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BALANCED LOAD FREQUENCY CONTROL: CUSTOMIZED WORLD CUP ALGORITHM - DRIVEN PID OPTIMIZATION FOR TWO AREA POWER SYSTEMS

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A B S T R A C T

Finding a balance between the loads and generating demands in power systems is a significant challenge since power producers require important inputs such as security, reliability and quality. In this study, a unique method for balanced load frequency control (BLFC) is proposed in two-area power systems, integrating a customized World Cup Algorithm (CWCA)-Driven PID optimization. The primary objective is to enhance the stability and performance of power systems. For this purpose, the integral time-multiplied absolute error (ITAE) is minimized by evaluating the objective function using time-domain simulation. The proposed methodology aims to improve the overall response of the control system, ensuring a reliable and stable power supply. Within the scope of two-area power systems with BLFC, simulation results show the effectiveness and resilience of the CWCA-Driven PID Optimization. The outcomes of the proposed PID controller-based CWCA approach are contrasted with the existing methods.

1. INTRODUCTION

Load frequency control "(LFC)" is essential in power systems as it is responsible for ensuring the system frequency and power exchange between different areas are maintained at the intended scheduled values. A crucial concern in stabilizing the LFC power system is the development of appropriate control mechanisms (Liu J et al., (2019)). In the world of power systems, load frequency control, or LFC, is essential because it acts as a pivot to preserve the delicate equilibrium between energy production and consumption. Load frequency control plays the role of the conductor in the complex network of electrical grids when customer demand for energy is varying (Saranyaa J.S and Fathima A.P (2023)).

In the evolving field of power systems, it is crucial to maintain a stable frequency to ensure grid stability. To keep the system frequencies in allowable bounds, LFC plays a critical role in that situation by carefully controlling the balance between energy generation and consumption. The complexity of work increases in linked power systems, particularly those divided into

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many sections (Kumar R and Sharma V.K (2020)). Power systems are complex networks of power plants, converters and transmission lines that work together to distribute electrical energy. The inherent dynamic nature of these systems presents a significant challenge: ensuring a consistent frequency. The fundamental purpose of LFC is to act as a regulatory mechanism that maintains a balance between the production and consumption of electricity (Pappachen A and Fathima A.P (2017)).

In the framework of linked electrical networks, where multiple power stations and loads are integrated, control of load frequency is very important. Because these networks are interconnected, an issue in one area of the system can have repercussions that affect the reliability of the entire system (Tungadio D. H and Sun Y (2019)). As a protector against these disruptions, LFC modifies power generation to offset oscillations and bring the system back to balance. LFC is essential to guarantee the power systems' financial viability. (Shrestha A and Gonzalez-Longatt F (2021)).

LFC enhances the economics of power production by maximizing the use of existing generation resources and reducing needless frequency variations. Considering the current status of the energy business, it is extremely important where load balancing is an intricate process rendered difficult by the use of alternative sources of energy (Cheng Y et al., (2020)). As changes in the global energy sector continue, including the growing focus on renewable energy and the adoption of smart grid technology, the significance of load frequency management becomes even more prominent. The shift towards a more efficient and decentralized power infrastructure requires flexible and responsive control methods (Latif A et al., (2020)).

Large-scale power systems consist of several sources of generation, such as thermal, hydro, nuclear, gas and renewable energies (RE) power plants, which are divided into multiple control zones. The zones are interconnected via tie-lines to facilitate contracted power transfer between them (Impram S et al., (2020)). The complicated balance of power production and load demands is a key element of power systems. Unexpected changes in load demand can cause significant departures from the system's usual operating condition in terms of frequencies. These oscillations might undermine the stability and dependability of the overall electrical grid (Yang W et al., (2018)).

Conventional power plants, which were the mainstay of energy production, have witnessed a gradual decrease in utilization over the last thirty years. The decrease might be ascribed to a convergence of forces that have together transformed the energy sector (Gielen D et al., (2019)). The decreasing availability of fossil fuels, which served as the primary energy source for conventional power plants, is a crucial factor. Economic factors have influenced the shift of the energy sector away from conventional power plants (Mahmud K et al., (2020)). The challenges of LFC are intensified in linked power systems, where zones are defined based on geographical or operational factors. Every section of the interconnected system has its own distinct collection of demands and power sources, which further complicates the intricate interplay of power dynamics (Naga Sai Kalyan C.H andSambasiva Rao G (2020)).

Naderipour A et al., (2023) suggested a novel meta-heuristic algorithm, known as the whale technique, developed for optimizing fuzzy controllers' inputs as well as outputs, their scaling coefficients and fractional-order controllers' fraction orders. Xu Y et al., (2018) suggested a new technique in energy storage for a renewable energy integrating micro-grid (REMG) that depends on pumping hydropower energy storage (PHES).

Abazari A et al., (2019) presented an innovative LFC model for self-sufficient combined micro-grids that incorporates renewable energy resources. An inherent challenge in operating isolated micro-grids is the management of the uncommon structure and sporadic fluctuations of sources of renewable energy, a low-inertia system. Saxena S (2019) presented a straightforward method for constructing fractional-order (FO) controllers using the internal modeling control (IMC) approach for the power systems LFC issue. To create robust controllers, the suggested method used the FO filter, model-order reduction and CRONE's concept inside the IMC architecture. Lu K et al., (2019) introduced a durable proportional-integral (PI) controller. The controller's parameters were determined using constrained population extremal optimization. That approach was applied to solve the linked two-area system network's LFC issue. The optimization procedure utilized the reliable performance index as the fitness function, with the $H\infty$ constraint described using the linear matrix inequality technique.

Yu et al., (2019) presented a flexible fuzzy controller with several inputs and one output that were built using a supervisory methodology for an agent-based system. The primary goals were to control the oscillation frequencies of each component and lower the linked system's total production costs. The suggested controller's design phase included the LFC and controlling controller loops. Yan Z and Xu (2020) introduced a cooperative data-driven approach to the multiple area energy system LFC. The method operates in an ongoing action domain and depends on multi-agent deeper reinforcement learning (MA-DRL). The suggested method looks for the best integrated control schemes for several LFC controllers. That was achieved using a combination of nonlinear and adaptive techniques, utilizing centralized learning and decentralized implementation.

Oshnoei A et al., (2020) introduced an effective control system to integrate dispersed Battery Energy Storage System (BESSs) into LFC using BESS aggregators with limited communication networks. A two-layer Model Prediction Control (MPC) was created to tackle uncertainties related to system operation. Optimizing the control signals was the strategy's goal, improving the performance of Battery Energy Storage Systems (BESSs) and allowing them to make a greater impact on LFC.

Tian E and Peng C (2020) introduced a memory-based event-triggering H∞ LFC technique for power systems. That method operates in the limitations of a bandwidth-constrained open network. The presented Memory-based Event Triggering Scheme (METS) benefits from the utilization of a sequence of the most recent signals that have been released. That method was developed to address unpredictable malicious attacks caused by an unsecured network. Khosraviani M et al., (2018) enhanced the combination of the adaptable fuzzy slide mode and controllers with a PID by using a multi-objective optimization technique to govern the rapid adaptation of connected power systems following a load shift.

Weitenberg E et al., (2018) introduced a decentralized leak integral controller for frequencies restoration, which was derived from a standard lag element. It examined the controller's constant state, asymptotic optimal performance, noisy rejection, rapid performance and resilience qualities used in conjunction with a nonlinear & multivariable power system model.

Dehkordi N.M et al., (2018) introduced an innovative distributed noise-resilient secondary management system for the frequency and voltage regeneration of isolated micro inverter-based distributed generation systems (DGs) in the event of additive noise. Current distributed approaches are formulated as secondary management systems that function based on the assumption of flawless communication networks between DGs. Khooban M.H et al., (2017) introduced a novel adaptable and time-dependent controller for regulating the load frequency in an isolated microgrid. A randomized multi-objective optimization approach was used to optimize the controller's parameters. The objective was to facilitate accurate monitoring of the standard frequency while accounting for photovoltaic (PV) systems, wind generation, vehicle-to-grid (V2G) electric vehicles and load disruptions.

Mallada E et al., (2017) introduced a sophisticated load-side frequency monitoring mechanism that was developed to ensure that the grid remains in operating limits. The controllers owned the ability to restore the balance between supply and demand, stabilize the frequency at its intended value and maintain the flow of power across different regions. Dashtdar M et al., (2022) suggested an ANN-based proportional-integral (PI) controller for regulating the frequency of an island mode microgrid. The suggested PI controller's construction involves adjusting its coefficients in real time using an Artificial Neural Network (ANN), allowing it to respond to alterations in the network frequency. Abou El Ela A.A et al., (2020) introduced a Jaya optimizer that is adapting itself and multi-population elite (SAMPE), a modified version of the Jaya algorithm, to create an ideal layout for a proportional-integral-derivative controller (PID). To mitigate the effects of input signal interruption, the PID controller includes a derived term that is filtered.

The proposed approach aims to enhance the overall responsiveness of a control system, assuring an accurate and constant power supply.

1.1 Key Contribution

The proposal of employing CWCA for load frequency control is the main contribution of this research.

- This work introduces the Customized World Cup Algorithm (CWCA) for Balanced Load Frequency Control. This integration provides a distinct viewpoint and establishes the framework for sophisticated power system optimization.
- The goal of this study is to improve power system stability by CWCA-Driven PID Optimization, which optimizes PID controllers. Reducing integral time-multiplied absolute errors is the goal of a singular objective function.
- This research validates the efficacy of CWCA-Driven PID Optimizer using time-domain simulation. Credibility of the method is increased by comparison study using Z-N, PSO, GSA and PSO-GSA.

2. FORMULATING THE PROBLEM

2.1 The MAPS model

The power system concept is extended by involving Two thermal energy plants that do not reheat, as seen in Figure 1. The main components comprise the speed-governing mechanism, generator and turbine in each area, featuring two output and three inputs. In this case, the reheating thermal unit/turbine mentioned is considered as a single entity, along with several other reheat thermal units. The control signals $(v_1 v_2)$ handle the inputs, which include the energy variation in (ΔP_{TIE}) and the energy variation in the demand$(\Delta P_{D1}\ \Delta P_{D2})$. The results consist of the area controller defects $(ACE_1$ and $ACE_2)$ and the variances in system frequency $(\Delta f_1 and\ \Delta f_2)$. The PID controller is effective at controlling unpredictable conditions inside the system. In the two halves of the model under consideration, PID controllers are used. Figure 2 demonstrates the PID architecture. To reduce the noise's impact on input signals, some sort of filter has been fitted to the derivative component. The mathematical representation of the transferring factor of the PID controller (TF_{PIDm}) is in Equation (1-3).

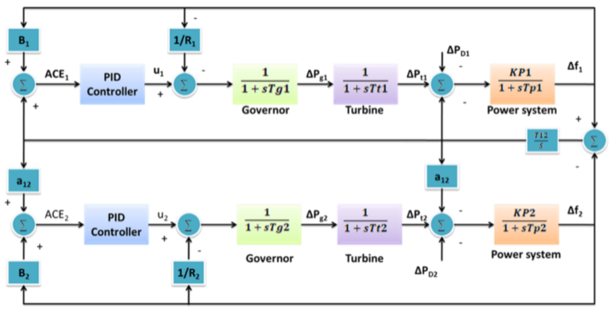


Figure 1. Schematic illustration of the two area electricalsystem

$$TF_{PIDm} = \left(K_p + K_i \left(\frac{1}{t}\right) + K_d \left(\frac{1}{\frac{1}{m}+\frac{1}{t}}\right) \right) \quad (1)$$

Errors related to area control are passed into the controllers ($ACE_1 and\ ACE_2$) that are derived from:

$$ACE_1 = A_1 \Delta f_1 + \Delta P_{TIE} \quad (2)$$

$$ACE_2 = A_2 \Delta f_2 + b_{12} \Delta P_{TIE} \quad (3)$$

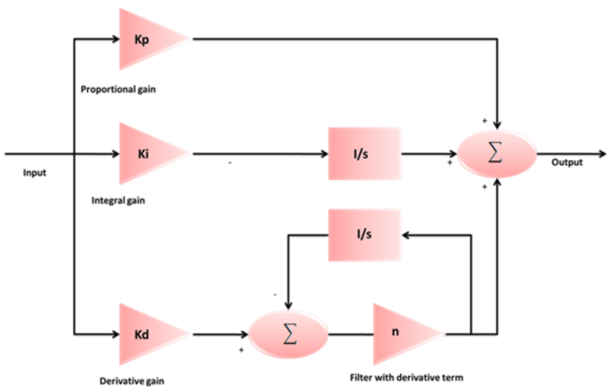


Figure 2. Diagram of a PID controller with a derivative filtering component

2.2 The Objective Function

As the PID controller is constructed, the purpose of it is considered to reveal the requirements and limitations of the system as effectively as possible. Here are a few instances of practical AGC control requirements:

- This means that the frequency variation must go back to zero after the load is adjusted.
- The median of the amount of deviation must be low as it is practically possible.
- The control loop has to be sufficiently stable.
- Every location should be able to sustain its own weight under normal conditions; if there is a disruption in the load, the flow of electricity among areas should be revived to its designed value. The optimal PID controller gains are found by modifying a time-domain target function according to integral criteria as follows in Equation (4-6):

$$I_2 = ITAE = \int_0^{S_{sim}} |\Delta f_1| + |\Delta f_2| + |\Delta P_{TIE}|. s. ds \quad (4)$$

Furthermore, I_2 can be extended to consider lowering the tie-line power transfer as well as the frequency oscillations' peak overshoots in each zone. It is advantageous for this fitness form's evolution to have a damping ratio that is high enough to offer some stability. The controller parameter values represent the limitations of the issue. Consequently, one may refer to the design problem as the subsequent issue of optimization.

$$minimize\ I \quad (5)$$

$$Kp_{min} \leq Kp \leq Kp_{max},$$
$$Ki_{min} \leq Ki \leq Ki_{max}$$
$$Kd_{min} \leq Kd \leq Kd_{max} \quad (6)$$
$$n_{min} \leq n \leq n_{max}$$

Where I can correspond to I_1 orI_2. The subscripts "min" and "max" indicate the smallest and highest values for each controller parameter. The boundary of the filtering factor n is chosen to be from 0 and 500, yet the corresponding values are found to be from 0 to 3.

3. MATHEMATICAL MODEL OF THE SUGGESTED WORLD CUP OPTIMIZATION ALGORITHM

The process of optimizing a problem involves determining its global minimum or maximum solution. Meta-heuristics are a class of optimization algorithms derived from physics, human social behavior and nature. They can even work together in some situations to create a hybrid structure to increase productivity. Numerous algorithms such as particle swarm optimization, genetic algorithms, CWCA algorithms and quantum invasion weed optimization have been developed to address various complex issues. The original version of the CWCA Algorithm has been proposed in recent years. The benefits of this approach are demonstrated by a variety of applications, including neural network optimization, PID design for AVR systems, DC motor speed control, robust power system stabilizer control, solving ordinary differential equations and image segmentation.

This method is based on a global football competition that takes place every four years. In order to determine which team is the greatest and becomes the World Cup champion, this tournament challenges several teams. The final World Cup championship will display the best global optimal based on the mathematical model of this procedure. This approach, similar to previous Meta-heuristic algorithms, comprises two crucial components: exploration (resembling prodigious teams that defy expectations and emerge victorious) and exploitation (such as superior teams). The CWCA method begins with initializing a set of randomly generated populations, referred to as teams. Let M be the number of variable dimensions (M_{var}) and

N represents the number of continents for an optimization problem are shown in Equation (7-11).

$$Continent = \begin{bmatrix} w_{d1,1} & w_{d2,1} & \cdots & w_{dN,2} \\ w_{d1,2} & w_{d2,2} & \cdots & w_{dN,2} \\ \vdots & \vdots & \ddots & \vdots \\ w_{d1,M_{var}} & w_{d2,M_{var}} & \cdots & w_{dN,M_{var}} \end{bmatrix} \quad (7)$$

The notation $w_{j,i}$represents the team of the ith position in the jth country.

The teams' ranking scores can be determined using the score function (f_r).

$$f_r(continent_j) = f_r(w_{dj,1}, w_{dj,2}, \ldots\ldots, w_{j,M_{var}}) \quad (8)$$

Hierarchical position influences the ability to discover a comprehensive answer on a global scale. Here, the initial n highly skilled teams are placed in the initial seed, while the remaining n less skilled teams are categorized as the second seed. The other teams are classed in a hierarchical manner, similar to the first and second teams. The mathematical representation of the "Rank" is as follows:

$$Rank = \frac{(\beta \times \sigma + \underline{W})}{2} \quad (9)$$

The parameter β represents a modifier applied to the standard deviation and it is in the range of [0, 1].

$$\underline{W} = \frac{1}{m} \sum_{j=1}^{m} W_j \quad (10)$$

$$\sigma = \sqrt{\frac{1}{m-1} \sum_{j=1}^{m} (W_j - \underline{W})^2} \quad (11)$$

In this context, m represents the population size, whereas $\underline{W}$and σ represents the mean value and standard deviation of variable$\underline{W}$, respectively.

The "Play-Off" is an important factor inside the CWCA. After selecting the two most powerful teams from each group to advance to the next stage of the competition, the remaining teams shall be eliminated. Meanwhile, the third-ranked team from each seed is given an opportunity for a further chance to rejoin the competition through a Play-Off. To update the solutions for the next round (the next competition), the play-off utilizes the previous competition rating information. In order to accomplish this, the CWCA utilizes a dual-component vector is in Equation (12-15)

$$Pop = [W_{Best}, W_{Rand}] \quad (12)$$

Where Pop is a matrix with dimensions $M \times N$ that represents the new population, W_{Rand}represents a random value in the limits of the problem interval and $W_{Best}$is defined as follows:

$$\frac{1}{2} \times bd \times (Va - Ka) < W_{Best} < \frac{1}{2} \times bd \times (Va - Ka) \quad (13)$$

The variables Va and Ka represent the upper and lower limits of the problem constraints, whereas bd is the precision parameter that determines the accuracy between Ka and Va.

$$CM_{j+1}^{i} = e(CM_{j+1}^{i}) \quad i = 1,2, \ldots\ldots, l \quad (14)$$

The symbol l represents the dimension of the map, whereas $e(CM_{j+1}^{i})$is the function that generates the models.

The CWCA method is characterized by its superior capability to escape from local optima during convergence. The parameter W_{Rand}in the proposed CWCA method is represented using the Sinusoidal map in the following manner: The suggested CWCA algorithm's flowchart is illustrated in Figure 3.

$$W_{Rand,l} = bo_l^2 \sin \sin (\pi o_l)$$

$$o_0 \in [0,1], b \in (0,4] \quad (15)$$

Where k represents the number of iterations.

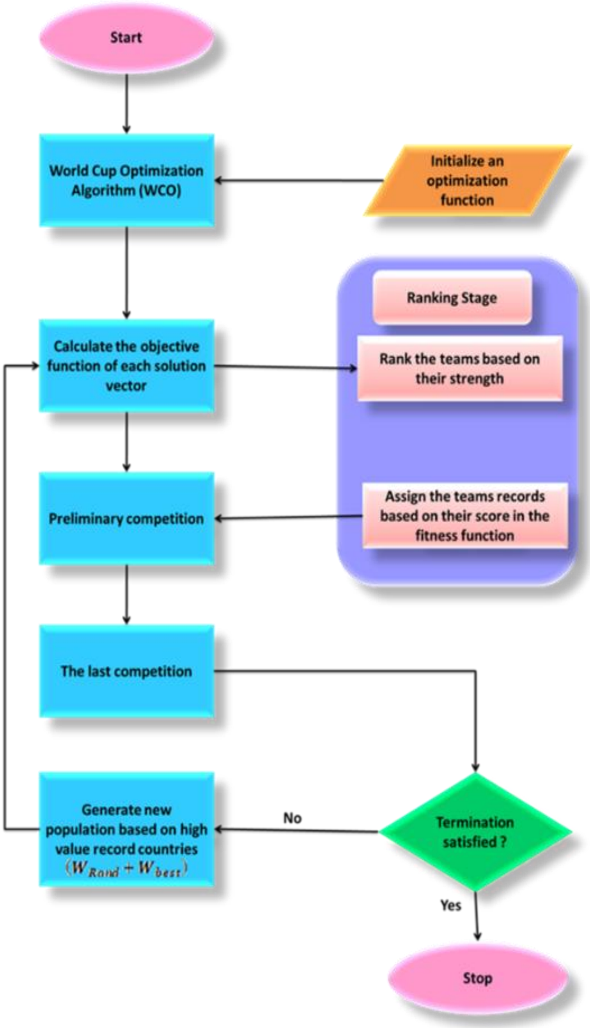


Figure 3. Flowchart of the suggested CWCA algorithm

4. RESULT

4.1 Experimental setup

The assessments were carried out using a personal PC running Windows 7 Ultimate. The Pentium IV processor on the machine, which ran at 2.9 GHz, had 4 GB of RAM in total. MATLAB R2023b was used to perform the recommended technique.

This section uses the proposed CWCA algorithm to optimize the ITAE's goal function. In addition, the particle swarm optimization (PSO) (Veerasamy V et al., (2019)), Ziegler-Nichols (Z-N) (Veerasamy V et al., (2019)), gravitational search algorithm (GSA) (Veerasamy V et al., (2019)) and optimized-gravitational search algorithm (PSO-GSA) (Veerasamy V et al., (2019)). These approaches are employed for comparison. Three distinct test scenarios are conducted; each involving unique sets of perturbations. A population of 10 is used in each simulation run, with a maximum of 100 repetitions allowed. To provide an accurate assessment of the various approaches, tests are carried out using the same quantity of functional executions. Based on the chosen function of the objective and the step change position, the following three cases are investigated:

- Scenario 1: Introducing a sudden change in load, specifically in area 1.
- Scenario 2: involves a step load perturbation that affects only area 2.
- Scenario 3: entails a sudden increase in load in areas 1 and 2.

4.2 Simulation Result for Scenario 1

Area 2 stays unchanged in this scenario, but Area 1 receives an additional load enhancement of 0.1 for each unit $(p.u)$. The pertinent simulation results for scenario 1's assessed ITAE-reducing techniques are shown in Table 1. The optimal settings for controller parameters and the ITAE value objectives for K_P, K_i, K_d and n in every region, as well as the tabulated data, are displayed together. The suggested CWCA algorithm obtained a minimum value of 0.0734 in comparison to PSO, Z-N, GSA as well as PSO-GSA, which had minimal ITAE scores of 0.0779, 2.077, 0.0791 and 0.0789, respectively. Comparing the suggested CWCA to PSO, Z-N, GSA along with PSO-GSA, the ITAE values are improved to 1.949, 2.077, 3.455 and 1.959 percent, respectively.

Furthermore, Figure 4 (a), (b) and (c) displays the variances in wavelength and tie-line power responses for each location.

Table 1 The pertinent simulation results for scenario 1's assessed ITAE preventive measures.

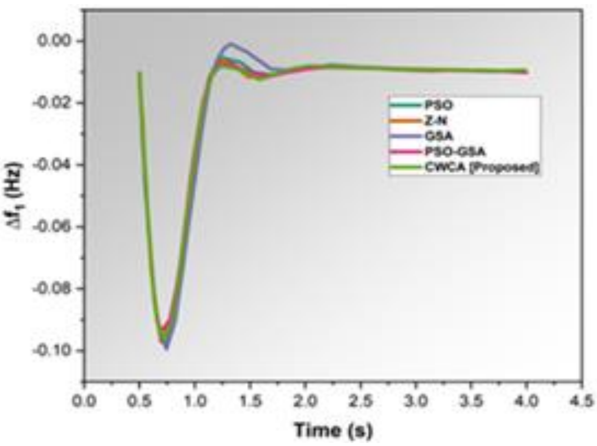
Algorithm		PSO	Z-N	GSA	PSO-GSA	Proposed CWCA
Controller parameters	K_{P1}	1.8166	1.9494	1.7201	1.9702	1.9851
	K_{i1}	2.9996	3.234	3.123	3.135	2.9985
	K_{d1}	0.6754	0.6906	0.5384	0.6183	0.6783
	n_1	88.211	72.986	372.96	385.68	115.23
	K_{P2}	2.2364	1.5843	2.9899	2.9856	2.9791
	K_{i2}	0.5187	0.5306	1.1332	1.6561	0.8296
	K_{d2}	1.8534	1.1095	1.9578	2.7638	1.1501
	n_2	146.14	425.47	332.12	497.93	15.502
Value of ITAE		0.0779	0.078	0.0791	0.0789	0.0734
ITAE Enhancement % compared to the suggested (CWCA)		1.949	2.077	3.455	1.959	-

As illustrated in Figure 4(a), (b) and (c), when it comes to minimizing the fitness function, In comparison to existing approaches that are in use, such PSO, Z-N, GSA and PSO-GSA, the proposed CWCA algorithm performs better.

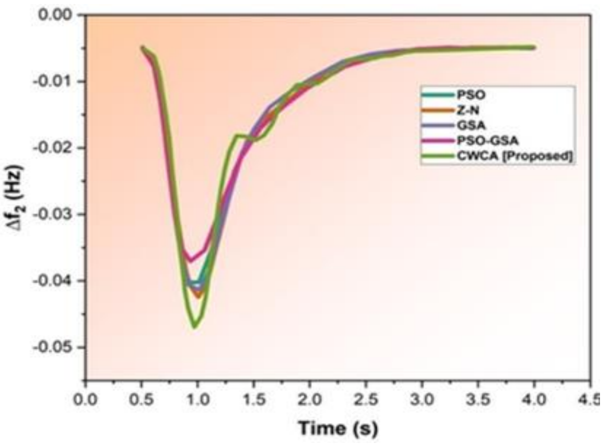
Table 2 presents a comparison of the efficacy of many previous control methods with the suggested PID controller for CWSA, based on settling Time and ITAE. In comparison to the results of the GSA, Z-N, PSO and PSO-GSA, which discover 3.4795, 2.6475, 1.7379, 0.8911respectively, the suggested CWCA technique yields a minimal ITAE of 0.0744. The recommended CWCA-based PID controller is shown to perform better in this table than in other previous optimization strategies with respect to Tie-line energy variances, frequency settling Time and minimum ITAE value.

Table 2. Performance comparison of several alternative control strategies with the recommended CWSA-based PID controller

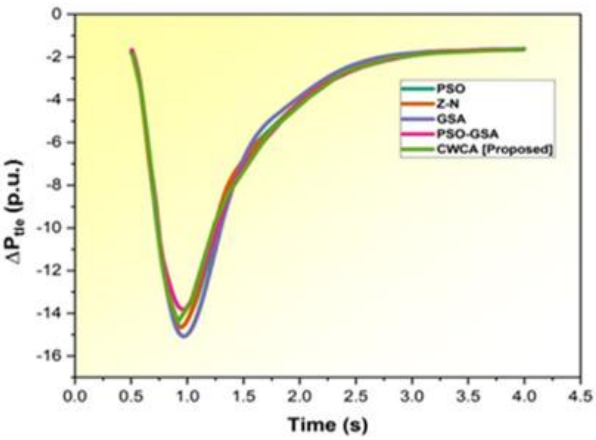
Optimization Technique	Settling Time (s)			Objective Value
	ΔP_{TIE}	ΔF_2	ΔF_1	ITAE
PSO	27.27	44.01	45.08	3.4795
Z-N	8.37	10.39	10.69	2.6475
GSA	7.35	6.09	6.52	1.7379
PSO-GSA	6.75	7.16	7.96	0.8911
Proposed CWCA	3.49294	2.89341	2.295834	0.0744



(a) Dynamic Tie-Line Power Variability and Response in ΔF_1.



(b) Dynamic Tie-Line Power Variability and Response in ΔF_2.



(c) Dynamic Tie-Line Power Variability and Response in ΔP_{TIE}.

Figure 4. Dynamic Tie-Line Power Variability and Response

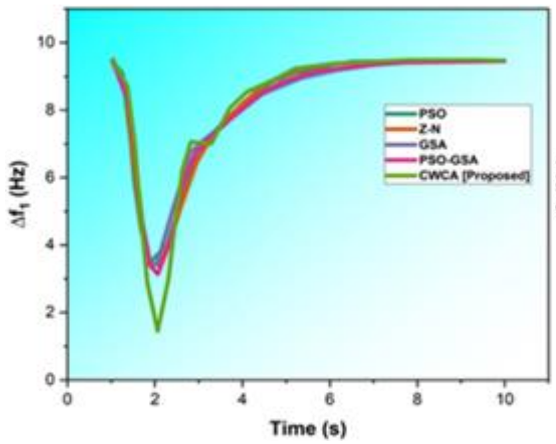
4.3 Simulation result for Scenario 2

In this case, area 1 stays unchanged while area 2 has a step load increase of 0.1 $p.u.$ Table 3 displays the pertinent simulation results for the assessed ITAE prevention strategies. Together with the tabulated data, the ITAE objective values coupled with finest controller parameter values for K_P, K_i,K_d and n in each area are displayed. The minimal ITAE scores of PSO, Z-N, GSA as well as PSO-GSA were 0.086, 0.097, 0.086 and 0.0826, respectively; by comparison, the recommended CWCA method yielded a minimum value of 0.0654. When the proposed CWCA is compared to PSO, Z-N, GSA and PSO-GSA, the ITAE values are likely enhanced to 2.1665, 3.4221, 8.1381 and 7.6873 percent, in that order.

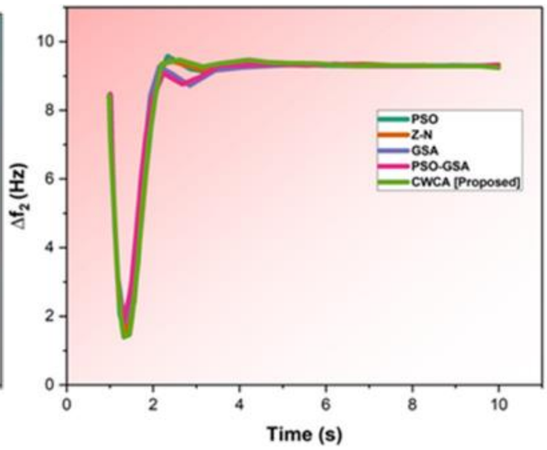
Additionally, Figure 5 (a), (b) and (c), displays the variances in frequency and tie-line power responses for each area. As seen in Figure 5(a), (b) and (c), the recommended CWCA performs better than PSO, Z-N, GSA and PSO-GSA in terms of reducing the fitness function.

Table 3. The pertinent simulation results for the assessed ITAE prevention strategies in scenario 2

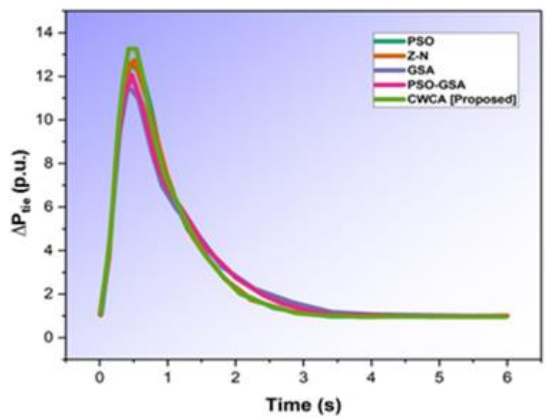
Algorithm		PSO	Z-N	GSA	PSO-GSA	Proposed CWCA
Controller parameters	K_{P1}	2.8421	2.117	2.6822	2.3948	2.8945
	K_{i1}	0.4762	1.9979	0.5092	1.2983	0.6098
	K_{d1}	3.123	2.503	1.3792	1.1794	0.9960
	n_1	307.67	57.929	409.98	501	15.045
	K_{P2}	1.9882	1.9103	2.5546	2.3328	1.9651
	K_{i2}	2.9964	3.223	3.223	2.9706	2.9987
	K_{d2}	0.6997	0.7106	0.7618	0.7757	0.6765
	n_2	501	372.58	410.88	136.87	166.90
Value of ITAE		0.086	0.097	0.086	0.0826	0.0654



(a) Changing Tie-Line Power's Reaction inΔF_1



(b) Tie-Line Power's Variable Reaction inΔF_2



(c) Tie-Line Power's Dynamic Behavior in ΔP_{TIE}

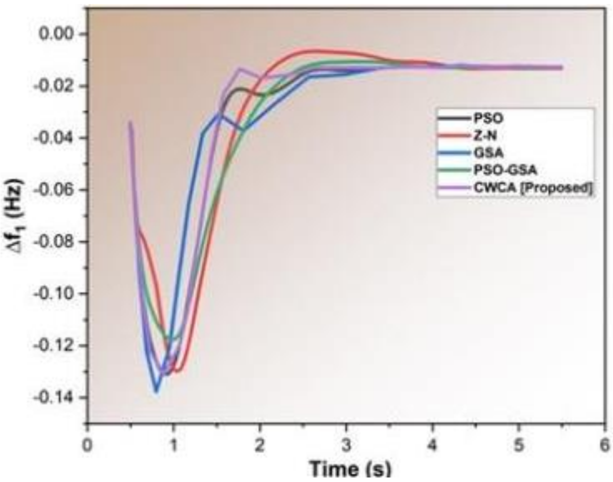
Figure 5.

4.4 Simulation result for Scenario 3

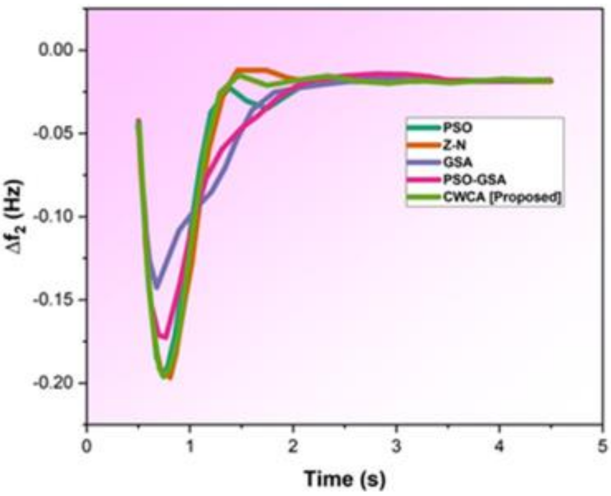
In this scenario, areas 1 and 2 are subjected to step load increases of 0.1 $p.u$ and 0.2 $p.u$ respectively, yet both areas experience a simultaneous variation. The pertinent results from the simulation for the assessed ITAE preventive measures are shown in Table 4. Together, the tabulated data, the optimal control parameters for K_P, K_i,K_d and n in each area, as well as the ITAE objective values are displayed. Compared to PSO, Z-N, GSA and PSO-GSA, all had minimal ITAE scores of 0.2726, 0.2372, 0.3121 and 0.2454, respectively, the suggested CWCA method obtained a minimum value of 0.1363. It is likely that the ITAE values are improved to 18.97, 56.29, 37.13 and 61.89 percent, respectively, when comparing the proposed CWCA to PSO, Z-N, GSA and PSO-GSA. Figure 6 (a), (b) and (c) displays the variances in frequency and tie-line power responses for each location.

Table 4 The pertinent results from the simulation for the assessed ITAE prevention strategies in scenario 3

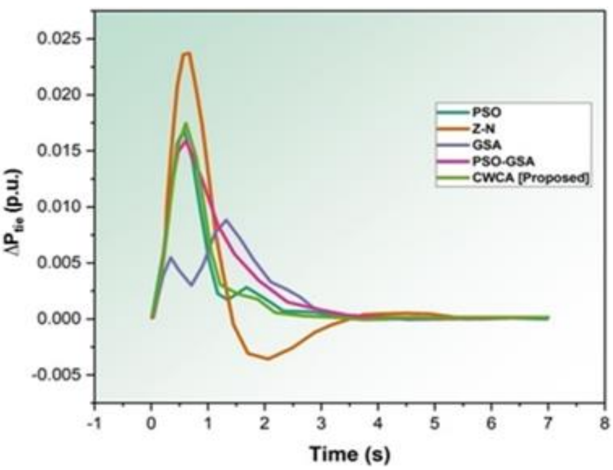
Algorithm		PSO	Z-N	GSA	PSO-GSA	Proposed CWCA
Controller parameters	K_{P1}	1.9122	2.3068	1.6717	1.8764	1.9204
	K_{i1}	2.8685	2.9434	2.9589	3.123	2.9948
	K_{d1}	0.8436	1.6944	2.9589	0.9387	0.5772
	n_1	139.4	85.267	0.5809	392.97	67.018
	K_{P2}	1.9795	1.3472	147.93	392.97	1.5654
	K_{i2}	2.959	2.9588	2.5342	1.662	2.9895
	K_{d2}	0.6627	0.6789	0.9099	2.6835	0.4620
	n_2	340.95	489.78	332.65	501	448.90
Value of ITAE		0.2726	0.2372	0.3121	0.2454	0.1363
ITAE Improvement % of proposed (CWCA)		18.97	56.29	37.13	61.89	-



(a) Tie-Line Power Fluctuations and Dynamic Resonance Changes in ΔF_1.



(b) Tie-Line Power Fluctuations and Dynamic Resonance Changes in ΔF_2.



(c)Tie-Line Power Fluctuations and Dynamic Resonance Change sin ΔP_{TIE}.

Figure 6. Tie-Line Power Fluctuations and Dynamic Resonance Changes

In this regard, Table 5 shows the settling timeframes for the tie-line power and frequency variations in areas 1 and 2. This table demonstrates how well the suggested CWCA method performs in obtaining the lowest settling times 0.8804 and 2.1305s for the tie-line power and area 2 frequency deviations, respectively. It finds the lowest settling period 2.1967s among the others.

Table 5. Areas 1 and 2's settling times for changes in frequency and tie-line power.

Methods	ΔF_1	ΔF_2	ΔP_{TIE}
PSO	2.5343	1.9693	3.2625
Z-N	3.7834	1.7293	3.3571
GSA	3.1722	2.1993	3.5722
PSO-GSA	2.3596	3.2665	3.6186
Proposed CWCA	2.1967	0.8804	2.1305

5. CONCLUSION

This work introduces an innovative meta-heuristic optimization method known as the Customized World Cup Optimization (CWCA). The CWCA methodology is used for maximizing the LFC variables of the PID controller in two area electrical systems. PID controller, incorporating a filter, has been developed utilizing the CWCA approach that is suggested to reduce ITAE. Three cases of step load increment disturbances in regions 1 and 2 are addressed. MATLAB R2023b was used to implement the suggested method. The suggested CWCA algorithm is evaluated against other strategies, such as PSO, GSA, Z-N and PSO-GSA. When comparing the minimal ITAE scores of PSO, Z-N, GSA and PSO-GSA had values of 0.0791, 2.077, 0.0791 and 0.0789, respectively with the CWCA method, obtained a minimum value of 0.0734. Within the first scenario. PSO, Z-N, GSA and PSO-GSA had minimum ITAE scores of 0.086, 0.097, 0.086 and 0.0826, in that order. In contrast, the suggested CWCA approach produced a minimum value of 0.0654 in scenario 2. In scenario 3, the suggested CWCA approach obtained a minimum value of 0.1363, in contrast to PSO, Z-N, GSA and PSO-GSA, which each had the lowest ITAE scores of 0.2726, 0.2372, 0.3121 and 0.2454, respectively. Comparisons show that our CWCA method outperforms other existing approaches, achieving the best results under all scenarios. Challenges that the algorithm might face include bigger and more dynamic power systems, inaccurate models and communication delays. In the future to overcome these obstacles for better performance, incorporate real-time monitoring, machine learning, cybersecurity, advanced control techniques, sustainability and comprehensive field testing.

References:

Abazari, A., Monsef, H., & Wu, B. (2019). Coordination strategies of distributed energy resources including FESS, DEG, FC and WTG in load frequency control (LFC) scheme of hybrid isolated micro-grid. *International Journal of Electrical Power & Energy Systems,109, 535-547.*https://doi.org/10.1016/j.ijepes.2019.02.029

Abou El Ela, A. A., El-Sehiemy, R. A., Shaheen, A. M., &Diab, A. E. G. (2020). Optimal design of PID controller based sampe-jaya algorithm for load frequency control of linear and nonlinear multi-area thermal power systems. *International Journal of Engineering Research in Africa,50, 79-93.*https://doi.org/10.4028/www.scientific.net/JERA.50.79

Cheng, Y., Azizipanah-Abarghooee, R., Azizi, S., Ding, L., &Terzija, V. (2020). Smart frequency control in low inertia energy systems based on frequency response techniques: A review. *Applied Energy, 279, 115798.*https://doi.org/10.1016/j.apenergy.2020.115798

Dashtdar, M., Flah, A., Hosseinimoghadam, S. M. S., & El-Fergany, A. (2022). Frequency control of the islanded microgrid including energy storage using soft computing. *Scientific Reports,12(1), 20409.*https://doi.org/10.1038/s41598-022-24758-6

Dehkordi, N. M., Baghaee, H. R., Sadati, N., & Guerrero, J. M. (2018). Distributed noise-resilient secondary voltage and frequency control for islanded microgrids. *IEEE Transactions on Smart Grid,10(4), 3780-3790.*https://doi.org/10.1109/TSG.2018.2834951

Gielen, D., Boshell, F., Saygin, D., Bazilian, M. D., Wagner, N., &Gorini, R. (2019). The role of renewable energy in the global energy transformation. *Energy strategy reviews, 24, 38-50.*https://doi.org/10.1016/j.esr.2019.01.006

Impram, S., Nese, S. V., & Oral, B. (2020). Challenges of renewable energy penetration on power system flexibility: A survey. *Energy Strategy Reviews,31, 100539.*https://doi.org/10.1016/j.esr.2020.100539

Khooban, M. H., Niknam, T., Blaabjerg, F., &Dragičević, T. (2017). A new load frequency control strategy for micro-grids with considering electrical vehicles. *Electric Power Systems Research,143, 585-598.*https://doi.org/10.1016/j.epsr.2016.10.057

Khosraviani, M., Jahanshahi, M., Farahani, M., &Bidaki, A. R. Z. (2018). Load–frequency control using multi-objective genetic algorithm and hybrid sliding mode control-based SMES. *International Journal of Fuzzy Systems,20, 280-294.*https://doi.org/10.1007/s40815-017-0332-z

Kumar, R., & Sharma, V. K. (2020). Whale optimization controller for load frequency control of a two-area multi-source deregulated power system. *International Journal of Fuzzy Systems, 22(1), 122-137.*https://doi.org/10.1007/s40815-019-00761-4

Latif, A., Hussain, S. S., Das, D. C., &Ustun, T. S. (2020). State-of-the-art of controllers and soft computing techniques for regulated load frequency management of single/multi-area traditional and renewable energy based power systems. *Applied Energy,266, 114858.*https://doi.org/10.1016/j.apenergy.2020.114858

Liu, J., Gu, Y., Zha, L., Liu, Y., & Cao, J. (2019). Event-triggered $ H_\infty $ load frequency control for multiarea power systems under hybrid cyber-attacks. *IEEE Transactions on Systems, Man, and Cybernetics: Systems,49(8), 1665-1678.*https://doi.org/10.1109/TSMC.2019.2895060

Lu, K., Zhou, W., Zeng, G., & Zheng, Y. (2019). Constrained population extremal optimization-based robust load frequency control of multi-area interconnected power system. *International Journal of Electrical Power & Energy Systems,105, 249-271.*https://doi.org/10.1016/j.ijepes.2018.08.043

Mahmud, K., Khan, B., Ravishankar, J., Ahmadi, A., &Siano, P. (2020). An internet of energy framework with distributed energy resources, prosumers and small-scale virtual power plants: An overview. *Renewable and Sustainable Energy Reviews,127, 109840.*https://doi.org/10.1016/j.rser.2020.109840

Mallada, E., Zhao, C., & Low, S. (2017). Optimal load-side control for frequency regulation in smart grids. *IEEE Transactions on Automatic Control, 62(12), 6294-6309.*https://doi.org/10.1109/TAC.2017.2713529

Naderipour, A., Abdul-Malek, Z., Davoodkhani, I. F., Kamyab, H., & Ali, R. R. (2023). Load-frequency control in an islanded microgrid PV/WT/FC/ESS using an optimal self-tuning fractional-order fuzzy controller. *Environmental Science and Pollution Research, 30(28), 71677-71688.*https://doi.org/10.1007/s11356-021-14799-1

Naga Sai Kalyan, C. H., &Sambasiva Rao, G. (2020). Frequency and voltage stabilisation in combined load frequency control and automatic voltage regulation of multiarea system with hybrid generation utilities by AC/DC links. *International Journal of Sustainable Energy, 39(10), 1009-1029.*https://doi.org/10.1080/14786451.2020.1797740

Oshnoei, A., Kheradmandi, M., &Muyeen, S. M. (2020). Robust control scheme for distributed battery energy storage systems in load frequency control. *IEEE Transactions on Power Systems,35(6), 4781-4791.*https://doi.org/10.1109/TPWRS.2020.2997950

Pappachen, A., &Fathima, A. P. (2017). Critical research areas on load frequency control issues in a deregulated power system: A state-of-the-art-of-review. *Renewable and Sustainable Energy Reviews,72, 163-177.*https://doi.org/10.1016/j.rser.2017.01.053

Saranyaa, J. S., &Fathima, A. P. (2023). A Comprehensive Survey on the Current Trends in Improvising the Renewable Energy incorporated Global Power System Market. *IEEE Access.*https://doi.org/10.1109/ACCESS.2023.3252574

Saxena, S. (2019). Load frequency control strategy via fractional-order controller and reduced-order modeling. *International Journal of Electrical Power & Energy Systems, 104, 603-614.*https://doi.org/10.1016/j.ijepes.2018.07.005

Shrestha, A., & Gonzalez-Longatt, F. (2021). Frequency stability issues and research opportunities in converter dominated power system. *Energies,14(14), 4184.*https://doi.org/10.3390/en14144184

Tian, E., & Peng, C. (2020). Memory-based event-triggering H∞ load frequency control for power systems under deception attacks. *IEEE transactions on cybernetics,50(11), 4610-4618.*https://doi.org/10.1109/TCYB.2020.2972384

Tungadio, D. H., & Sun, Y. (2019). Load frequency controllers considering renewable energy integration in power system. *Energy Reports,5, 436-453.*https://doi.org/10.1016/j.egyr.2019.04.003

Veerasamy, V., Abdul Wahab, N. I., Ramachandran, R., Vinayagam, A., Othman, M. L., Hizam, H., &Satheeshkumar, J. (2019). Automatic load frequency control of a multi-area dynamic interconnected power system using a hybrid PSO-GSA-tuned PID controller. *Sustainability,11(24), 6908.*https://doi.org/10.3390/su11246908

Weitenberg, E., Jiang, Y., Zhao, C., Mallada, E., De Persis, C., &Dörfler, F. (2018). Robust decentralized secondary frequency control in power systems: Merits and tradeoffs. *IEEE Transactions on Automatic Control,64(10), 3967-3982.* https://doi.org/10.1109/TAC.2018.2884650

Xu, Y., Li, C., Wang, Z., Zhang, N., & Peng, B. (2018). Load frequency control of a novel renewable energy integrated micro-grid containing pumped hydropower energy storage. *Ieee Access,6, 29067-29077.*https://doi.org/10.1109/ACCESS.2018.2826015

Yan, Z., & Xu, Y. (2020). A multi-agent deep reinforcement learning method for cooperative load frequency control of a multi-area power system. *IEEE Transactions on Power Systems,35(6), 4599-4608.*https://doi.org/10.1109/TPWRS.2020.2999890

Yang, W., Norrlund, P., Saarinen, L., Wsitt, A., Smith, B., Yang, J., & Lundin, U. (2018). Burden on hydropower units for short-term balancing of renewable power systems. *Nature communications,9(1), 2633.*https://doi.org/10.1038/s41467-018-05060-4

Yu, D., Zhu, H., Han, W., &Holburn, D. (2019). Dynamic multi-agent-based management and load frequency control of PV/fuel cell/wind turbine/CHP in autonomous microgrid system. *Energy,173, 554-568.*https://doi.org/10.1016/j.energy.2019.02.094

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