Combined fuzzy PID regulator for frequency regulation of smart grid and conventional power systems

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ABSTRACT

In continually increasing area and structure of modern power system having burden demand uncertainties, the use of knowledgeable and vigorous frequency power strategy is essential for the satisfactory functioning of the Power system. A combined fuzzy proportional-integral-derivative (CFPID) controller is suggested for frequency supervision of the power system. To optimize the controller parameters, a review of sine and cosine work adjusted improved whale optimization algorithm (SCiWOA) has been utilized. The next practical application of power-system frequency control is performed by designing a CFPID controller using the proposed SCiWOA technique for a smart grid system having inexhaustible sources like sun oriented, wind, photovoltaic and capacity gadgets like a battery, flywheel just as module electric vehicles. The first advantages of the SCiWOA tuned CFPID controller over hybrid-particle-swarm-optimization and pattern-search (hPSO-PS) adjusted fuzzy proportional-integral (FPI) controller, hybrid bacterial foraging optimization algorithm-particle swarm optimization (hBFOA-PSO) adjusted proportional-integral (PI) controller, genetic algorithm (GA) tuned proportional and integral (PI) controller, BFOA adjusted PI controller, jaya algoritm (JA) tuned PID with derivative filter (PIDN) controller and teaching learning based optimization (TLBO) tuned proportional-integral-derivative (PID) controller are demonstrated for the two-area non-reheat thermal power system. The second advantages of the SCiWOA tuned CFPID controller over artificial-bee-colony (ABC) tuned PID controller, SOSA tuned PID controller and Firefly algorithm (FA) tuned PID controller are demonstrated for two-area reheat thermal power system. It is seen that SCiWOA based CFPID controller is more effective in controlling the recurrence comparative with PID regulator.

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1. INTRODUCTION

With the increasing addition of unpredictable renewable sources, such as solar & wind power, electrical vehicles, distributed energy sources, and random load variations, modern power systems are susceptible to frequency fluctuations [1]. In such a situation, an appropriate controller is needed for frequency control. In frequency control of power system (PS) has been performed by grey wolf optimization (GWO) tuned proportional-integral (PI) or proportional-integral-derivative (PID) controllers and a comparison has been made with alike optimization methods [2]. In artificial-bee-colony (ABC) technique is employed for tuning the values of PID and PI controllers for frequency control of a reheat thermal PS [3]. A teaching learning-based optimization (TLBO) technique is proposed for frequency control of two test systems [4]. A symbiotic organism search (SOS) based PID controller has become suggested for recurrence control of three test systems [5]. A relative performance examination of conventional controllers in LFC by firefly algorithm method has been discussed [6]. A hybrid Firefly algorithm (FA) and pattern search scheme is employed for frequency control of multi-area PS including generation rate constraint (GRC) [7]. A PID with a filter optimized by the Jaya algorithm has been suggested for frequency regulation of an interconnected PS [8]. For a standard two-area non-reheat power system, genetic algorithm (GA) and bacterial foraging optimization algorithm (BFOA) techniques have been applied for tuning the PI controllers [9], [10]. A modified differential evolution (DE) optimized fuzzy PID has been recommended for load frequency control of power systems in presence of flexible alternating current transmission system (FACTS) controller [11]. A hybrid-particle-swarm-optimization and pattern-search (hPSO-PS) optimized fuzzy PI controller was employed for frequency control of multi-area interconnected PS [12]. A fuzzy aided PID with filter-fractional order-integral (FPIDN-FOI) controller optimized by imperialist competitive algorithm was proposed for various tests PS [13]. A hybrid-BFOA PSO algorithm for AGC of non-linear and linear interlinked PS has been performed in [14]. As indicated by no free lunch (NFL) suggestion, no procedure is fighting fit to every problem. Whale optimization algorithm (WOA) is a lately suggested technique grounded on the stalking skill of the Humpback whale [15]. Though WOA is an efficient method, it has a penchant to be struck in local bests with inferior convergence characteristics. Different alterations of WOA have been proposed in writing for the execution enhancement of the unique WOA method. Authors have proposed to use levy flight trajectory, inertia weights, simulated annealing (SA), fixed correction factors, and hybridization with DE to advance the performance of WOA [16]-[21]. Likewise, sine and cosine capacities are locked in for deciding the control boundary 'c' of WOA in the enhancement cycle. The extended calculation is at first checked on benchmark works and compared with different methodology. To enhance the exhibition of the fuzzy logic controller, PID regulators can be joined with fuzzy logic controller (FLC). The boundaries of the combined fuzzy proportional-integral-derivative (CFPID) regulator are streamlined by the proposed SCiWOA strategy [22], [23].

The first aim of this work is designed for SCiWOA tuned CFPID controller over hPSO-PS tuned FPI controller, hybrid bacterial foraging optimization algorithm-particle swarm optimization (hBFOA-PSO) adjusted PI controller, GA adjusted PI controller, BFOA adjusted PI controller, JA adjusted PIDN controller and TLBO adjusted PID controller are demonstrated for the two-area non-reheat thermal power system. The second aim of this work is designed for SCiWOA tuned CFPID controller over ABC adjusted PID controller, symbiotic organisms search algorithm (SOSA) adjusted PID controller and FA adjusted PID controller are demonstrated for two areas reheat thermal power system.

The chief object of the work includes:

a) To propose a sine and cosine work adjusted improved whale optimization algorithm (SCiWOA) calculation for fathoming advancement undertakings.
b) To propose a combined fuzzy PID (CFPID) regulator for recurrence guideline of PS.
c) To assess the viability of SCiWOA based CFPID regulator in a brilliant network framework and assess its proficiency under various genuine dubious situations like inaccessibility of inexhaustible sources, expanded burden interest, variety in sources, and burden, and expansion in correspondence delay.
d) To evaluate the effectiveness of the proposed frequency control approach in standard test power systems and equate its performance over some newly proposed approaches in the literature for identical systems.

2. RESEARCH METHOD

2.1. Smart grid system for investigation

The smart grid system concentrated in aqua-electrolysers, fuel-cell, diesel engine generator, wind turbine generator, aqua electrolysers, flywheel energy storage system, battery energy storage system, solar photo-voltaic and so on as demonstrated in Figure 1 [24]-[26].

2.2. Modelling of components

The components of a smart grid system are represented by the transfer function.

a) Wind turbine generator

The breeze power yield is demonstrated as (1).

$$P_{WP} = \frac{1}{2}\rho A_R C_P V_W^3 \quad (1)$$

The transfer function is shown (2), *N* signifies no of units.

$$G_{WTG_N}(s) = \frac{K_{WTG}}{1+sT_{WTG}} = \frac{\Delta P_{WTG}}{\Delta P_{WP}} \quad (2)$$

Here N=1 to 3

b) Photovoltaic cell

The power response of PV is shown (3).

$$P_{PV} = \eta \cdot S \cdot \varphi[1-0.005(T_a+25)] \quad (3)$$

Where η is efficiency, S is the area of PV array and φ is solar irradiation. The transfer function of PV is given by (4).

$$G_{PV}(s) = \frac{K_{PV}}{1+sT_{PV}} = \frac{\Delta P_{PV}}{\Delta \phi} \quad (4)$$

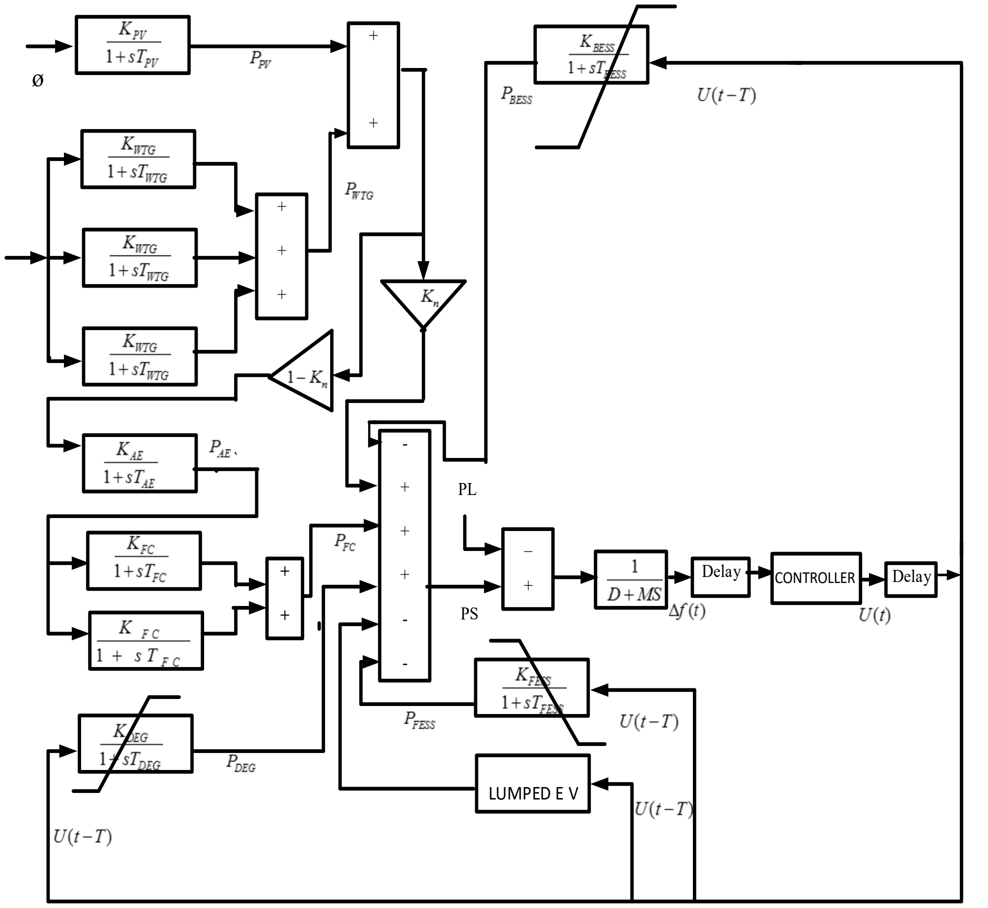

Figure 1. Smart grid system under study [24]-[26]

c) Aqua electrolyser (AE)

An AE is a whole power made by wind and PV cells.

$$G_{AE}(s) = \frac{K_{AE}}{1+sT_{AE}} = \frac{\Delta P_{AE}}{U_2} \quad (5)$$

d) Fuel cell

$$G_{FC_N}(s) = \frac{K_{FC}}{1+sT_{FC}} = \frac{\Delta P_{FC}}{\Delta P_{AE}} \quad (6)$$

Here N=1 to 2

e) Diesel engine generator

$$G_{DEG}(s) = \frac{K_{DEG}}{1+sT_{DEG}} = \frac{\Delta P_{DEG}}{\Delta U} \tag{7}$$

f) Energy stockpiling framework model

All the energy stockpiling components follow up on the nonlinear zone.

$$G_{FESS}(s) = \frac{K_{FESS}}{1+sT_{FESS}} = \frac{\Delta P_{FESS}}{\Delta U} \tag{8}$$

$$G_{BESS}(s) = \frac{K_{BESS}}{1+sT_{BESS}} = \frac{\Delta P_{BESS}}{\Delta U} \tag{9}$$

g) Displaying of electric vehicle

The LFC wave managed to EV which burns through genuine force during charging. The photos and address beyond what many would consider possible and dependable of time of EV. The set-aside energy system processes the total battery set aside energy in a close-by control network and its specific is gotten in [27].

h) Demonstrating of intensity framework

It is stated by (10).

$$G(s) = \frac{1}{D+sM} \tag{10}$$

Where D is given as damping constant and M is inertia constant.

2.3. Structure of combined fuzzy PID regulator

The standard encounters for engineering fuzzy logic control are data-based course of action, control tuning cutoff focuses, and backing work. One system for arranging a sensitive controller is the web tuning of a critical figuring and makes the structure tangled. Another system for getting sorted out FLC is utilized for a PID regulator and tunes the information scaling parts and PID limits [28], [29]. In initial approach, the scaling-factors are staying stable whereas in next approach the scaling factors are picked steadily when the regulator is working. To crush the above drawbacks, combined fuzzy PID (CFPID) is stated as uncovered in Figure 2. To build the system versatile in nature, the data is capable cushy similarly as really to the PID regulators. The ampleness of regulator can be improvised by Fuzzy standard base and adjusted the scaling-factors adjustable to dependably resuscitate the yield acquire. For the stated CFPID controller, a huge load of fixed control regulations and five-three-sided interest limits are picked as showed up in Figure 3. The enrollment limits are given out etymological parts like positive-small, positive-big, zero, negative small, and negative big as introduced in Table 1. For the required expansion of the CFPID regulator, scaling factors are adjusted by the SCiWOA procedure. For the present article, mamdani padded prompting motor is utilized. An integral square error (ISE) premise which intends to restrict the repeat deviation (Δf) similarly as control attempts (Δu) is taken as target fill in as:

$$J = \int_0^T [kn \cdot w_1 \cdot (\Delta f)^2 + (1 - w_1)(\Delta U)^2] \cdot dt \tag{11}$$

In both sections in (11) competitively inquiry procedure, *kn* is allocated a value of 50. To give equal weight to both the components of the objective function, w_1 is assigned a value of 0.5.

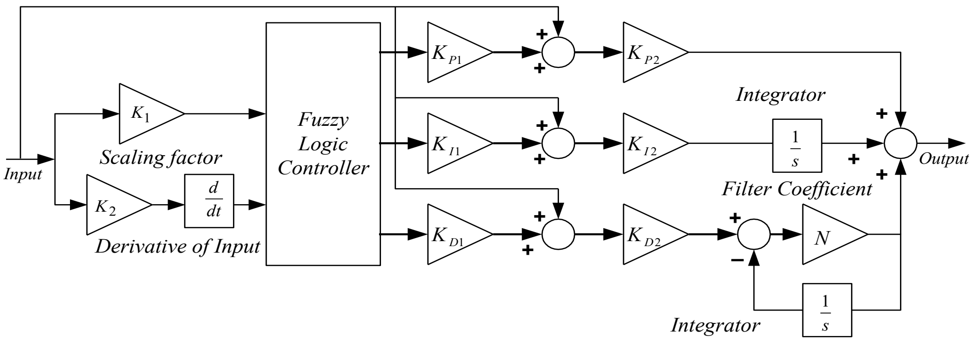

Figure 2. Combined fuzzy PID regulator

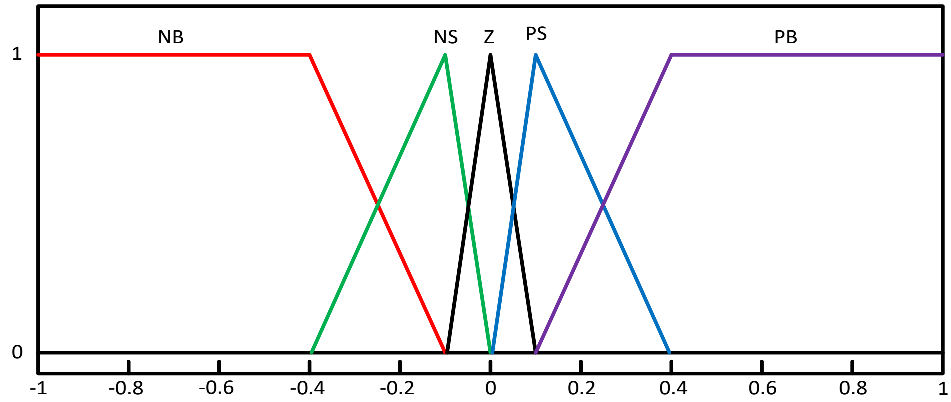

Figure 3. Membership function of error and change of error of FLC

Table 1. Fuzzy principle-base

e / de	N-B	N-S	Ze	P-S	P-B
N-B	N-B	N-B	N-S	N-S	Ze
N-S	N-B	N-S	N-S	Ze	P-S
Ze	N-S	N-S	Ze	P-S	P-S
P-S	N-S	Ze	P-S	P-S	P-B
P-B	Ze	P-S	P-S	P-B	P-B

2.4. Review of sine cosine adjusted improved WOA (SCiWOA)

Whale advancement measure is set up on humpback whales for testing of food or prey. Whales like to chase the prey nearby to the water surface. Contracting enclosing strategy and winding refreshing position are the two ways to deal with approaches utilized for this. These techniques are clarified by (12)-(14).

$$\vec{f} = \left|\vec{e}\,.\vec{z}^{*}(t) - \vec{z}(t)\right| \tag{12}$$

$$\vec{z}(t+1) = \vec{z}^{*}(t) - \vec{C}\,.\vec{f} \tag{13}$$

$$\vec{z}(t+1) = \vec{f}'\, e^{kl}.\cos(2\pi l) + \vec{z}^{*}(t) \tag{14}$$

So $\vec{z}^{*}(t)$ is the best solution, t is current repetition and $\vec{Z}(t)$ = position vector e = distance among ith and the best whale obtained till now. In (14), $\vec{f}' = \left|\vec{z}^{*}(t) - \vec{z}(t)\right|$ = distance from i^{th} whale to finest found prey till now, 'k' equal to the contour of the logarithm spiral. 'l' = arbitrary number.

The vectors $\vec{C}$ and $\vec{e}$ are the adjustment vectors.

$$\vec{C} = 2\,\vec{c}\,\vec{r} - \vec{c} \tag{15}$$

$$\vec{e} = 2\,\vec{r} \tag{16}$$

Here $\vec{r}$ = arbitrary number selected between 1 & 0.

$$\vec{c} = 2 - t\frac{2}{ITER_{MAX}} \tag{17}$$

Whereas ‘ $\vec{c}$ ’ equal to distance control parameter and $ITER_{MAX}$ is here maximum iteration. Stated SCiWOA utilizes sine and cosine functions for control parameter ‘ $\vec{c}$ ’in the process as (18).

$$\vec{c} = \begin{cases} 1 - sin\left(\frac{\pi}{2}\left(\frac{t}{ITER_{MAX}}\right)\right) & if RND < 0.5 \\ 1 - cos\left(\frac{\pi}{2}\left(\frac{t}{ITER_{MAX}}\right)\right) & if RND \geq 0.5 \end{cases} \tag{18}$$

The related equations are:

$$\vec{F} = \left|\vec{E}.\vec{Z} * (t) - \vec{Z}(t)\right| /SF \tag{19}$$

$$\vec{Z}(t+1) = (\vec{Z} * (t) - \vec{C}.\vec{F})/SF \tag{20}$$

$$\vec{Z}(t+1) = (\vec{F}'.e^{kl}.cos(2\pi l) + \vec{Z} * (t))/SF \tag{21}$$

Accordingly in the present SCiWOA technique, the area of search specialists is changed by scaling-factors as (22) and (23) as:

$$\vec{F} = (\vec{E}.\vec{Z}_{rand}(t) - \vec{Z})/SF \tag{22}$$

$$Z(\vec{t+1}) = (\vec{Z}_{rand} - \vec{C} \cdot \vec{F})/SF \tag{23}$$

so the scaling-factor is differed as shown (24).

$$SF = \begin{cases} 2 - \frac{t}{ITER_{MAX}} & if RND1 < 0.5 \\ 1/(2 - \frac{t}{ITER_{MAX}}) & if RND1 \geq 0.5 \end{cases} \tag{24}$$

Here $RND1$ is equal to self-assertive incentive.

3. RESULTS AND DISCUSSION

The PV cell and wind generator are presented in Figure 4(a). The outputs of controllable sources are regulated by the proposed controller to minimize the power imbalance and hence the frequency fluctuations. The percentage development in J value with stated SCiWOA technique contrasted to WOA for CFPID controller is found to be 7.87%. The load power and power difference is shown in Figure 4(b).

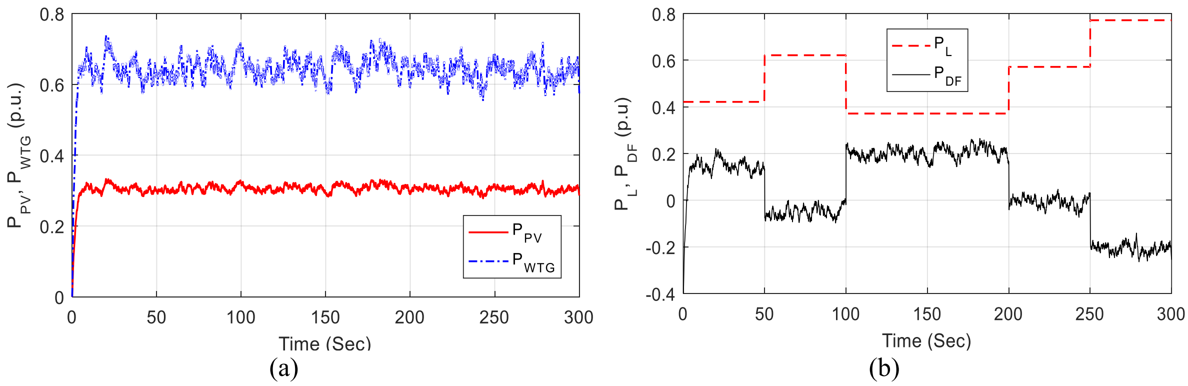

Figure 4. (a) Variation of P_{PV} and P_{WTG} and (b) load power and power difference

3.1. Comparison of frequency control approaches

SCiWOA tuned CFPID is a commonly employed two-area power system. Firstly, a two-area non-reheat thermal system given in Figure 5 is considered. SCiWOA tuned CFPID is equated with stated optimization-based control like TLBO tuned PID, GA tuned PI, hPSO-PS adjusted FPI, JA adjusted PIDN, BFOA adjusted PI, and hBFOA-PSO adjusted PI. So it is seen that the proposed SCiWOA adjusted CFPID gives better results as compared to other techniques.

The effective result with SCiWOA adjusted CFPID for over and above SLP is conveyed in Figure 6. Secondly, an interconnected two-area reheat thermal system as presented in Figure 7 is assumed. The outcomes of ABC, SOSA, FA adjusted PID controller for the same system are too gathered. The comparative system performances are presented in Figure 8. The proposed SCiWOA adjusted CFPID related to publish results.

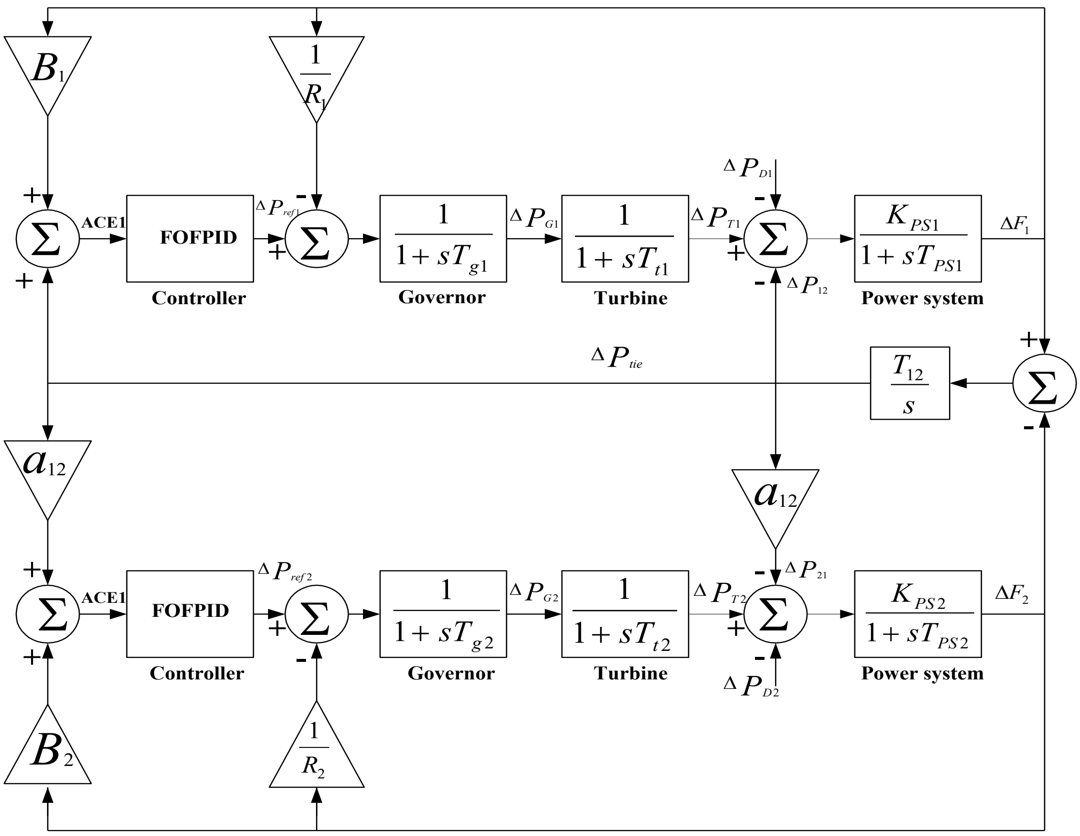

Figure 5. Two areas non-reheat thermal PS

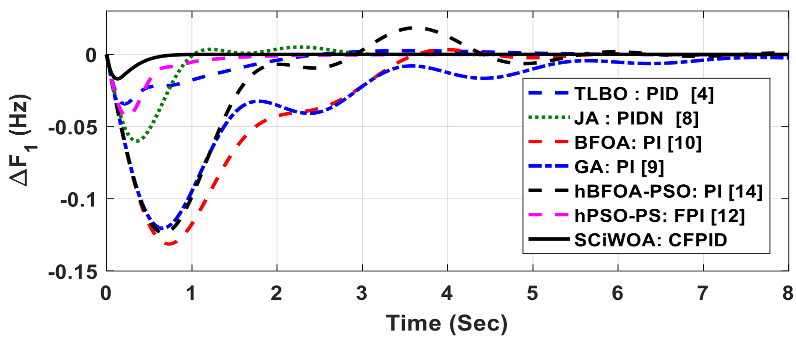

Figure 6. ΔF_1 at 5% of SLP for area-1: Two areas non-reheat PS

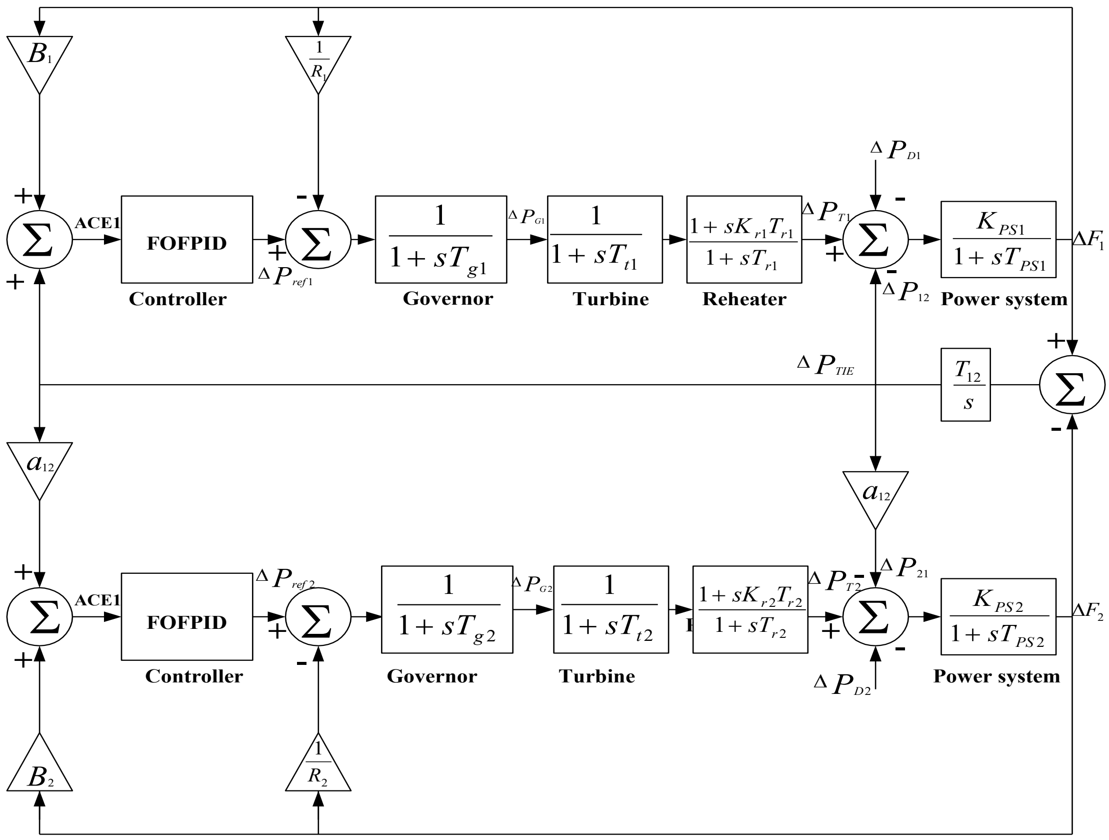

Figure 7. Two areas reheat thermal PS

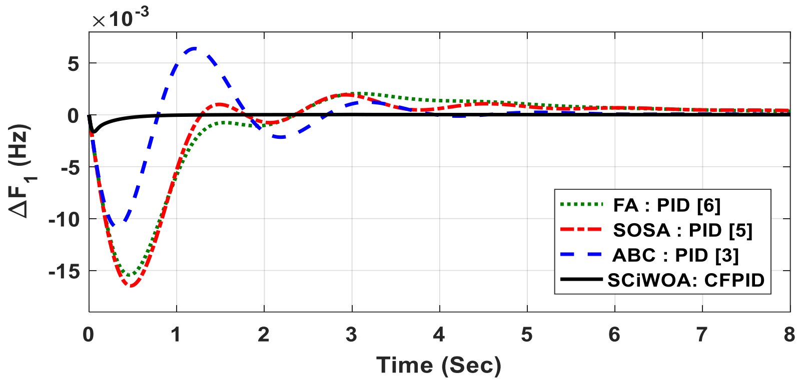

Figure 8. ΔF_1 at 1% of SLP for area-1: Two areas reheat PS

4. CONCLUSION

In this investigation, a sine cosine work embraced improved WOA (SCiWOA) strategy was introduced for taking care of streamlining issues. Recommended SCiWOA strategy utilizes sine and cosine capacities for 'c' and scaling-factors which are used to move the movement size in the location reviving the formula of search authorities in the cycle. The proposed SCiWOA procedure is utilized to tune a combined fuzzy PID (CFPID) structure for recurrence control of brilliant framework congaing sun-powered, photovoltaic, wind and flywheel, battery similarly as plug-in electric vehicles. The proposed SCiWOA based CFPID controller over hPSO-PS adjusted FPI controller, hBFOA-PSO adjusted PI controller, GA adjusted PI controller, BFOA adjusted PI controller, JA adjusted PIDN controller and TLBO adjusted PID controller are demonstrated for the two-area non-reheat thermal power system. The next proposed SCiWOA based CFPID controller over ABC adjusted PID controller, SOSA adjusted PID controller and

FA adjusted PID controller are demonstrated for two areas reheat thermal power system. It is seen that SCiWOA adjusted CFPID controller is better than conventional PID controllers and maintains frequency stability under many uncertain frameworks. For the two regions non-warm framework, the rate decrease in ISE, IAE, ITSE, and ITAE with stated SCiWOA tuned CFPID contrasted with the best-distributed after-effects of hPSO-PS adjusted fuzzy PI are discovered to be 86.27%, 92.93%, 75.74%, and 86.73% respectively. For the two territory reheat PS, the rate decrease in ISE, IAE, ITSE, and ITAE with stated SCiWOA adjusted CFPID contrasted with the best-distributed consequences of ABC tuned PID are discovered to be 98.7%, 92.84%, 93.74%, and 95.54% individually.

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