1995)	Application of fuzzy logic controller for AGC, incorporating linguistic variables and fuzzy rules to manage system uncertainties.	Fuzzy rule base can become complex; tuning of fuzzy parameters is challenging.	Results indicated better dynamic response and stability over traditional controllers, but lacked extensive real-world validation.
[3] Zhang et al. (2017)	Proposed a distributed model predictive control approach for load frequency control in multi-area systems with Doubly Fed Induction Generators (DFIGs).	Computational complexity due to predictive modelling; may require significant computational resources.	Achieved effective frequency stabilization and reduced control effort, with simulations verifying robustness against disturbances.
[4] Sagor et al. (2024)	Developed a PID controller optimized using the Pelican Optimization Algorithm for frequency regulation in multi-area systems.	Performance may vary with different optimization algorithms; dependency on initial conditions.	Showed significant improvements in frequency response metrics, including reduced oscillations and faster settling times compared to traditional PID controllers.
[5] Sahu & Prusty (2020)	Integrated eco-AGC strategies with SSO-based fractional order controllers, focusing on frequency and tie-line power management.	Complexity in controller design and tuning; potential computational overhead.	Enhanced performance in terms of frequency stability and economic efficiency, demonstrated through various test scenarios.
[6] Li et al. (2016)	Connected AGC and economic dispatch through an optimization framework, focusing on minimizing operational costs while ensuring stability.	Requires accurate demand forecasting and system data; may not account for real-time dynamics.	Performance analysis showed effective cost reduction and stable frequency control under various loading conditions.
[7] Cavin et al. (1971)	Utilized an optimal linear systems approach to address load-frequency control issues, focusing on linear state feedback.	Limited to linear system assumptions; may not handle non-linearities well.	Theoretical analysis indicated good performance in ideal conditions, though practical implementations faced challenges due to model simplifications.
[8] Gupta et al. (2021)	Hybrid Gravitational–Firefly Algorithm-based control method for hydrothermal two-area systems, aimed at optimizing load frequency control.	Complexity in hybrid algorithm integration; performance may depend on algorithm parameters.	Simulations showed improved frequency and power deviation responses, outperforming standard load frequency techniques.
[9] Huang et al. (2017)	Proposed a linear active disturbance rejection control (LADRC) approach for load frequency control in two-area systems.	May struggle with highly nonlinear systems; requires precise disturbance estimation.	Performance results highlighted robust disturbance rejection and improved transient responses compared to classical methods.
[10] Kumar & Singh (2022)	Implemented secondary controllers for load frequency control across multi-area power systems, focusing on coordination among areas.	Coordination complexity increases with the number of areas; may lead to communication delays.	Demonstrated effective load sharing and frequency maintenance across interconnected areas through simulation studies.
[11] Malik et al. (1988)	Developed a generalized approach to load frequency control, integrating various control strategies into a unified framework.	Complexity in implementation and adaptability to different systems; may require extensive tuning.	The generalized algorithm showed improved performance metrics in several case studies, indicating versatility.
[12] Rahmani & Sadati (2012)	Proposed a hierarchical robust control strategy for load-frequency management, emphasizing optimality and reliability.	Hierarchical structure may introduce delays; robustness may vary with system disturbances.	Analysis showed enhanced stability and robustness under varying operational conditions, validated through numerical simulations.

[13] Gupta et al. (2021a)	Employed hybrid intelligent optimization techniques for load frequency control in multi-source power systems.	Dependence on optimization technique performance; may not be universally applicable.	Results indicated significant improvements in frequency control and reduced computational time, validated through various scenarios.
[14] Dev et al. (2024)	Leveraged the Walrus optimization algorithm to enhance load frequency control and voltage regulation in interconnected systems.	Limited to specific optimization scenarios; may require parameter tuning.	Demonstrated superior performance in maintaining frequency and voltage levels during disturbances, validated through simulation results.
15] S. A. Rahim, 2018	The study employs two controllers to manage load frequency control in a two-area power system. The methodology includes modeling the power system dynamics and implementing control strategies using simulation tools.	The limitations include potential simplifications in the system model, such as neglecting real-world disturbances and non-linearities. The effectiveness of the controllers may vary under different operational conditions.	The performance analysis indicates improved stability and response time in load frequency control when using the proposed controllers compared to traditional methods, demonstrating the potential for enhanced system reliability.

Over all it can be concluded from the survey that THD minimization is open challenge for telecom inverters as they are designed at lower levels of inverters.

4. Proposed LFC based Two Area PS Designs

The current two-area LFC system with AGC to maintain frequency and power balance across two interconnected regions is depicted in Figure 2. The system uses governor and turbine dynamics as building blocks, ACE as the main signal, and K1 and K2 as proportional gain constants. 1/R1 and 1/R2 stand for frequency bias parameters and the droop coefficient, respectively, while inertia and load are the combined inertia and load characteristics. Frequency deviation and actual frequency measurements in each region are denoted by DF1, DF2, F1, and F2, while Ps stands for the planned power exchange between the two areas. By ensuring that both regions work together to maintain the frequency and planned power exchange, AGC coordination keeps one region from overcorrecting while the other stays unstable.

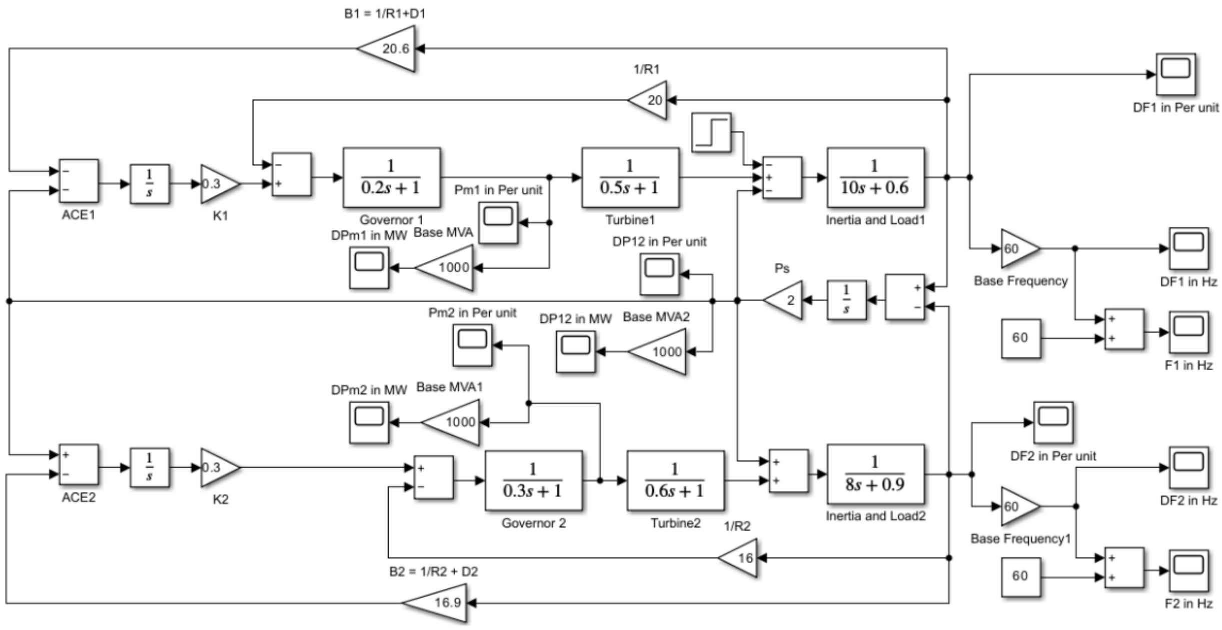


Figure 2 Existing 2 area LFC system with AGC

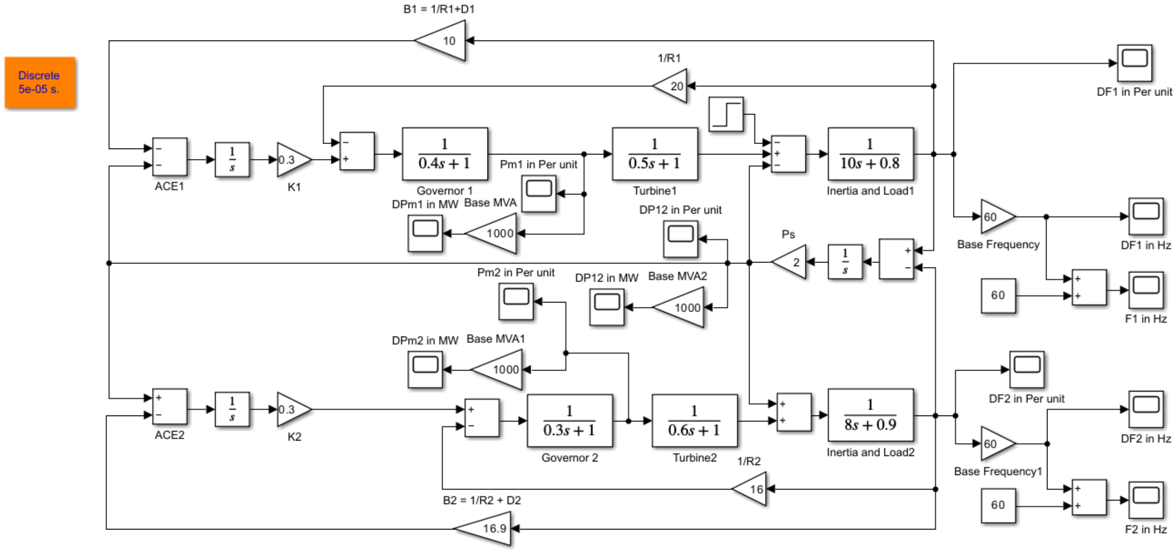


Figure 3 Modified damping in system 1 with reduced Gain Delay Response

As the modified system proposed diagram is illustrated in the Figure 3. representing the load imbalance and the respective changes made for ACE and LFC control. This research has proposed to investigate the impact of the imbalance in the PS performance by varying delay factor (or inertia T1) for the governor block as initial driving block. The T1 is changed to 0.4 from 0.2. Additionally, the load imbalance is created by increasing the load factor from 0.6 to 0.8 for the area 1 system.

A. Corrective Measures:

The proposed paper has investigated the impact of varying the feedback control factor

$$B_1 = \frac{1}{R_1} + D_1 \qquad (1)$$

The generalized transfer function of any power generator block is represented as

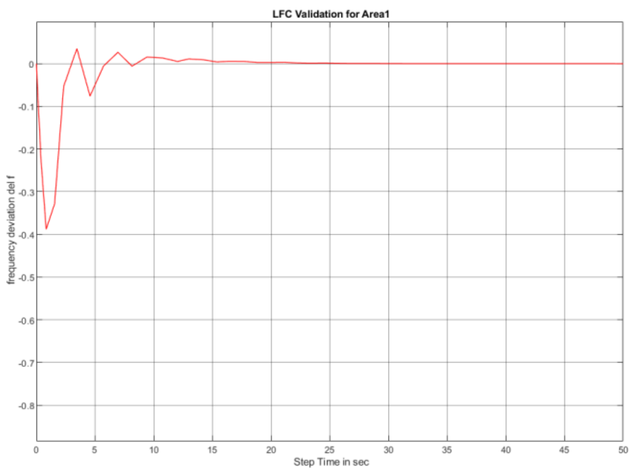
$$S = \frac{1}{Ts+1} \qquad (2)$$

Thus, in the proposed system an impact of varying the B1 as feedback gain to mitigate the imbalance in area 1 keeping the area 2 on stable operation. the B1 is varied from 20.6 to 10 for achieving the balance. Although in AGC system the gain factor K is essential but for experimentation the gain kept content and feedback gain is varied.

V Results and discussions

In this paper the impact of the inertia and load imbalance on the two area PS are investigated. and the results are plotted for the corrective measures taken for varying the feedback gain. The LFC system's step response for Area 1 is displayed in Figure 4. According to the graph, there is an early undershoot of about -0.05 p.u.

Fig. 4 validation of LFC area1



The answer then exhibits minor fluctuations before settling down gradually. It settles within 15-20 seconds, that is referred to as the settling time, after rising timing for roughly 2 to 3 seconds. Since no numerical data is collected, these values are visually approximated from the curve.

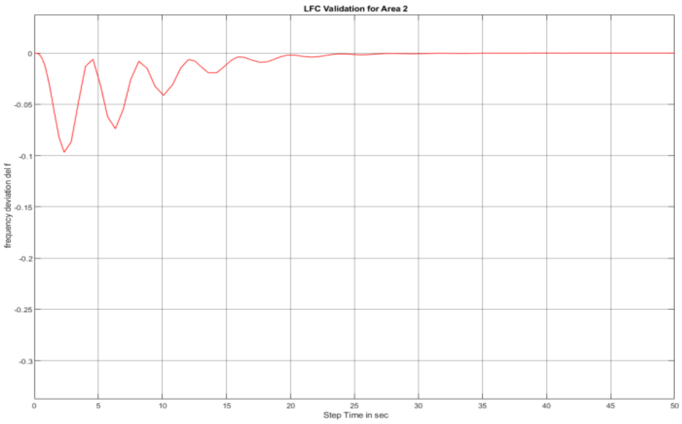


Fig. 5 validation of LFC area 2

The (LFC) system in Area 2's deviation in frequency response is shown in Figure 5. It is evident from the graph that the system first demonstrates an oscillation before stabilizing. An estimated −0.07 to −0.08 p.u. is the peak under shoot, which indicates a substantial decline under the final value. the area 2 system is considered as under damped system and have larger settling time of around 30 s. it is required to maintain the relatively faster settling time of closer to 20 s.

Although numerical data would be necessary for more precise results, the settling time s good is it is nearly between 10 and 15 seconds. or even less. Overall, the response demonstrates a system that is somewhat damped and stabilizes following a brief transient phase.

A. Results of Creative Measures

A comparison of Area 1's variation in frequency reactions following the implementation of feedback gain Control is shown in Figure 6. The B1 block is varied and reduced to make system faster stable for area1.

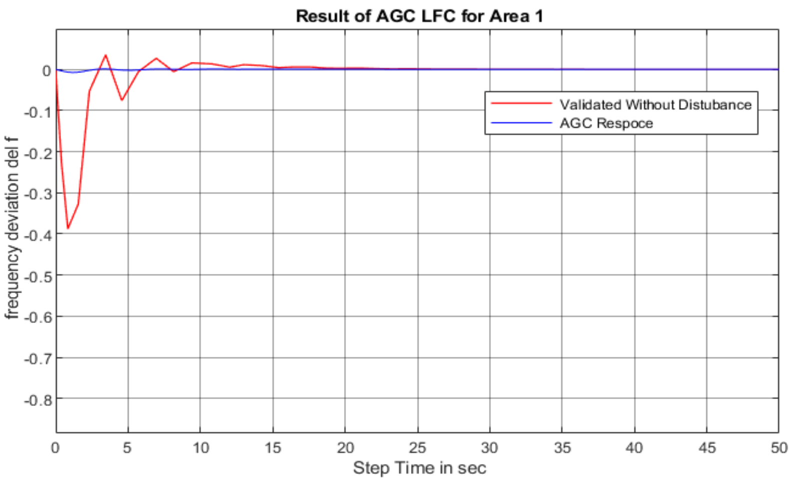


Fig. 6 comparative response after AGC control for area 1

Both replies have a rising time of roughly 0 to 5 seconds. While the blue curve (AGC Response) displays little variation, suggesting better damping, the red curve (Validated Without Disruption) reveals a substantial peak overshoot. Both the peak overshoot and the settling time are greatly decreased by the use of AGC. Assuming a settling requirement of ±2%, the graph indicates that the AGC response settles in 10 seconds. \

The blue curve repress the response after B1 correction and system is relatively have negligible overshoot and is more stable frequency response curve for area1.

All things considered, AGC enhances frequency regulation by accelerating and stabilizing the response. Numerical data collection would be necessary for exact optimal evaluation of parameters further.

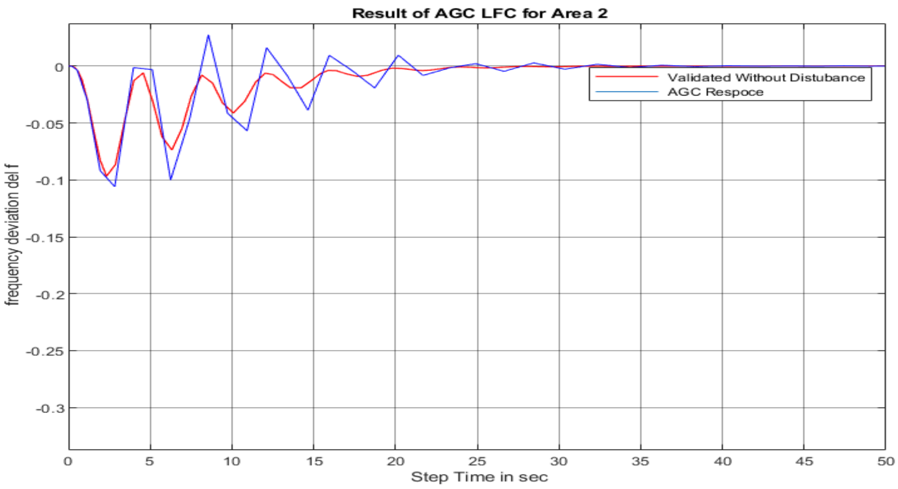


Fig. 7 Comparative respoke after AGC control. for area 2

The comparative results for system in Area 2's variation in frequency response after corrective measures is shown in Figure 7 without or with disturbance. There are oscillations in both replies, but the AGC response (blue curve) overshoots its negative peak a little more than the curve in red (Validated Without Disturbance). it is clear from the Figure 7 that blue curve after corrective measure has less transient variations and reaches to the stability relatively 5-10 s earlier then the frequency curve under disturbance as in red. However, because oscillations last longer before damping off, the AGC response has a longer settling time. The time needed to establish a steady state settling time (usually based on 2% or 5% criterion) is slightly increased by AGC, even if it aids in decreasing the oscillation magnitude and enhances control of frequency behavior. Numerical data collection using curves would be required to obtain precise values.

VI CONCLUSIONS

This study uses investigation methodology for LFC to examine the effects of AGC based feedback gain & delay controls in a two-area hybrids energy system. Investigated the impact of imbalance in the power system performance by varying delay factor.

Reduced the LFC curves overshoot and settling time is the main goal of the investigation. The study first validated the earlier results of two area PS. Then examines the effects of increasing the imbalance in area 1 of the suggested two-area network by increasing the load of area 1 and Generator 1's delay or inertia to create imbalance. Experiments looks into the way ideal gain control can reduce the imbalanced system's reaction and overshoot. Increased stability, greater dependability, enhanced frequency control, flexibility in adopting control techniques, and effective power sharing are some of the benefits of utilizing a two-area LFC systems.

As an corrective measure experiment varied the feedback control factor (B1) to mitigate the imbalance in area 1. it is concluded that AGC (with feedback control) enhances frequency regulation in Area 1 by accelerating and stabilizing the response. In Area 2, AGC reduces oscillation magnitude but slightly increases settling time.

In addition, the study examines several LFC approaches and tactics for two-area energy systems, stressing their drawbacks and effectiveness evaluation. Simulation verifies the suggested method, showing enhanced LFC responsiveness in both regions following AGC control.

A. Future scopes

In order to address security concerns, optimize LFC for multiple goals, apply sophisticated techniques in real-time, improve resiliency and fault-tolerant, integrate LFC with electrical power markets, develop LFC methods for micro grids, integrate alternative energy sources, use storage technologies for energy, and implement wide-area control to large interdependent electrical networks, the study focuses on these topics. The increasing level of complexity and unpredictability of contemporary grids are the focus of these approaches.

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