Optimal Frequency Control in Interconnected Power System using Grey Wolf Optimization and Firefly Algorithms

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Abstract. *The inclusion of renewable energy sources (RES) into electricity grids raises numerous concerns. Designing interconnected power networks with minimal frequency variations and tie-line power fluctuations has become a top priority. Due to the intermittent nature of renewable energy sources, power generator fluctuations depend on environmental circumstances. This work presents a unique hybrid Fractional Order Controller (FOC) adapted for load frequency control in interconnected power networks. The novel controller combines the advantages of two commonly used fractional-order proportional-integral-derivative (FOPID) and tilt-integral-derivative (TID) controllers. Grey Wolf Optimization (GWO) and Firefly Algorithm (FFA) techniques are used to determine the optimal controller parameters. Optimization of the different controller parameters of a three-area interconnected power system incorporating different types of renewable energy sources and loads is considered. The simulation results obtained were compared by incorporating FOPID, FOPIDTID with GWO, and FOPID-TID with FFA. It is observed that FOPID-TID with FFA gives better performance in terms of high mitigation of frequency fluctuations, tie-line power deviation, increased robustness and enhanced system stability over a wide range of parameters, uncertainty, and fast transient response.*

Keywords:

fractional order proportional-integral–derivative (FOPID), tilt integral derivative controller (TID), grey wolf optimization (GWO), firefly algorithm (FFA), load frequency control (LFC)

Nomenclature:

$G_{sp}(s)$: Transfer function of photovoltaic output
K_s , K_T : Gain of the photovoltaic cell
T_s, T_T : Time Constant of the photovoltaic cell
$G_{WTG}(s)$: Transfer function for the output of wind energy
K_{WTG}: Wind turbine module gain
T_{WTG}: Constant time period for wind module
$G_{DEG}(s)$: Transfer function for diesel engine generator
K_{DEG}: Gain for diesel engine generator
T_{DEG}: Time Constant for diesel engine generator
$G_{BESS}(s)$:Transfer function for battery energy storage system
K_{BESS}:Gain for battery energy storage system
T_{BESS}: Time Constant for battery energy storage system
T: Temperature constant
Δf : Frequency error
ΔPt: Switch in output power of turbine
ΔXg: Switch in position of governor
ΔP_T : Change in the generation of net power
ΔP_D: Alteration in the demand for load
ΔP_S : Error regulating net power
ΔP_{DG} : Alteration in production of DG power
ΔP_{PV}: Alteration in output power of PV
ΔP_W : Alteration in power of wind
ΔP_{BESS} : Alteration power of battery bank
Tt : The turbine's time constant
Tg: Time constant of the governor
Tp : Time constants of power system
Kp: Power system gain value
R: Coefficient of speed regulation
${}_0^C D_t^{-\alpha}$: Fractional operator
$\gamma(\alpha)$: Euler's gamma value

1. Introduction

The trend in power generation in recent decades is far away from large central power plants that uses synchronous generators for low-power and low-distributed generation (DG). A shift is highly required to include renewable energy sources in the energy grid [1]. The present energy sector is driving this transformation, which is hampered by issues with energy pricing, electrical system safety, the environment, and power quality [2]. The power networks are tailored to meet the specific needs of consumers, such as increased power supply reliability, improved voltage curves and a connection to the bus through an electrical equipment such as a voltage source inverter (VSI) [3-6]. Because of the employment of semiconductors, inverters exhibit nonlinear current-voltage characteristics [7]. These components provides a high switching frequency. As a result power quality is a major concern which should be taken care of in the system, notably while working in independent mode which relates to quality of voltage and frequency. In the isolated mode, load generation and demand imbalances cannot be corrected by load frequency control (LFC) [8-9]. That's why for managing electric parameters, utility companies typically employ classical controllers in combination with integral (I), proportional integral (PI), and proportional integral derivative (PID). The Ziegler and Nichols technique is used to compute the PID controller's gain for efficient operation. The dynamic properties of system load and generation, on the other hand, render this strategy inefficient for systems with substantial disturbances [10-12]. A fuzzy logic and artificial intelligence-based method is used to change the controller gain value in order to tune the parameters of controllers. Although the standard neural network controller and the fuzzy logic design both include adaptive features to deal with the dynamic system's nonlinearity, both performance depends on network design [13]. The implementation of a traditional load frequency controller requires a significant amount of time with prior knowledge. Therefore, the evolution of computational intelligence group methodology is employed to attain the enhanced performance of a traditional controller [14].

To improve the reliability of classic controllers during uncertainties, the researchers have developed FOPID (Fractional Order PID) where the controllers moved from integral order to fractional order. This uses fraction terms in integral PID control terms and PID control terms in derivative PID terms (in integral) [15]. Due to the additional adjustment of the integral differential operator parameters, fractional PID controllers are suitable for a broader operating range, stabilizes setting quickly, offer better responsiveness and reliability. In load frequency control applications, the FOPID controller outperforms the integral order PID controller in terms of system responsiveness. The frequency variation of the system can be reduced to a minimum by the use of an FOPID controller. The parameters of the controller are optimized through intelligent methodologies. The integral time absolute error [16] can be used to adjust the frequency deviation.

There are a few different ways to figure out the most cost-effective solution for load frequency control of the system, multi-objective optimized dispatch [17], period-based multi objective optimized scheduling [18], GWO (Grey Wolf Optimization) [19], PSO (Particle Swarm Optimization), and more. The generation of solar and wind power is highly variable and can be significantly be affected by weather conditions [20]. Consequently, an optimization approach that is based on a static structure and mathematical model will be rendered invalid when the above criteria are altered. Multi-agent consistency has become increasingly popular in recent years to increase the flexibility of agent networks that manage switching topology [21-22].
Secondary control method is a control strategy based on infinite time convergence [23]. Secondary control technique used is also a control strategy based upon infinite time convergence, i.e. it is essential for improvement of the system's convergence rate when changing the system [24-28]. When compared to other well-known meta-heuristic approaches, GWO is able to deliver extremely competitive results for a variety of benchmark functions [29-32]. The capacity of GWO for exploration and exploitation is however limited. Local optimum solutions are easily generated, but computation time is poor [33-35]. In order to increase speed and accuracy, GWO is therefore enhanced in this research.

This work offers a modified FOPID and TID controller for controlling LFC in three-area linked power systems. Furthermore, the parameters of the suggested control are improved using Grey Wolf Optimisation (GWO) and the Fire Fly Algorithm. The findings were produced using the MATLAB Simulink platform.
The main contribution of this paper is

- Design of three area hybrid power system consisting of thermal unit, renewable energy sources and battery storage system through Matlab/Simulink environment.
- A cascade of FOPID and TID controller for controlling LFC in three-area linked power systems to minimize area control error.
- Efficacy of cascade FOPID-TID controller has proven in comparison individual FOPID and TID controller through numerous simulations.
- Furthermore, the parameters of the suggested controller are improved using Grey Wolf Optimisation (GWO), Fire Fly Algorithm (FFA) and Particle Swarm Optimization (PSO).

- The supremacy of FFA based cascade controller has proven in comparison with GWO based and PSO based cascade controller.
- Finally the robustness of cascade controller is compared with the single individual controller.

2. Modelling of Power System Components

In this contemplate work the power generation and energy storage system is connected to the local grid which has been used to generate and supply energy. Subsequently, the re-generation of various power sources, such as photovoltaic (PV), wind, DG, etc., is carried out using the hybrid framework's linearized model as shown in Fig. 1. To meet the load power requirements, the wind turbine, solar panels, and energy cell are connected to the generating bus by DC/ AC converters in the meantime. The energy cell and battery storage system are then connected via a transformer to the producing bus. To ensure that the primary frequency remains within a predetermined range, the BESS optimizes the power sharing between battery and fuel cell through the FOPID Controller.

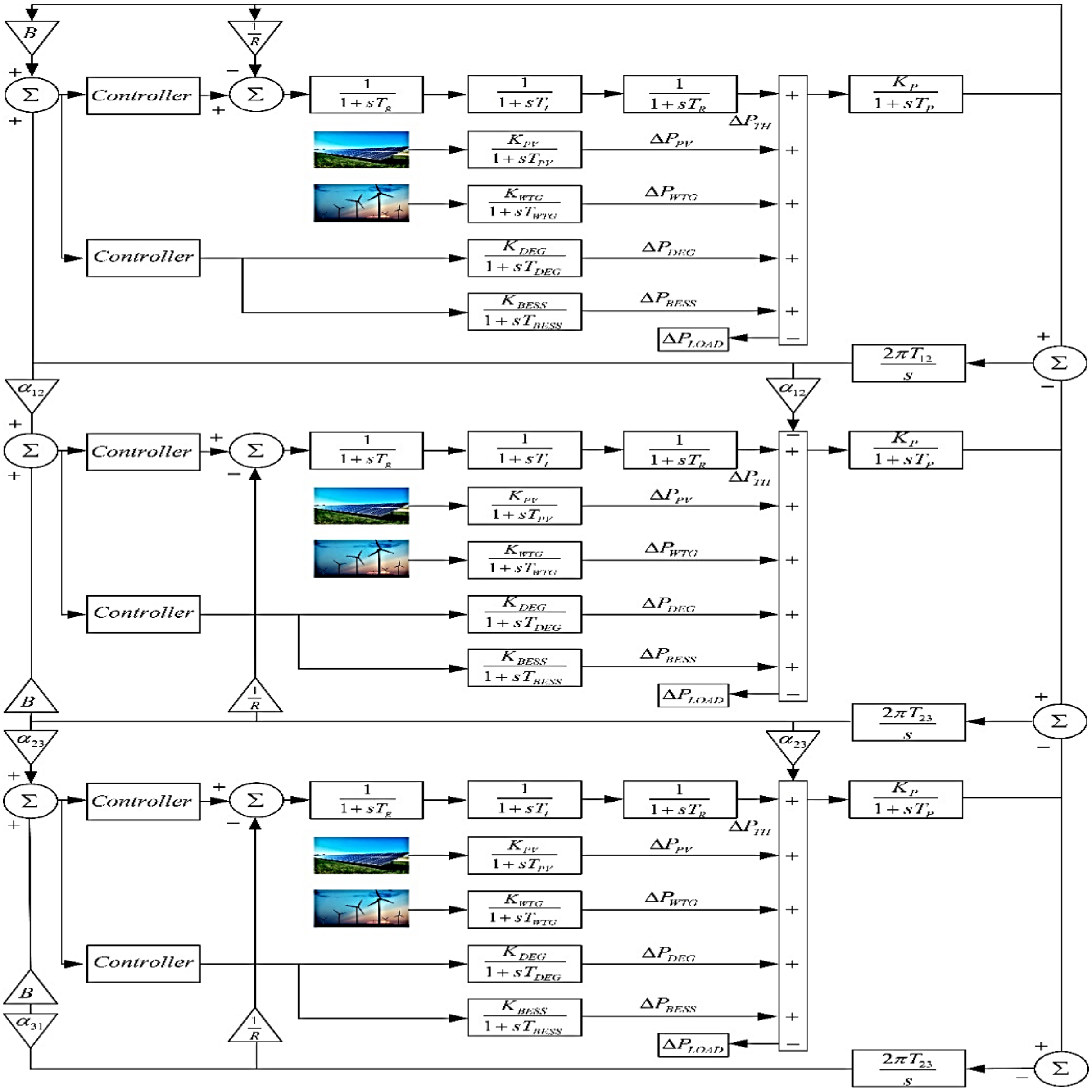

Fig.1 Equivalent linear model of the proposed three area system

A. Model of Solar Power System

Solar network, connectivity, and protection components make up the photovoltaic system. The matrix is made up of different solar cells. A parallel-connected power source and diode make up a solar cell. The light that strikes the battery has an impact on the current source's output. The transfer function-based linearized equation is defined as [13];

$$G_{sp}(s) = \frac{K_S}{1+sT_S}\frac{K_T}{1+sT_T} \quad (1)$$

B. Model of Wind power

Since wind power changes its power and wind speed in real time more quickly than other energy sources, connecting wind turbines will result in changes in grid frequency. In order to maintain wind balance at both high and low speeds, energy storage devices are also utilised. In this work, the energy conversion of wind speed is explained by linearizing the system with a first order delay function. A wind turbine's output power is expressed as a function of the specific wind speed at which the turbine is operating. The transfer function-based linearized equation for wind power output is defined as [14, 15];

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

C. Model of Diesel Engine Generator

Diesel generators harness the power of the internal combustion engine to convert fuel into mechanical power, which is then converted into electrical power by an electric generator. A diesel generator included within a MG attempts to provide enough compensation in the event of any output shortages or a power outage brought on by any technical issues. The DEG is capable of filling the power gap on its own and can lessen the power gap between suppliers and load demand. The transfer function-based linearized equation for diesel engine generator output is defined as [17]

$$G_{DEG}(s) = \frac{K_{DEG}}{1+sT_{DEG}} \quad (3)$$

D. Model of Battery Energy Storage System(BESS)

The fundamental concept is to electro-chemically transform electricity into a form that can be stored in a cell as electrolytes. The electrolytes in the cell interact with the electrodes during discharge, and a reversible process produces electrical current. To increase the stability of the power system, it offers more damping oscillations. This storage technology is more efficient due to its increased energy density and ease of initial access. The controller's signal excites the BESS, which is connected in the control loop. They serve the system as a source or load depending on the demand. It is expected that the power system's storage components will have rate limitations in order to operate in a non-linear zone. In addition, the rate limitation helps regulate the electro-mechanical characteristics of the elements and protects against mechanical shock caused by sudden frequency variations. The transfer function-based linearized equation for battery energy storage system output is defined as [18]

$$G_{BESS}(s) = \frac{K_{BESS}}{1+sT_{BESS}} \quad (4)$$

E. Model of frequency deviation(Δf)

The deviation in frequency Δf is represented as [19]:

$$\Delta f = \frac{K_{PS}}{1+T_{PS}}.\Delta P_S \quad (5)$$

Where the change in net power controlling error can be expressed as the difference between change in net power and change in load demand i.e.

$$\Delta P_S = \Delta P_T - \Delta P_D \quad (6)$$

$$\Delta P_T = \Delta P_{PV} + \Delta P_{WTG} + \Delta P_{DG} + \Delta P_{SMES} + \Delta P_{BESS} \quad (7)$$

3. Problem Formulation

The frequency deviation (Δf) of the MG can be decreased by altering the load frequency using a PID controller. Because Δf is a relatively small number, the frequency deviation of the MG is optimized to the desired level by squaring it. It entails altering the MG's frequency while minimizing the target function in order to enhance overall system performance. According to Fig. 1, the system's state vector $x(t)$ is represented [30, 31] as,

$$x\,(t) = [\Delta f(\,t) + \Delta P_t(t\,) + \Delta P_s(t\,) + \Delta X_g(t)] \quad (8)$$

Mathematically load frequency model can be represented [30, 31] as;

$$\ddot{x}(t) = A_x\,(t) + B\,_u(t) + F(\,\Delta P_p\,(t) + \Delta P_d(t)) \quad (9)$$

Optimized PID controller configurations are designed to respond effectively and consistently after each load variation. The parameters optimized according to objective functions such as overshoot, settling time and error calculation. Percentage error is the difference in percentage of the reference and the output voltage. Error integration function ITAE (Integral time absolute error) is considered for the error calculation as ITAE uses absolute error accumulation by time. The error is being minimized by using ITAE. The ITAE equation is represented [32] as:

$$ITAE = \int_0^t (|\Delta f_1|) + (|\Delta f_2| + |\Delta f_3|)) + (|\Delta P_{12}|).tdt + (|\Delta P_{23}|).tdt + (|\Delta P_{31}|).tdt \quad (10)$$

4. Controller Design

A. TID controller

TID controller is used in LFC for improving the frequency response of three area hybrid power system. In this case, the proportional component of PID is replaced with a tilted component having a transfer function$S^{-1/n}$. This formation results close approximation to optimal transfer function hence providing improved feedback loop. The design of TID controller is shown in Fig.3 which consists of three tuning parameters (K_p, K_i and K_D). The transfer function for this controller is:

$$G_{cs}(s) = K_P S^{-1/n} + K_I S^{-1} + K_D S \quad (11)$$

TID controllers have simpler tuning, better rejection ratio and smaller effects of plant parameter variation as compared to conventional PID controller.

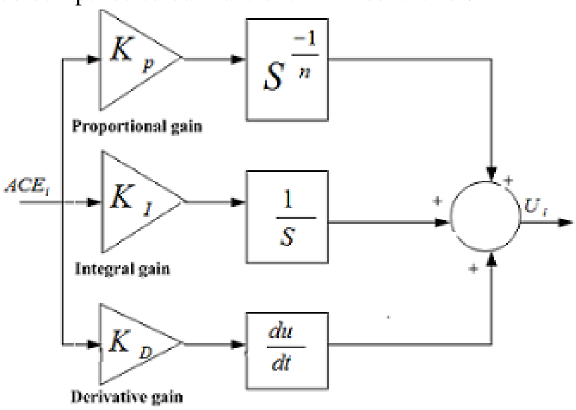

Fig. 2 Structure of TID controller

B. FOPID Controller

Fractional calculation is widely used in control systems. The controller uses fractional differentiation, and integral. Podlubny's FOPID offers more flexibility in terms of the gain phase properties and is more robust when the gain changes. Fractional controller is an extension of PID controller. In this article, the optimization of the controller's settings is carried out to meet specific requirements. Fig. 4 describes the typical structure of FOPID controller from which the control loop arrangement transfer function equation can be described, which is written [23] as:

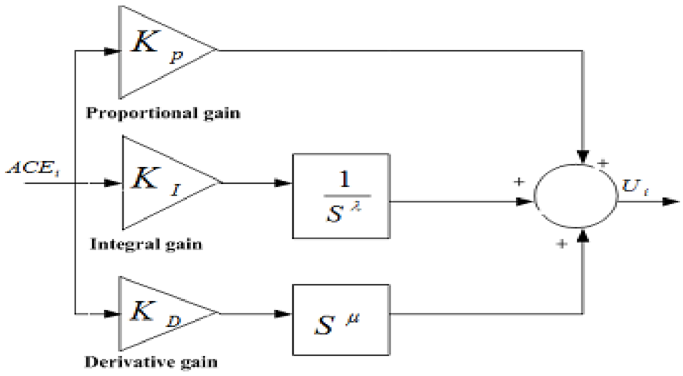

Fig. 3 FOPID Controller structure

$${}_0^cD_t^{-\alpha} f(t) = \frac{1}{\gamma(\alpha)} \int_c^t (t-\tau)^{\alpha-1} f(\tau) d\tau \quad (12)$$

Where ${}_0^cD_t^{\alpha}$ is the fractional operator$n-1 \le \alpha \le n$, n is an integer and $\gamma(\alpha)$ is the Euler's gamma function.

$$G_c(s) = K_p + K_i/S^{\lambda} + K_d S^{\mu} \quad (13)$$

The FOPID controller is seen schematically in Fig 3. Five tuning parameters are included in this structure: three controller gains(K_p, K_i, K_d) and two fractional order Integral-differential operators (λ, μ). This controller structure may be used to build a traditional PID controller for λ=1andμ=1.

5. Solution Methodology

A. Grey wolf algorithm

GWO is a revolutionary meta-heuristic algorithm that simulates the social hierarchy and hunting behavior of grey wolves. Grey wolves in the wild generally live in packs and have a rigid social order. Another important swarm behavior of grey wolves is group hunting. In nature, grey wolves hunt in three stages: tracking with approaching the prey, surrounding with disturbing the prey, and attacking the victim. Each solution in such a model is viewed as a wolf, also known as a search agent. In a D-dimensional search space, all search agents conduct searches. The fitness function determines whether the present location is favorable or not based on the fitness value of each search agent.

Alpha (α), beta (β), delta (δ), and omega (ω) make up the four tiers of the social hierarchy of grey wolves, from high to low. The wolves are compelled to continuously yield to the other powerful wolves. Although they are in the same hierarchy as alpha and beta wolves, delta wolves are the omega leader. Hence we can mathematically represent the social hierarchy of grey wolves. In addition to wolves' social structure, the act of collective hunting serves as a crucial basis for the creation of mathematical models. In order to comprehend how GWO may be able to solve optimization issues, several points need to be stated.

- The proposed social hierarchy is designed to ensure that GWO maintains the most successful solutions obtained during the iteration process. The encircling mechanism is intended to create a circular environment around the solutions, which can be expanded to a larger size, similar to a hyper-space.
- Candidate solutions can have hyper spheres with a variety of random assisted by random parameters A and C.
- The suggested hunting technique enables potential solutions to find the likely location of the target.
- The adaptive values of *a* and *A ensures* exploration and exploitation.
- The ability to adjust parameters *a* and *A* enables GWO to seamlessly transition between exploration and utilization.
- As A decreases, exploration ($|A|\geq 1$) takes up half of iterations and exploitation takes up the other half ($|A|<1$).
- The GWO requires only two adjustments (*a* and *C*).

Grey wolves' circling habit may be described mathematically [24] as:

$$\vec{D} = \left|\vec{C}\,\vec{X_P}(t) - \vec{X}\right| \quad (14)$$

The updated position vector is expressed as follows:

$$\vec{X}(t+1) = \left|\vec{X_P}(t) - \vec{A}.\vec{D}\right| \quad (15)$$

$$\vec{A} = 2\vec{ar_1} - \vec{A}$$

$$\vec{C} = 2\vec{r_2}$$

Where t is the current iteration and $\vec{A}$ and $\vec{C}$ are coefficient vectors, $\vec{X_P}$ is the prey's location vector, and $\vec{X}$ denotes the position vector of a grey wolf.

B. *Firefly Algorithm(FFA)*

A meta-heuristic optimization method called the firefly algorithm was physiologically motivated by the activity of fireflies. The fireflies used in the firefly algorithm are nature-based interacting agents [10]. The algorithm is developed using the following guidelines:

- Because fireflies are unisex, they are attracted to one another.
- The attractiveness of the firefly has a direct relationship to their attraction. As a result, fireflies are drawn to and migrate in response to increased levels of brightness.
- The distance has an inverse relationship with light level. The value of the objective function is represented by the brightness level.
- The typical values used in this study are as per following: β_0= 1, γ = 1 and α = 0.8.

The attractiveness β of the fireflies as a function of distance(r) is defined [25] as:

$$\beta(r) = \beta_0 e^{-\gamma r^2} \quad (16)$$

The distance between any two different fireflies $S_i$and S_j is expressed as Euclidean distance by the base firefly algorithm [35] as:

$$r_{ij} = \|S_i - S_j\| = \sqrt{\sum_{k=1}^{=n}(S_{ik} - S_{Jk})^2} \quad (17)$$

6. Simulation Results and Discussions

The system model in this work includes renewable energy sources like solar and wind. The load is linked across a battery supply and a diesel generator. The input of the system receives the feedback. In MATLAB/Simulink, the hybrid system is created. The frequency deviation and tie line power for step response and random load are researched in order to examine the controller performance. The performance of the FOPID-TID controller is analysed and the GWO and FFA are used to optimize the controller parameters.

A. *Case Study*

The load demand is being changed randomly. A frequency mismatch develops, leading to the model being simulated and graphs being created for study. Again the obtained results are compared by considering the effect of solar temperature and irradiance in order to obtain the minimum objective function.

a. *Random load*

Here, area 1, area 2, and area 3 are all subjected to random load disturbance. For improved frequency management, this system makes use of a modified FOPID-TID controller. To compare these controller performances, numerous simulation results are employed. It is evident from the simulation results that the FOPID-TID controller using the FFA approach performs better dynamically. By contrasting the system's impacts with the GWO and FFA techniques, a comparative study was carried out. The performance comparison of the FOPID-TID controller with GWO and FFA is shown in Table 2. Once more, the system with FOPID-TID controller has its ITAE computed using the objective function. Table 1 makes it evident that the percentage error when utilising the FOPID-TID controller with the FFA approach is 1.004%, which is less than when utilising the FOPID-TID with GWO and FOPID, which are 2.96% and 1.41%, respectively. Thus, FOPID-TID-FFA produces the system's optimal outcome.

The graphical results of frequency deviation obtained by applying random load disturbance to area 1 is shown in Fig 4 from which it is pretty vigilant that FFA optimized FOPID controller gives foremost outcome than GWO optimized FOPID controller and FOPID. For area 1 the frequency deviation obtained by using FOPID controller is 4.71 whereas for GWO optimised FOPID-TID and FFA optimised FOPID-TID it is 3.94 and **2.68** respectively.

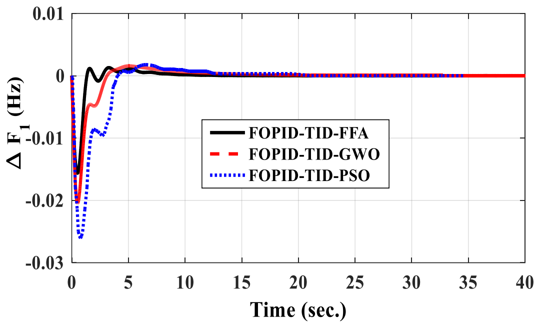

Fig. 4 Frequency variation for area 1

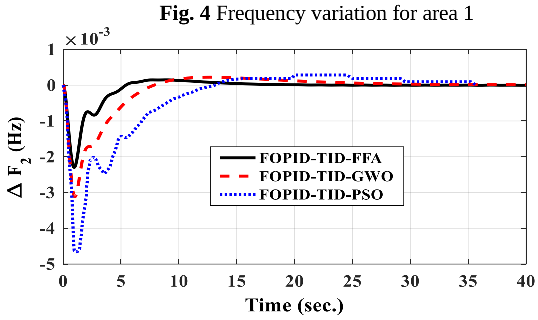

Fig. 5 Frequency variation for area 2

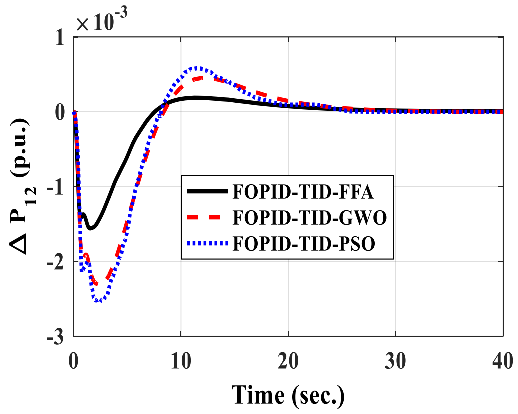

Fig. 6 Tie line power variation T_{12}

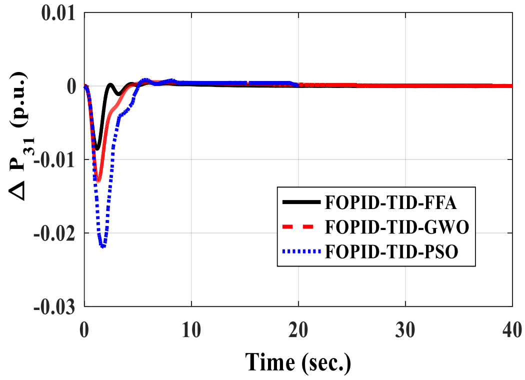

Fig. 7 Tie line power variation T_{31}

Table 1 Performance comparison for random variation

Controller/ Controller with optimization	Settling time in sec	Overshoot in pu	Percentage Error	Δf_1 in Hz	Δf_2 in Hz	Δf_3 in Hz	ΔP_{12} in pu	ΔP_{23} in pu	ΔP_{31} in pu
FOPID-TID-PSO	2.96	1.91	3.01	4.71	1.08	2.26	1.61	2.44	2.98
FOPID-TID-GWO	1.84	1.52	1.49	3.94	0.98	2.04	1.24	2.23	1.99
FOPID-TID-FFA	1.44	1.13	1.06	2.68	0.46	1.66	1.08	1.96	1.08

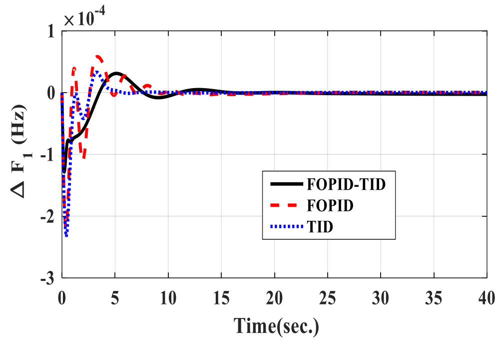

Fig. 8 Area 1 frequency variation

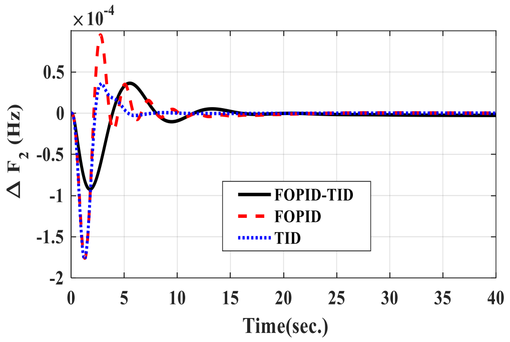

Fig. 11 Area 2 frequency variation

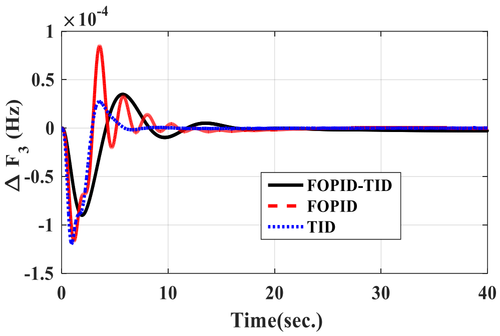

Fig. 9 Area 3 frequency variation

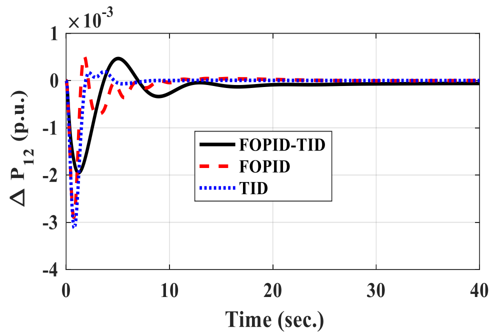

Fig.12 Tie line power variation T_{12}

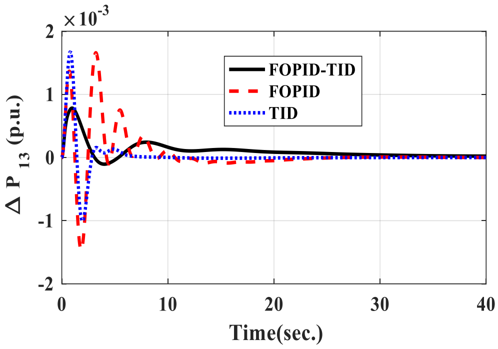

Fig. 10 Tie line power variation T_{13}

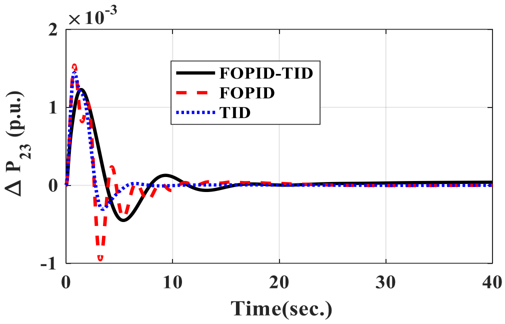

Fig.13 Tie line power variation T_{23}

Table 2 Performance assessment of controllers optimized by FFA algorithm

Performances	Controller	Δf_1 *in Hz*	Δf_2 *in Hz*	Δf_3 *in Hz*	ΔP_{12} *in pu*	ΔP_{23} *in pu*	ΔP_{31} *in pu*
Undershoot (U_{sh}) in pu	FOPID-TID	-0.1527	-0.9211	-0.8426	-0.4421	-0.0014	-0.0025
	FOPID	-0.1985	-1.5424	-1.0437	-1.9523	-1.8145	-0.0512
	TID	-0.2149	-1.7222	-1.2431	-2.8962	-2.2021	-0.0978
Overshoot (O_{sh}) in pu	FOPID-TID	0.0215	0.0001	0.0000	0.0057	0.2001	0.2078
	FOPID	0.0462	0.0043	0.0024	0.2541	0.8183	0.7900
	TID	0.0653	0.0213	0.0427	0.3014	1.2451	1.3157

The graphical results of frequency deviation obtained by applying random load disturbance to area 2 is shown in Fig. 5 from which it is pretty vigilant that FFA optimized FOPID controller gives foremost outcome than GWO optimized FOPID controller and FOPID. For area 2 the frequency deviation obtained by using FOPID controller is 1.08 whereas for GWO optimised FOPID-TID and FFA optimised FOPID-TID it is 0.98 and **0.46** respectively.

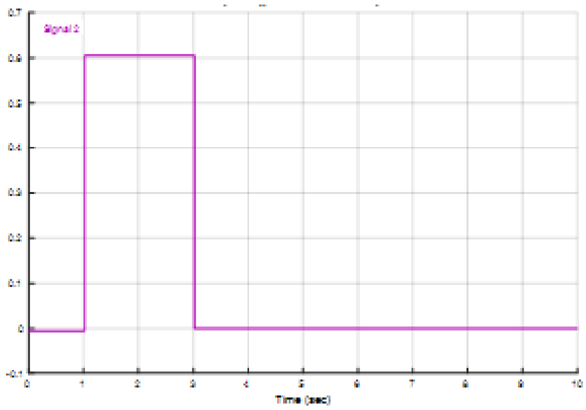

Fig. 14 Graphical representation of random load variation

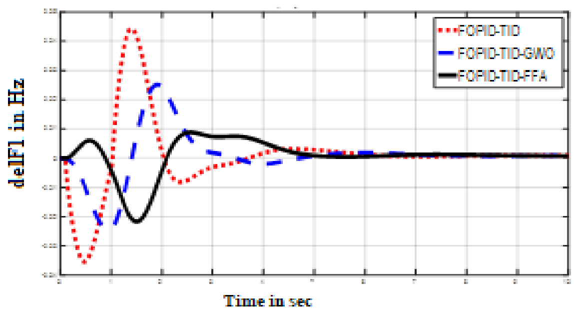

Fig. 15 Frequency deviation of Area 1

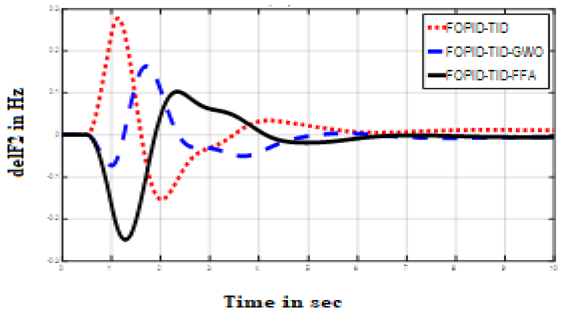

Fig. 16 Frequency deviation of Area 2

The graphical results of frequency deviation obtained by applying random load disturbance to area 3 is shown in Fig.6 from which it is pretty vigilant that FFA optimized FOPID controller gives foremost outcome than GWO optimized FOPID controller and FOPID. For area 3 the frequency deviation obtained by using FOPID controller is 2.26 whereas for GWO optimised FOPID-TID and FFA optimised FOPID-TID it is 2.04 and **1.66** respectively.

The graphical results of tie line power deviation P_{12} obtained by applying random load disturbance is shown in Fig.7 from which it is pretty vigilant that firefly optimized FOPID controller gives foremost outcome than GWO optimized FOPID controller and FOPID. The tie-line power deviation P12 obtained by using FOPID controller is 1.61 whereas for GWO optimised FOPID-TID and FFA optimised FOPID-TID it is 1.24 and **1.08** respectively.

The graphical results of tie line power deviation P_{23} obtained by applying random load disturbance is shown in Fig.8 from which it is pretty vigilant that firefly optimized FOPID controller gives foremost outcome than GWO optimized FOPID controller and FOPID. The tie-line power deviation P_{23} obtained by using FOPID controller is 2.44 whereas for GWO optimised FOPID-TID and FFA optimised FOPID-TID it is 2.23 and **1.96** respectively.

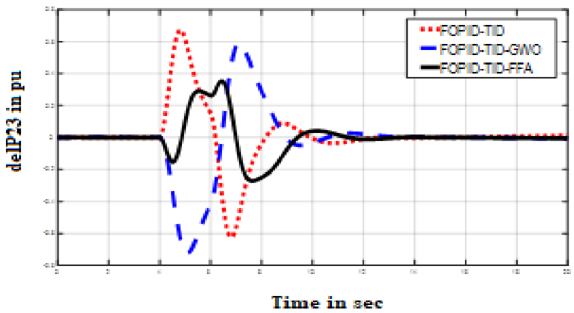

Fig. 17 Tie line Power deviation P_{23}

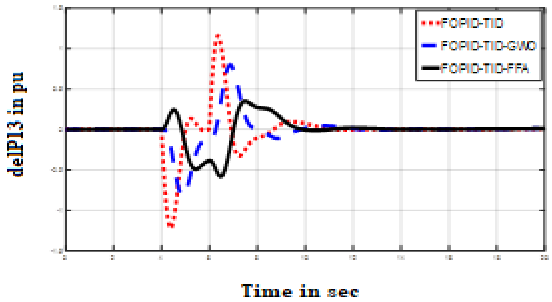

Fig. 18 Tie line Power deviation P_{31}

The graphical results of tie line power deviation P_{31} obtained by applying random load disturbance is shown in Fig.9 from which it is pretty vigilant that firefly optimized FOPID controller gives foremost outcome than GWO optimized FOPID controller and FOPID. The tie-line power deviation P_{31} obtained by using FOPID controller is 2.98 whereas for GWO optimised FOPID-TID and FFA optimised FOPID-TID it is 1.99 and **1.08** respectively.

Table 3 Values of parameters in the block diagram

Parameter	Values
T_{BESS}	0.1
K_{WTG}	1
K_{BESS}	1
T_g	0.08
T_t	0.4
R	3
T_{WTG}	1.5

The parametric values of the block diagram such as T_{BESS}, K_{WTG}, K_{BESS}, T_g, T_t, R and T_{WTG} are represented in Table 3.

7. Conclusion

In this paper, frequency control in three area interconnected system is presented for improved performance and stability. The system comprises of distributed generations such as solar PV, Wind, DEG and BESS where the impact of uncertainty in the output power is being studied for frequency stability analysis. The variations in the load and intermittency of the renewables like PV and wind are considered as disturbances for designing the frequency controller. A conventional FOPID controller is developed for frequency control in the system. Further, optimization techniques such as GWO and FFA are proposed for optimal tuning of the parameters such as settling time, peak overshoot and percentage error of modified FOPID-TID controller. It is observed that FFA optimized FOPID-TID provides superior frequency control than GWO optimized FOPID-TID and conventional FOPID controllers under various operational situations.

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