International Journal of Research in Engineering, Science and Management
Volume-2, Issue-12, December-2019
www.ijresm.com | ISSN (Online): 2581-5792

Load Frequency Control of 2-Area System by Whale Optimization Algorithm

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***Abstract*: Now a day's power system is expanding due to increasing load demand. It is also typical task to maintain load demand and load frequency on behalf of stability limits. To meet load demand energy generator plays important role which uses automatic generation control process to maintain stability limits and load demand. In this presented work we proposed whale optimization technique to get PIDN controller optimized parameters for load frequency control purpose. For this purpose, we consider hybrid system having two areas i.e. thermal (thermal system with no reheat turbine) and photovoltaic (PV) system. PV system is designed by maximum point tracking (MPPT). For various loading conditions and disturbances, simulation is performed for Area-1, Area-2, parameter variation of nominal loading, time constant of steam turbine (T_t), time constant of steam governor (T_g). Performance analysis is carried out by MATLAB /SIMULINK software and simulated results are compared with different optimization techniques like a GA for optimal tuning of PI controller, firefly algorithm for optimal tuning of PI controller. WOA shows superior response towards other optimization techniques.**

***Keywords*: Automatic Generation Control; WOA Algorithm; Load Frequency Control; PIDN Controller**

1. Introduction

Due to increasing load demand power system becomes more complex to maintain their system parameters within permissible limits. For manage tie line power constant and system frequencies to its prescribed values are also a vital problem. To maintain tie line power and load frequency AGC plays an important role in power system to manage such kind of problem [1]. Due to sudden load changes and disturbances produced active power becomes less than power demanded which resulting into decreasing in system frequency and vice versa. Decrement of frequency like this is undesirable and required to damp out quickly to manage the tie line power constant to its prescribed limit. For this purpose, AGC is used because constant frequency can't achieve by speed governor alone. So a robust control system with AGC is required to keep the load changes in permissible limits and maintain system frequency and damp out oscillations [2].

Main target behind LFC is to provide the frequency and power of tie line within specified range to meet changing load demand and various disturbances suddenly occur in power system [3]. To meet out this goal various researches are also going on which consists of many types of optimization techniques like PSO, GSA, DE, GWO, GA and ABC algorithms for load frequency control [6]-[7]. All algorithms are applied for an AGC problem and their results are compared to get most optimized solution of such problem [7]-[8], [10].

In this presented work, load frequency controller is designed for 2-Area system which consists PV grid and thermal generator via WOA is proposed. The system performance is evaluated with studies and devises a fresh algorithm for optimization i.e. WOA. Likewise, these results corroborate the preeminence of the anticipated method in fine-tuning controller compared with recent algorithm of firefly algorithm in same interconnected system. In this work WOA technique is applied in PIDN controller [9].

A. Objective Function

Main agenda behind this paper is to maintain constant load frequency and improve power quality by improving voltage stability. For this purpose, recent optimization technique known as WOA is used to tune optimal parameter of controller gains in load frequency problem for thermal & PV grid system. In this paper conventional integral controller is replaced by a PIDN controller which is stated by the following equation [11]:

Objective function J is set using:

$$J = \int_0^\infty t(|\Delta f_1| + |\Delta f_2| + |\Delta P_{tie}|).\,dt \quad (1)$$

Response of system is increased by reduce the equation (2-5).
Minimizing J is subjected to:

$$K_{pi}^{min} \le Kpi \le K_{pi}^{max} \quad (2)$$
$$K_{Ii}^{min} \le K_{Ii} \le K_{Ii}^{max} \quad (3)$$
$$K_{d}^{min} \le K_{di} \le K_{di}^{max} \quad (4)$$
$$N_{Ii}^{min} \le N_{Ii} \le N_{Ii}^{max} \quad (5)$$

2. System model

A. AGC in a Two Area Hybrid System

Fig.1 shows system considers hybrid system which composing of 2-areas (thermal-thermal system with no reheat turbine) and photovoltaic (PV) system. The PV system is design by maximum power point tracking (MPPT). Here two areas are considered, Area-1 is a thermal system which having generator, turbine, governor and re heater and Area -2 is associated with photovoltaic system [4]. This system analysis with different algorithm and different controller [9].

$$G_{PV} = \frac{-18S + 900}{S^2 + 100s + 50} \tag{6}$$

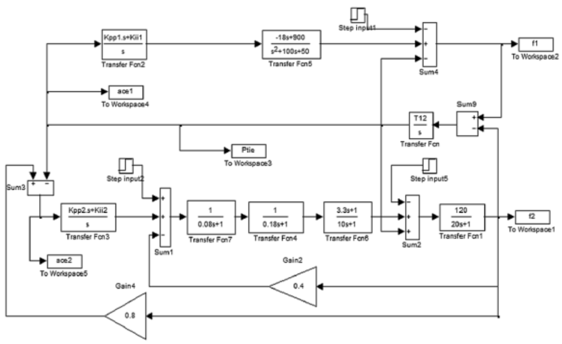

Fig. 1. 2-Area Hybrid System with LFC

3. WOA Tuned PIDN Controller

A. *Whale Optimization Algorithm(WOA)*

It is a population based metaheuristic optimization algorithm which shares a general characteristics regardless to their nature. Search process ID categorized into exploration and exploitation phase. Optimization process consists operators to globally explored the search space. Design variables are randomized as possible using phase perturbation method.. Exploitation is defined as "Process of investigation in detail with respect to promising area(s) of the search space". To meet exact balance between exploitation and exploration the most compatible task in the algorithm development [4].

B. *Mathematical Modeling of WOA*

This section consists explanation of mathematical modeling of encircling prey, spiral bubble net feeding maneuver and search for prey technique [5].

1) Encircling Prey

In this section Humpback whales identified the position of prey and encircled the target. If the target prey is near to optimum value then best search agent is defined. These agents regularly update the position of prey to beast search agent.

This entire process is representing through some set of equations which mathematically written as:

$$\vec{D}=\left|C\overrightarrow{X*}(t) - \vec{X}(t)\right| \tag{7}$$

$$\vec{X}(t+1)=\overrightarrow{X*}(t) - \vec{A}.\vec{D} \tag{8}$$

Vectors, $\vec{A}$ and $\vec{C}$ are calculated as follows:

$$\vec{A} = 2\,\vec{a}\,.\,r\text{-}\,\vec{a} \tag{9}$$

$$\vec{C} = 2.\,\vec{r} \tag{10}$$

2) Bubble Net Attacking Method

This phase is also known as exploitation stage, to implement the mathematical model of bubble net behavior of two strategies of humpback whales are designed. This explained as follows:

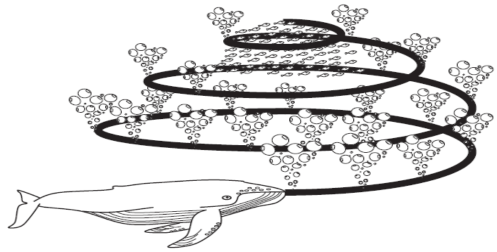

Fig. 2. Bubble-net feeding Behaviour of Humback Whales

Shrinking Encircling Mechanism

Gain is decrease by the value of vector $\vec{a}$ in equation 1.9.Remind that fluctuation range of $\vec{A}$ is also decreased by $\vec{a}$. $\vec{A}$ is a random value in the interval (-a, a) where a is reduced from 2 to 0 over the course of iterations. Setting of random variables for $\vec{A}$ in (-1,1) ,new position of search agent will be defined at anywhere in original position of the agent.

Spiral updating position

Figure represent the spiral updating position in which distance between whale located at (X, Y) and Prey located at (X*, Y*) is calculated. Between the position of whale and prey to mimic the helix shaped movement spiral equation for Humpback whales is written as [4]:

$$\vec{A}(t+1)= \overrightarrow{D'}.e^{bl}.\cos(2\pi l)+ \overrightarrow{X*}(t) \tag{11}$$

$\overrightarrow{D'} = |\overrightarrow{X*}(t)\text{-}\vec{X}(t)|$ =Represent the distance of the ith whale to the prey best solution.

Search for prey (exploration phase)

To search for exploration variation of the $\vec{A}$vector can be utilized. Remind that humpback whales search randomly, according to the position of each other so the vector $\vec{A}$ is selected between range of (-1,1).Exploration mechanism and $|\vec{A}|>1$ emphasized exploration allowed the WOA algorithm to perform a global search. Mathematical model for prey phase is as follows:

$$\vec{D} = |\vec{C}.\,\vec{X}_{rand}\text{-}\vec{X}| \tag{12}$$

$$\vec{X}(t+1) = \vec{X}_{rand}\text{-}\vec{A}.\vec{D} \tag{13}$$

C. *PIDN Controller*

For most of the industrial applications PIDN is popular feedback controller which gives excellent control towards different dynamic characteristics of process plant. It have three basic mode which is proportional mode, derivative mode and integrative mode. Structure of PIDN controller is shown in fig. 3. [11].

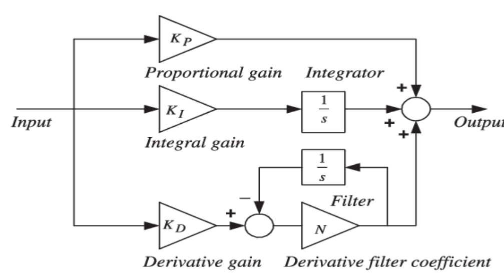

Fig. 3. Structure of PID Controller with Derivative Filter Control

Two dissimilar PIDF controllers are proposed in this paper for 2-Area system. Structure of proposed PIDF controller is shown in fig. 3. Where- N is the derivative filter coefficient. PIDF controller control inputs are area control errors and PIDF controllers output is input of power system i.e. u_1 and u_2.

Controller transfer function is given by: $G(s) = \frac{PIDFoutput}{PIDFinput}$

$$G(s) = \{K_p + k_i(\frac{1}{s}) + K_d \frac{N(s)}{s+N}\} \quad (14)$$

4. Result and Discussions

Proposed system uses whale optimization algorithm to optimized PIDN (PID controller with derivative filter) controller parameters. For this purpose, system considers hybrid system which composing of two areas (thermal-thermal system with no reheat turbine) and photovoltaic system. PV system is design by maximum power point tracking (MPPT). Simulation result is studied with various condition and disturbances as change in area1, area2, change in both area, various parameter variation (nominal loading, time constant of steam turbine (T_t), time constant steam governor(T_g). The system is evaluated by various algorithms as genetic algorithm (GA) for optimal tuning of PI controller, firefly algorithm (FA) for optimal tuning of PI controller, WOA for optimal tuning of PIDN controller. The system used ITAE based objective function. Fig.4 shows a MATLAB/SIMULINK model of hybrid system composing of two area (thermal-thermal system with no reheat turbine) and photovoltaic (PV) system.

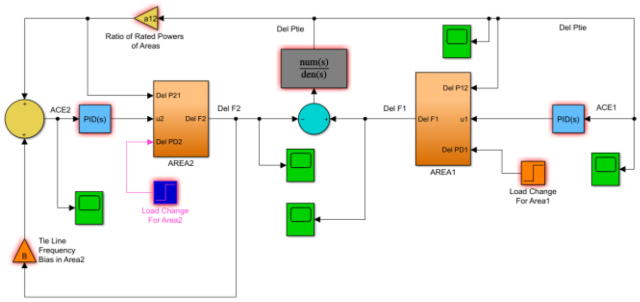

Fig. 4. MATLAB/SIMULINK Model of 2- Area Load Frequency Control

Fig. 5 shows the best cost function with an iteration of WOA algorithm & table 1 shows parameters of PIDN controller.

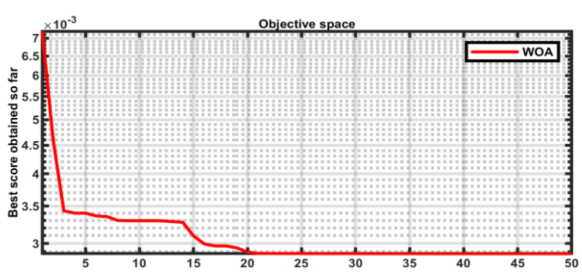

Fig. 5. Best Cost vs. Iteration Graph of WOA Algorithm

A. Result of WOA Optimized PIDN Controller

Table 1
Optimized PI & PIDN Controller Parameters Optimized by Different AI Technique

Types of Area	Controller Gain	ITAE=12.1244 GA PI	ITAE=7.4259 FA PI	ITAE=0.0433 WOW PIDN
Area-1	K_P	0.5663	0.8811	12.1856
	K_I	0.4024	0.5765	1.0
	K_D	0	0	0.9884
	N_1	-	-	500
Area-2	K_P	0.5127	0.7626	20
	K_I	0.7256	0.8307	20
	K_D	0	0	2.6309
	N_2	-	-	481.89

B. Case-1:10% Step Load Change in Area-1

It can be seen from fig. 6 to 8 that the proposed controller more powerful dynamic response and lesser settling time as compared to the GA, FA optimized PI controller. The designed controllers are show the satisfactory operation when employs WOA PIDN controller. The comparison of different settling time & different techniques are shown in table 2.

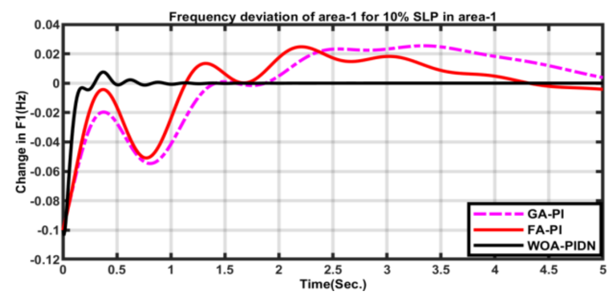

Fig. 6. Frequency deviation curve of Area-1 when 10% step load change in Area-1

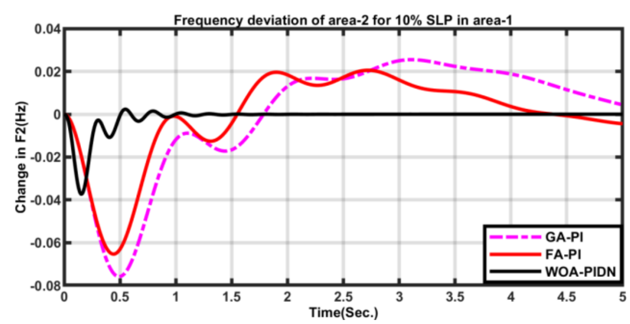

Fig. 7. Frequency deviation curve of Area-2 when 10% step load change in Area-1

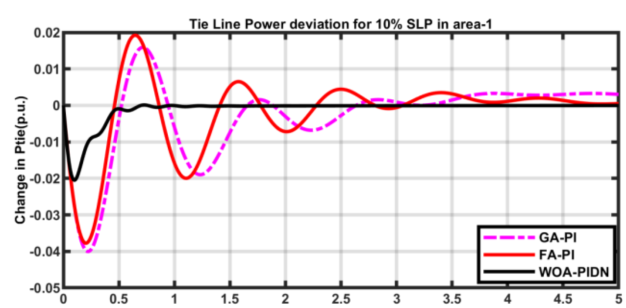

Fig. 8. Tie line power deviation curve of Area-1 when 10% step load change in Area-1

Table 2

Comparison of Settling Time of Area-1 with GA-PI and FA-PI & WOA-PIDN Controller

Optimized Technique	Settling Time(Second)		
	ΔF_1	ΔF_2	ΔP_{tie}
GA-PI	4.8642	4.8803	3.5850
FA-PI	4.5212	4.8165	4.5242
WOA- PIDN	0.6432	0.9674	0.8770

C. *Case-2: 10% Change in Both Area*

Different dynamic responses of frequency and tie line power deviation curve is shown in figure 9 to11. Finally, the proposed controller have a lower settling time compared with GA-PI and FA-PI controller and system response shows steady state quickly. Comparison of different settling time & different techniques are shown in table 3.

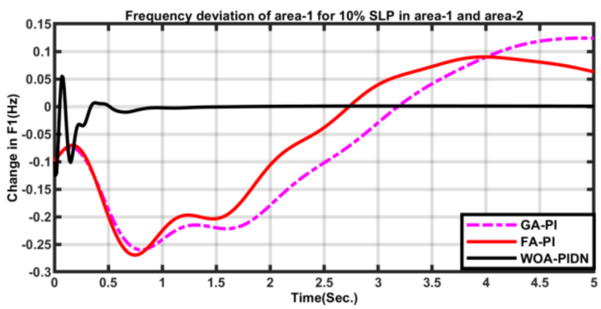

Fig. 9. Frequency deviation curve of Area-1 when 10% step load change in Area-1 & 2

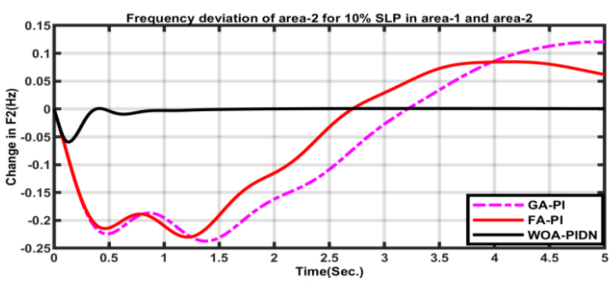

Fig. 10. Frequency deviation curve of Area-2 when 10% step load change in Area-1 & 2

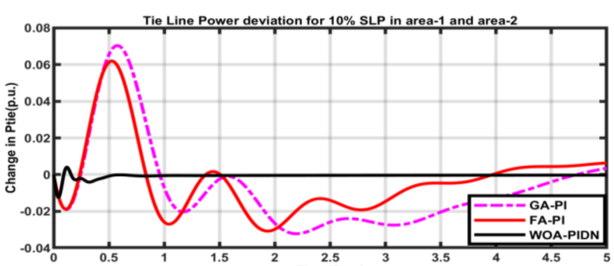

Fig. 11. Tie line power deviation curve for 10% step load change in Area-1 & 2

Table 3
Comparison of Settling Time Change in Area-1 & 2 with GA-PI and FA-PI & WOA-PIDN Controller

Optimized Technique	Settling Time (Second)		
	ΔF_1	ΔF_2	ΔP_{tie}
GA-PI	4.4268	4.5107	4.8879
FA-PI	4.8515	4.8560	4.7871
WOA- PIDN	1.2649	1.6067	1.0040

D. *Case-3 Parameter Variation*

Fig. 12 to 17 shows the dynamic response analysis of 2-Area thermal system with 50% increase/decrease in nominal loading, time constant of steam turbine (T_t), time constant of steam governor (T_g). Table 4 concludes that proposed WOA-PIDN controller show effective and stable response and settle down very quickly. Table 4 shows various parameters variation with settling time.

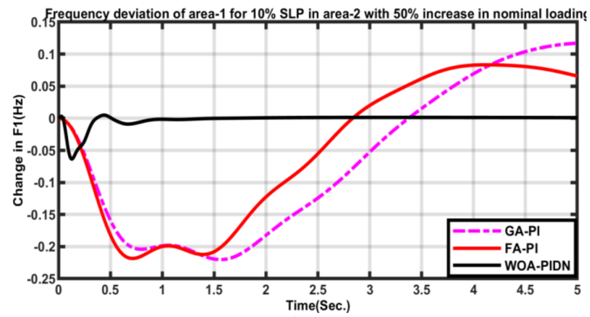

Fig. 12. Frequency deviation curve of Area-1 with 50 % Increase in Nominal Loading

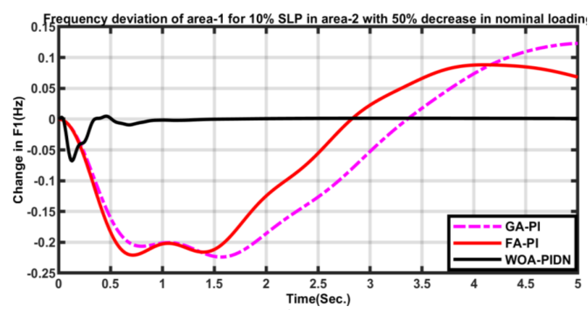

Fig. 13. Frequency deviation curve of Area-1 with 50 % Decrease in Nominal Loading

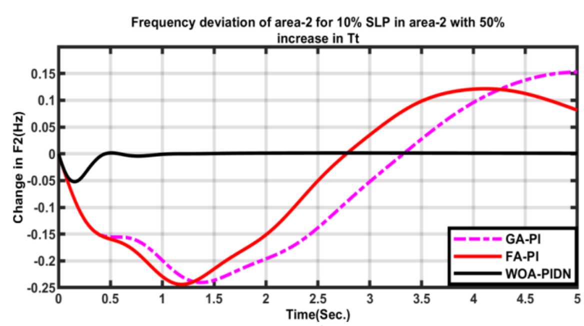

Fig. 14. Frequency deviation curve of Area-2 with 50 % Increase in T_t

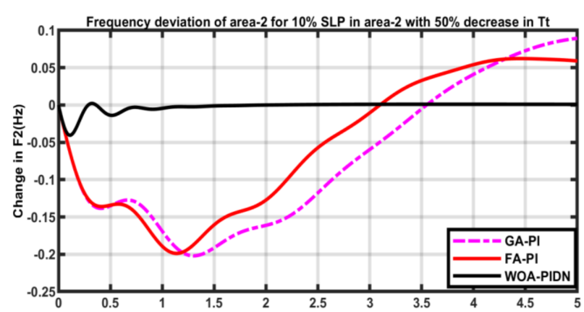

Fig. 15. Frequency deviation curve of Area-2 with 50 % Decrease in T_t

Table 4
Parameter Varations at Different Algorithm

Change in system Parameters	% Change	Proposed WOA-PIDN Technique			FA-PI Technique[9]		
		ST (Sec.)			ST (Sec.)		
		ΔF_1	ΔF_2	ΔP_{tie}	ΔF_1	ΔF_2	ΔP_{tie}
Nominal Loading Condition	+50	1.4791	1.6366	1.0009	4.8519	4.8238	4.7759
	-50	1.4521	1.6336	1.0009	4.8639	4.8385	4.7867
T_t	+50	1.0217	1.1090	1.0529	4.9170	4.9086	4.8226
	-50	1.9870	2.0725	3.4806	4.6275	3.9954	4.7236
T_g	+50	1.3923	1.4656	0.9995	4.8805	4.8649	4.7777
	-50	1.5646	1.7357	1.0232	4.8268	4.7819	4.7673

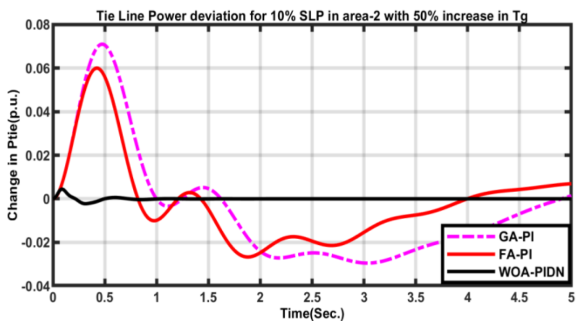

Fig. 16. Tie Line Power Deviation with 50 % Increase in T_g

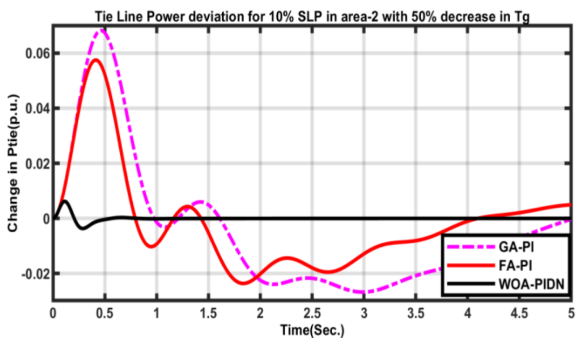

Fig. 17. Tie Line Power Deviation with 50 % Decrease in T_g

5. Conclusion

The system parameters are optimized using WOA with PID controller with derivative filter (PIDN). The system performance compare with different algorithm as GA-PI and FA-PI controller as same interconnected power system. The proposed system performance is analysis with various condition as change in Area-1, Area-2 and both area and different parameter variation. All the condition WOA-PIDN controller based system shows best performance and improves the stability of the system. Finally, WOA-ITAE system shows very good performance and settle down very quickly.

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