Load frequency control of three area power system using optimal tuning of fractional order proportional integral derivative controller with multi objective grey wolf optimization

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B. Prakash Ayyappan*, Dr. R. Kanimozhi**

*Assistant Professor, Department of Electrical and Electronics Engineering, V.S.B Engineering College, Karur – 639 111, Tamilnadu, India.

**Assistant Professor, Department of Electrical and Electronics Engineering, University College of Engineering, Anna University BIT Campus, Tiruchirappalli - 620024, Tamilnadu, India.

*Email: prakashayyappan78@gmail.com; Corresponding Author.

ABSTRACT

In an interconnected electrical power system, load frequency control is a most important ancillary service essential for maintaining the electrical system reliability at an adequate level. A Multi-Objective Grey Wolf Optimization (MOGWO) algorithm is introduced for maintaining a balance among exploitation and exploration stages and provides the best value of fitness. During the occurrence of the disturbance in the output of the system the optimization is implemented with Firefly Algorithm (FFA) and MOGWO which is tuned carefully and also the parameters are compared with three-area three-source model of the power system. A Fractional Order Proportional and Derivative (FOPID) controller is a PID controller whose derivative and integral orders are fractional rather than integer. The FOPID controller supports the better stability of the designed model with controlled deviation in frequency and grid tie line power deviations. In this proposed research work, optimal tuning of parameters of various controllers like PI, PID and FOPID in the power system is to regulate frequency in a multi-area multi-source model which is designed with the hydro-thermal-gas generation units. The output performance of the model designed is estimated from simulation results by means of MATLAB-SIMULINK tool. The dynamic performances of the system are studied with 1% or 2% step load perturbation in one Area. Sensitivity analysis reveals that the FFA and MOGWO optimized FOPID controller parameters obtained at nominal condition of loading, size and position of disturbance and system parameters are robust and need not be reset with wide changes in system.The simulation results show the effectiveness of FOPID controller in the presence and the absence of the FF and MOGWO algorithms considered and in that MOGWO algorithm is executed appropriately and it has improved the performance based on metrics such as overshoot, undershoot, and settling time.

Key words: Load Frequency Control, Fractional Order Proportional Integral Derivative Controllers, Fire Fly Algorithm, Multi Objective Grey Wolf Optimization algorithms.

INTRODUCTION

Load frequency control is of great importance in electric power system operation to damp frequency and voltage oscillations originating from load variations or sudden changes in load demands (B.Prakash Ayyappan and R.Kanimozhi 2021). In an interconnected power system that consists of several control areas, as if the system parameter varies then the grid tie-line power will change and the frequency deviations will occur (Sabah Daniar, Mojtaba Shiroei and Tahmat Aazami 2016). In a power system with huge interconnections, transient conflicts promote disturbances inside the system (S.Selvakumaran, V.Rajasekaran and R. Karthigaivel 2014). These instabilities result in imbalance among load and the generation that affected the general working of the power system (Beyda Tasar, Hasan Giiler and mehmet Ozdemir 2015). To maintain such balance, the governing system of prime mover assists in controlling the frequency of the system and later schedules the grid tie-line flow (A.Fakharian, R.Rahmani 2016). LFC executes an essential part in power system procedure to resolve complexities occurring because of variations in load. Also, LFC comprises a system that governs speed as the initial controller equalizes with power generated by means of load demand. The frequency tuning of system estimable is carried out by the secondary type of control loop (K.Vijayakumar, T.Manigandan 2016). The LFC holds the responsibility to maintain frequency in the desired range even after the disturbances. Similarly, the exchange of power among various control areas is also controlled by methods comprising of LFC

(S.Anbarasi and S.Muralidharan 2016). In recent years, several approaches to control have been offered in power systems for better control of load frequency. The secondary type of frequency control that is only known to be LFC or AGC is responsible to regulate power system frequency and comprises of two major goals (Van Van Huynh, Hoang-Duy Vo, Bach Hoang Dinh, Thanh-Phuong Tran and Minh Hoang Quang Tran 2018). They are frequency maintenance in the desired level and to control power exchange by main grid tie-lines among several control areas. The major part of the third control level is to re-dispatch units for generation and additional reserve even after disturbances occur in server (P.N.Topno and S.Chanana 2018). With increased penetration level of the energy sources in the power system and changes in load demand, which mainly improve the uncertainties in the system and hence variations in frequency are determined. For such an increase in the fluctuation of active power, apart from the demand of stochasticity, power system frequency will be of high oscillations (P.Praveena, H.S.Shubhanka, V.Neha, P.Prasath and G.S.Veda 2019). Hence, upcoming power systems require highly robust and also optimal methods of LFC to handle these issues. A lot of control methods have been recommended for LFC with interconnected power systems A.Nayak and M.K.Maharana 2019). Among the methods roposed, PI controller is most commonly used for industrial purposes. PI has constant gain, which is designed with desired conditions to operate and usage is also simple, while possibilities of frequency oscillations are high (B.Prakash Ayyappan and R.Kanimozhi 2021). The designing is such that this controller shows the least dynamic performance against parameter changes in the system and conditions of non-linearity like rate constraint generation. PID controller has a static controller for parameters, which has active power system as well as the pattern differs with respect to expansion (Amit Kumar and Sathans Subag 2017). Thus, the fixed parametric PI or PID controller is forced to offer optimal performances. To resolve these challenging uncertain and dynamic circumstances, fuzzy logic is suggested by several researchers. PID controllers combine components like proportional, integral and the derivative to attain standard equations. Despite the simple and wide usage this controller type has its own disadvantages (K.S.Rajesh and S.S.Dash 2019). A Fractional Order Proportional and Derivative Controller (FOPID) for LFC can be designed similar to PID, but the difference as FOPID controllers has five parameters to be determined so that it has two additional degrees of freedom to better tune dynamic features than that of PID (Ruchika Lamba, Sunil Kumar and Swati Sondhi 2019). The foremost task of LFC is to keep the frequency constant against the randomly varying active power loads, which are also referred to as unknown external disturbance. Another task of the LFC is to regulate the grid tie-line power exchange error (H.H.Alhelou, M.E.Hamedani-Goishan, R.Zamani, E.Heydarian-Forushani and P.Siano 2018). The insisted importance of knowledge regarding multi-area power systems the proposed approach based on tuning of PID controllers through simulation. The proposed control system had ability to influence positivity in complete dynamic response and provided improved controllability in spite of sudden system modifications, when compared to control system with classical decouple approach. PID-fuzzy-PID hybrid controller tuned by MGWO technique was suggested control method is found to be robust during random load application; the recommended controller is tested in a multi-source interconnected system and proves the flexibility in load frequency control (Amit Kumar and Sathans Suhag 2017).

POWER SYSTEM MODEL FOR LFC

The model of load frequency response in a single-area power system with interconnected sources of energy comprises of thermal-hydro-gas. In all the three areas of a power system, the generation units include thermal-hydro-gas sources in figure 1. The three-area model comprises of a system with a diesel generator, governor, turbine, and the re-heater. Power system with several control areas is connected via grid tie-lines with each other to enhance the efficiency and consistency that makes the power system complex and non-linear in nature.

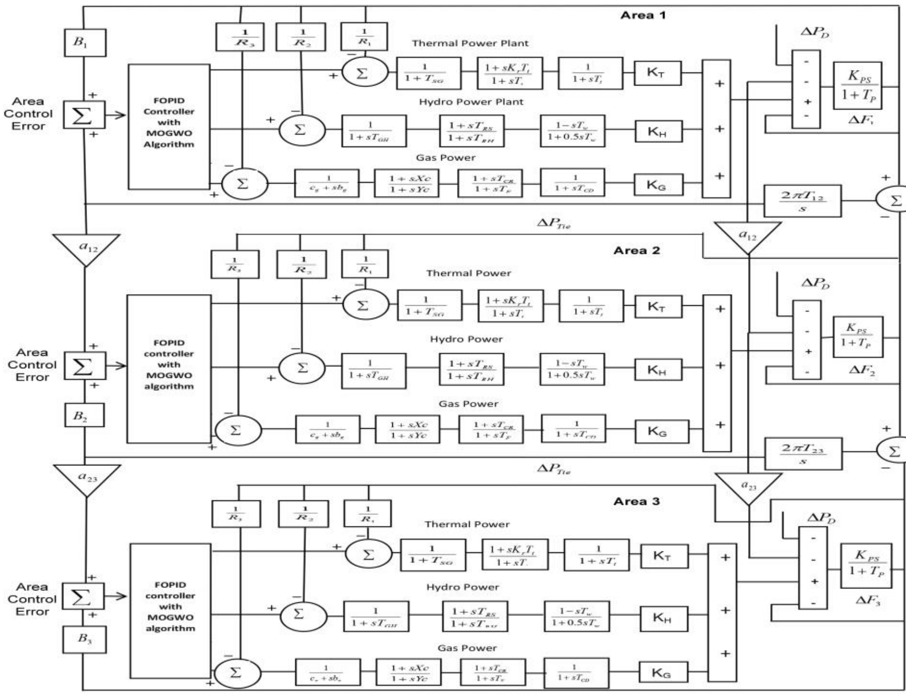

Figure 1 Power System Model of Three-Area with Multi-Source System

A power system that has many areas interconnected needs to operate at its respective minimal frequency for better synchronization. Power control and exchanging with various generating units for maintaining frequency and power flow of grid tie-lines among several areas of control in its minimal values are a major objective of controlling the load frequency. The FOPID controller easily attains iso-damping property offering better performance outcomes of the system with higher-order. Also, it is more stable and robust than PID. Further, this controller can achieve enhanced responses for the system with maximum phase. The FOPID controller consists of only two additional parameters, namely (λ) the order of the integral part and (μ) the order of the derivative part, while K_P, K_I, and K_D are the controllers as in a conventional PID controller. The concept of fractional order deals with the differential equations using fractional calculus. FOPID controller has the transfer function which can be represented in the eqn. (1);

$$U(s) = K_P + \frac{K_I}{S^{\lambda}} + K_D S^{\mu} \quad (1)$$

where, K_P, K_I, and K_D are gain parameters of PID, λ and μ *are* the orders of integrator and differentiator respectively.

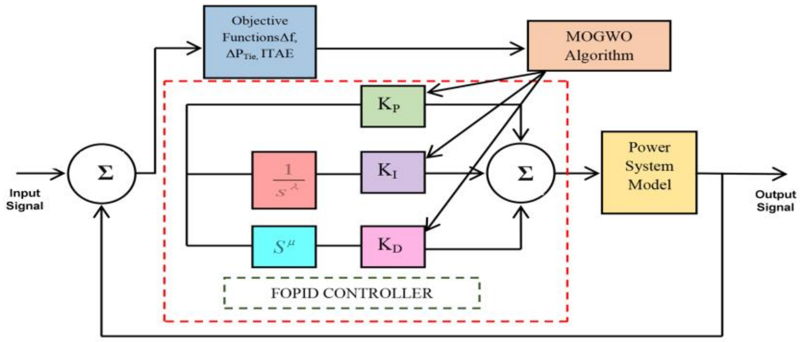

Figure 2 System Model using FOPID and MOGWO Algorithm

Better results can be expected by fine tuning all the five parameters of the FOPID control. The criteria of performances normally taken in control design include Integral of Time multiplied Absolute Error (ITAE), and Integral of Squared Error (ISE). Among the three types of controllers considered, the proposed FOPID controller with MOGWO shown in figure 2 gives better results than the other two controllers. The calculation of the objective function of the ITAE is performed by the eqn. (2);

$$J = ITAE \int_0^t \left(|\Delta f_1(t)| + |\Delta f_2(t)| + |\Delta f_3(t)| + |\Delta P_{Tie1}| + |\Delta P_{Tie2}|\right).dt \tag{2}$$

Similarly, for the other objective function of ISE values were determined based on the algorithms considered in this work. The estimation of the ISE objective function is done using the following eqn. (3)

$$J = ISE \int_0^t |e^2(t)|.dt \tag{3}$$

In the equation above, Δf_1, Δf_2, and Δf_3 are the frequency deviations of system; ΔP_{Tie} is incremental alteration in power grid tie-line and 't' indicates simulation time range.

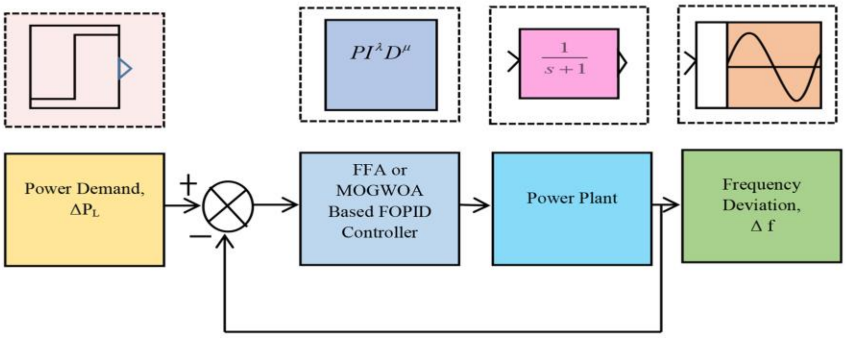

Figure 3 General Overview of Firefly and MOGWO Algorithm

These metaheuristic algorithms are often nature-inspired, and now a days, they are among the most widely used algorithms for optimization. The performance of FOPID based multi objective grey wolf optimization algorithms is compared with FFA-FOPID and the proposed algorithm provides better results. Figure 3 represents the general overview of the algorithm. The multi-objective grey wolf optimization algorithm has similar features as well as comparative advantages just like the optimization algorithm of GWO.

SIMULATION RESULTS

This section provides the performance results of the proposed multiple area and multiple source models with the modified algorithm of GWO and FFA. The power system model is developed using the simulation software environment of MATLAB/SIMULINK tool. Both the objective functions of ITAE and ISE are simulated in the block of simulink and the data for controller is obtained. The dynamic performances of the system are studied with 2% step load perturbation in one Area. Due to the load perturbation the frequency and tie-line power changes are measured and the stability of the system is recovered by the proposed controller. The performance metrics mainly focus on the settling time, peak overshoot, and undershoot.

Table 1 Settling time of controllers in MAMS without optimization algorithm

Controller	Settling Time in seconds				
	Δf_1	Δf_2	Δf_3	ΔP_{tie1}	ΔP_{tie2}
PI	7.39	7.24	6.85	6.5	7.1
PID	6.45	6.5	5.86	4.85	5.2
FOPID	5.3	3.8	4.6	4.2	4.7

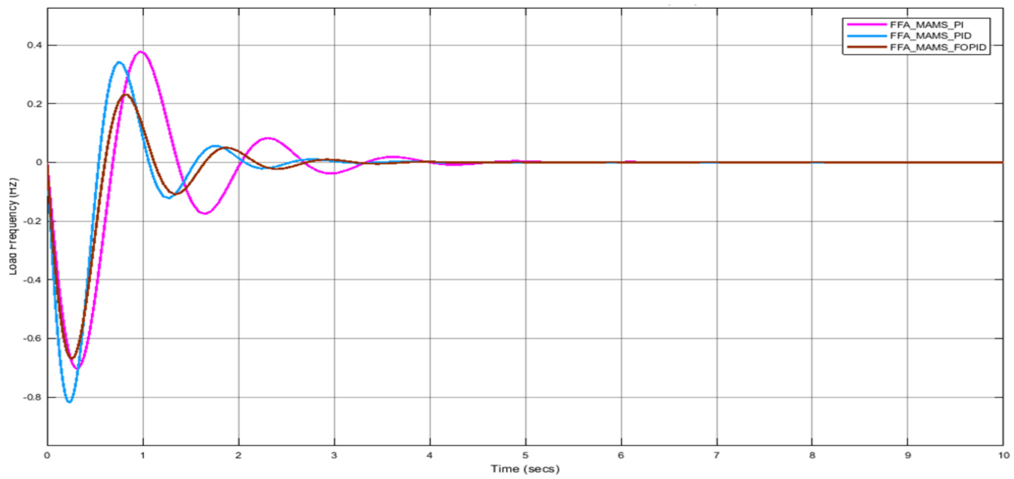

Figure 4 Multi-area Multi-source using FFA

Similarly, time of settling is attained by FOPID in less time than the other controllers. The above Table.1 results were obtained in multi area multi source system without optimization with the load variation of 2% in power system are given. The power system with multi-area and multiple sources was simulated with the implementation of FFA algorithm. In this, performance variations were better than those of in single-area power system.

Table 2 Settling time of controllers in MAMS with FFA

Controller	Settling Time in seconds				
	Δf_1	Δf_2	Δf_3	ΔP_{tie1}	ΔP_{tie2}
PI_FFA	5.3	6.2	4.35	5.2	6.3
PID_FFA	3.8	3.62	3.5	3.5	5.3
FOPID_FFA	4.5	4.3	3.4	3.2	5.6

The offered controller FOPID exhibited reduced settling time among the three controllers considered. Figure 4 gives a graphical view of the controllers with comparison with algorithm of FFA applied and the results are shown in Table.2. Results from simulation explain the different outputs acquired for multiple area and also multiple sources in the model system. Overall performance of FOPID gave better results than PI and PID controllers as shown in figure 5.

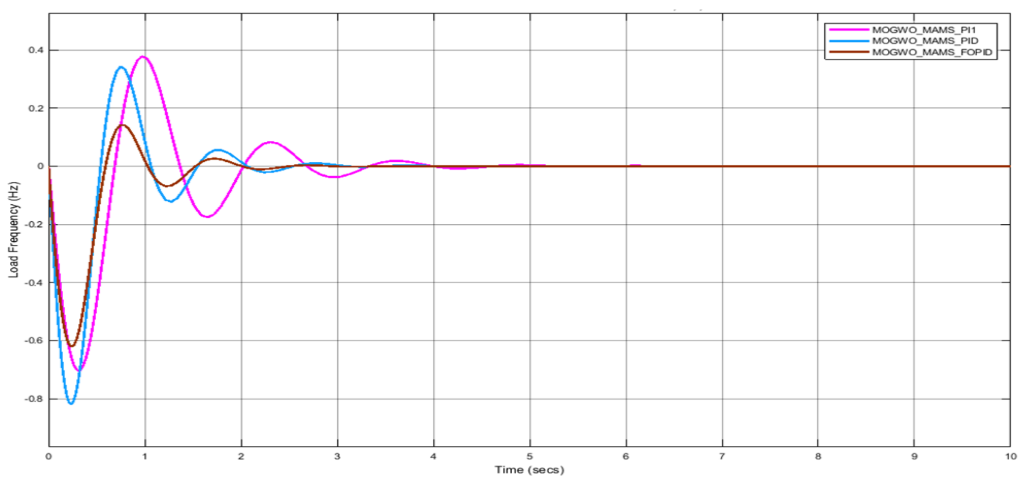

Figure 5 Multi-area Multi-source using MOGWO

From Table.3, the settling time of the proposed FOPID based MOGWO algorithm is substantially shorter than that of other controllers.

Table 3 Settling time of controllers in MAMS with MOGWO

Controller	Settling Time in seconds				
	Δf_1	Δf_2	Δf_3	ΔP_{tie1}	ΔP_{tie2}
PI_MOGWO	6.1	5.8	3.9	4.9	6.1
PID_MOGWO	6.2	6.42	3.57	4.05	5.8
FOPID_MOGWO	3.2	2.8	3.3	2.8	3.2

The performance result showed that the change of outputs obtained from the simulation were better for the FOPID controller, while the other two displayed performances quite less than

FOPID. The incremental changes in the frequency and grid tie-line power values of controllers with and without FFA as well as MOGWO algorithm are shown in Table.4. From this Table, the deviations in individual area frequencies Δf_1, Δf_2, Δf_3 were obtained**.** The grid tie-line power alterations such as ΔP_{tie1}, ΔP_{tie2} increase based on the type of controller used along with the algorithm implemented. The PI, PID, and the FOPID controllers have gain values with respect to the number of areas and the sources considered.

Table 4 Deviations in frequency and tie-line power in MAMS power system

Controller	Δf_1	Δf_2	Δf_3	ΔP_{tie1}	ΔP_{tie2}
PI	-0.1004	-0.0246	-0.0021	-0.0737	-0.0267
PID	-0.1159	-0.0109	0.0086	-0.1136	-0.0023
FOPID	-0.1159	-0.0109	0.0086	-0.1112	0.0113
PI_FFA	-0.0221	-0.1347	-0.0179	0.1304	-0.1526
PID_FFA	-0.0253	-0.1056	-0.0457	0.126	-0.1513
FOPID_FFA	-0.0253	-0.1056	-0.0457	0.0589	-0.0859
PI_MOGWO	-0.005	0.0261	0.005	-0.0361	0.0311
PID_MOGWO	-0.0058	-0.0081	0.0453	-0.043	0.0372
FOPID_MOGWO	-0.0058	-0.0081	0.0453	0.0147	-0.0208

For the multiple area and the multiple sources designed for the power system model, the gains calculated are shown in Table.5.

Table 5 Gain of PI, PID, FOPID controllers with multi-area power system model

Controller	Thermal					Hydro					Gas				
	K_P	K_I	K_D	λ	μ	K_P	K_I	K_D	λ	μ	K_P	K_I	K_D	λ	μ
PI_A1	0.9	0.02	-	-	-	1.9	0.05	-	-	-	2.956	0.1895	-	-	-
PI_A2	1.109	1.1954	-	-	-	0.7545	1.0231	-	-	-	2.013	0.234	-	-	-
PI_A3	1.056	0.235	-	-	-	0.5512	0.9874	-	-	-	1.354	0.01	-	-	-
PID_A1	0.9	0.02	0.02	-	-	1.9	0.05	0.01	-	-	9.554	0.49	0.09	-	-
PID_A2	1.109	1.8597	1.2793	-	-	0.6524	1.6786	0.5736	-	-	1.1466	1.8503	0.3622	-	-
PID_A3	5.559	0.05	0.5461	-	-	2	0.06	0.02	-	-	1	0.03	0.01	-	-
Fopid_A1	0.9234	0.1624	0.0314	0.6	0.2	4.0026	2.0052	0.0541	0.6	0.3	0.2152	0.213	0.021	0.5	0.2
Fopid_A2	1.9234	0.1625	0.0354	0.5	0.2	-0.902	0.5235	-0.042	0.6	0.3	0.2152	0.213	0.021	0.5	0.2
Fopid_A3	1.023	0.0321	0.0123	0.3	0.2	0.201	0.0621	0.021	0.5	0.2	5.3254	0.7845	0.0395	0.5	0.2

From Table.6, it can be explained that among the three controllers, FOPID has better undershoot and overshoot values with reduced time for settling. When the algorithm of MOGWO was implemented along with controllers, improvements were observed and this enhanced the performance efficiency of the power system model designed in the work. In Table.7, the values represent the settling time of frequencies and grid tie line power between the areas with and without the implementation of FFA and MOGWO algorithms.

Table 6 Overshoot (O_{sh}), Undershoot (U_{sh}), settling time frequency (f_{Ts}) of controllers with algorithm for MAMS

Controller	Δf_1			Δf_2			Δf_3			ΔP_{tie1}			ΔP_{tie2}		
	F_{Ts}	O_{sh}	U_{sh}	F_{Ts}	O_{sh}	U_{sh}	F_{Ts}	O_{sh}	U_{sh}	F_{Ts}	O_{sh}	U_{sh}	F_{Ts}	O_{sh}	U_{sh}
PI	-0.091	0.022	-0.3535	-0.0826	0.3123	-0.3214	-0.0091	0.0407	-0.044	0.0092	0.601	-1.1157	-0.0916	0.3528	-0.3648
PI_FFA	-0.1429	-0.1398	-0.6023	-0.12	0.3231	-0.4025	-0.0225	0.041	-0.0521	-0.0012	0.4664	-1.0098	-0.143	0.3644	-0.4529
PI_ MOGWO	0.0124	-0.1942	0.0231	0.0249	0.3319	-0.2506	-0.0016	0.0424	-0.0346	-0.0012	0.3692	-0.8915	0.0269	0.3739	-0.2844
PID	-0.0815	-0.0476	-0.3169	-0.0655	0.2624	-0.1733	-0.0195	0.2745	-0.2615	0.0156	0.5435	-1.2964	-0.0822	0.5254	-0.3942
PID_ FFA	-0.1491	-0.1671	-0.2521	-0.0939	0.2682	-0.2202	-0.544	0.2648	-0.244	-0.0014	0.3877	-1.1989	-0.1487	0.5195	-0.4101
PID_ MOGWO	0.0279	-0.0342	-0.1797	-0.0117	0.27	-0.19	0.0397	0.3022	-0.1321	-0.0023	0.3868	-1.1673	0.0281	0.5582	-0.2774
FOPID	-0.0499	0.0402	-0.4014	-0.0018	0.0194	-0.0064	-0.0474	0.2515	-0.1285	0.0025	0.2259	-0.9825	-0.0458	0.2658	-0.1355
FOPID_ FFA	-0.0989	-0.1292	-0.2361	-0.0035	0.0196	-0.0083	-0.0945	0.2567	-0.0832	-0.0015	-0.0687	-0.7687	-0.0989	0.2708	-0.0877
FOPID_ MOGWO	-0.0358	-0.1136	-0.2331	-0.0023	0.0194	-0.0082	-0.0362	0.2299	-0.0594	0.0042	0.0057	-0.8198	-0.0375	0.3034	-0.0695

Table 7 Settling Time of various controllers with optimization algorithm in MAMS system

CONCLUSION AND DISCUSSION

In this paper, to control the frequency in load, various conventional controllers were considered for better tuning. However, the proposed FOPID controller provides much better response than the aforesaid controllers. This paper introduced a MOGWO based optimization, the stages of both exploitation and exploration were altered and high importance was given to fittest wolf in order to acquire the updated wolf position at the time of iteration. The proposed MOGWO and FF algorithms were compared for improving the optimization in the system. The dynamic performances of the system were studied with 2% step load perturbation in one Area. The metrics overshoot, undershoot, and settling times of frequency were analyzed with each simulation output. The FOPID controller with MOGWO implemented exhibited better performance results with reduced settling time of frequency. Also, the analysis based on grid tie-line of power according to deviation in frequency was carried out. ITAE and ISE obtained from the simulation results by the help of FFA and MOGWO algorithms with P, PI, PID and FOPID controllers. Overall comparison of the system provided with performance metrics for each controller with the algorithms implemented had higher efficiency of model designed. In future, this model of power system will be further extended to multiple energy sources and multiple areas with highly efficient optimization algorithms in restructured environment. The damping measures, such as the value of the ITAE index, the maximum peak value, peak time and settling time parameters are analysed with system oscillation mode and the relative FOPID with MOGWO gives better results. The use of Resilience Random Variance Reduction Technique and Revolutionary Energy Balance Control approaches will improve the stability of the multi-source interconnected system.

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