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A Practical Modeling Approach For Improving Automatic Generation Control (AGC) System Performance Through Advanced Simulation And Optimization.

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Abstract:

This study addresses the critical challenge of maintaining system stability in modern, complex power grids by focusing on **Load Frequency Control (LFC)**. The research aims to enhance LFC performance in a hydrothermal and wind-integrated power system. It achieves this by comparing four advanced optimization algorithms—Particle Swarm Optimization (PSO), Moth Flame Optimization (MFO), Binary MFO (BMFO), and the novel Harries Hawks Optimization (HHO)—to tune LFC parameters. The manuscript provides a comprehensive overview of LFC principles, its role in a deregulated energy market, and the implications of integrating intermittent renewable energy sources. The findings highlight how these AI-based methods improve the system's ability to swiftly and stably restore frequency and power balance, ensuring operational integrity in an evolving energy landscape.

Keywords: Load Frequency Control (LFC) Particle Swarm Optimization (PSO) Moth Flame Optimization (MFO), Harries Hawks Optimization (HHO) independent power producers (IPPs) Automatic Generation Control (AGC).

I. INTRODUCTION

The stability and reliability of large-scale interconnected electrical power systems fundamentally depend on the continuous maintenance of a balance between total generated power and the aggregate load demand, including associated system losses. The dynamic and stochastic nature of consumer load and the physical limitations of generation-side tracking mechanisms create a continuous mismatch between supply and demand. This imbalance manifests as deviations in the nominal system frequency and unscheduled power flows between control areas, which can lead to equipment malfunction, reduced power quality, and potential system instability. Consequently, robust control mechanisms are essential to ensure that both frequency and inter-area tie-line power are maintained as close as possible to their scheduled values.

Historically, power generation, transmission, and distribution were managed by vertically integrated utilities (VIUs), which held a monopoly over their service territories. Within this traditional structure, control of the grid was centralized. However, a global trend towards deregulation and market restructuring has led to the unbundling of these functions and the emergence of independent power producers (IPPs). This shift has introduced a complex, competitive environment where the economic and physical aspects of generation are decoupled from transmission and distribution. In this new paradigm, the control challenge is compounded by the need to operate within market-based bidding and dispatch mechanisms, necessitating more sophisticated and adaptable control systems.

This manuscript provides a comprehensive overview of Load Frequency Control (LFC), a critical component of Automatic Generation Control (AGC). LFC acts as the primary feedback loop to restore the generation-load balance in real-time. By continuously monitoring the Area Control Error (ACE), a composite signal representing deviations in frequency and tie-line power, the LFC system dispatches commands to generation units to regulate their mechanical power input. The objective of LFC is to drive the ACE to zero, thereby maintaining system frequency at its nominal value and ensuring scheduled power exchanges are met.

This paper examines the principles and implementation of LFC, highlighting its integral role in ensuring the high-level of power quality and operational integrity required in modern, deregulated electrical grids. We also explore the implications of market-based operations on LFC performance and discuss the future directions for control systems in an evolving energy landscape.

Automatic Gain Control (AGC) and Power System Modeling.

Automatic Gain Control (AGC), or more commonly, Automatic Generation Control, is a crucial function in power systems. It works to provide a rapid response to system disturbances, such as the sudden loss of a generator, and to continuously maintain frequency within an acceptable range during normal operations. The ability to quickly increase or decrease power output is vital, and sources with this capability, like hydropower plants and gas turbines, are often used for AGC. As battery storage technology advances, it's also becoming a key resource for providing this fast-response capability.

The study of AGC often relies on modeling power systems, typically as single-area or multi-area linear models. These models are essential for understanding how to stabilize system performance, especially as grid demands increase and variable renewable energy sources become more prevalent. One proposed method to handle increased communication delays in LFCs (Load Frequency Controls) is the use of an analytic-graphically based PI-AGC regulator for a single-area power system.

Hydrothermal Systems.

The term "hydrothermal" has its roots in earth sciences, combining "hydro" (water) and "thermos" (heat). It refers to geological processes involving the movement of hot water within the Earth's crust, often heated by magma from the mantle. This process plays a significant role in creating new oceanic crust at mid-ocean ridges and is a major contributor to the transportation of essential minerals like calcium and magnesium, which help regulate the Earth's carbon dioxide balance. The term was first coined by the British geologist Sir Roderick Murchison to describe how water under high pressure and temperature forms various rocks and minerals.

Modeling Power Plants

i. Thermal Power Plants

In coal-based thermal power a plant, fuel is burned to create high-temperature, high-pressure steam. This steam flows through a turbine with multiple stationary and rotating blades. As the steam passes through the stationary blades, its velocity increases. The high-velocity steam then hits the rotating blades, causing them to turn and generate torque on a central shaft. This rotating shaft is connected to a generator that produces electricity.

These plants typically use a multi-phase steam cycle, which can be modeled to analyze and optimize performance. A key component is the **governing system**, which manages steam flow to regulate speed. For smaller units (under 100 MW), non-reheat turbines with a single phase are common. A pilot valve-controlled oil servomotor acts as the primary mover, measuring speed to regulate signals, while emergency stop valves are used for quick shutdowns.

ii. Hydropower Plants

Hydropower plants are categorized by their head (the vertical drop of water), such as low, medium, and high head. Turbines in these plants convert the potential and kinetic energy of water into mechanical energy.

In **impulse turbines**, like the Pelton wheel, high-velocity water jets are directed at buckets on a runner, causing it to spin. This process relies on the momentum change of the water.

In contrast, **reaction turbines**, like the Francis turbine, are often used for low to medium head conditions. In this design, the turbine is fully immersed in water, and energy is extracted from both the kinetic energy of the moving water and the pressure head. Reaction turbines generally require larger water passages and operate at lower speeds, which often necessitate a slightly larger generator diameter to produce the required torque.

In power systems, frequency fluctuations are a natural consequence of the constant variation in electricity demand. These fluctuations can disrupt power exchanges between interconnected areas. **Load Frequency Control (LFC)** is the primary mechanism used to manage these fluctuations by precisely adjusting the output of generation units. The main goal of LFC is to minimize the **Area Control Error (ACE)**, a metric that quantifies the imbalance between generation and load. The LFC system continuously responds to changes in demand to drive the ACE to zero, ensuring system stability.

To enhance LFC effectiveness, modern power systems are increasingly using **hybrid control models** that combine conventional controllers with advanced **artificial intelligence (AI)** algorithms. These AI algorithms, such as **Particle Swarm Optimization (PSO)**, **Genetic Algorithms (GA)**, and **Fuzzy Logic (FL)**, are used to tune and optimize controller parameters for improved performance.

- **LFC based on PSO:** PSO is a powerful optimization algorithm used to fine-tune controller settings. For instance, it's used to precisely tune membership functions in fuzzy logic controllers and optimize the gains of PID controllers, leading to more robust and responsive frequency control.
- **LFC based on GA:** GA, an evolutionary algorithm, has also been applied to LFC to find optimal control strategies. Researchers have used multi-objective GAs to tune controllers for multi-area power systems, even accounting for non-linear effects like governor dead bands.
- **Other AI models:** Other AI-based approaches have also been explored, including using algorithms like Teaching-Learning-Based Optimization (TLBO) and implementing observer-based robust integral sliding mode controllers for systems with significant variable energy sources like wind power.

These advanced methods are designed to handle the growing complexities of power grids, particularly with the integration of renewable energy sources, which are often intermittent and unpredictable.

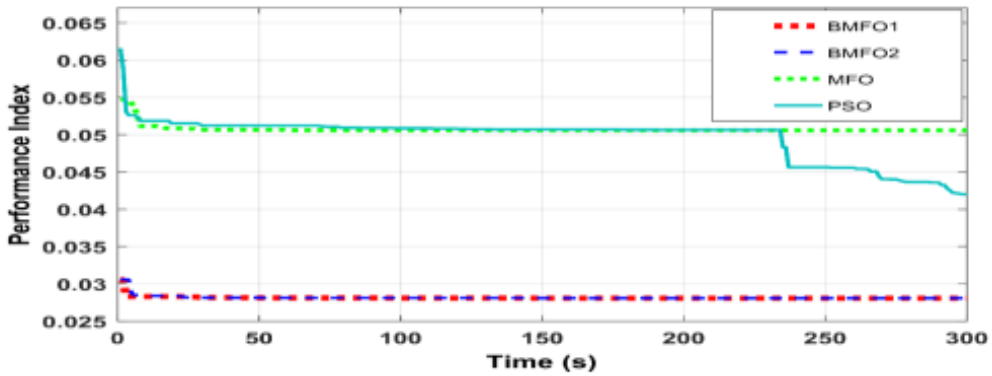
Controller Architectures

LFC systems can be configured in a few ways. A **centralized controller** uses a single control unit connected to all areas of the power system to manage all parameters and maintain equilibrium. A **decentralized controller** uses multiple control units, with each unit responsible for its own specific area. A **single agent** approach involves control actions taken only on a specific distributed generation system. These different architectures offer varying levels of control complexity and responsiveness.

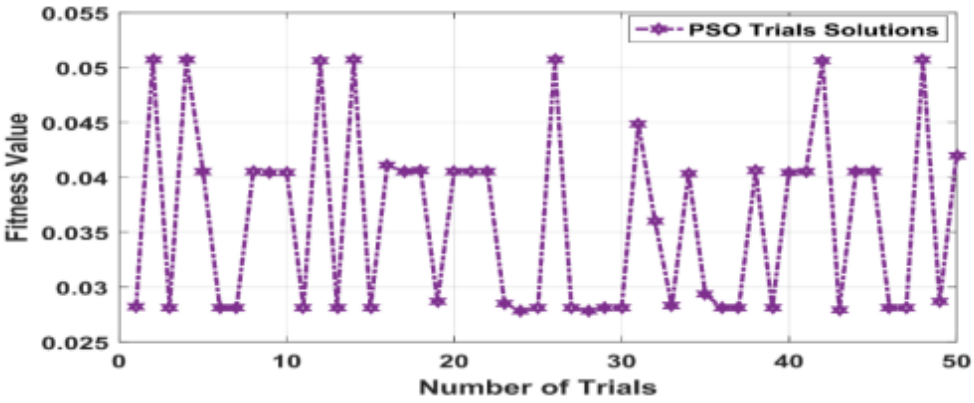
RESULTS AND DISCUSSIONS:

Table: 1 Improved gain values of PI controller for expected scheme with various algorithm

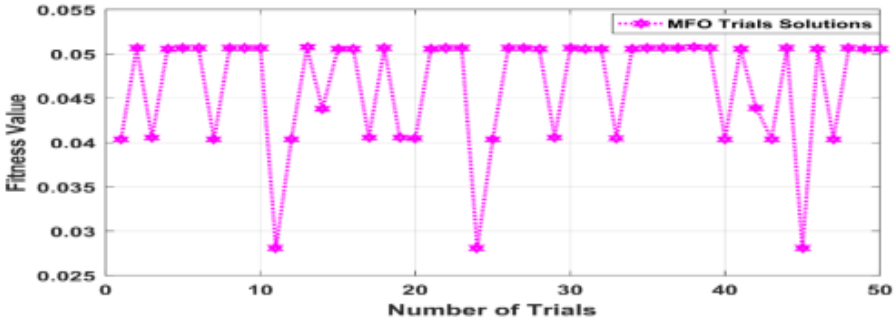
Controller type	Controller parameters			
	Area-1		Area-2	
	pK_1	$Int.K_1$	PK_2	$Int.K_2$
PSO	0.43007	-7.02E-06	0.18516	-0.72609
MFO	0.42333	-0.60889	0.21424	-0.99806
BMFO1	0.43126	-0.0002	0.18435	9.71E-06
BMFO2	0.45025	-9.06E-07	0.18545	-1.90E-06



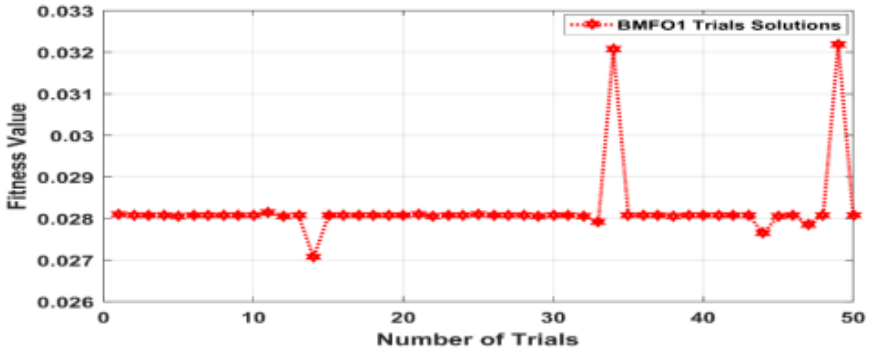
Graph: 1 Performance index vs. number of trials graph for various Controllers



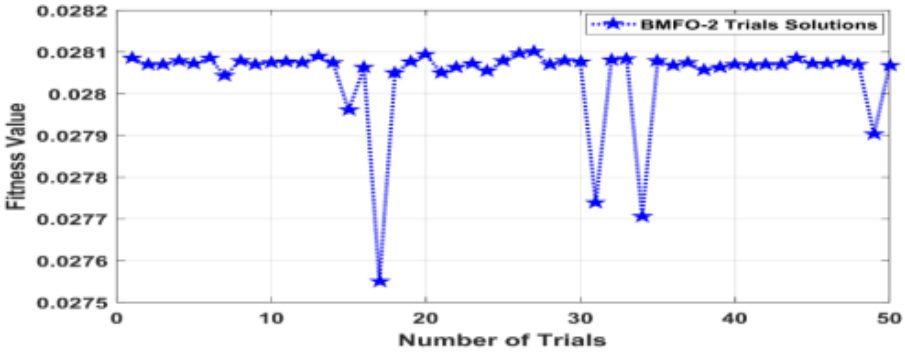
Graph: 2 Performance index vs. number of trials graph for PSO Controller



Graph: 3 Performance index vs. number of trials graph for MFO Controller



Graph: 4 Performance index vs. number of trials graph for BMFO1 Controller

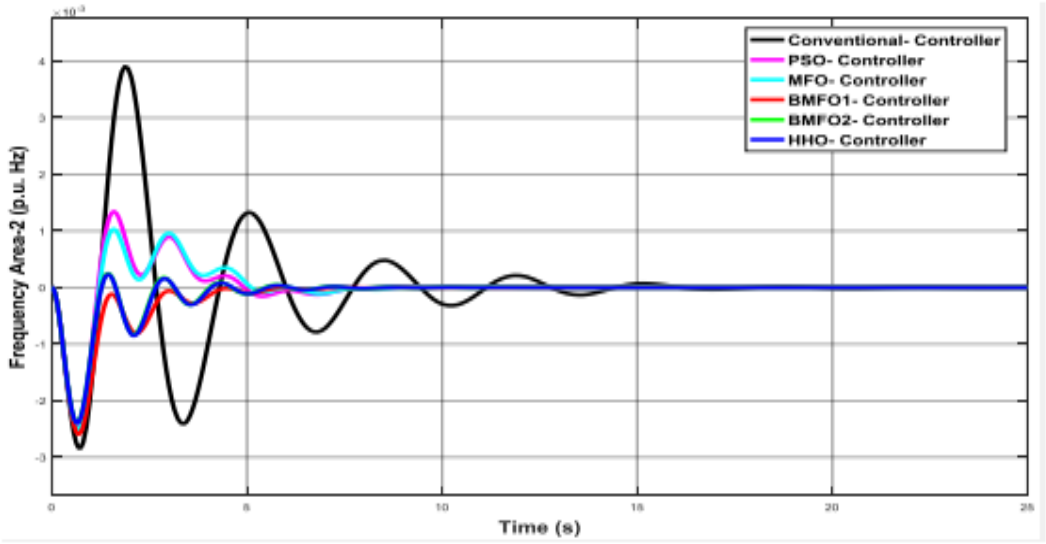


Graph: 5 Performance index vs. number of trials graph for BMFO2 Controller

Frequency with various controller under Unilateral Contract

Table: 2 Frequency with various controllers under Unilateral Contract

Controller	Delay Time	Rise Time	Peak Over shoot Time	Settling Time
Conventional	1.05	1.186	1.375	22
PSO	0.8833	1.05	1.186	21.430
MFO	0.8833	1.05	1.145	21.3
BMFO1	0.9667	1.05	1.145	21.02
BMFO2	0.8833	1.05	1.087	20.1



Graph: 6 Dynamic responses

It is possible to manipulate the active power regulation of the Load Frequency regulation (LFC) system via the complex adjustment of many controllers and sources included within the system. In the complex world of power system networks, there are three main categories that may be made about the possible interconnections of controllers. These classifications are discussed below. The central controller, the solitary agent, and the decentralized controller are the essential modes of control that may be found within this complex domain.

These categories describe the fundamental modes of control. In the case that there is a central controller, there is only one control unit that is used and it is coupled with all areas within the power system network. This is done for the goal of controlling parameters of those regions and maintaining the equilibrium between generation and demand. In addition, the control action is only carried out on the specific distributed generation system when using the single agent technique

CONCLUSION:

This study aims to improve **load frequency regulation (LFC)** in a complex, integrated power system that includes hydrothermal and wind energy sources. The primary goal is to maintain the nominal frequency of the system and ensure its response to load variations is both swift and stable.

To achieve this, the research employs and compares four different optimization algorithms to control LFC across an interconnected system. The optimizers used include Particle Swarm Optimization (PSO), Moth Flame Optimization (MFO), Binary MFO (BMFO), and the newly developed Harries Hawks Optimization (HHO).

The paper also reviews current LFC models and addresses the challenges they face, particularly in modern power systems with micro grids and intermittent renewable energy sources. These challenges are crucial to solve in order to maintain system frequency, voltage, and active power within acceptable limits. The growing trend of micro grids, which can operate in both grid-connected and isolated modes, presents new control issues due to the unpredictable nature of their renewable sources and storage systems.

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