AGC Investigation in Wind-Thermal-Hydro-Diesel Power System with 1 Plus Fractional Order Integral Plus Derivative Controller

Jyoti Ranjan Padhi, Manoj Kumar Debnath, Sushobhan Pal, Sanjeeb Kumar kar

Abstract*: This research paper consists of the working of the 1 plus Fractional order integral plus derivative (1-FOI-D) controller implemented in a two area hybrid source interconnected system containing Wind-Thermal-Hydro-Diesel units. The Symbiotic Organisms Search (SOS) algorithm is used here for the optimization process for the 1-FOI-D controller's scaling factors, when the system is subjected to a step load perturbation (SLP) of about 1% in the first area. Here the performance of 1-FOI-D controller is compared with the traditional PID controllers tuned by the SOS optimization. Then the robustness of the introduced controller which is used in the two-area interconnected system is analyzed by applying the load perturbations in both the areas simultaneously. The results of individual controllers are compared on the basis of various time response evaluative factors such as peak overshoots, settling time and peak undershoot.

Index Terms*: Symbiotic Organisms Search Algorithm, Optimal Controller Design, Fractional order controller, Load Frequency Control.

I. INTRODUCTION

Now a days the power system control is one of the major issues, researchers/engineers are working upon. The factors prompting the power generation at suitable cost are operating efficiencies, transmission losses and above all the fuel cost. The problems arise when one is working on the interconnected power system. Changes in the real power affect the frequency of the power system while on the other hand the voltage magnitude is affected by the changes in the reactive power. What happens is that, whenever the load suddenly increases or decreases it affects the current drawing capacity of the system and also the rotational speed of the turbine caused because the electrical torque (Te) increases or decreases with respect to the mechanical torque (Ta) and this affects the accelerating torque (Ta). As the prime mover is connected directly to the turbine shaft so the output generation of the generators is getting affected and hence the system faces the problem of fluctuations in frequency, voltage and tie-line power [1]. Hence it's a challenge for the researchers to bring the whole system's frequency, output voltage and tie-line power in their desired state after the system is projected to some disturbances. The certain two control strategies for such problems are Load Frequency Control [2] and Automatic Voltage Regulator.

Earlier governor was solely responsible for maintaining system nominal frequency but this method of frequency control is found insufficient for the system. So in addition to primary governor control loop additional secondary control action is added in the system. The initial work on LFC was introduced by Cohn. Concordia et al. [3] and Cohn [4] elaborated the requirement of LFC in unified power system to achieve the regulation of frequency and interline power. Ohba and Satoshi together worked upon an advanced design of LFC by considering uncertainties in power systems [5]. Further the performance analysis of load frequency control was done by Gross and George [6]. Researcher, Chang worked upon the LFC by using fuzzy gains which schedule the PI controllers [7]. Shabani in collaboration with other researchers worked upon a robust PID controller for LFC optimized by imperialist competitive algorithm [8]. Later, Nimai Charan Patel worked upon an advance controller namely optimal PID controller with an extra derivative filter attached in a cascaded form for LFC of non-linear power system [9]. K.Akbari Moornani presented about the robustness in fractional PID based controller basically in closed loop systems [10]. Y Wang and R Zhou combined a robust control design technique using the riccati equation approach and an adaptive control for LFC using the system parametric uncertainties [11]. V.H.Haji and C.A.Monje worked upon the fractional order fuzzy-PID control optimized by PSO [12]. Seyedali Mirjalili proposed a new optimization algorithm called the Ant-Lion optimization [13]. M.R.Sathya researched and analysed on LFC of an interconnected power system containing PI controllers tuned by the Bat inspired algorithm [14]. Many other optimization technologies were also used further like optimal gravitational search algorithm [15], Bacteria foraging optimization algorithm for LFC [16], Symbiotic organisms search by Cheng [17] and further Tejani worked upon this for the structural design optimization

Revised Manuscript Received on May 30, 2019.

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[18].
This paper is written and focuses upon the working of Load Frequency Control in an interconnected system by using the controllers like

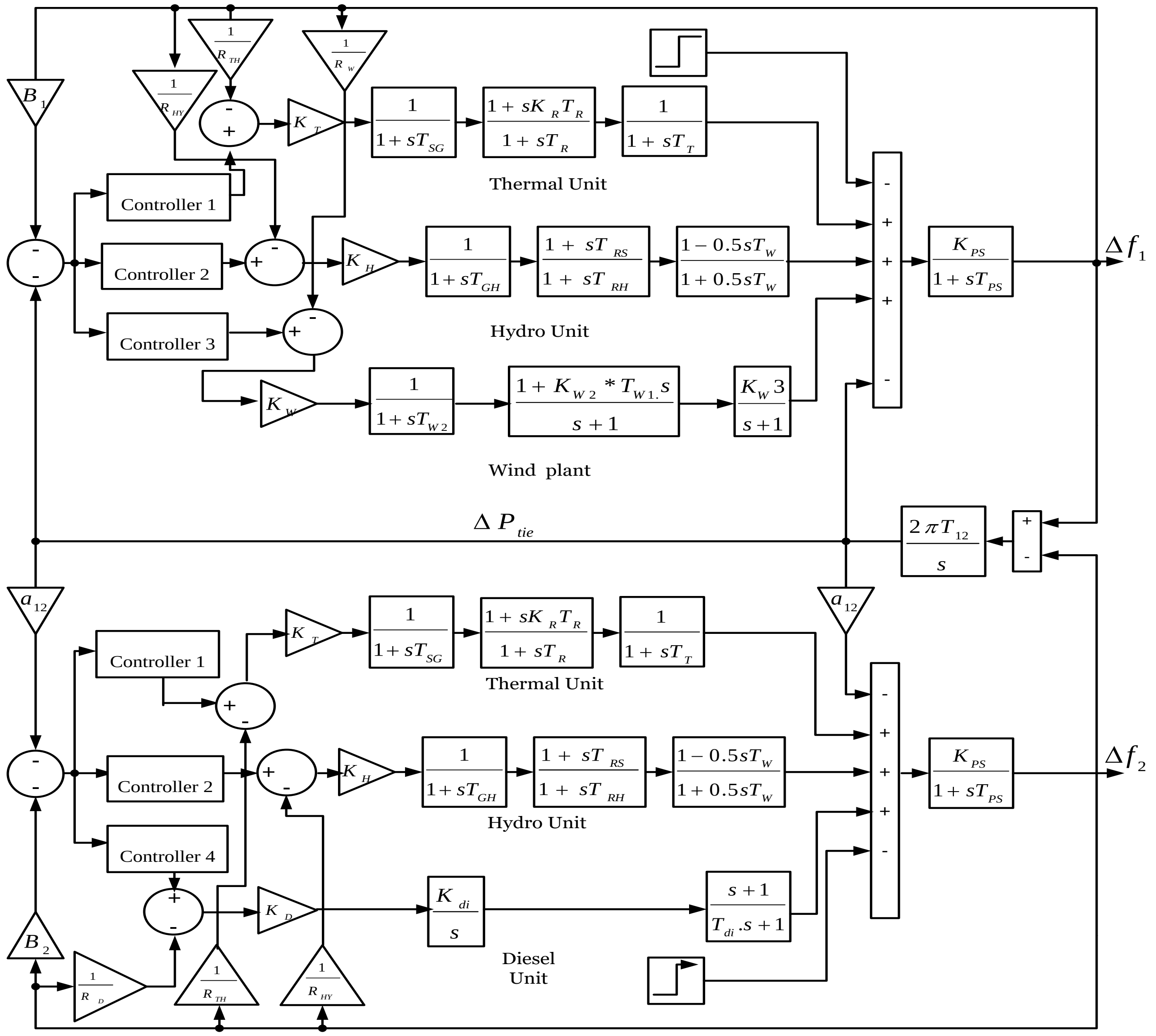

Fig.1. Wind-Thermal-Hydro-Diesel based interconnected system.

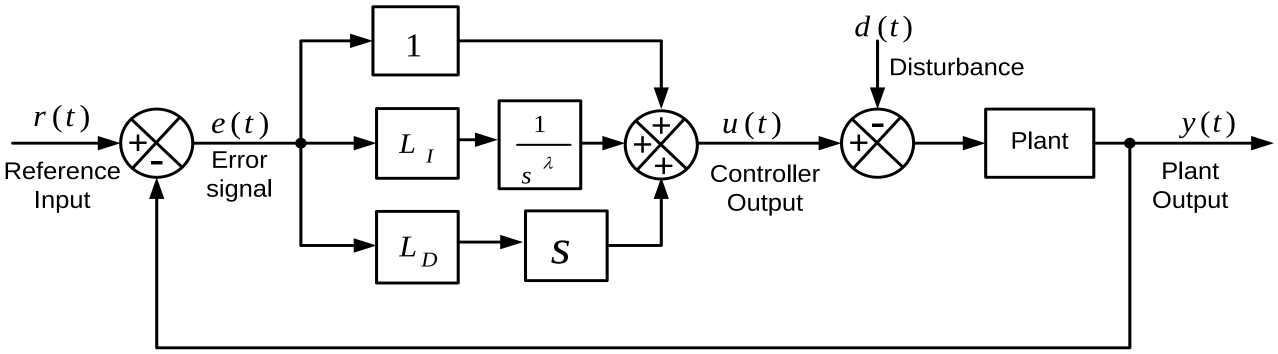

Fig.2. Framework of 1 plus Fractional order integral plus derivative (1-FOI-D) controller.

Proportional-Integral-Derivative controller, 1 plus Fractional order integral plus derivative (1-FOI-D) controller and then challenging these controller`s result with the new 1-FOI-D controller tuned by the Symbiotic Organisms Search (SOS) algorithm [19-20]. Here a two-area hybrid source interconnected system is considered having these above mentioned controllers and then the output results of all the controllers are analysed in the certain aspects like settling time, peak-overshoot and peak-undershoot. Then the robustness of the proposed controller is checked by changing the loading of both the control areas simultaneously.

II. EXAMINED MODEL

In the current research paper the system to be used is two-area hybrid source interconnected system. The first control area consists of Wind-Thermal-Hydro generating units and the other control area consists of Diesel-Thermal-Hydro generating units. All the generating units consist of distinct 1-FOI-D controller for the regulation of the frequency and the tie-line power flow. Here the mentioned Fig.1 picturizes the transfer-function model and the particular controller position of the proposed system. Then the area-1 of the system is put under the 1% SLP (step load perturbation) so as to check the transient response of the system. All the fluctuations in the frequency and tie-line power flow are being minimized by the help of the Area Control Errors (ACE) present in both the control areas.

III. MENTIONED METHOD

A.Skeleton of Controller

In this system 1 plus Fractional order integral plus derivative (1-FOI-D) controllers were used in each of the areas. This controller is used to challenge the outcomes of the other controller like PID controller. The overall design of the selected controller is demonstrated in Fig.2. Explaining further about the 1-FOI-D controller, it consists of basically one control loop. The projected controller consist of three gain factors namely L_I, L_D and λ. The existing traditional PID controller is modified to extract better control action. The controller is basically based on fractional calculus. Here the integral part is of fractional order (λ) having range [0,1]. The proportional part is kept 1 and the derivative part is of non-fractional order. The gain factors of the projected 1-FOI-D controllers are tuned by SOS technique.

B. Symbiotic Organism Search Algorithm

Cheng and Prayogo worked upon a new type of optimization algorithm and the efficiency of this algorithm was tested upon more than twenty mathematical problems and even in some of the engineering design problems [21]. This stochastic optimization algorithm is based on the organisms present in the nature and their propagation and survival in the ecosystem. Such strategies are known as the symbiotic interaction strategies. The term Symbiosis was derived from “living together” i.e. the meaning of a Greek word. This word represents that relationship which is in between two distinct species.

Talking about how this algorithm works, It is found that initially a population is formed called ecosystem. Here organisms in the search space are generated randomly. Every individual organism represents a single candidate solution for a particular problem. In this algorithm each organisms is assigned with a fitness value and this reflects the adaption degree. The three phases which represents the real-world biological interactions area called as parasitism phase, commensalism phase and mutualism phase. In parasitism phase one among the organisms is benefited whereas another one is brutally harmed. On the other hand, in commensalism phase one of the organisms is benefited and another one is not even affected. And in mutualism phase both the selected organisms are benefited. Here every organism goes through all the three phases and the process is repeated till the termination criterion is not met.

IV. RESULT AND ANALYSIS

This research paper consists of a system having 1-FOI-D controller attached to it optimized by the Symbiotic Organism Search algorithm. The PID controller’s results is being analyzed and challenged by the 1-FOI-D controller. The result is analyzed and judged on the basis of the output of each controller in the aspects like settling time, peak overshoot and peak undershoot. The model is simulated using the MATLAB Simulink software and it became possible after we got the values of the controller gains by using the SOS algorithm. We got such results by applying the system a certain amount of step load perturbation which is of around 1% i.e. 0.01 p.u applied in the first control area. The ITAE objective function (integral time absolute error) for the SOS tuning process is expressed in equation (1). Individual SOS optimized gains of the controller, like proportional gains, integral gains, derivative gains and also the values of lambda (λ) are given in Table 1. After that rest other values like settling time (Ts), peak overshoot (Osh) and peak undershoot (Ush) of Δf1 of area 1, Δf2 of area 2 and ΔPtie between the areas 1 and 2 are given in Table 2. The supporting figures of the results including all the controllers tuned by the SOS algorithm are mentioned below. Fig.3 here shows the results of Time (t) (in sec) vs Δf1 (in Hz), Fig.4 shows the result of Time (t) (in sec) vs Δf2 (in Hz) and Fig.5 shows the result of Time (t) (in sec) vs ΔPtie (in p.u.). After going through the results and observing each and every criterion it is found that the 1-FOI-D controller is a better controller as far as it is compared with other mentioned controller like PID controller.

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$$ITAE = \int \left(|\Delta f_1| + |\Delta f_2| + |\Delta P_{tie}| \right) t.dt \qquad (1)$$

Table 1. SOS tuned optimum controller parameters (PID/1-FOI-D).

PID controller			
	L_P	L_I	L_D
Controller 1	1.1000	1.0000	1.0000
Controller 2	0.9261	0.5442	0.1000
Controller 3	1.5453	1.0472	1.0000
Controller 4	0.1000	1.1554	1.4288
1-FOI-D controller			
	L_I	λ	L_D
Controller 1	1.0361	0.7909	2.0000
Controller 2	1.2895	0.7237	1.1483
Controller 3	0.0728	0.6628	1.3087
Controller 4	1.1887	0.1054	0.1547

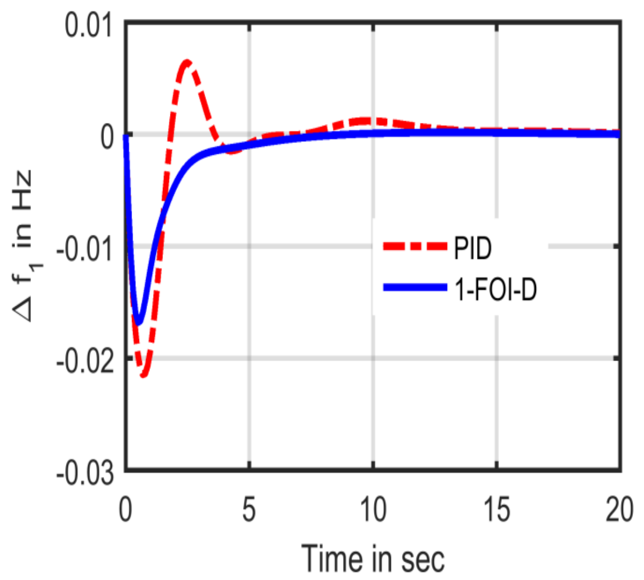

Fig.3. Swinging of frequency in area 1.

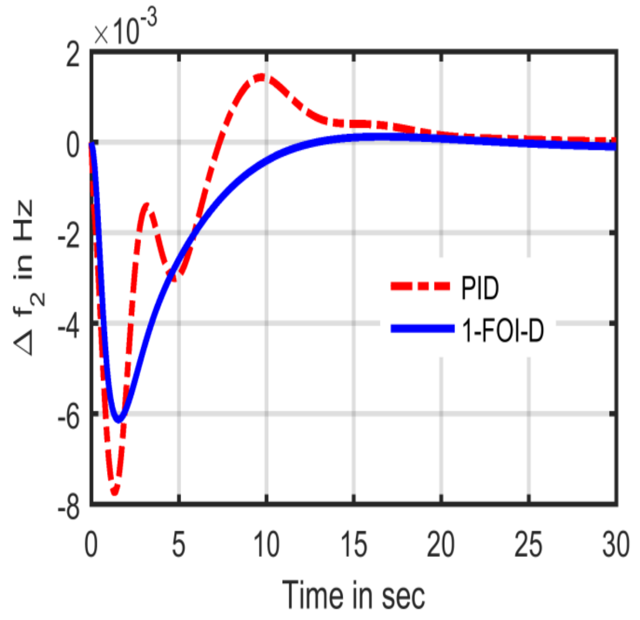

Fig.4. Swinging of frequency in area 2.

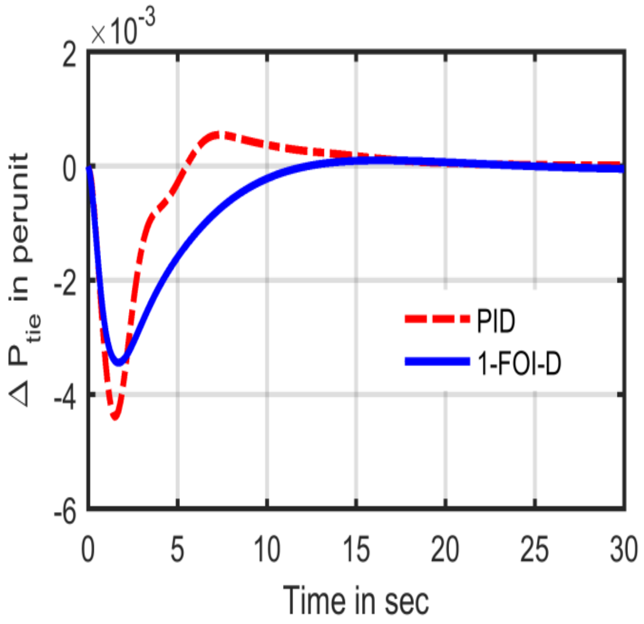

Fig.5. Swinging of tie-line power.

Table 2. Comparison of response indices of different methods.

Variations	**Performance Indices**	**PID**	**1-FOI-D**
Δf_1	Undershoot	-0.0214	-0.0168
	settling time	12.4900	6.3000
	$O_{sh} \times 10^{-3}$	6.4000	0.1795
Δf_2	Undershoot	-0.0077	-0.0061
	settling time	13.1900	9.6000
	$O_{sh} \times 10^{-3}$	1.4000	0.1270
ΔP_{tie}	Undershoot	-0.0044	-0.0034
	settling time	8.1900	7.3000
	$O_{sh} \times 10^{-3}$	0.5000	0.1027

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After thoroughly analyzing the controllers like PID and 1-FOI-D controller tuned by the optimization techniques like Symbiotic Organisms Search in the two area hybrid source interconnected system, the controller is tested for robustness. The robustness check of the 1-FOI-D controller was really very much necessary for this projected technique because this will show how much efficient this controller is to face some of the unlikely situations. The test is done by fluctuating the loading of both the control areas. A load perturbation of 1%(0.01 pu) is applied in both the control areas as a case study of robustness analysis. As expected we got the best results from the 1-FOI-D controller and it withstands some of the high transients in the system. The results of such tests are being mentioned below to show the proper outputs of the used controller and it proves that it is far better than the other compared controllers in every aspect, and cancels the disturbances from the signals. Thus this type of controllers helps us to bring back the steady state of the system after it is subjected to certain transients. Fig.6 shows the results of Time (t) (in sec) vs Δf1 (in Hz), Fig.7 shows the result of Time (t) (in sec) vs Δf2 (in Hz) and Fig.8 shows the result of Time (t) (in sec) vs ΔPtie (in p.u.). Fig.6-8 support the supremacy of the projected 1-FOI-D controller over PID controller.

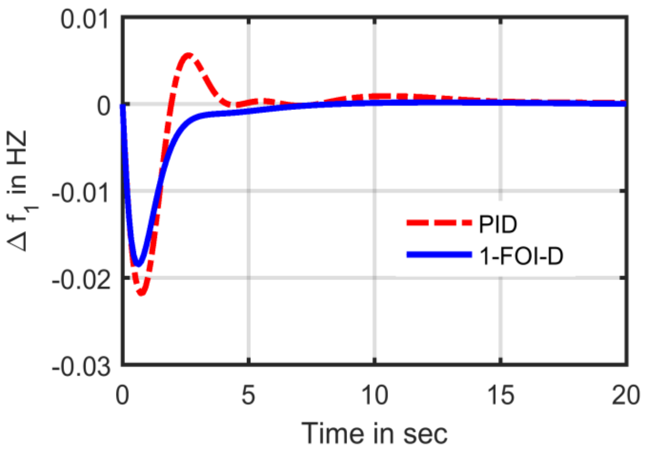

Fig.6. Swinging of frequency in area 1 due to load change in both the areas.

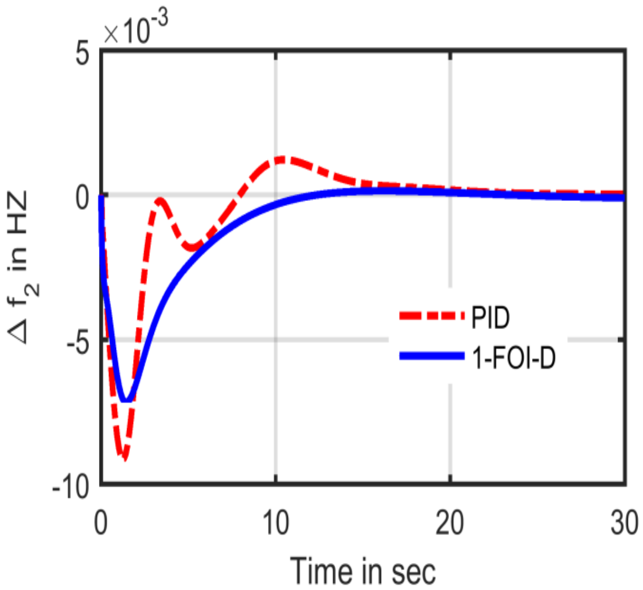

Fig.7. Swinging of frequency in area 2 due to load change in both the areas.

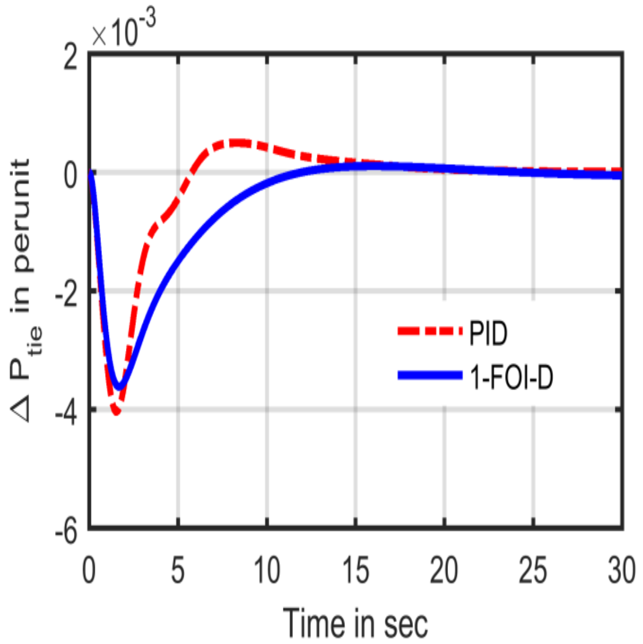

Fig.8. Swinging of tie-line power due to load change in both the areas.

V.CONCLUSION

This whole research paper was about the better working of the 1-FOI-D controller as far as it is compared with PID controller, all optimized by the Symbiotic Organisms Search algorithm. While analysing and working on a two area hybrid source interconnected system we conclude many of the things regarding the use of the controllers, the 1-FOI-D controller was found to be competent enough and more challenging over other controllers and gives the best results as expected. The controller was found to be working even better in its robustness testing and the results are accurate and very much satisfying with respect to others. Hence the supremacy of the 1-FOI-D controller which is optimized by Symbiotic Organisms

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Search algorithm, is proved over the PID controller.

REFERENCES

1. Saadat, Hadi. "Power system analysis.(2002)." 289-298.
2. Anderson, Paul M., and Aziz A. Fouad. Power system control and stability. John Wiley & Sons, 2008.
3. C. Concordia and L.K. Kirchmayer, 'Tie line power and frequency control of electric power systems,' Amer. Inst. Elect. Eng. Trans., Pt. II, Vol. 72, pp. 562 572, Jun. 1953.
4. N. Cohn, 'Some aspects of tie-line bias control on interconnected power systems,'Amer. Inst. Elect. Eng. Trans., Vol. 75, pp. 1415-1436, Feb. 1957.
5. Ohba, Satoshi, Haruka Ohnishi, and Shinichi Iwamoto. "An advanced LFC design considering parameter uncertainties in power systems." 2007 39th North American Power Symposium. IEEE, 2007.
6. Gross, George, and Jeong Woo Lee. "Analysis of load frequency control performance assessment criteria." IEEE Transactions on power systems 16.3 (2001): 520-525.
7. Chang, C. S., and Weihui Fu. "Area load frequency control using fuzzy gain scheduling of PI controllers." Electric Power Systems Research 42.2 (1997): 145-152.
8. Shabani, Hamed, Behrooz Vahidi, and Majid Ebrahimpour. "A robust PID controller based on imperialist competitive algorithm for load-frequency control of power systems." ISA transactions 52.1 (2013): 88-95.
9. Patel, Nimai Charan, et al. "Load frequency control of a non-linear power system with optimal PID controller with derivative filter." 2017 IEEE International Conference on Power, Control, Signals and Instrumentation Engineering (ICPCSI). IEEE, 2017.
10. Akbari Moornani K, Haeri M. Robustness in fractional proportional–integral–derivative-based closed-loop systems''. IET Control Theory Appl 2010;4(10):1933–44.
11. Wang Y, Zhou R, Wen C. New robust adaptive load-frequency control with system parametric uncertainties. IEE Proc Gener Transm Distrib 1994;141 (3):184–90.
12. V. H. Haji, C. A. Monje, "Fractional order fuzzy-PID control of a combined cycle power plant using Particle Swarm Optimization algorithm with an improved dynamic parameters selection," Appl. Soft Comput., vol. 58, pp. 256–264, 2017.
13. Mirjalili Seyedali. The ant lion optimizer. Adv Eng Softw 2015;83:80–98.
14. Sathya MR, Ansari M Mohamed Thameem. Load frequency control using Bat inspired algorithm based dual mode gain scheduling of PI controllers for interconnected power system. Int J Electr Power Energy Syst 2015;64:365–74.
15. Kumar Sahu Rabindra, Sidhartha Panda, Saroj Padhan. Optimal gravitational search algorithm for automatic generation control of interconnected power systems. Ain Shams Eng J 2014;5:721–33.
16. E. S. Ali, S. M. Abd-Elazim, "Bacteria foraging optimization algorithm based load frequency controller for interconnected power system", Int J Elect Power Energy Syst 2011;33:633–8.
17. Cheng, Min-Yuan, and Doddy Prayogo. "Symbiotic organisms search: a new metaheuristic optimization algorithm." Computers & Structures 139 (2014): 98-112.
18. Tejani, Ghanshyam G., Vimal J. Savsani, and Vivek K. Patel. "Adaptive symbiotic organisms search (SOS) algorithm for structural design optimization." Journal of Computational Design and Engineering 3.3 (2016): 226-249.
19. Sahu Rabindra Kumar, Panda Sidhartha, Sekhar GT Chandra. A novel hybrid PSO-PS optimized fuzzy PI controller for AGC in multi area interconnected power systems. Int J Electr Power Energy Syst 2015;64:880–93.
20. Alomoush Muwaffaq Irsheid. Load frequency control and automatic generation control using fractional-order controllers. Electr Eng 2010;91:357–68.
21. Cheng, Min-Yuan, and Doddy Prayogo. "Symbiotic organisms search: a new metaheuristic optimization algorithm." Computers & Structures 139 (2014): 98-112.

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