Application of Smell Agent Optimization Algorithm on Load Frequency Control for two Area Interconnected Power System

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Abstract: Electrical energy is one of the important requirements for the development of every society. Electrical power demand always fluctuates. Every area/subsystem of an interconnected power system is expected to take care of the output with respect to frequency deviation of the system and maintain interchange with other area/subsystem within the operating conditions. Mismatch between Power generation and load demand causes frequency deviation which may cause system collapse. Load Frequency Control (LFC) is one of the methods to achieve frequency stability. Nigeria experienced over 40 grid collapse from 2015 to 2021 which result to total blackout as a result of mismatch between load and generation. This research considers the three hydro power plants and the sixteen thermal power plants of Nigerian power network as area-1 and area-2 respectively. Area-1 has the capacity of 1,967MWand area-2 has the capacity of 9,532MW. From the simulation results, the performance of the proposed SAO was compared with that of GWO and PSO and it was found that SAO has better performance compared to PID, PSO and GWO by reducing the oscillation and the settling time of the frequency deviation and tie-line power change.

Keyword: *Automatic generation control; load frequency control; interconnected power systems; load deviation;frequency deviation; tie-lines power, Smell Agent Optimization (SAO)*

I. Introduction

Electrical energy is one of the important requirements for the development of every society. Electricity demand has become very important in human activities. Electrical energy isnot constant, it always fluctuates (increase or decrease). These fluctuations may cause system instability, which may result to system collapse. Therefore, the need for control of these fluctuations become necessary [1,2]. Power system stability is ability of a power network to develop a restoring force equal or greater than the disturbing forces in order to keep the system in state of equilibrium after subjected to a disturbance or is the ability of synchronous generators to remain in synchronism after subjected to a disturbance [3]. Mismatch between power generation and load demand will cause frequency instability [4]. Frequency instability is the inability of a power system to maintain system frequency within the specified operating limits. Generally, frequency instability is a result of a significant imbalance between load and generation, and it is associated with poor coordination of control and protection equipment, insufficient generation reserves, and inadequacies in equipment responses [5]. Every area/subsystem of an interconnected power system is expected to take care of the output with respect to frequency deviation of the system and maintain interchange with other subsystem/areas within predetermined value [1]. The process of controlling or bring back the stability between generation and load in every control area through speed control is called Load Frequency Control (LFC). Due to the dynamism in load demand with respect to time, the balance in real power and reactive power is destabilized. This results in wandering of frequency and tie-line power. Large deviation of frequency may result to system failure. This necessitated the study of LFC [1,6,7].

II. Load Frequency Control (LFC)

Stability in power system is the capability of the system to return to stable operation after perturbed by disturbances [5]. Load demand in power system always varies, as a result of this, there will be imbalance between generation and the load demand. The rising and falling of the load demand results to deviation of system frequency and tie-line interchange power from their scheduled value. High deviation of system frequency may lead to system collapse [1, 5]. For a stable operation of power system, the total power generated match with the total load demand associated with system loses. Sudden change in demand will lead to frequency deviation in the system which may yield to catastrophic effect [3]. One of the important methods of controlling the frequency deviation as a result of change in load demand is Load Frequency Control (LFC) [3].The goal of the LFC is to maintain stable frequency of the system at zero steady state errors, and to provide load sharing among areas in a multi area interconnected power system [1]. In addition, the power system should fulfill the proposed dispatch conditions [5]. Power systems are divided into control areas connected with tie-lines. All generators are supposed to constitute a coherent group in each control area. From the experiments on the power system, it can be seen that each area needs its system frequency to be controlled [1,8].

The electricity industry in Nigeria is a massive apparatus that primarily consists of subsystems for generation, transmission, and distribution [9]. When the load consumes more energy than is generated overall, the system frequency begins to diverge from the ideal 50Hz level [9]. Without additional generation or load-shedding, the power system will experience frequency collapse (loss of stability and out of sync)and this is among the causes of a power system problems [8,9]. Nigeria's installed grid power generation currently has 23 grid-connected generating plants with total installed capacity of 14,242 MW (available capacity 6,136.2 MW) [10,11]. From this generation capacity, the hydropower has 1930MW of installed capacity (available capacity 1,325MW) while the thermal based generation has an installed capacity of 12,312 MW (available capacity of 4,965.7 MW) [9,11].Considering the functional Nigerian hydro power generation stations as one area and the functional thermal generation stations as another area. Assuming each generation station as a machine belonging to the area and all machines which are said to be coherent. Nigerian power sector has experienced over 40 grid total collapse from 2015-2022. Four were recorded between January to July 2021 and eight times in 2022 [9]. These outages or grid collapses occurred as a result of disturbances along transmission grid or system collapse in some generation plants. Some of these disturbances could be massive drop of load from a sub-station, load rejection by Discos, uninstructed generation overload, failure/tripping of major line or equipment etc [10]. The frequency of Nigerian power system fluctuates as a result of this continuous change in the load demand, this is because the speed of the prime mover reduces when load is increased or the speed of the prime mover increases when load is decreased while the water/steam/fuel intake is kept constant or when the water/steam/fuel intake increases while the load is constant, the speed increases[9]. These mismatch between the generation and the load affect the speed of the prime mover which is responsible for the frequency deviation of the system. It is mandatory to eliminate mismatches between power generation and load demand [1]. This research is aimed to investigate the application of optimization algorithm to improve the stability of frequency deviation for two-area power system through Introducing PID controller into the two-area network, Optimize the PID parameters using Smell Agent Optimizing Algorithm, and Validate the proposed SAO by comparing it with PSO and GWO.

Because of the importance of frequency control in power system, many research have contributed a lot in this area. Concordia and L.K. Kirchmaye presented the idea of load frequency control in 1954 [4]. Since then, a lot of research work has been carried out in this area. Ant Colony Optimization (ACO) is used for optimal tuning of PID controller for LFC of single area with reheat thermal system. The proposed algorithm is compared with Ziegler-Nichols (ZN) tuned. Load frequency control strategy for Nigerian power system using artificial bee colony optimized PI controller is presented in [11], In [12], the author presented the PID, fuzzy logic and neuro-fuzzy to optimize the LFC of Nigerian network by designing the system into two area networks. The results obtained shows that neuro-fuzzy controller better response than the fuzzy logic. The Author considered load disturbance of 0.01 pu in one area only. [13] presents a control system for improving the transient response time of speed/load-frequency of a gas turbine in a refinery in Nigeria. PID controller that will improve the transient response of a HDGT in a refinery in Nigeria. PID controller and Integral controller are applied to a single area hydro-turbine power system to improve the stability in the system. PID produced better results compared to Uncontrolled and integral controller.

The optimal tuning of Proportional-Integral-Derivative (PID) controller for both Load Frequency Control (LFC) and Automatic Voltage Regulator (AVR) of two area interconnected power system is presented in [14]. The LFC controls the frequency and thereby the active power flows in the system whereas the AVR maintains the voltage profile thereby controlling the reactive power flow in the system. A step disturbance is applied in the Area 1 and the dynamic performance of the system is analyzed by analyzing the system frequency, tie line power flow and the system voltage. PID controller has been optimally tuned for both LFC and AVR for two area system in the presence of step disturbance of 0.1875*p.u* applied to area 1 and system response is studied. The author recommended improvement using any optimization algorithm. In [15] PID parameters are tuned for LFC of two areas network presented. The selection of the optimum PID parameters is obtained by PSO and evolutionary PSO algorithm. The performance of the two algorithms were compared by computing the settling time and overshoot. It was found that EPSO converge faster than PSO. The Author considers change in demand at area 1 only and the settling time is large for both PSO and EPSO (17.3s and 17.2s respectively. Also, in [16] the author applied fire-fly optimization algorithm (FOA) modifies PID controller (FOA PID1) for LFC of two area network system. Fire-fly optimization algorithm optimize the modified proportional integral derivative controller better than the GA optimization PI (GA PI) and bacterial-foraging optimization algorithm optimize PI controller (BFOA PI) when step load disturbance of 10% in area 1 and step load disturbance of 20% in area 2 and simultaneous step load change of 20% in area and 10% of area 2. In [17], the use of fuzzy logic techniques is incorporated with PI controller is proposed for LFC problem for two-area network system to eliminate the output deviation and to keep good transients' response. The author considers the step disturbance of 187.5MW and 250MW at area-1 only. The author in [18] Developed optimum load LFC of a multi-area power system using PID controller parameter regulation based on a heuristic optimization technique called seeker optimization algorithm to eliminate the power system oscillations. The result of controller of provides better damping in comparison GA and POS based PID controllers. Two-area network system connected through tie lines is presented in [19], the frequency warning at the areas and rise power flows in the interconnected line as a result of unexpected load variations which cause difference between the power generated and demanded . The performance of the intelligent adaptive neuro-fuzzy interface system (ANFIS) controllers was compared with ANN, fuzzy and conventional PI, PID based approaches and thus showed better dynamic response.The PID parameters were tuned using (PSO-GSA) for two area networks. In this study, the load demand of 10 MW and 20 MW is applied to area1 and area2 respectively. The Author considered increase in load in both areas, and the settling time for the proposed algorithm a little big [20]. Two controllers, integral controller and fuzzy logic controller are used for LFC of two-area network, when a step fault of 0.2*p.u* is put into area 1, fuzzy logic controller produced better result (steady state error and percent overshoot) than the conventional integral controller. The author considered change in load in area 1 only [21]. The LFC using intelligent controllers for two-area network experienced unexpected changes in load in each area is considered in [22]. The PID parameters are tuned using Fuzzy Logic and ANN-NARMA-L2 when disturbance in load of 0.07*p.u* was put to Area-1 and 0.05*p.u* to Area-2. The Author considered increase of load in both areas. PID parameters were tuned using Ant-colony algorithm for AGC of three area network systems. The proposed Ant Colony Optimization algorithm damps the oscillations and reduced the settling time compared to conventional controller. The paper presented 0.01*p.u* of disturbance in one area [23]. Grey Wolf Optimization (GWO) is introduced to optimize the PI and PID parameters for automatic load frequency control of two area network system. The disturbance of the 2% and 3% are introduced to the 2 areas in relative manner. The Author considered load increase in both area and did not consider change in load in both areas simultaneously [24].A controller named tilt integral derivative is presented as the added controller for Load Frequency Control for two area interconnected network. The change in Frequency deviation is studied when there is increase and decrease of 25% and 50% in area 1 and area 2. The Author considered the disturbance separately [25]. The Load Frequency Control problem for multi-area network is addressed using Distributed model predictive control (DMPC) method. The paper considered a load increase of 20% at area 1and load increase of 15% at area 2. The output response in both areas of the proposed control scheme is quite large (30 sec) [26].

From the literatures reviewed, it is obvious that several attempts have been made in frequency stability through load frequency control. Most of the algorithm used have some drawbacks of falling into local optima or large number of iterations, slow convergence, and bad local searching ability, trial and error nature. This research will present a novel optimization algorithm Smell Agent Algorithm (SAO) which has the ability to by-cut trap into local optima and has less iteration compared to other algorithms, this algorithm will optimize the parameters of the PID when the system is subjected perturbation in load in the areas. The proposed SAO will be compared with performance of PSO and gray wolf optimization algorithm for validation. The PSO and GWO are chosen because of their similarities and some common features with SAO (such as population, position and velocity of candidates).

III. MATERIALS AND METHOD

This part provides the methodology of the research. This research work will be carried out in different stages on the proposed frequency control of the two-area network. These include, the study of the response of the system when there is no load deviation in the system, when there is load change at area 1 only, at area 2 only, load deviation at both area 1 and 2 simultaneously and introduce control strategies to stabilize the frequency back to nominal frequency (50Hz). The employment of PID controller will be presented. Smell Agent Optimization algorithm will be employed to optimize the PID parameters and validate the proposed SAO with PSO and GWO also will be discussed. Table 3.1. present the parameters used in simulation and the simulation is carried out using Matlab/Simulink environment.

Table 3.1: Parameters

SNO	PARAMETER	AREA 1	AREA 2
1	Speed regulation	R_1=0.05	R_2=0.0625
2	Frequency sensitivity load coefficient	D_1=0.6	D_2=0.9
3	Inertia constant	H_1=5	H_2=4
4	Base power	2,000MW=2500MVA	10,000MW=12,500MVA
5	Governor time constant	T_{g1}=0.2sec	T_{g2}=0.3sec
6	Turbine time constant	T_{T1}=0.5sec	T_{T2}=0.6sec
7	Frequency	50Hz	50Hz
8	Gain K	K_1=0.3	K_2=0.3
9	ΔP_L	600mw	1074mw

Modelling

An isolated power system is presented in Figure 3.1, it contains the speed governor, the turbine and the power system comprising of load connected to generator [10].

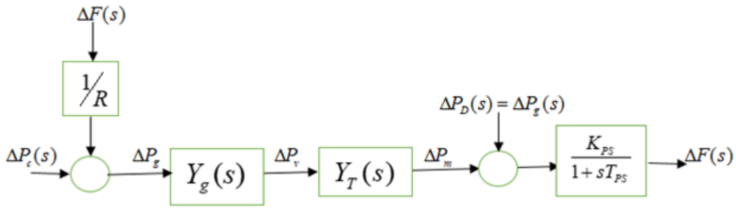


Figure 3.1 An isolated power system [27,28]

The transfer function of the speed governor $Y_g(s)$

$$\mathrm{Y}_g(s)=\frac{\Delta P_v(s)}{\Delta P_g(s)} \quad (1)$$

$$\mathrm{Y}_g(s)=\frac{1}{1+sT_g(s)} \quad (2)$$

The change in turbine power ΔP_m depends on the corresponding valve (or gate) power change ΔP_v and response characteristics of the turbine.

$$\mathrm{Y}_T(s)=\frac{\Delta P_m(s)}{\Delta P_v(s)}=\frac{1}{1+sT_T} \quad (3)$$

The power system (Load and machine) transfer function is

$$Y_p(s) = \frac{1}{1 + sT_p(s)} \quad (4)$$

3.2.1 Interconnected Power System

Tie-lines are used to connect various parts of an interconnected power supply. Through the tie-line that connected the two locations, electricity is exchanged when the frequencies in the two areas are different.

The Nigerian electric power system under study is basically an interconnection of hydro are geographically located in the Northern parts of the country and thermal area in the south [12]. In this research, the hydro generation station is considered as area 1 and the thermal generation as area 2. These two areas are interconnected by the tie line between Jebba and Oshigbo, and each of these areas comprises of several coherent turbines connected in the area. Figure 3.2 presents the power system for two areas system.

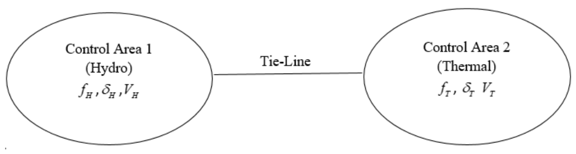


Figure 3.2 Two areas power system [29]

The power flow on the tie-line from hydro to thermal area is given by [13]

$$P_{tie,\mathrm{HT}} = \frac{V_H V_T}{X_{HT}} Sin(\delta_H - \delta_T) \quad (5)$$

V_H and V_T are the voltage at equivalent terminal of machines of Hydro and Thermal area.

δ_H and δ_T are the power angles of equivalent machine of Hydro and thermal areas.

line reactance between the hydro and the thermal areas

$$P_{tie,\mathrm{HT}} = T_{HT}(\Delta\delta_H - \Delta\delta_T) \quad (6)$$

Where T_{HT} is the synchronizing torque coefficient which is given by

$$T_{HT} = \frac{|V_H||V_T|}{X_{HT}} Cos(\delta_H^0 - \delta_T^0) \quad (7)$$

Considering the relationship between area power angle and frequency, Eq. (8) can be rewritten as:

$$\Delta P_{tie,\mathrm{HT}} = 2\pi T_{HT}(\int \Delta f_H - \int \Delta f_T) \quad (8)$$

$$T_{HT} = \frac{|V_H||V_T|}{X_{HT}} Cos(\delta_H^0 - \delta_T^0) \quad (9)$$

$$\Delta P_{tie,\mathrm{HT}}(s) = \frac{2\pi}{s} T_{HT}(\Delta f_H(s) - \Delta f_T(s)) \quad (10)$$

The tie-line power deviation is

$$\Delta P_{tie_{T,\mathrm{H}}} = T_{H,T}(\Delta\delta_H - \Delta\delta_T) \quad (11)$$

And the reference angle $\Delta\delta$ is $\Delta\delta = 2\pi \int_0^t \Delta f dt$

$$\Delta P_{tie_{\mathrm{H,T}}} = T_{HT}(\int_0^t \Delta f_H dt - \int_0^t \Delta f_T dt) \quad (12)$$

Taking the Laplace

$$\Delta P_{tie_{H,T}} = \frac{2\pi T_{HT}}{s}(\Delta F_H(s) - \Delta F_T(\mathrm{s})) \quad (13)$$

Each area comprises of several coherent turbines connected in the area. Therefore, the turbine parameters are lumped to achieve the equivalent values [29].

For the time constants of the thermal are calculated as

$$T_{H_{Area}} = \frac{\sum_{j=1}^{n} \frac{P_{H_{Area}}}{P_{H_{Unit\ j}}} T_{H_{Unit\ j}}}{n} \quad (14)$$

Where: $T_{H_{Area}}$ is the Hydro time constant of the area, $P_{H_{Area}}$ is the area capacity, $P_{H_{Unit\ j}}$ is the capacity of the thermal unit *j*, $T_{H_{Unit\ j}}$ is Hydro time constant of the area, n is the number of thermal unit in the area.

$$T_{t_{area}} = \frac{\sum_{j=1}^{n} \frac{P_{t_{area}}}{P_{t_{unit\ j}}} T_{t_{unit\ j}}}{n} \quad (15)$$

Where: $T_{t_{area}}$ is the Thermal time constant of the area, $P_{t_{area}}$ is the area capacity, $P_{t_{unit\ j}}$ is the capacity of the thermal unit *j*. and n is the number of thermal units in the area.

The equivalent self-regulation R_{area} for each of the two areas is obtained by

$$\frac{1}{R_{area}} = \sum_{i} \frac{1}{R_{unit\, i}} \quad (16)$$

Where: R_{area} is the equivalent regulator for the area, $R_{unit\, i}$ is the regulator of an area[30-32]

3.5 PlD Controller

PID controller consist of three independent parameters. These include proportional P, the integral I and derivative D.

Mathematical form

$$u(t) = K_P e(t) + K_i \int_0^t e(t^{'})dt^{'} + K_d \frac{de(t)}{dt} \quad (17)$$

Where K_p , K_i *and* K_d denote the coefficients for the proportional, integral, and derivative terms respectively [1,33].The choice of PID controller is to ensure good response in terms of under/overshoot and settling time.

To optimize the PID parameters, suitable objective function needs to be developed. This objective function (*J*) is the sum of the area control errors (ACE1 and ACE2) in each area as shown in equation (3.20) and (3.21).The objective function (J) is a function of error and time. Therefore, Integral of Time-Multiplied Absolute Error criterion (ITAE) is considered as function to be optimized. ITAE is selected among the other integral based objective function because it produces less overshoot/undershoot and settling time relate to others [34].

The objective function as

$$J = \int_0^{S_t} t\left(\left|B_1\Delta f_1\right| + \left|B_2\Delta f_2\right| + \left|\Delta P_{tie}\right|\right)dt \quad (18)$$

Min *J*

Subjected to,

$$\left.\begin{aligned} k_{P^{\min}} &\le k_P \le k_{P^{\max}}, \\ k_{I^{\min}} &\le k_I \le k_{I^{\max}}, \\ k_{D^{\min}} &\le k_D \le k_{D^{\max}} \end{aligned}\right\} \quad (19)$$

$$ACE_1 = B_1\Delta f_1 + P_{tie12error} \quad (20)$$

$$ACE_2 = B_2\Delta f_2 + P_{tie12error} \quad (21)$$

3.8 Smell Agent Optimization (SAO) algorithm

The theory behind how a smelling agent learns to detect a smell source gave rise to the Smell Agent Optimization (SAO), a recently discovered algorithm. The developers of the algorithm contend that an organism, including humans, can perceive smell substances and instinctively track the smell substances to identify their source when its olfactory capacity is well-developed [35,36]. Smell Agent Optimization (SAO) is an optimization algorithm use for combinatorial optimization problems. The concept of Smell Agent Optimization undergoes three modes: sniffing, trailing and random modes. In sniffing mode, the smell molecule expels from a source towards the agent with in search space [37,38]. Smell Agent Optimization is classified into 3 modes, these include:

3.8.1 Sniffing mode: this is the capacity of an agent to sense the presence of smell in a surrounding. Let q be the number of molecules of smell coming from a source within a search space, and the n be the dimension or size of the search space. The individual member of this evaporating smell molecule can be assigned a vector position using [35,38]

$$X_i^t = [x_{q,1}^t, x_{q,2}^t, \ldots x_{q,n}^t] \quad (22)$$

where*i=1, 2, 3, …, n*

Smell molecule expel in Browinian form, every smell molecule is designated a velocity using

$$V_i^t = [\mathrm{v}_{q,1}^t, \mathrm{v}_{q,2}^t, ..., \mathrm{v}_{q,n}^t] \qquad (23)$$

where*i=1, 2, 3…, n*

The current position and the velocity of the agent which is the updated position of the smell molecule is given by eqn (3.28) and (3.29) respectively:

$$X_i^{(t+1)} = X_j^{(t)} + \left[V_j^{(t)} + r^o \times \sqrt{\frac{3kT}{m}} \right] \qquad (24)$$

Where; $Xi^{(t+1)}$ is the current position of the molecule, $X_j^{(t)}$ is the previous position of molecule and r^0 is a random number which stochastically guide velocity update.

$$V_i^{(t+1)} = V_j^{(t)} + r^o \times \sqrt{\frac{3kT}{m}} \qquad (25)$$

3.8.2 Trailing mode: After the agent sniffs the smell, the agent will identify the source of the smell by following the smell molecules with highest strength through olfaction (olf) [37,40].

$$olf = \frac{f(x_{Agent})}{\sum_{i=1}^{N} f(x_i) / N} \qquad (26)$$

Where: olf is the olfaction capacity (which is the function of the fitness of the agent and the entire sniffing process), $f(x_{Agent})$ is the fitness of the agent, $f(x_i)$ is the fitness of the individual smell molecules, and N is number of smell molecules.

The trailing of the agent is modelled as shown in:

$$X_i^{t+1} = X_i^{(t)} + r_1 \times olf \times (X_{agent}^{(t)} - X_{(i)}^t) - r_2 \times olf \times (X_{worst}^{(t)} - X_{(i)}^t) \qquad (27)$$

r_1 and r_2 are random numbers generated at different intervals.

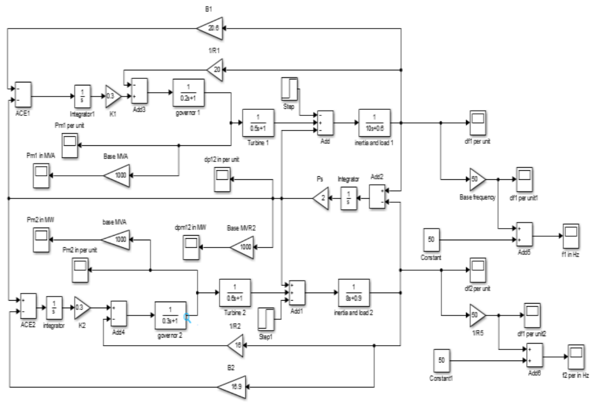
3.8.3 Random Mode: When the agent fails to locate the source of the smell molecule, the agent maybe trapped into local minima leading to its inability to continue trailing, the agent will go into Random mode to look for the smell molecule source. The random mode is described as:

$$X_i^{t+1} = X_i^{(t)} + r_3 \times SM \qquad (28)$$

Where *SM* is a constant indicating the step movement, and r_3 is random number which stochastically penalizes the value of the step movement [35-38].

3.3 Simulation

The proposed schematic diagram for the two-area network is presented in figure 3.3. it has only integral controllers, The system consists of two parallel operating areas of power system network, area-1 consists of Hydro power generators and area-2 has thermal power generators, each area consists of three blocks (Governor, Turbine and Generator/load) with two feedback loops (speed regulation loop and the Area Control Error). Each area has three inputs (the two feedback loops and the step disturbance) and 10 display scopes. The system operates at nominal frequency of 50Hz. The synchronizing power coefficient is computed from the initial operating condition and is given to be P_s



= 0.2*pu.*

Figure 3.3 the proposed Simulation model of two area LFC

The 10 scopes are $P_{m1}\ p.u$ and $P_{m2} p.u$ are the output of the governor which displays the mechanical power in per unit for area1 and area2 respectively, P_{m2} MW and P_{m1} MW are the output of the governor which displays the mechanical power in mega-watt for area 1 and area 2 respectively, dP_{12} MW and $dP_{12}\, p.u$ tie-line power change in megawatt and per unit respectively, $\partial f_1\, p.u$ and $\partial f_2\, p.u$ are the change in frequency in per unit for area 1 and area 2 respectively, $\partial f_1 Hz$ and $\partial f_2 Hz$ are the change in frequency in Hz for area 1 and area 2 respectively.

IV. RESULTS AND DISCUSSION

This section produces the results and discussion of the simulation carried out in the previous section. The simulation results were generated for the LFC of two-area power system. These results include: No load change in the system, increase in load in area 1 only, decrease in load in area 2 only, increase in load in area 1 and decrease in load in area 2 simultaneously, PID control strategy, The optimized PID parameters using Smell Agent Optimizing Algorithm (SAO) and validate by comparing the SAO based controller with particle swarm optimization method.

4.1 Simulation Results

The two-area power systems presented in Figure 3.3 was simulated when the system experience dynamic responses of*0.24pu* load change in area-1 and *0.085pu* load change at area-2. The plots of frequency deviation and tie line power for the six different scenarios are presented in Figure 4.1.1 to figure 4.1.6

4.1.1 Scenario 1: No load change in the network

The response of the system is considered when there is no load change disturbance in both area 1 and area 2 that is, $\delta P_{L_1} = 0$ and $\delta P_{L_2} = 0$. The frequency deviation of both area 1 and 2, tie line power and the mechanical power responses are is presented in Figure 4.1a to e.

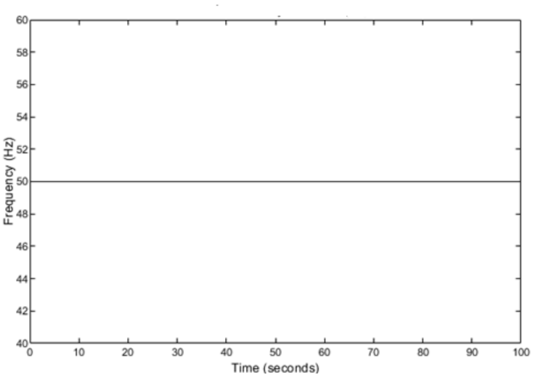


Figure 4.1a Frequency deviation for Area 1

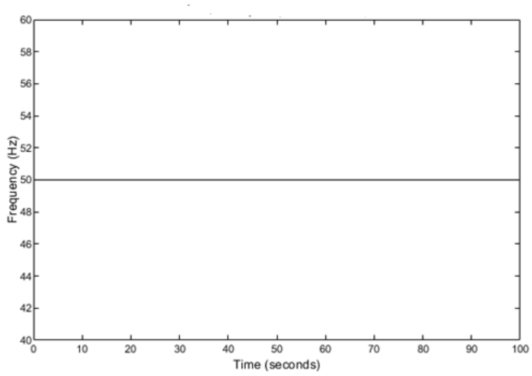


Figure 4.1b: Frequency deviation for Area 2

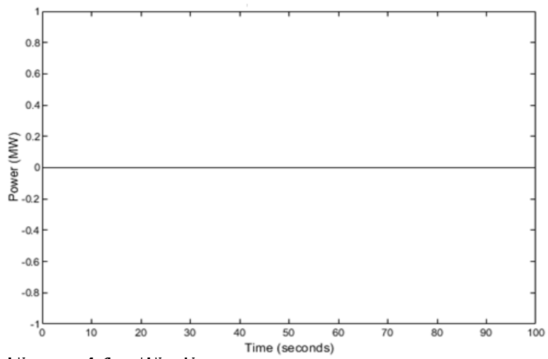


Figure 4.1c: Tie line power

Table 4.1 Summary of no-load change results

	Controller	Overshoot		Undershoot		Settling time		Objective function
		Area-1	Area-2	Area-1	Area-2	Area-1	Area-2	
1	PID	0	0	0	0	0	0	0
2	PSO	0	0	0	0	0	0	0
3	GWO	0	0	0	0	0	0	0
4	SAO	0	0	0	0	0	0	0

The performance of PID, PSO, GWO and SAO when there is no load change in the system is presented in Table 4.1. The system operates at normal condition because no disturbances in the system

4.1.2 Scenario 2: Primary controller

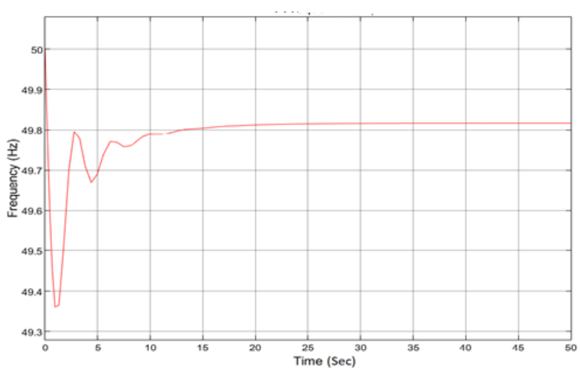


Figure 4.2 a. Frequency deviation for Area 1

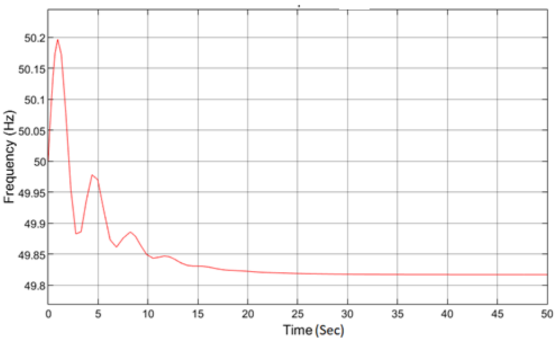


Figure 4.2b frequency deviation for Area 2

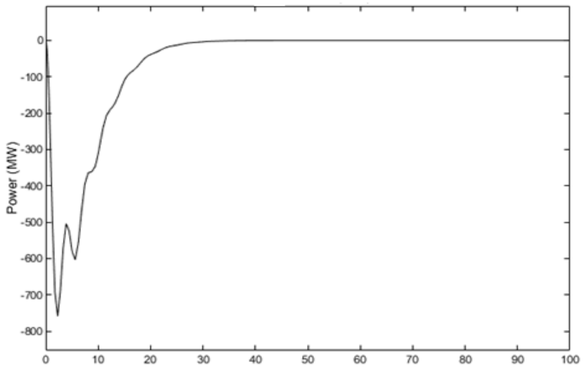


Figure 4.3c Tie line power

4.1.3 Scenario 3: conventional PID controller

In this section, the performance of PID controller is investigated when there is change in load in both areas of $\delta P_{L_1} = 0.24$ and $\delta P_{L_2} = 0.08592$ area1 and area2 respectively. Figure 4.3a 4.3b presents the frequency deviation of area 1 and area 2 respectively, tie line result is also presented in figure 4.3c.

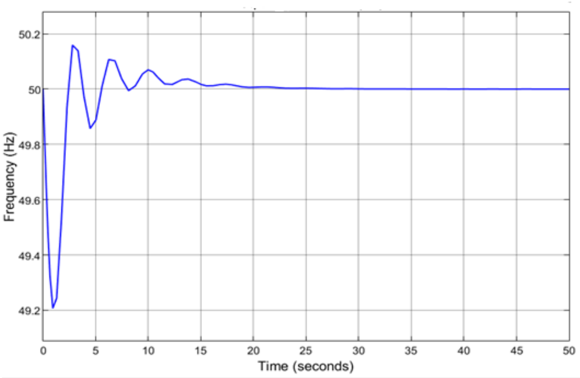


Figure 4.3a frequency deviation for Area 1

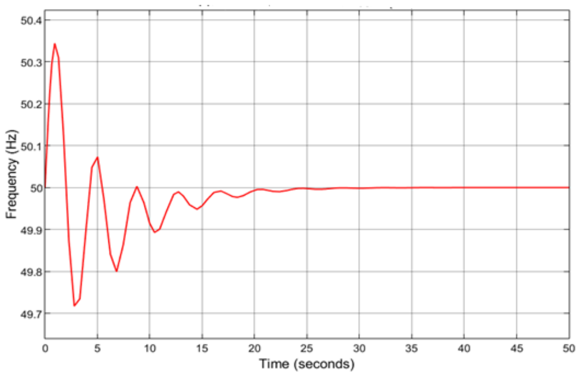


Figure 4.3b frequency deviation for Area 2

Table 4.2 Performance of PID controller

	SCOPE	Overshoot		Undershoot		Settling time (s)	
Area	AREA	Area-1	Area-2	Area-1	Area-2	Area-1	Area-2
1	Frequency deviation (Hz)	50.02Hz	50.35Hz	49.72Hz	49.73Hz	27s	28s
2	Mechanical power (MW)	900MW	300MW	-750MW	-1600mw	22s	23s
3	Tie line power (MW)	0		-750MW		29s	

The performance of PID controller is investigated when there is change in load of $\delta P_{L_1} = 0.24$ at area 1 and $\delta P_{L_2} = 0.08592$ area 2. The controller is able to reduce the oscillation and the settling time.

4.1.4Scenario 4: Increase in load in area 1 only

The system was studied in the presence of load increase in area 1 only. The performance of PID, PSO, GWO and SAO controllers ware studied and the plots of frequency deviation and tie line power for the conventional controller, PSO, GWO and SAO are presented in Figure 4.4.

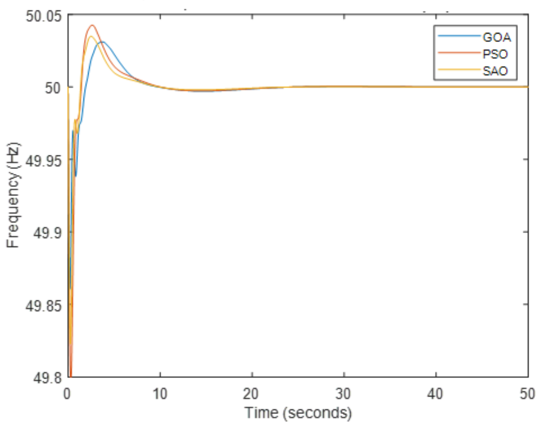


Figure 4.4a frequency deviation for Area-1

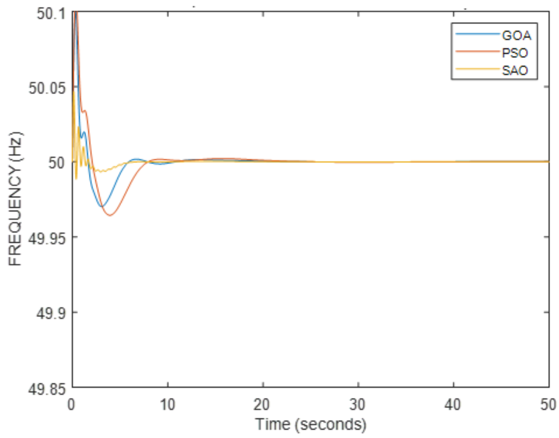


Figure 4.4b frequency deviation for Area-2

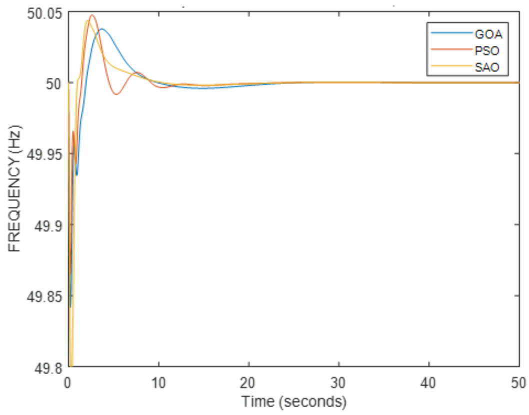


Figure 4.5a frequency deviation for Area 1
Figure 4.4b frequency deviation for Area-2

Table 4.3 Performance of PID,PSO,GWO and SAO when load change at Area 1 only.

	Controller	Overshoot		Undershoot		Settling time (s)		Objective function
		Area-1	Area-2	Area-1	Area-2	Area-1	Area-2	
1	PID	50.05	50.025	49.19	49.8	40	80	
2	PSO	50.04	50.1	49.98	49.965	11	11	0.05792
3	GWO	50.03	50.07	49.86	49.97	10.23	10	0.04704
4	SAO	50.035	50.3	49.99	49.99	9.07	5	0.0231

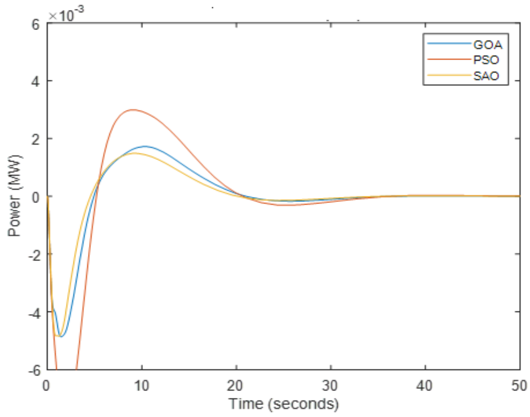


Figure 4.4c Tie-Line power (MW)

The performance of PID controller is investigated when there is change in load of $\delta P_{L_1} = 0.24$ at area 1 and $\delta P_{L_2} = 0$ at area 2. The objective functions of the controllers show SAO has better performance compared to PID, PSO and GWO.

4.1.5Scenario 5: Decrease in load in area 2 only

In this case, the load change is only applied to area-2 while the load disturbance at area-1 is zero ($\delta P_{L_1} = 0$ and $\delta P_{L_2} = 0.08592$).

The performance of PID, PSO, GWO and SAO controllers ware studied and presented in Figure 4.5.

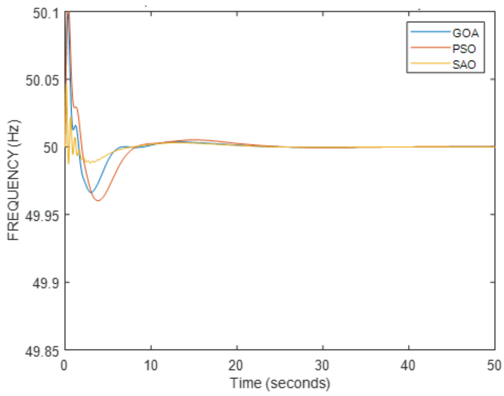


Figure 4.5b frequency deviation for Area 2

Table 4.4b Performance of PID,PSO,GWO and SAO when load change at Area 2 only

	Controller	Overshoot (Hz)		Undershoot (Hz)		Settling time (s)		Objective function
		Area-1	Area-2	Area-1	Area-2	Area-1	Area-2	
1	PID	50.1	50.35	49.2	49.83	40	32	
2	PSO	50.04	50.1	49.98	49.965	9	11	0.02892
3	GWO	50.025	50.07	49.93	49.97	8.7	10	0.028946
4	SAO	50.032	50.3	49.9	49.99	7.89	5	0.02019

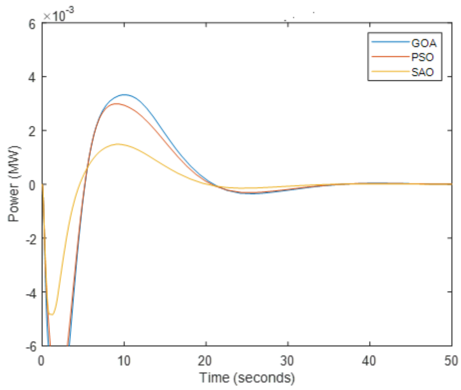


Figure 4.5c Tie-Line power (MW)

The performance of PID controller is investigated when there is change in load of $\delta P_{L_1} = 0$ at area 1 and $\delta P_{L_2} = 0.08592$ at area 2. The objective functions of the controllers shows SAO has better performance compared to PID, PSO and GWO. The controllers are able to reduce the oscillation and the settling time.

4.1.6Scenario 6: Increase in load in area 1 and decrease in load in area 2 simultaneously.

The performance of PID, PSO, GWO, and SAO controllers were investigated when there is change in load of $\delta P_{L_1} = 0.24$ at area 1 and $\delta P_{L_2} = 0.08592$ area 2 simultaneously. The performance of PID, PSO, GWO and SAO controllers ware studied and the plots of frequency deviation and tie line power for the conventional controller, PSO, GWO and SAO are presented in Figure 4.6.

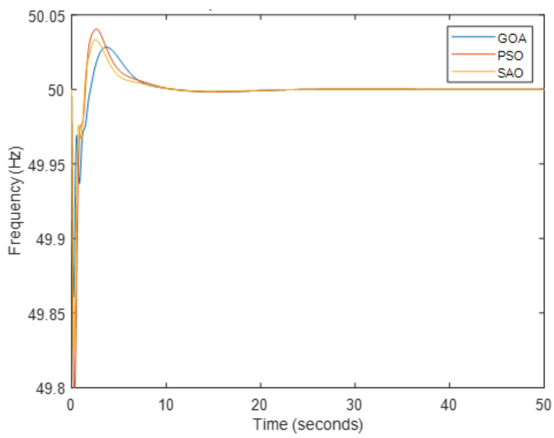


Figure 4.6a frequency deviation for Area-1

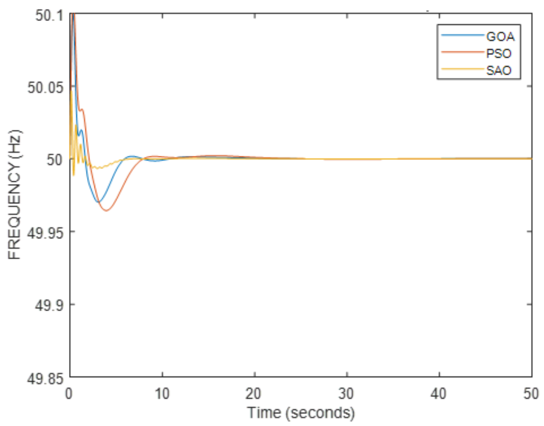


Figure 4.6b frequency deviation for Area-2

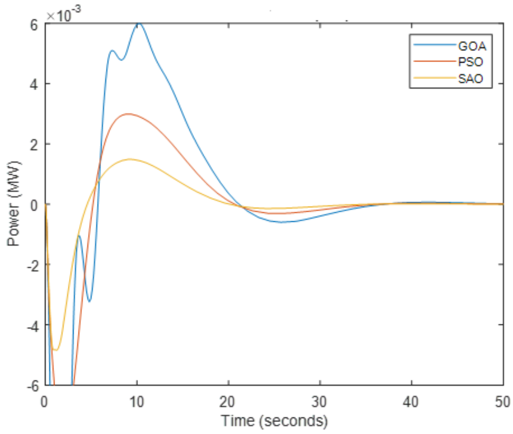


Figure 4.6c Tie-Line power (MW)

Table 4.5 Performance of PID,PSO,GWO and SAO when load change at Area 1 and Area 2.

	Controller	Overshoot		Undershoot		Settling time (s)		Objective function
		Area-1	Area-2	Area-1	Area-2	Area-1	Area-2	
1	PID	50.075	50.4	49.99	49.98	100	35	---------
2	PSO	50.05	50.13	49.98	9.6	35	9	0.014632
3	GWO	50.035	50.093	49.99	49.65	27	12	0.025882
4	SAO	50.04	50.07	50	49.98	8	9	0.020189

The performance of controllers was investigated when there is change in load of $\delta P_{L_1} = 0.24$ at area 1 and $\delta P_{L_2} = 0.08592$ at area 2. The objective functions of the controllers show SAO has better performance compared to PID, PSO and GWO. The controllers are able to reduce the oscillation and the settling time.

V. Conclusion

In power system, the mismatch between the total power generated and the total electrical load demand causes frequency deviation. Area frequency and tie-line power interchange both fluctuate in an interconnected power system as a power load demand does. The term "LFC" stands for power system frequency control. LFC has generally been a part of automatic generation control (AGC), and it is currently one of the key research control groups. This simulation was carried out under 6 different scenarios, these are; No load change in the system as first case, increase in load in area 1 only case 2, case 3 as decrease in load in area 2 only, increase in load in area 1 and decrease in load in area 2 simultaneously as case 4, introduce PID control case 5, optimize the PID parameters using Smell Agent Optimizing Algorithm (SAO) and validate by comparing the SAO based controller with particle swarm optimization method as case 6.In this research, PID controller was introduced into the two-area power system and the performance of PID controller is investigated when there is change in load of $\delta P_{L_1} = 0.24$ at area 1 and $\delta P_{L_2} = 0.08592$ area 2. The controller is able to reduce the oscillation and the settling time of the frequency deviation and tie-line power change.A novel optimization algorithm knowns Smell Agent Optimization algorithm was also used to optimize the PID parameters when there is increase of $\delta P_{L_1} = 0.24\,p.u$ in load in areas-1 and decrease in load of $\delta P_{L_2} = 0.08592\,p.u$ in area-2. The simulation was done when the network experienced load change in area-1 only as case-1, load decrease in area-2 only and load increase in area-1 and load decrease in area-2 simultaneously. From the simulation results, the proposed algorithm Smell Agent Optimization algorithm optimized the PID parameters and obtained good results.The performance of the proposed SAO was compared with that of GWO and PSO and it was found that SAO has better performance compared to PID, PSO and GWO by reducing the oscillation and the settling time of the frequency deviation and tie-line power change.

5.2 Recommendations

The followings are recommended for further studies.

- Energy storage device can be included into the system
- The newly constructed power plant should be considered
- The system can be extended to LFC of micro-grid or smart-grid system
- Price-based LFC techniques can be used to improve frequency profile of the system
- The performance of the suggested method can be increased by incorporating additional metaheuristics or evolutionary algorithms.

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