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# Optimal Frequency Control of Multi Area Power System Under Restructured Environment

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**ABSTRACT-** This paper presents the intend of a Tilt Integral Derivative (TID) controller for addressing the Load Frequency Control (LFC) issue in a multi-area restructured electric power system. The recommended TID controller configurations are refined by means of a narrative methodology known as the Hunger Games Search (HGS) algorithm. A multi-area electric power system including different producing units is worn to assess the efficacy of the anticipated TID controller based on HGS. The effectiveness of HGS's optimization has been confirmed to surpass that of other prominent optimization techniques, such as the Slime Mould and Artificial Gorilla Troop algorithms. The simulation outcome demonstrates that the anticipated TID controller using HGS markedly improves system frequency constancy underneath diverse load interruption scenarios.

**Keywords:** TID controller, Load frequency control, Hunger Games Search algorithm.

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## 1. INTRODUCTION

LFC is an essential component of power system management, guaranteeing the stability and dependability of energy supply by preserving the equilibrium between power production and consumption. It pertains to frequency fluctuations that may result in system instability and even blackouts. Due to the ongoing discrepancies in frequency, generation, and tie-line power between total generation and reported power consumption, all values deviate from their designated line power levels. Therefore, it is essential to maintain system integrity in real time by precisely aligning power production, load demands, and associated losses. The operational dependability of a network is promptly influenced by any deviation in frequency from its specified range [1-2]. Traditionally, a power system was managed by a singular entity known as a vertically integrated utility (VIU), which oversaw all facets of generation, transmission, and distribution. This VIU exploited its monopoly to provide electricity at regulated rates, offering consumers no alternative choices and leading to a significant price disparity. Numerous studies have been undertaken on conventional power systems, encompassing hydro and thermal energy sources [3-5].The implementation of the PID controller led to significant improvements in frequency stability, reducing fluctuations to within ±0.5 Hz shortly after system startup, thereby demonstrating the effectiveness of this control approach in maintaining stable frequency regulation in micro grid environments [6-8]. In order to efficiently manage these fluctuations, a PID controller is suggested, with the goals of minimizing overshoot, decreasing settling time, and normalizing the system response. The Simulink tool is used to assess the controller's effectiveness [9-12]. The electric utility industry, which includes distribution businesses (DISCOMs), transmission companies (TRANSCOs), and generating companies (GENCOs) within the DISCO framework, has been liberalized to make it more available to job seekers. An ISO, a significant business body, is responsible for overseeing clients in the competitive market. AGC is a supplementary system that proficiently regulates production by rectifying frequency and output discrepancies, so providing stable and dependable operation [13-16]. Several methods have been researched to optimize controller parameters [17–20].

## 2. POWER SYSTEM STRUCTURE

The hydro-thermal system used in Load Frequency Control (LFC) is a coordinated multi-area power system combining both hydroelectric and thermal power plants to maintain system frequency and tie-line power flow within desired limits. Each area typically consists of a generator unit—thermal units use steam turbines with reheat mechanisms, while hydro units use water turbines characterized by water starting time constants. Frequency regulation in both areas is managed through speed governors connected to respective turbines, with control actions influenced by frequency deviations and tie-line power changes.

Automatic Generation Control (AGC) is employed to generate a control signal based on the Area Control Error (ACE), which accounts for both frequency deviation and tie-line power imbalance. The thermal unit's dynamics are slower but stable, whereas the hydro unit responds quickly but with non-linear behavior due to water inertia. These areas are interconnected via a tie-line that allows power exchange based on generation-load mismatch.

A restructured power system is one that moves away from the old, vertically integrated utility model and towards a more decentralised, competitive, and market-based structure. Deregulation in the electrical sector refers to the progression of amending the law and policy governing corporate operations to provide consumers with a selection of energy firms. In a deregulated electricity market as shown in *figure 1*, consumers and energy suppliers have the freedom to invest their resources in the preservation and perfection of power production and transmission infrastructure as they perceive vigorous. The power generated by Genco's assets is distributed extensively via the trade utilities network. Customers get advantages through the ability to assess and contrast prices and amenities, along with the adoption of stochastic techniques.

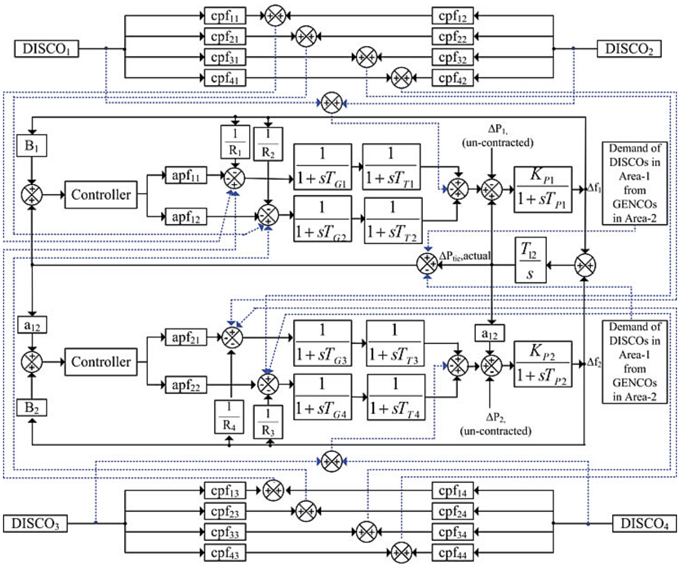


**Figure 1.** Block Diagram of Deregulated Multi area Power system

## 3. HUNGER GAME SEARCH ALGORITHM

The essential homeostatic need of an animal, termed "hunger," serves as the impetus for a dynamic, fitness-oriented search methodology designed for beginner users and decision-makers. The HGS integrates the conception of hunger keen on its algorithm by developing and using an adaptive weight that mimics the impact of hunger throughout each search phase. This allows The HGS to accurately represent the experience of engaging in The Hunger Games. It conforms to the computationally rational principles (games) of almost all animals, which augment survival and food procurement. The approach exceeds other optimization strategies in efficacy due to its dynamic nature, clear structure, and superior solution and elucidation quality. The flowchart of HGS algorithm is exposed in *figure 2*.

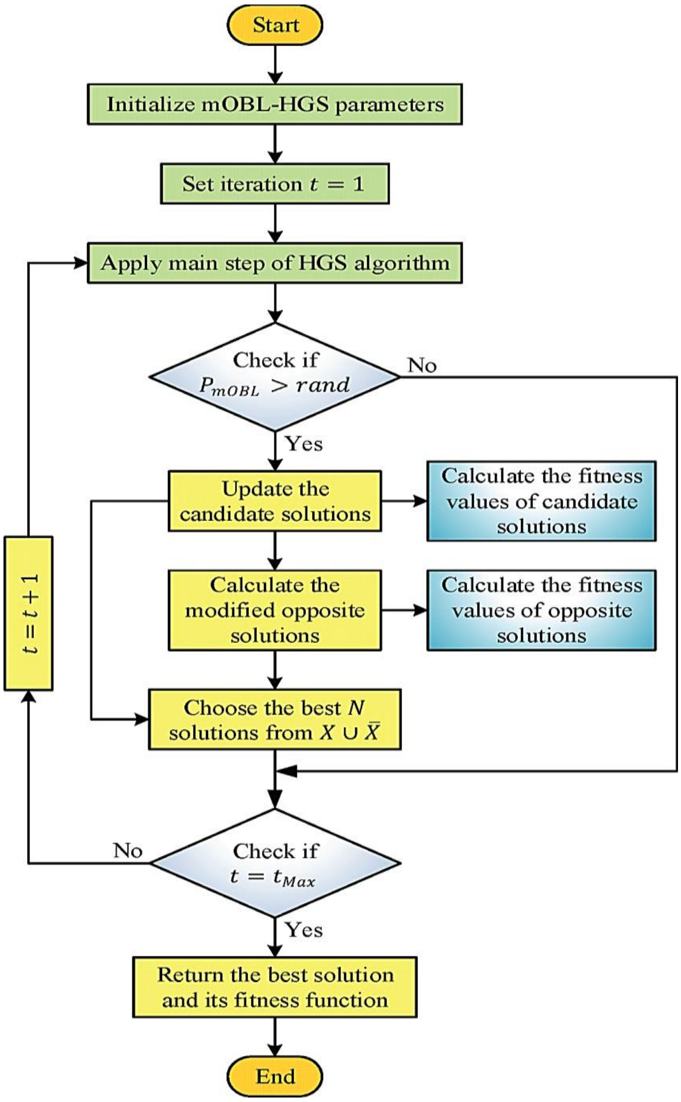


**Figure 2.** Flowchart of HGS algorithm

**Step 1: Approach food**

X_new = X_old + α * (food - X_old) (1)

Where:
X_new is the new pose of the tribute
X_old is the current location of the tribute
α is a learning rate parameter
food is the position of the food resource (optimal solution)

**Step 2: Hunger Role:**

H (i) = (F (i) - F_avg) / (F_max - F_min) (2)

Where:
H (i) is the hunger value of tribute *i*
F (i) is the fitness value of tribute *i*
F_avg is the average fitness value of all tributes
F_max is the maximum fitness value among all tributes
F_min is the minimum fitness value among all tributes

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## 4. TID CONTROLLER

A TID controller is a control method used in diverse industrial applications, such as process control, robotics, and power systems. It is a modification of the conventional PID controller, with an extra "tilt" term that enhances stability and robustness. *Figure 3* shows the block diagram of TID Controller.

$$T.F\ (TID) = K_T\ (1/s)\ \hat{}\ n + K_I/S + K_D S$$

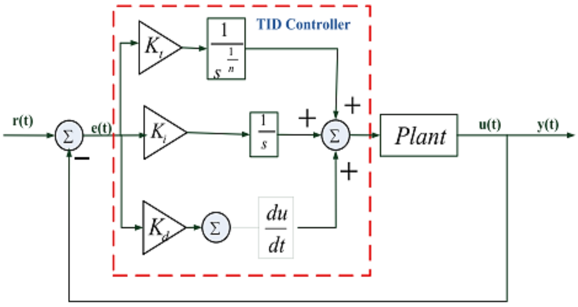


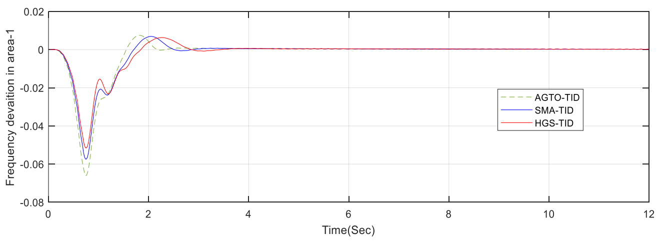

**Figure 3.** Block diagram of TID Controller

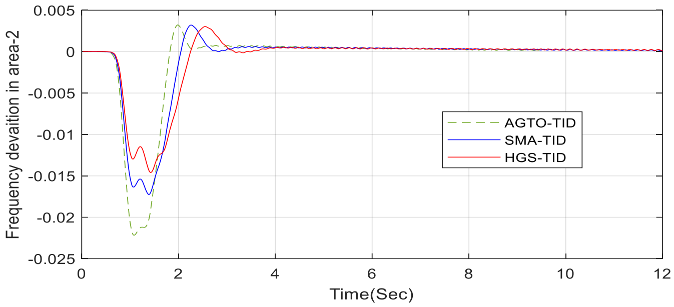
## 5. RESULTS AND DISCUSSION

Deregulated power systems comprise hydro-thermal systems in each region. A 0.05% load disturbance was applied to each location. A GRC limit of 0.05 percent is enforced at a certain point in the configuration process. GDB is more precisely defined as the replacement rate of the steam valve distinctive in the nonexistence of torque. A limitation of 0.06% may be enforced in the presence of the GDB.

### 5.1. Pool-Co Based Transaction

A pool co-based transaction transpires when DISCOs within the same vicinity collaborate with any GENCOs in the region to share a load. *Figure 4* illustrates the temporal response characteristics of the Hydro-Thermal system under pool-co based settings. The configuration modeling of the LFC model hydro-thermal system has been regulated using the offered optimization strategies. The article presents the simulation findings for the optimum tuning of different optimized controllers, including SMA, AGTO, and HGS based on TID, using a fixed step load perturbation (SLP) of 0.05 pu MW. *Figure 4 (a)* illustrates the frequency variations (Δf1) in area-1, *figure 4 (b)* depicts the frequency variations (Δf2) in area-2, and *figure 4 (c)* depicts the tie-line power fluctuation with a variety of controllers. *Table 1* presents a comparative examination of characteristics for different AGTO, SMA, and HGS-based TID controllers.



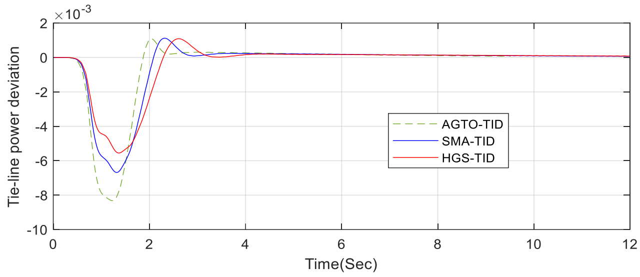




**Figure 4.** Response characteristics plots for various algorithms (a) $\Delta f_1$ (Hz), (b) $\Delta f_2$ (Hz), (c) $\Delta P_{tie12}$ (pu MW)

The application of the MOF controller for angular position control on the SRV02 plant necessitates the utilization of the experimental facility. This involves the intricate process of interfacing the hardware model with the Simulink diagram, a task efficiently accomplished through the QuaRC software. By leveraging QuaRC, the hardware and software components seamlessly integrate, enabling cohesive operation and real-time interaction. Furthermore, the development of the model is facilitated by the QuaRC library, complemented by the robust capabilities of the MATLAB/Simulink Real-Time Workshop. Together, these tools and frameworks empower researchers to bridge the gap between theoretical concepts and practical implementation, facilitating experimentation and validation in a controlled environment.

In this experimental setup, the continuous analog signal from the potentiometer undergoes conversion into discrete form through the DAQ and is subsequently measured by the HIL read. The control law is then computed within the Simulink environment and applied to the DC motor of the model using the HIL write. This conversion of the discrete form signal into a continuous form is facilitated by the DAC, as depicted in *figure 5*. Within this framework, the MOF controller aims to minimize the error signal between the measured angular position and the desired one. Notably, the control signal is updated at intervals of 0.0025 seconds (Δ) and applied to the control DC motor through the DAQ port of the Q8 terminal board at a slower rate of 0.01 seconds ($\tau$).

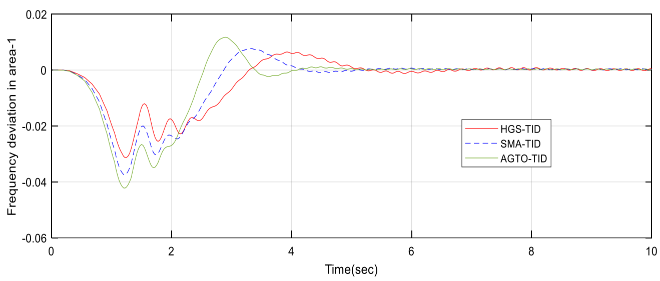
The experimental study focuses on tracking the angular position of the load shaft of SRV02, with the results depicted in *figure 6*. Throughout the experiment, stringent measures are taken to ensure that the motor voltage remains below 10 V, guaranteeing optimal performance. The observed performance metrics include a *tp* of 0.172 seconds, indicating the duration taken to reach the maximum deviation from the desired set-point, and ess of 0.0134 radians. Remarkably, the *ess* is negligible, highlighting the accuracy of the control system. Moreover, the Mp is recorded at 5.21%, significantly lower than the desired Mp specification of 5%, affirming the effectiveness of the control strategy in achieving the desired control objectives.

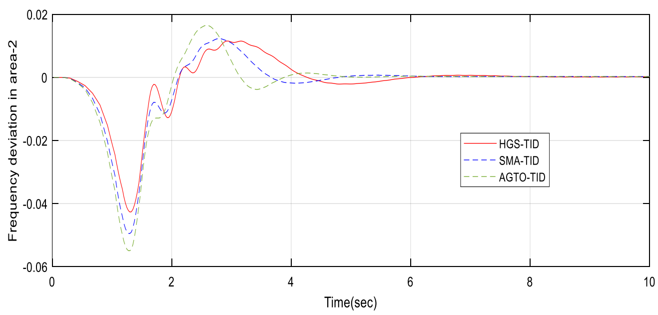
**Table 1. Comparison of various parameters under pool-co based transactions**

| S. No. | PO | | | PU | | | ST | | | ISE |
|---|---|---|---|---|---|---|---|---|---|---|
| | $\Delta f_1$ | $\Delta f_2$ | $\Delta P_{tie}$ | $\Delta f_1$ | $\Delta f_2$ | $\Delta P_{tie}$ | $\Delta f_1$ | $\Delta f_2$ | $\Delta P_{tie}$ | |
| AGTO-TID | 0.0028 | 0.0032 | 0.001 | 0.0069 | 0.026 | 0.0086 | 4.1 | 4.5 | 4.2 | 0.0031 |
| SMA-TID | 0.0018 | 0.0027 | 0.0008 | 0.0054 | 0.019 | 0.0066 | 3.6 | 4.1 | 4.1 | 0.0023 |
| **HGS-TID** | **0.0013** | **0.0024** | **0.0007** | **0.0051** | **0.016** | **0.0054** | **3.1** | **3.5** | **3.6** | **0.0014** |

## 5.2. Bilateral Based Transaction

A bilateral agreement occurs when a Distribution Company (DISCO) collaborates with a Generation Company (GENCO) in a distinct region to share the load. The configuration modeling of the LFC model hydro-thermal system has been regulated via the use of several suggested optimization approaches. This presents the simulation findings for the optimum tuning of different optimized controllers, including SMA, AGTO, and HGS, based on TID, using a fixed step load perturbation (SLP) of 0.05 pu MW. *Figure 5 (a)* depicts the frequency variations (Δf1) in area-1, *figure 5 (b)* depicts the frequency variations (Δf2) in area-2, and *figure 5 (c)* demonstrates the tie-line power fluctuation using different controllers. *Table 2* presents a comparative analysis of parameters for different AGTO, SMA, and HGS-based TID controllers.



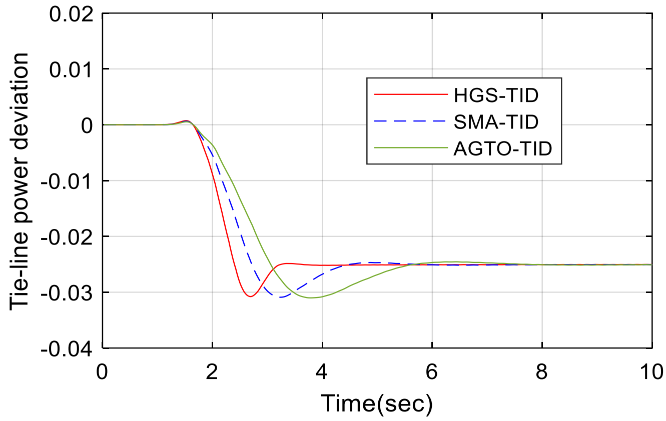



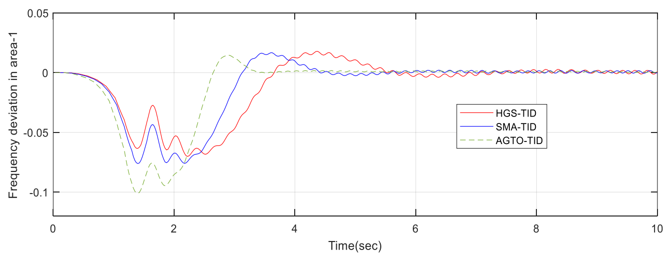

**Figure 5.** Response characteristics plots for various algorithms (a) $\Delta f_1$ (Hz), (b) $\Delta f_2$ (Hz), (c) $\Delta P_{tie12}$ (pu MW)

**Table 2. Comparison of various parameters under pool-co based transactions**

| S.No | PO | | | PU | | | ST | | | ISE |
|---|---|---|---|---|---|---|---|---|---|---|
| | $\Delta f_1$ | $\Delta f_2$ | $\Delta P_{tie}$ | $\Delta f_1$ | $\Delta f_2$ | $\Delta P_{tie}$ | $\Delta f_1$ | $\Delta f_2$ | $\Delta P_{tie}$ | |
| AGTO-TID | 0.018 | 0.016 | 0.008 | 0.048 | 0.052 | 0.036 | 4.9 | 6.8 | 5.1 | 0.082 |
| SMA-TID | 0.013 | 0.013 | 0.006 | 0.042 | 0.050 | 0.030 | 4.4 | 5.9 | 4.7 | 0.074 |
| **HGS-TID** | **0.011** | **0.011** | **0.005** | **0.034** | **0.041** | **0.028** | **4.2** | **5.5** | **3.4** | **0.061** |

## 5.3. Contract violation Transaction

The contract is debased once the disco requests an exorbitant quantity of power above its true value. The contract has been violated. In the framework of a two-area structure by two distribution companies in each area. The LFC hydro-thermal system model, the simulation findings for the best adjustment of several optimized controllers the SMA, AGTO, and HGS-based TID are executed, with a fixed step load perturbation (SLP) of 0.05 pu MW taken into account for this scenario. *Figure 6(a)* depicts the fluctuations in frequency (*Δf1*) observed in area-1, as seen in *figure 6 (b)* depicts the fluctuations in frequency (Δf2) that transpire in area-2 and *figure 6(c)* depicts the variance in tie-line power using various controllers. *Table 3* Illustrates the performance of different optimization techniques beneath contract violation condition.



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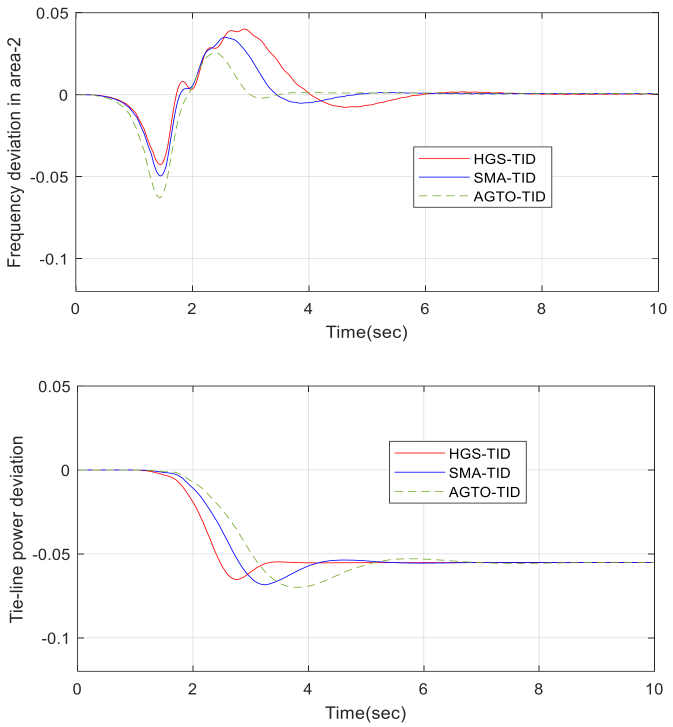


**Figure 6.** Time response characteristics plots for various algorithm (a) $\Delta f_1$ (Hz), (b) $\Delta f_2$ (Hz), (c) $\Delta P_{tie12}$ (pu MW)

**Table 3. Comparison of various parameters under pool-co based transactions**

| S.No | PO | | | PU | | | ST | | | ISE |
|---|---|---|---|---|---|---|---|---|---|---|
| | $\Delta f_1$ | $\Delta f_2$ | $\Delta P_{tie}$ | $\Delta f_1$ | $\Delta f_2$ | $\Delta P_{tie}$ | $\Delta f_1$ | $\Delta f_2$ | $\Delta P_{tie}$ | |
| AGTO-TID | 0.014 | 0.032 | 0.0039 | 0.09 | 0.06 | 0.06 | 5.3 | 4.9 | 4.9 | 0.2722 |
| SMA-TID | 0.008 | 0.036 | 0.0041 | 0.08 | 0.04 | 0.055 | 4.7 | 4.4 | 4.7 | 0.1516 |
| **HGS-TID** | **0.006** | **0.04** | **0.0016** | **0.07** | **0.03** | **0.05** | **4.3** | **4.2** | **4.3** | **0.1188** |

The Pool co-based transaction simulates a centralized market where an Independent System Operator dispatches generators based on least-cost bidding, reflecting real-time or day-ahead markets. The bilateral transaction models direct agreements between buyers and sellers, mimicking deregulated markets where prices and quantities are privately negotiated, offering flexibility and long-term planning. The contract violation-based scenario represents situations where parties fail to meet contractual obligations, reflecting real market conditions requiring penalties and real-time balancing to maintain system reliability. Together, these scenarios capture essential aspects of market behavior—centralized optimization, decentralized freedom, and enforcement—making the simulation more realistic and representative of actual power markets.

Implementing Hunger Games Search–tuned TID controllers in real-time systems faces challenges like high computational complexity, slow convergence, and limited adaptability to dynamic changes. Real-time constraints and hardware limitations may hinder online tuning. Offline tuning or simplified versions of HGS are preferred to ensure stability and timely controller response. **HGS involves iterative, population-based optimization, which can be computationally intensive and unsuitable for systems with strict timing constraints. Offline tuning or simplified HGS variants are preferred for real-time stability.**

## 5. CONCLUSIONS

The main role of these controllers is to quickly stabilize frequency and regulate voltage levels. The paper primarily focuses on the decrease of overshoot, peak time, and settling time, hence enhancing the energetic concert of the system. The Slime Mould Algorithm (SMA) mimics the adaptive foraging behavior of slime moulds using oscillatory movement and feedback-based position updates to balance exploration and exploitation. It dynamically adjusts weights based on fitness to guide agents toward optimal solutions. The Artificial Gorilla Troop Optimizer (AGTO) is inspired by the social structure of gorillas, where agents explore new areas or follow a dominant leader (silverback) to improve search efficiency. AGTO models exploration through random movement and exploitation via leader-following behavior. Both algorithms are effective for complex optimization and are often compared with the Hunger Games Search for performance in solving real-world problems. Analysis of the simulation data reveals a significant decrease in overshoot, peak time, and settling time of the system under abrupt load disturbances when the HGS-TID Controller outperforms the AGTO and SMA-based TID Controllers.

**Conflicts of Interest:** The authors declare no conflict of interest.

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