An Osprey Inspired Optimization-Based Planning of Controllers for Wind Energy Enriched Hybrid Power System

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ABSTRACT

Increasing public consciousness across the globe due to rapid growth in literacy rate, world leaders are forced to improve human development index (HDI). In order to improve HDI, a large amount of power unit is required for setting up devices for automation to reduce human effort in day-to-day life. To satisfy this increasing amount of energy demand, conventional power source is not sufficient and hence green and non-conventional energy sources are required. In this paper, a multi sources power with wind power as one of the sources is considered in 2-area system. 4-sources of energy are integrated in 2-area system with 2 sources of energy in each area. Hybrid power network is then subjected with disturbances to evaluate system performance with different controllers considered in the paper. The proposed work in this paper is processed and simulated using MATLAB/SIMULINK tool. In this paper, Osprey Inspired Optimization is proposed for efficient planning of controller for immediate damping of fluctuations in the power network due to sudden incoming disturbances or loading.

Keywords: *FOPID-OIO, ITMWAE, Frequency, Controller, Generation Control Challenges.*

1. INTRODUCTION

Conventional power plants uses fossil fuels for energy extraction and hence emitting a lots of harmful gases which is very harmful for all living beings on the earth and hence technology must be innovated to utilize green energy in surplus amount to reduce number of units generating from conventional power plant. In this paper, wind energy is considered as one of the sources to be integrated in the power network. Wind energy is enormous, green and freely available across the globe and hence it should be utilized in abundant amount to curb the generation of power from conventional power plant. In the current work, wind power is integrated as one of the sources of power in test system. Wind power modelling is briefly described by authors in [1]. The transfer function of wind power plant describing its dynamic behaviour is realized by eq.(1).

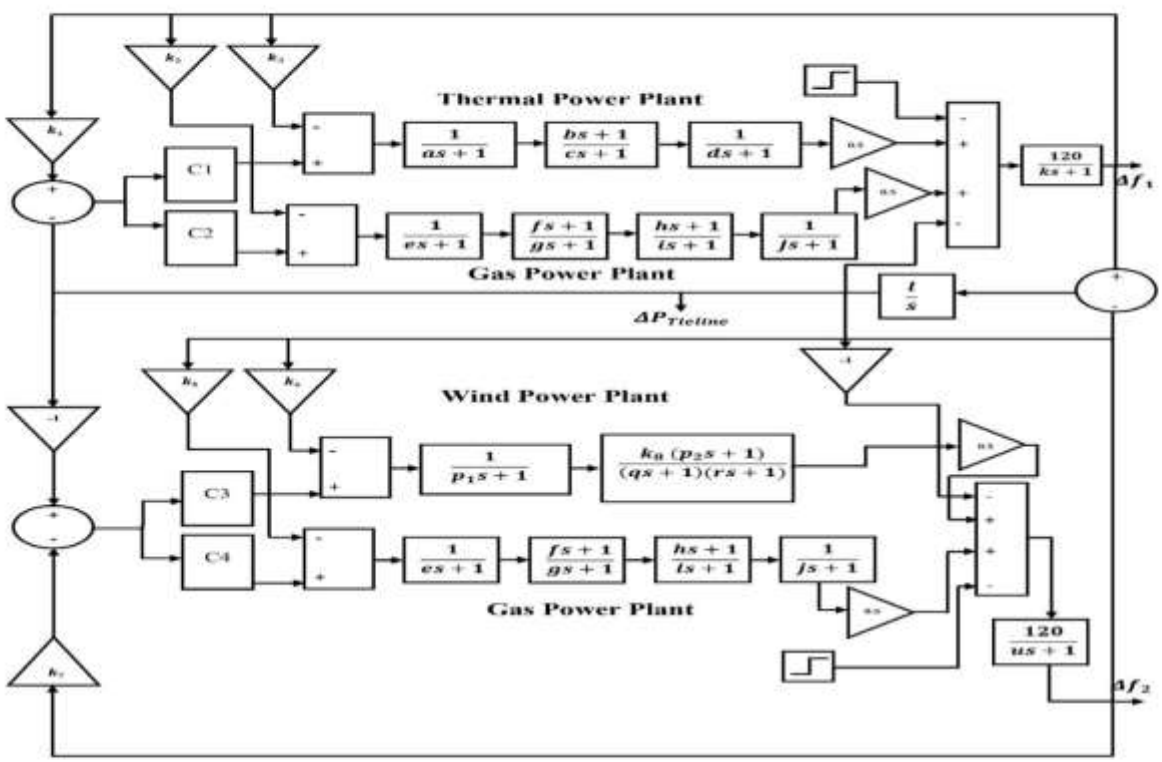
$$H_{wp}(s) = \frac{k_8(ps+1)}{(qs+1)(rs+1)} \quad (1)$$

Where q and r are main and parasitic time constant. k_8 is main gain constant and p is time constant of the wind power plant considered in the paper. Technical limitations of simulation model of wind power plant is described with illustration in [2] by authors. In [3], authors have proposed technique of damping fluctuations in output power from wind energy source. In multi area power systems, frequency of power system is successfully controlled with the help of hybrid controllers by authors of [4]. Designing and optimization of fitness or cost function is given by authors in [5-6]. A Meta heuristic technique, PSO (Particle Swarm Optimization) is used by authors of [5-6] for

optimization problem. Implementation of fractional order controller for inverted pendulum case is given by authors in [7]. Also tunning of parameters for controller has been estimated using PSO in [7]. Damping of fluctuations in frequency with several communication delays is controlled using fractional order controller in [8] by authors. Load frequency problem in presence of distributed generation is solved appreciably using fractional order PID controller with the help of optimization technique by authors in [9]. Tunning of controllers using Krill Herd technique is presented by authors in [10] for renewable power network controlling. Salp Swarm algorithm is used for tunning PI-TDF (Proportional Integral Tilt Derivative with Filter) controller for load frequency control of hybrid power system in [11]. Generation control in 2-area system in deregulated environment is done in presence of parameter variations of 25%, 35% and 50% in [12] by authors. Result obtained in [12] with these variations are satisfactory. Energy source considered in [12] is thermal system and gas system. Sliding mode controller is employed by authors in [13] in power system with energy storage to control the fluctuations in frequency due to disturbances. In power network where electric vehicles are connected in large amount for charging is investigated for load frequency control of the network in [14]. Multi area power system with disturbances having communication delay is controlled by employing cascaded PID controller by authors in [15]. Application of Osprey optimization in the engineering problems are shown in [16] and compared to other opimization technique to show its robustness in optimizing cost function. Authors of [17] has considered 2-area system for stability improvement of power network in various loading condition and successfully achieved the objective using TLBO (Teaching Learning based Optimization) algorithm.
After going through detailed research survey, it is observed that the scope for green energy integration in power network for keeping our earth green is still an area of hotspot research. Also, it is seen that wind energy is not uniform

Fig.1. Test System Modelling.

and its speed keeps on varying and hence a robust controller is required for better resilience of the power system. Hence in this paper an osprey inspired optimization is proposed for tunning of fractional order controller to improve



system performance during period of disturbances.

2. TEST SYSTEM MODELLING

Here, in this paper, four generating power stations are integrated in 2-area network. Thermal power and gas power generating station is integrated in first area (area-1) and wind power and gas power generating station is integrated in second area (area-2). A detailed transfer function model of test system is given in fig.1. 4 units of controllers are fitted for 4 units of power sources in the test system. Proposed controller in this paper is compared with other controllers in terms of several parameters considered in this paper for evaluation such as rise. time, settling time, overshoot, peak time etc. controller is needed for efficient controlling of fluctuations or oscillation in the system. Test system has been designed for processing the desired result proposed in this paper. A detailed figure of the test system has been shown in fig.1. Different cases have been considered with combinations of controllers fitted in the test system. Also, load has been varied to check the resilience of the system and the performance of the controllers have been compared. Values of parameters used in test system is given in table 1.

In fig.1, controllers are named as C1- Controller1, C2- Controller2, C3- Controller3 and C4- Controller4. Also, Gas power plant is comparably less harmful than conventional thermal power plant and wind power plat is completely greener and harmless. Value of parameters used in proposed test system is given in table 1.

TABLE 1. VALUE OF PARAMETERS USED IN TEST SYSTEM

Parameters	Value	Parameters	Value
a	0.06	**m**	0.08
b	3	**n**	0.50
c	10	**p_1**	4
d	0.3	**p_2**	1
e	0.049	**q**	2
f	0.6	**r**	0.025
g	1.1	**u**	20
h	-0.01	**k_1**	0.4312
i	0.239	**k_2**	1/2.4
j	0.2	**k_3**	1/2.4
k	20	**k_5**	1/2.4
l	0.272	**k_7**	0.4312
k_6	1/2.4	**k8**	0.4

3. PROPOSED METHODOLOGY

When power network is subjected with sudden disturbances or loading, network parameters will get change and this change need to be compensated as soon as possible to get rid of situation of synchronization loss. This fluctuations in the power network have been mathematically modelled by considering changes in different parameters such as frequency and tie line power. The fitness function considered in this paper is ITMWAE (Integral of Time Multiplied Magnified Weighted Absolute Error) and it is given by eq.(2):

$$\text{ITMWAE}=s_1\int_0^t|\Delta f_1|\,dt+s_2\int_0^t|\Delta f_2|\,dt+\ s_3\int_0^t|\Delta P_{tie}|\,dt \tag{2}$$

$$s_1=w_1*M\ ; \tag{3}$$

$$s_2=w_2*M\ ; \tag{4}$$

$$s_3=w_3*M\ ; \tag{5}$$

Here, M =10

Where, M is magnification factor;

w_1=0.2, w_2=0.5, w_3=0.3

w_1, w_2 and w_3 are priority based weighted values attached to frequency and tie line power changes.

s_1, s_2, and s_3 are priority based magnified weighting factor and the values are s_1=2, s_2=5, s_3=3.

$|\Delta f_1|, |\Delta f_2|$ is absolute frequency change.

$|\Delta P_{tie}|$ is absolute tie line power change.

$s_1$and s_2 are magnified weighted value attached to frequency.
s_3 is magnified weighted value attached to tie line power.

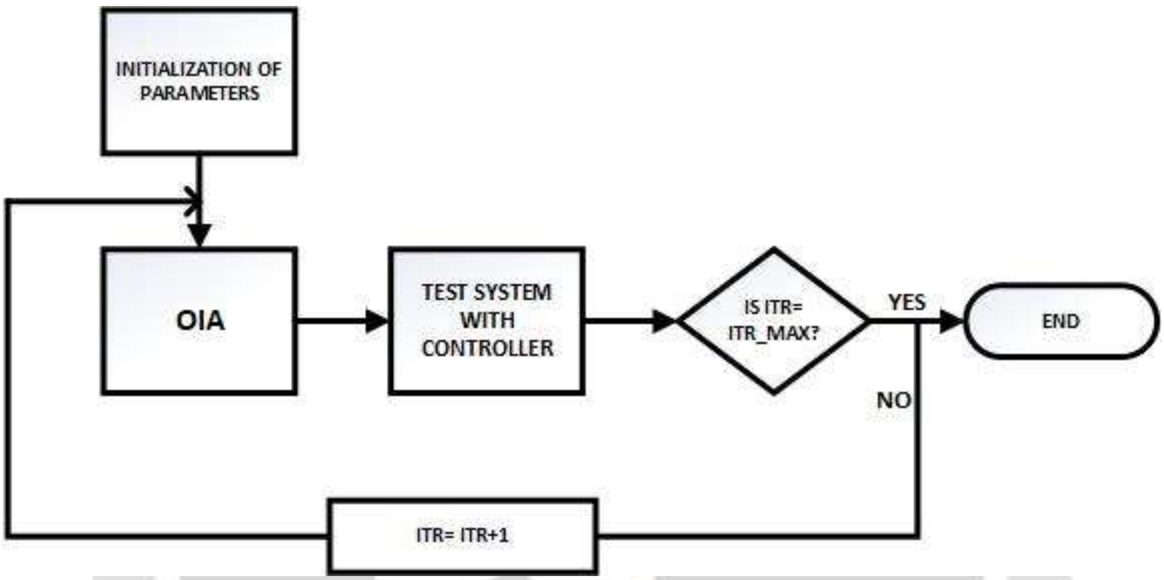


Fig.2 Flowchart of proposed method

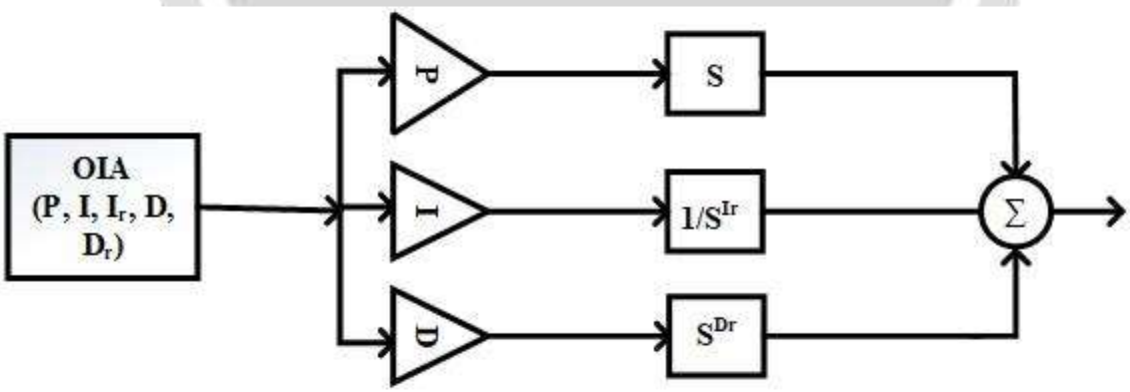


Fig.3. Tunning of FOPID controller using PSO.

Classical PI control has potential to control the overall response of a conventional plant but for the non-conventional power plant such as wind power plant one needs to go for novel type of controller such as TID (Tilt Integral Derivative) controller, Fractional order PID controller etc. In the current paper Fractional PID controller with 5 uncertain variables has been considered for the load-frequency control of 2-area system with 4 units of power sources. A suitable meta heuristic technique OIA has been hybridized with fractional PID controller for determining uncertain variables using suitable cost function. Flowchart for tunning of controllers is shown in fig.2 using meta heuristic technique PSO. Transfer function equation for FOPID-PSO controller is shown in eq.(6):-

$$FOPID(S) = P * S + I * \frac{1}{S^{I_r}} + D * \quad (6)$$

Transfer function equation for PID controller is as shown in eq.(7):-

$$PID(S)=P+I*1/S+D*S \quad (7)$$

3.1. OPTIMIZATION TECHNIQUE

(A) Osprey Inspired Optimization (OIA)

OIA is developed on the basis of behavior of bird namely osprey. Osprey is also called fish hawk. The strategy of osprey in catching fish from a river or sea and then take it at suitable place to eat it comfortably is natural intelligent strategy and hence this strategy can be utilized by human to solve real life solution. In this paper, fluctuations in power network due to sudden disturbances is solved using the intelligent strategy of catching fish by osprey. This intelligent strategy is mathematically modelled to optimize the proposed fitness function considered in this paper.

Stepwise implementation of OIA:-

i. Initialization of population

Position of osprey is randomly initialized in search space using eq.(8)

$$p_{ij} = lb_j + rand * (ub_j - lb_j) \quad (8)$$

Where, i is the number of osprey(solution) and j is the number of problem variable.

ii. Evaluation of osprey's fitness using fitness function or objective function.

iii. Phase 1(PH1): Location identification for hunting of fish by osprey.

The set of fish for each osprey is given by eq.(9)

$$FP_i = \{P_k | k \in \{1,2,3, \ldots\ldots N\} \wedge F_k < F_i\} \cup \{P_{best}\} \quad (9)$$

Where FP_i is set of fish position for i[th] osprey and P_{best} is the best osprey or solution

Updated position of osprey is calculated using eq.(10)

$$p_{ij}^{PH1} = p_{ij} + rand * (SF_{ij} - I_{ij} * p_{ij}) \quad (10)$$

$$P_i = \begin{cases} P_i, F_i^{PH1} < F_i \\ P_i, \ else \end{cases} \quad (11)$$

Where PH1 is phase 1 i.e. identification of fish location by i[th] osprey

iv. Phase 2(PH2):-Carrying out fish to suitable position for eating.

Suitable position for eating fish can be calculated using eq.(12)

$$p_{ij}^{PH2} = p_{ij} + \frac{lb_j + rand*(ub_j - lb_j)}{t} \quad (12)$$

Updated position of osprey can be given by eq.

$$P_i = \begin{cases} P_i, F_i^{PH2} < F_i \\ P_i, \ else \end{cases} \quad (13)$$

v. Repetition of phase 1 and phase 2 till maximum iteration is attained.

(B) Particle Swarm Optimization (PSO)

PSO is a meta heuristic optimization technique or algorithm and can be used for solving both maximization or minimization problem. In this paper, minimization of fitness function ITMWAE considered in this paper is going to be done. Particle velocity of the swarm is updated using equation as shown in eq. (14).

$$v_i^{f+1} = q * v_i^f + u_1 * rand * (p_{best} - x_i^f) + u_2 * rand * (g_{best} - x_i^f) \quad (14)$$

Where, v_i^f is the current velocity; v_i^{f+1} is the updated particle velocity; u_1, u_2 is the constriction factor; q is the weighting factor of the PSO algorithm and x_i^f is the current position of the particle of the swarm.

Position is being updated using equation (15) as follows: -

$$x_i^{f+1} = x_i^f + v_i^{f+1} \quad (15)$$

4. RESULT AND DISCUSSION

Case-a: Test system with 4-FOPID-OIA controllers.
Case-b: Test system with 4-FOPID-PSO controllers.
Case c: Test system with 4-PI controllers.
Area-1: Area-1 consists of 2-power units namely thermal power plant and gas power plant.
Area-2: Area-2 consists of 2-power sources units namely wind power plant and gas power plant.

A. Case-1

Under case-1, power network is subjected with sudden loading of 200 MW in area-1 and 300 MW in area-2 and then the performance of different controllers are evaluated to verify the resilience of proposed controller in the paper. Tuned parameters value obtained after implementation of different optimization technique is given table 3.

TABLE 2. FITNESS VALUE FOR CASE-1.

	Case -a	**Case-b**	**Case -c**
Fitness value	1.42650467695130	4.15731125306042	441.658069739561

As per table 2, teste system fitted with 4-FOPID-OIA is more efficient as compared to other controllers.

TABLE 3. TUNED PARAMETER OBTAINED AFTER OPTIMIZATION.

Parameters	**Osprey**	**PSO**
P(1)	1	25
I(1)	25.53489	1
Ir(1)	0.9	0.101318
D(1)	13.2175	25
Dr(1)	0.9	0.9
P(2)	30	11.32535
I(2)	8.857631	25
Ir(2)	0.9	0.9
D(2)	1	1
Dr(2)	0.9	0.9
P(3)	27.60595	25
I(3)	29.58149	11.87728
Ir(3)	0.1	0.9
D(3)	30	24.99364
Dr(3)	0.9	0.451381
P(4)	1	1
I(4)	30	1
Ir(4)	0.9	0.1
D(4)	6.310594	2.041653
Dr(4)	0.83499	0.9

TABLE 4. FREQUENCY ANALYSIS FOR AREA-1 UNDER CASE-1

PARAMETERS	Case -a	Case-b	Case -c
Rise Time	1.5533e-04	9.0864e-04	17.5536
Settling Time	3.3848	4.9371	19.9217
Settling Min	53.0129	51.6818	116.4835
Settling Max	61.0882	60.0473	120.5298
Overshoot	1.8374	0.2154	0
Undershoot	0	0	0
Peak	61.0882	60.0473	120.5298
Peak Time	1.8100	7.2837	20

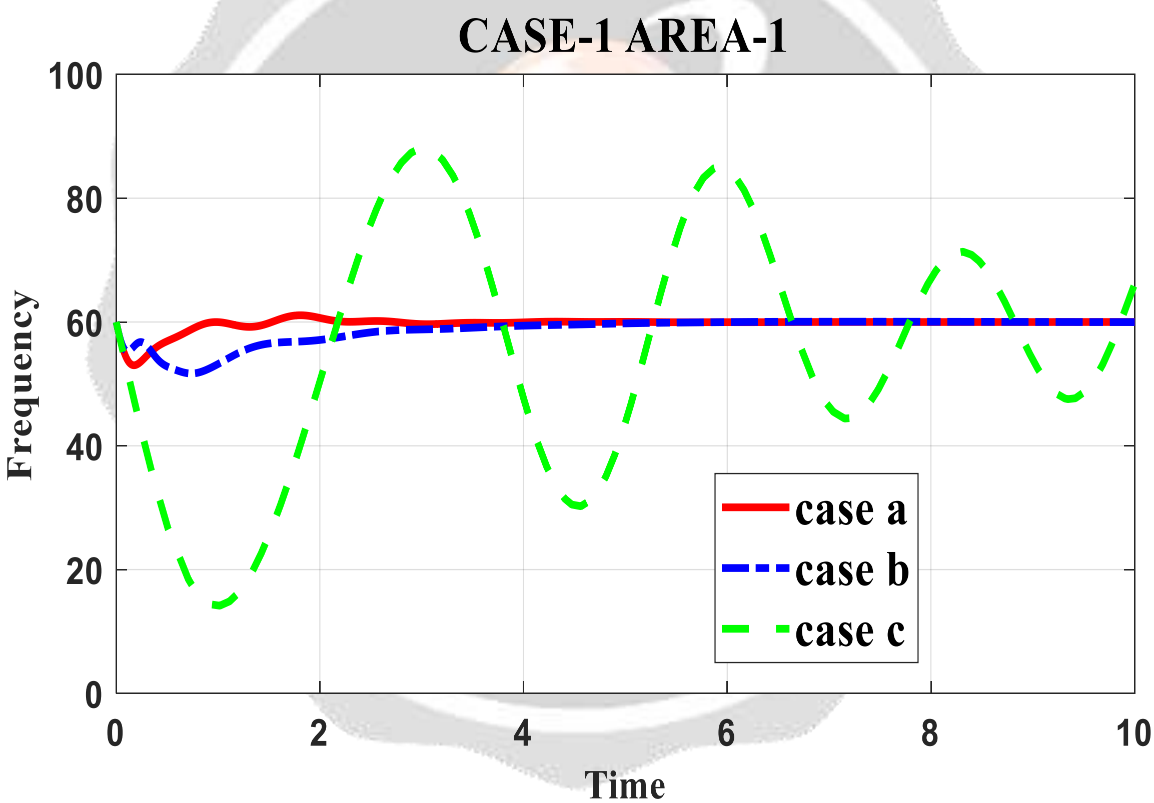


Fig.4. frequency response graph for area-1 under case-1

Going through table 4 and fig.4 for area-1, it can be inferred that case-a is the best when compared with case-b and case-c. settling time and peak time for case -a is the least. Test system is able to recover its frequency to normal point i.e. 60 HZ.

TABLE 5. FREQUENCY ANALYSIS FOR AREA-2 UNDER CASE-1

PARAMETERS	Case -a	Case-b	Case -c

Rise Time	7.8075e-05	5.9760e-04	0.3063
Settling Time	4.0911	3.9625	19.9585
Settling Min	43.0164	33.6860	-5.2351
Settling Max	67.3044	62.8749	100.7019
Overshoot	12.1938	4.9325	391.5280
Undershoot	0	0	25.5525
Peak	67.3044	62.8749	100.7019
Peak Time	0.7101	1.0946	2.5523

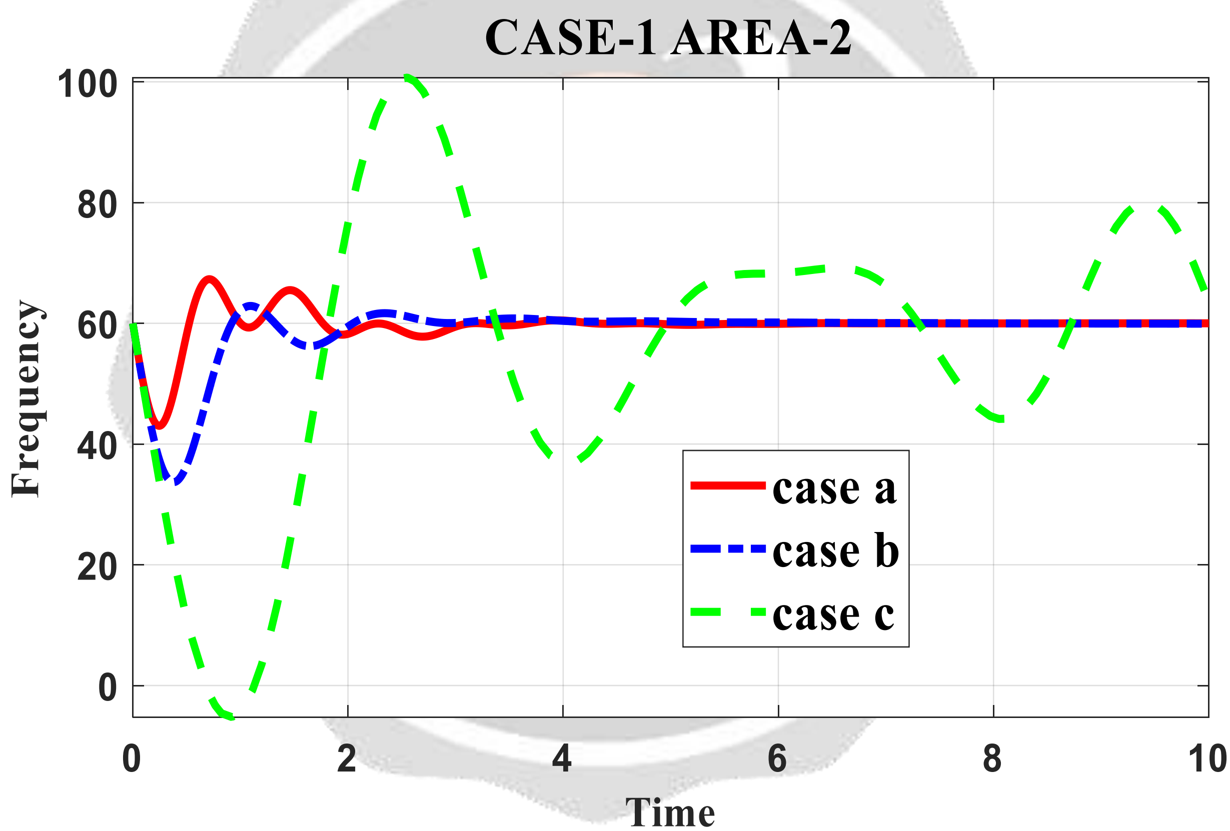


Fig.5. frequency response graph for area-2 under case-1

From fig.5 and table 5, it can be concluded that test system with 4-FOPID-OIA is the most efficient controller for area-2. The red line is dominating blue and green line in terms of recovering frequency to 60HZ.

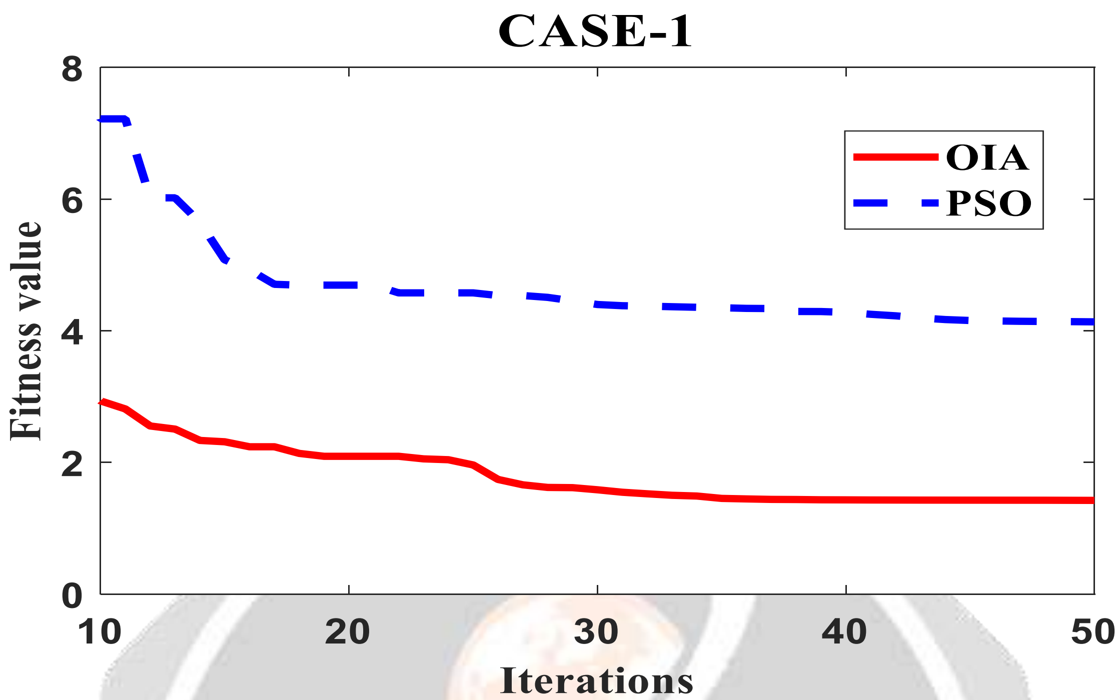


Fig.6. convergence graph for case-1

Robustness of OIA in optimizing fitness function considered in the paper can be observed from fig.6.

B. Case-2

Under case-2, power network is subjected with sudden loading of 300 MW in both area-1 and area-2 and then the robustness of proposed controller in the paper is compared with other controllers considered in the paper for comparison. Tuned parameters value obtained after implementation of different optimization technique is given table 7.

TABLE 6. FITNESS VALUE FOR CASE-2.

	Case -a	**Case-b**	**Case -c**
Fitness value	1.18700792230537	1.98171860690637	715.556126411364

As per table 6, performance of test system with proposed controller is found to be the best.

TABLE 7. TUNED PARAMETER OBTAINED AFTER OPTIMIZATION

Parameters	**Osprey**	**PSO**
P(1)	3.468647	13.68985
I(1)	30	25
I_r(1)	0.9	0.1
D(1)	30	6.449898

$D_r(1)$	0.680931	0.9
P(2)	30	1
I(2)	14.31291	25
$I_r(2)$	0.885801	0.9
D(2)	1	1
$D_r(2)$	0.9	0.108967
P(3)	1	1
I(3)	29.97432	25
$I_r(3)$	0.9	0.9
D(3)	30	25
$D_r(3)$	0.9	0.9
P(4)	1	1
I(4)	22.77427	25
$I_r(4)$	0.652117	0.690146
D(4)	5.253055	5.922786
$D_r(4)$	0.9	0.9

TABLE 8. FREQUENCY ANALYSIS FOR AREA-1 UNDER CASE-2

PARAMETERS	**Case -a**	**Case-b**	**Case -c**
Rise Time	2.0069e-04	3.2950e-04	10.9691
Settling Time	2.0226	2.1668	19.9884
Settling Min	50.7279	46.3863	-33.5207
Settling Max	60.3324	61.0431	142.0000
Overshoot	0.5994	1.8140	29.1563
Undershoot	0	0	30.4888
Peak	60.3324	61.0431	142.0000
Peak Time	1.8304	1.8050	18.0520

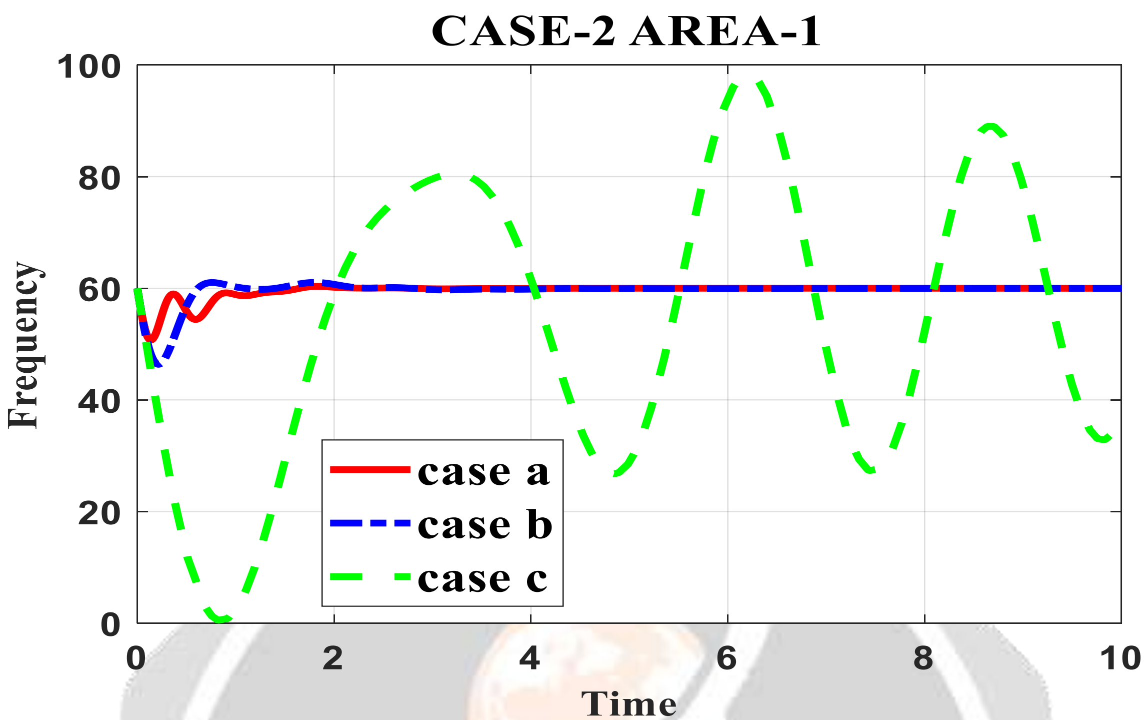


Fig.7. frequency response graph for area-2 under case-2

Going through table 8 and fig.7, it can be inferred that case-a is the best when compared with case-b and case-c for area-1. settling time for case -a is the least for area-1. Frequency response specification mentioned in table 8 speaks about the robustness of OIA in optimizing performance of test system with proposed controller.

TABLE 9. FREQUENCY ANALYSIS FOR AREA-2 UNDER CASE-2

PARAMETERS	Case -a	Case-b	Case -c
Rise Time	1.7923e-04	3.3134e-04	0.1432
Settling Time	3.0617	3.0013	19.9907
Settling Min	42.3619	42.3342	-11.1580
Settling Max	65.7341	64.1687	125.1409
Overshoot	9.6010	7.0277	206.7267
Undershoot	0	0	27.3487
Peak	65.7341	64.1687	125.1409
Peak Time	0.7534	1.4639	19.3224

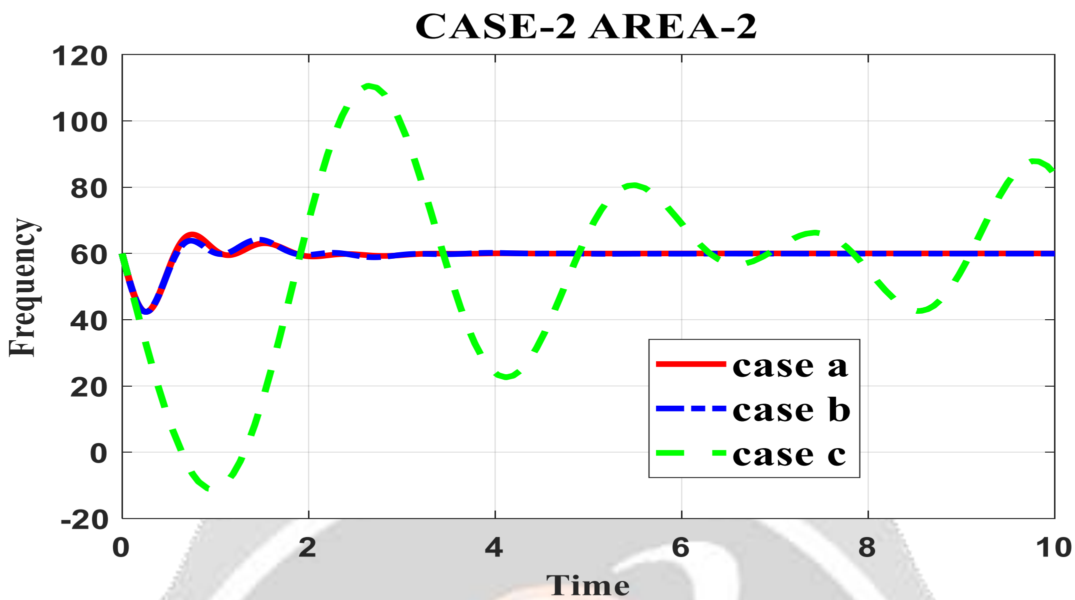


Fig.8. frequency response graph for area-2 under case-2

For area-2, performance of fractional order controller is approximately same for both OIA and PSO. Although controller with OIA is slightly better.

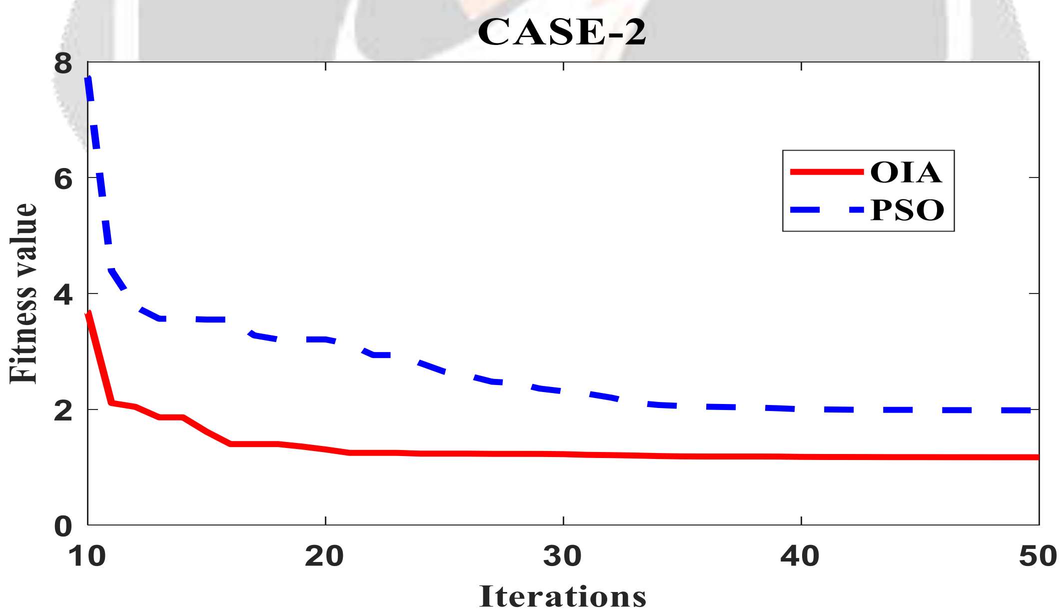


Fig.9. convergence graph for case-2

Robustness of OIA in optimizing fitness function ITMWAE considered in the paper is better as compared to PSO as per fig.9. Overall, it can be inferred that osprey inspired optimization has proved to be efficient optimizing technique in improving system performance.

5. CONCLUSION

A 2-area 4-unit power plant with wind energy as one of the energy sources has been considered for planning of controllers for improved resilience in the power transmission network in case of disturbance or sudden loading. Two different cases of loading have been considered on the test system and after that test system is evaluated by fitting different controllers into it. Test system fitted with 4-FOPID-OIA controller unit has proved to be performing efficiently in damping oscillations and recovering frequency of both areas as compared to other controllers considered in the paper. Value of fitness function obtained in table 2 and table 6 shows the robustness of FOPID when tuned with OIA technique is the best. Convergence graph shown in fig.6 and fig.9 shows the performance of OIA and PSO in optimizing fitness function considered in the paper. Overall, the maiden application of proposed OIA technique to tune fractional order controller in this paper is able to damp the oscillation in the test system with wind power plant efficiently.

7. CONFLICT OF INTEREST AND DATA AVAILABILITY STATEMENT

On behalf of all authors, the corresponding author states that there is no conflict of interest and all data generated or analysed during this study are included in this published article.

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