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**RESEARCH ARTICLE - ENGINEERING**

AGC Including ELD and Emission Coordination Using Sine Cosine Algorithm

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Abstract

The aim of conventional AGC is to regulate the demand load of the area with taking into account the sharing power with the others area and also the frequency deviation and tie-line power deviation within minimum error steady-state. The proposed coordination's goal is to regulate the demand load between the interconnected area when taking into account the optimal dispatch and emission effect. The two-area that be consist of three units in each one (hydro, thermal, and gas) is used of proposed system. The optimization algorithms were used to find the best operating point of the system by tuning the integral gain are located in ACE that named primary control and Generation allocation logic named secondary controller. The Particle Swarm Optimization (PSO) and Sine Cosine Algorithm (SCA) are used to tune gains of the integral (I) controller to show the superiority in identifying robust controller. The simulation results prove that the SCA with proposed coordination is very effectiveness as compared with PSO algorithm in enhance the dynamic performance and reduce overshoot, maximum frequency deviation, and net tie line power flow deviation error for a given load change and disturbed the demand load between two-area as economic.

Keywords: AGC; ELD; SCA algorithm’s; algorithm; coordination ELD and AGC

1. Introduction

The basic purpose power system is to maintain sufficient generation to fulfill load at the lowest possible utility cost. This goal must be reached while keeping the frequency of the system within the defined tolerance range. The power system, which is commonly referred to as the power system control area [1-5], is made up of massive linked power generators. Because of the open competitive market between many generations and distributors, the electricity industry's landscape has changed. As a result, the electricity sector plays a critical role in ensuring a constant supply of energy, low operating costs, and all other economic aspects of the electricity system [6-11]. The linked power system's reliable and low-cost functioning is dependent on multiple layers of the automatic generating control system, which ensures that the generator's power production is followed by changes in electric power demands.

Automatic generation control (AGC) adjusts output generation at 'all times', whereas economic load dispatch adjusts the 'participation factors every few minutes' to reduce the overall generating cost of the system [12]. The researchers previously addressed the issues of Automatic Generation Control [13-14]. For a single area as well as a multi-source interconnected power system, a resilient and decentralized controller [15-22] is proposed. The AGC keeps the system stable by performing generation control as needed to meet load demand. Rather than improving economic efficiency, the majority of these efforts are aimed at improving AGC control performance, such as stability and transient dynamics. AGC techniques with an ELD feature that operates on a slower time scale and interacts with the AGC frequency stabilization function are described in references [23-24]. However, each power plant's generation should be planned within the range, be cost-effective, and in terms of economics, maintain a balance between generation and demand [31]. To improve economic performance, AGC should be combined with economic load dispatch (ELD). The genetic algorithm (GA) has been used to study load frequency control with economic load dispatch for a variety of applications [25]. in [12] the authors using different optimization technique (firefly, harmony search, genetic algorithm, Ant Colony Optimization).

Nomenclature

AGC	Automatic Generation Control	IAE	Integral Absolute of Error
ELD	Economic Load Dispatch	ITSE	Integral Time Square Error
PSO	Particle Swarm Optimization	ITAE	Integral Time Absolute Error
SCA	Sine Cosine Algorithm	PF	Participation Factor
ACE	Area Control Error	SLP	Step Load Perturbation
ISE	Integral Square of Error		

The genetic algorithm method using in multi-area five unit discussed in [26]. The use of the fuzzy control algorithm to study the economic load dispatch coordination with automatic generation control [27].

In the gap of previous studies have not focused on ELD with AGC. This study provides a new technique which is known as Sine Cosine Algorithm (SCA) and compared it with PSO algorithm in order to tune the gains of primary and secondary controller to operate the system as economically.

This paper organized as: section II described the proposed system. Section III described Modeling of Classical Economic Load Dispatch. Section IV described Coordination of AGC and ELD Using Base Point and Participation Factor. Section V described the algorithm of SCA. Finally illustrated the simulation result and conclusion in section VI.

2. Research Method

In order to overcome the AGC issues and to maintain generation load balance and keeping system frequency within acceptable ranges, the coordination of AGC with ELD is used. The aim of proposed coordination can be expressed into two key tasks:

1- Calculated the cost operation of the power system by economic load dispatch (ELD), which in turn assigned the online generating units with the goal of fulfilling total system demand in the most cost-effective way possible. This optimization is performed discretely every few minutes.

2- However, the load varies from one ELD run to the next. To keep the system frequency within acceptable bounds, the outputs of online generators must be changed in response to changes in demand.

In order to perform the proposed coordination, the power system under study which include two –area six unit is explained as below:

2.1. Power system under study

A two-area, six-unit nonlinear system with diverse energy sources is considered in the first stage of AGC analysis. In this regard, the first control area, which has a rated capacity of 1200MW, consists of a thermal system, a hydro system, and a gas generating system that generates power to meet the connected load demand of 700MW. The second control area has a rated capacity of 1470MW and uses the same generating units that generates power to meet the connected load demand of 1100MW. The input fuel coefficient and quadratic equation is listed in table 1. The transfer function of each station is showing in fig. 1. The parameters of thermal, hydro, and gas station are depicted in appendix.

3. Modeling of Classical Economic Load Dispatch

The most equations and constraints that need to coordinate the ELD and AGC are explained as follows [28]:

3.1. Quadratic cost function

The cost of operation plays an important part in the economic operation of generating units. It is assumed that the function of cost Ci is known for each unit. The problem is to achieve each unit of power generation in such a way that the total cost of production (the objective function) as specified by.

$$C_t = \sum_{i=1}^{ng} C_i = \sum_{i=1}^{n} \alpha_i + \beta_i P_i + \gamma_i P_i^2 \tag{1}$$

Where the total cost of production is C_t, C_i is i^{th} unit cost of production, P_i is the i^{th} unit generation, P_D is the total demand, and n_g is the number of dispatch able units.

3.2. Constraints on equality and the expense of additional fuel

The optimum load dispatch condition is:

$$\beta_i + 2\gamma_i P_i = \lambda \tag{2}$$

The total load demand is calculated by adding all of the generation. It can be stated as follows:

$$\sum_{i=1}^{ng} P_i = P_d \tag{3}$$

Equation (3) is the equality constraints. Without limits of generator, for economic operation, all units must be operating at the same incremental cost with satisfying equation (3). For finding the solution, Equation (2) is to be solved for P_i.

$$P_i = \frac{\lambda - \beta_i}{2\gamma_i} \tag{4}$$

The relations provided by equation (4) are known as (coordination equations), and they are functions of incremental cost λ. Analytic solution may be found for λ when we substitute for P_i in Equation (2), that is

$$\lambda = \frac{P_D + \sum_{i=1}^{ng} \frac{\beta_i}{2\gamma_i}}{\sum_{i=1}^{ng} \frac{1}{2\gamma_i}} \tag{5}$$

The value found for λ from equation (5) is to be substituted in equation (2) to get the generation optimal scheduling.

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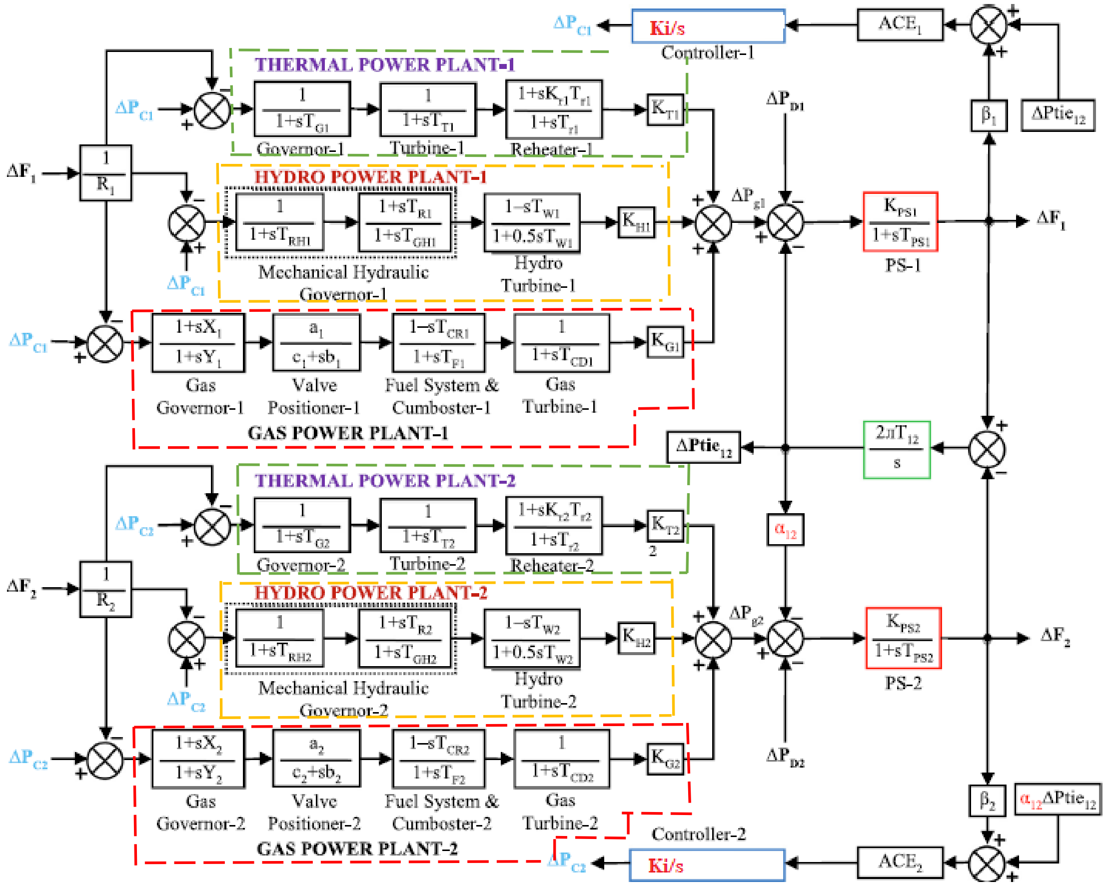


Fig. 1 Transfer function model of two-area six-unit power system model

4. Coordination of AGC and ELD Using Base Point and Participation Factor

T Assume that the cost versus output power equation has the first and second derivatives (F'_i and F''_i). The machine incremental cost changes from $\lambda°$ to $\lambda°+\Delta\lambda$ as the unit load is shifted by a sum ΔPi. On this single unit, a slight change in output power,

$$\Delta\lambda_i = \Delta\lambda \cong F''i\,\Delta Pi \tag{6}$$

This holds true for each of the "system's N units", implying that

$$\Delta P_1 = \Delta\lambda / F''_1 \tag{7}$$

$$\Delta P_2 = \Delta\lambda / F''_2 \tag{8}$$

$$\Delta P_N = \Delta\lambda / F''_N \tag{9}$$

The relationship of $\Delta\lambda$ and ΔP_i is shown in Fig, 2.

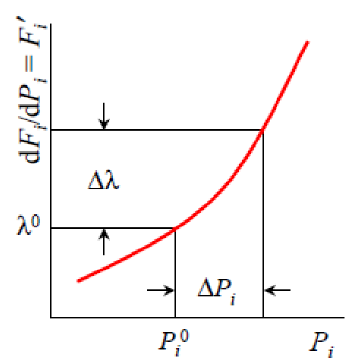


Fig. 2 Relationship of $\Delta\lambda$ and ΔP_i

The number of the individual unit changes is, of course, the overall change in generation (change in total system demand). Generation total change (= system demand total change) is, the sum of changes of individual units.

Let the generators total demand equal P_D, where

$$P_D = P_{\text{load}} + P_{loss} \tag{10}$$

then

$$\Delta P_D = \Delta P_{D1} + \Delta P_{D2} + \cdots + \Delta P_{DN} \tag{11}$$

Each unit participation factor is

$$p_{fi} = \left(\frac{\Delta P_i}{\Delta P_D}\right) = \frac{(1/F_i^{"})}{\sum_i (1/F_i^{"})} \tag{12}$$

The computer accomplishment of such an economic dispatch scheme is easy. It could be achieved by providing tables of F_i'' values as a function of load levels and devising an easy scheme to look up these data and calculate the factors using the current load plus the expected rise.

A less elegant method of calculating participation factors would be repeated computing of economic dispatch at $P_D^{\circ}+\Delta P_D$. The participation factors are calculated by subtracting the base-point values of economic generation from the current values of economic generation and dividing the difference by ΔP_D.

If (ΔP_D)is the total load change in the system, then the following equations represent the generation change of each individual unit:

$$\Delta P_{Gi} = Pf_i \times \Delta \mathrm{P}_D \tag{13}$$

$$P_{ides} = Pf_i \times \mathrm{P}_{base} \tag{14}$$

$$\sum_{i=1}^{n} \mathrm{Pfi} = 1 \tag{15}$$

where “ P_{ides} is the desired output from i^{th} unit and pfi, the participation factors for i^{th} unit while ΔP_{Gi}, the incremental change from the base point generation of the individual unit”. The frequency control error is calculated and put into the ELD to determine the particepation value for each unit. Sensing and propagating changes in the electric load in the power system that back to the area control error controls the frequency of the power system. Fig. 3 depicts a two-area six-unit system with thermal, hydro, and gas power sources, as well as their linkages, including ACE, ELD participation value, tie line, and power system connections.

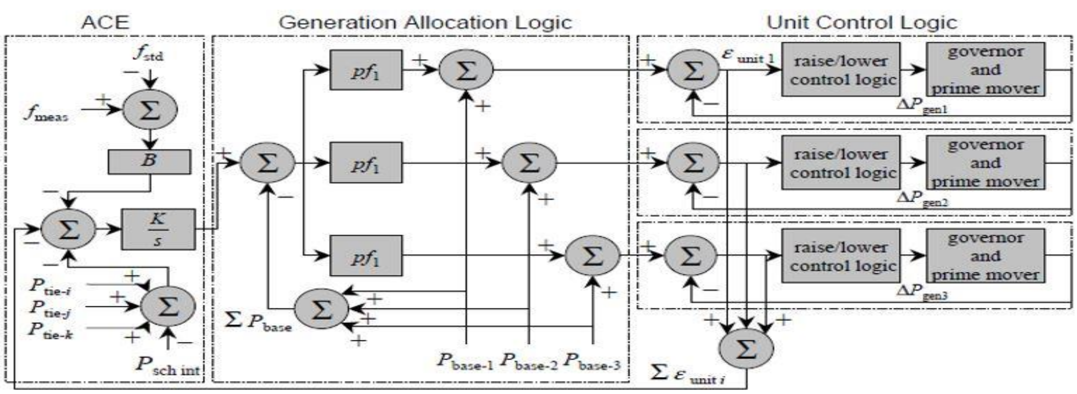


Fig. 3 Coordination of ELD with AGC

5. Sine Cosine Algorithms (SCA)

In general, population-based optimization algorithms start with a random number of solutions. [29]. This random set is evaluated on a regular basis by an objective function and enhanced by a set of rules that form the foundation of technique optimization. No solution can be found in a single sprint because population-based optimization strategies stochastically search for the optimal of issues with optimization. Regardless of the differences in stochastic population optimization algorithms, the likelihood of finding the global optimum improves with a large number of random solutions and optimization steps (iterative), The optimization process is typically divided into two stages: discovery and exploitation. The random solutions in the solution set are abruptly linked with a high randomness in the first point, allowing the promising areas of the search space to be recognized. However, random solutions move progressively over the operating process, and random differences are far lower than during the discovery phase.

The following updating positions are suggested in this work for the follo-wing two phases:

$$"X_i^{t+1} = X_i^t + r_1 \times \sin(r_2) \times |r_3 P_i^t - X_i^t|" \tag{16}$$

$$"X_i^{t+1} = X_i^t + r_1 \times \cos(r_2) \times |r_3 P_i^t - X_{i_i}^t|" \tag{17}$$

Where " X_i^t is the position of the current solution in *i-th* dimension at *t-th* iteration $r_1/ r_2 /r_3$ are random numbers, P_i is position of the destination point in *i-th* dimension, and | | indicates the absolute value".

These two equations are combined to be used as follows:

$$X_i^{t+1} = \begin{cases} X_i^{t+1} = X_i^t + r_1 \times sin(r_2) \times |r_3 P_i^t - X_i^t| & r_4 < 0.5 \\ X_i^{t+1} = X_i^t + r_1 \times \cos(r_2) \times |r_3 P_i^t - X_i^t| & r_4 \geq 0.5 \end{cases} \tag{18}$$

Where r_4 is the random number in [0,1]

There are four major parameters in (SCA), as the equations above show: r_1, r_2, r_3 and r_4. Parameter "r_1 determines the area of the next location (or direction of motion that can be in space between or outside the solution". The "r_2 parameter determines the distance to or beyond the endpoint of the movement". The "r_3 parameter provides a random weight for your destination to emphasize the effect of destination in the distance determination by stochastic means ($r_3 > 1$) or deemphasize ($r_3 < 1$)". Finally, the parameter r_4 is switches between the sine and cosine components in Eq. (18).
Because of the employment of the sine and cosine in this language, this the algorithm as known as the Sine Cosine Algorithm (SCA). The effects of Sine and Cosine mechanism on Eqs. (16) and (17) are illustrated in Fig. 4. The figure depicts how the suggested equations explain two solutions of search space. While a two-dimensional model is presented in the graphic above, the equation can be stretched to higher dimensions.

Fig. 4 Effects of Eqs. (13) and (14) on the next position

The cyclic sine and cosine function model allows a solution to be repositioned around another solution. It is possible to guarantee the usage of the space between two solutions. Solutions should be able to scan beyond the space between their respective destinations for searches [30]. The range of the sine and cosine functions, as seen on the Fig. 5. The fig. 5 shows a mathematical model of the effect of the functional sine and cosine of the spectrum in [−2, 2].

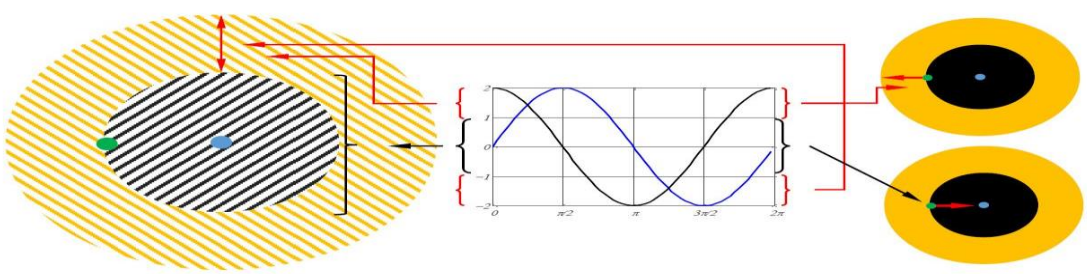


Fig. 5 Sine & cosine with range in [−2,2] allow a solution to go around or beyond the destination

6. Controller Structure and Objective Function

In order to investigate the aim of AGC for the two-area six units' scheme, the I controller is used. The respective ACEs are the control inputs of I controllers, and the outputs of I controllers are the inputs of power systems as shown in Fig. 6. For low computational burden and also for eliminating the steady state error of the controlled output to match the reference input exactly, the integral term (I) is used for primary and secondary controllers. The I controller transfer function is:

$$TF_{PID} = \frac{K_i}{s} \tag{19}$$

The K_i are the electric governor gain. The inputs to the I-controllers are the area control error (ACE) of respective areas and controlled inputs (u_1 ,u_2) to the plant with I-controller structure are defined as follows:

$$ACE_1 = B\Delta f_1 + \Delta P_{tie,12} \tag{20}$$

$ACE_2 = B\Delta f_2 - \Delta P_{tie,12}$ (21)
$u_1 = K_{i1} \int ACE_1 \, dt$ (22)
$u_2 = K_{i2} \int ACE_2 \, dt$ (23)

It obvious from these equations, the ACE is in terms of the (Δf_1 & ΔP_{tie}). The (Δf_1 & Δf_2) are the deviations in frequency, and ΔP_{tie} is the tie-line power deviation between area-1 and area-2. ACE is treated as the AGC system and the controlled output, which is used to detect any incompatibility between power generation and load demands.

For fixing the controller parameters, an objective function is formulated based on the predicted provisions and restraints. In engineering, the classical implemented objective functions are the IAE (integral-absolute error), ISE (integral-squared error), ITAE (integral-time-multiplied-AE) and ITSE (integral-time-multiplied-ISE).

Most used function is the ITSE due to its easier calculation and its permission to separate underdamped from overdamped system. The elements of negative error are eradicated because the ITSE squares it. In addition, the ITSE penalizes the errors which are large more than smaller ones and provides fast responses. As time passes, it allows small oscillations. The results explain that the tuning based on ITSE has less iterations for global convergence in comparison with other methods. The ITSE and other cost functions are:

$ISE = \int_0^T \{\Delta F_1^2 + \Delta F_2^2 + \Delta Ptie_{12}^2\} dt$ (24)

$IAE = \int_0^T \{|\Delta F_1| + |\Delta F_2| + |\Delta Ptie_{12}|\} dt$ (25)

$ITSE = \int_0^T t\{\Delta F_1^2 + \Delta F_2^2 + \Delta Ptie_{12}^2\} dt$ (26)

$ITAE = \int_0^T t\{|\Delta F_1| + |\Delta F_2| + |\Delta Ptie_{12}|\} dt$ (27)

where (T) is the final simulation time. The parameters of I controllers are limited in order to help the optimization algorithm to achieve the best parameter as fast time. So, the optimal AGC problem design can be formulated as follows:

$$\left.\begin{array}{l} K_{Imin} \le K_I \le K_{Imax} \text{ for AGC} \\ K_{Imin} \le K_I \le K_{Imax} \text{ for ELD} \end{array}\right\} \quad (28)$$

The equation (28), it is indicated the limited values of tune I by SCA and PSO algorithms. In order to illustrate the process of tuning gains for primary and secondary controllers, the flowchart is shown in fig. 7.

7. Simulation Results

The main goal is to evaluate the efficiency and the applicability of the proposed SCA algorithm in the electricity system with economic load dispatch to address the AGC issue. Two test systems, including the algorithm, are implanted. Hydro-Thermal-Gas power plant and dynamic output of two-area six-unit are being tested under natural and disturbed conditions. The MATLAB platform is used to simulate an interconnected power system. Test models are built in a SIMULINK environment, while a MATLAB code is written individually in the .m file of the proposed optimization technique. For each control area with the SCA algorithm, I controllers with ITSE-based fitness are built separately.

The parameters of transfer function in the figure 1 are listed in the appendix. Table 1 shows the economic values and table 2 shows the optimizer gains of primary and secondary controllers. To demonstrate the efficiency of the SCA in solving the system, a 0.05-p.u. step load perturbation (SLP) is applied to the first area (area 1) from t=0 to 400 s. (system load becomes 1050MW). In this article, the initial population consists of 20 search agents, with a maximum iteration of 10 iterative. The ITSE is used as an objective function to tune the parameters of the secondary controller, which acts as an AGC controller, as well as the parameters of the primary controller, which acts as a speed changer for the governor, to achieve the desired benefit of economic load dispatch. Table 1 also includes the optimal values for secondary and primary controllers. The cost function (J) is shown in Fig. 8 (a&b), with the ITSE value for the I controller being J=0.0075 for SCA algorithm and 0.008 for PSO algorithm.

At t=0 s to 400 s, the behavior of a power system with only AGC and without ED is investigated in the first step. The frequency response, the net tie-line power change, ACE of each area, deviation of mechanical power in each area1,

deviation of mechanical power in each area2, and the total mechanical power of each area are shown in Fig. 9 (a &b) to 15(a &b) respectively. It is obvious that all the dynamic responses during this period are deviated at zero in the steady state region which implies the AGC objective is investigated for regulating the own load of each area without interchange power between the two area. In another period (400 s to 600 s) at same figure, the integrated of ELD with AGC is considered in the proposed system with the same SLP (0.05 pu), and it is obvious that all the dynamic responses during this period are not deviated at zero at steady state region which means the ECO-AGC objective is investigated for regulating the load of each area with interchange power between the two area from the area of less operation cost to the area of high operated cost. That is, the SCA algorithm has superiority over PSO algorithm in terms of less over shoot and fast tracking with less minimum fitness error.

Finally, for robust test of the proposed coordination between ELD and AGC based on SCA for employing the integral parameters of secondary and primary controllers is considered at the last periodic in same figures which is started from 600 s to 1000 s, the ECO-AGC is considered with severe SLP (0.1 pu at area 1). It is obvious that all the dynamic responses during this period are responded for economic values and the interchange power through the tie line is increased due to the SLP is increased which means the ECO AGC is worked as economic.

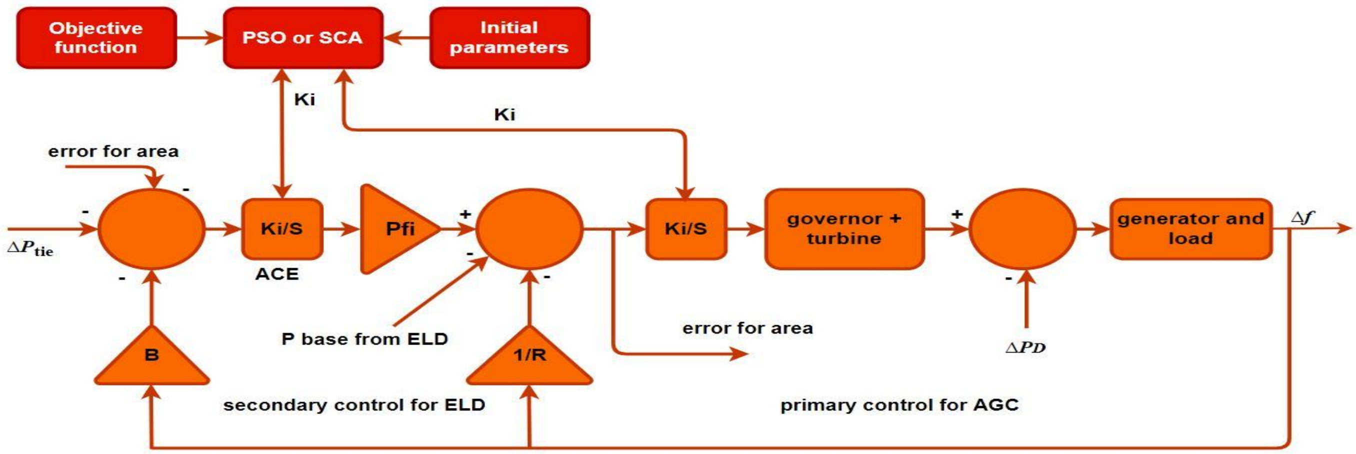


Fig. 6 Proposed Coordination of ELD and AGC with optimal Control

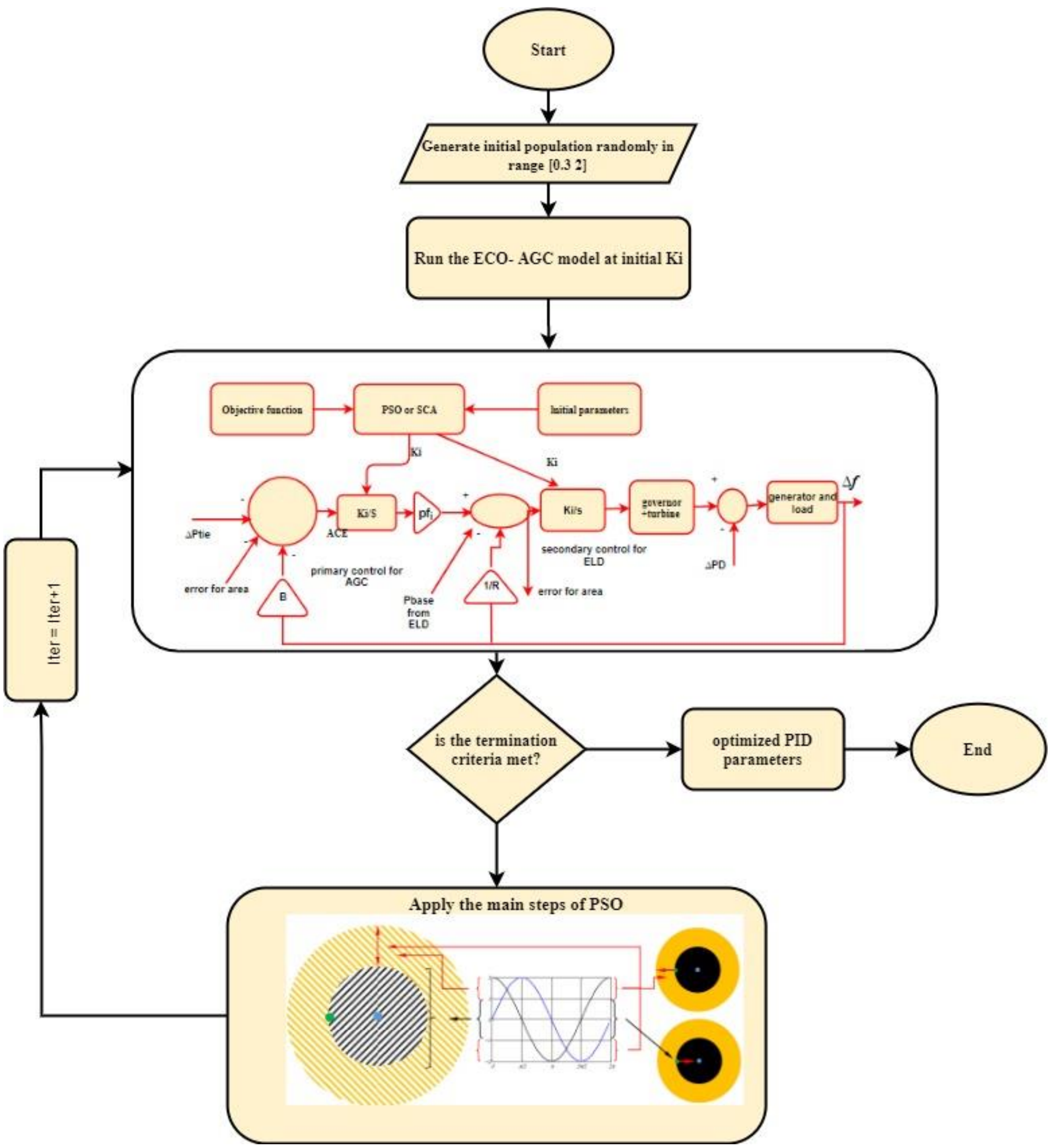


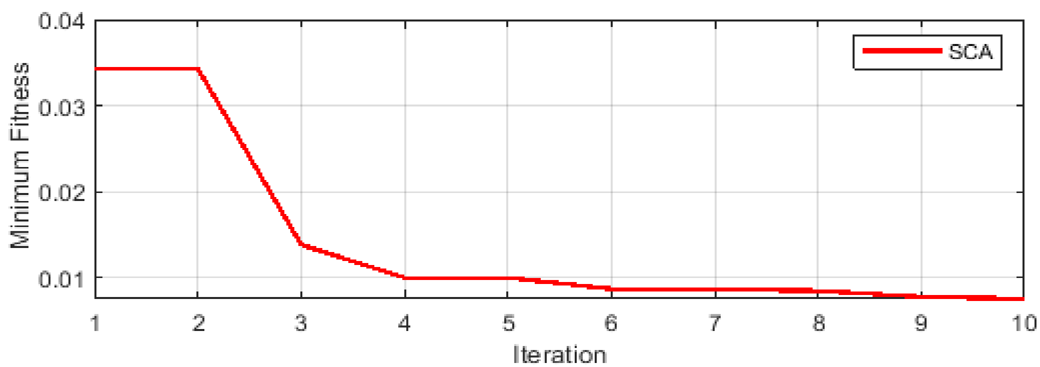
Fig. 7 Flowchart of proposed optimal ECO-AGC

Table 1 inputs constraints and results of economic load dispatch based

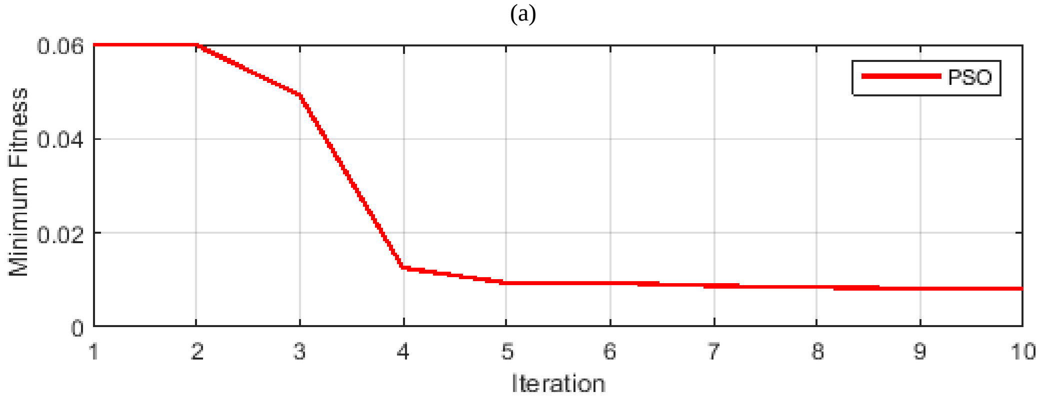
Parameter		Area 1		Area 2
Incremental cost (system lambda) $/MWh	λ_1	19.117271	λ_2	16.181335
Participation Factor	P_{f1}	0.469974	P_{f4}	0.398268
	P_{f2}	0.377918	P_{f5}	0.300866
	P_{f3}	0.152108	P_{f6}	0.300866
Optimal Dispatch	P_1	525.203762	P_4	524.675325
	P_2	400.000000	P_5	287.662338
	P_3	164.796238	P_6	287.662338
Total generation cost $/h	C_{T1}	20867.30	C_{T2}	18564.86
Load Demand MW	P_{D1}	1000	P_{D2}	1100
Generating Unit Cost Function	Unit1	$1122 + 15.84P1 + 0.003124P1^2$	Unit4	$950 + 13.41P4 + 0.002641P4^2$
	Unit2	$620 + 15.70P2 + 0.003880P2^2$	Unit5	$560.5 + 14.17P5 + 0.003496P5^2$
	Unit3	$156 + 15.94P3 + 0.009640P3^2$	Unit6	$560.5 + 14.17P6 + 0.003496P6^2$
Constraints MW	Unit1	150min. – 600max,	Unit4	140min. – 590max.
	Unit2	100min. – 400max.	Unit5	110min. – 440max.
	Unit3	50min. – 200max.	Unit6	110min. – 440max.

Table 2 Optimization gains based on SCA and PSO algorithms

Parameter	Area 1				Area 2			
	PSO		SCA		PSO		SCA	
Primary Integral controller gains	K_{i1}	1.2	K_{i1}	1.124	K_{i4}	1.1987	K_{i4}	1.1103
	K_{i2}	0.8820	K_{i2}	1.1942	K_{i5}	1.01457	K_{i5}	0.7668
	K_{i3}	0.38323	K_{i3}	0.4276	K_{i6}	0.31170	K_{i6}	0.4646
Secondary Integral controller gains	K_{i1}	1.2	K_{i1}	0.99549	K_{i2}	0.9910	K_{i2}	0.85321
Minimum fitness	**0.008**		**0.0075**		**0.008**		**0.0075**	



(a)



(b)

Fig. 8 Minimum fitness of the proposed algorithm for test system based on; (a) SCA, (b) PSO

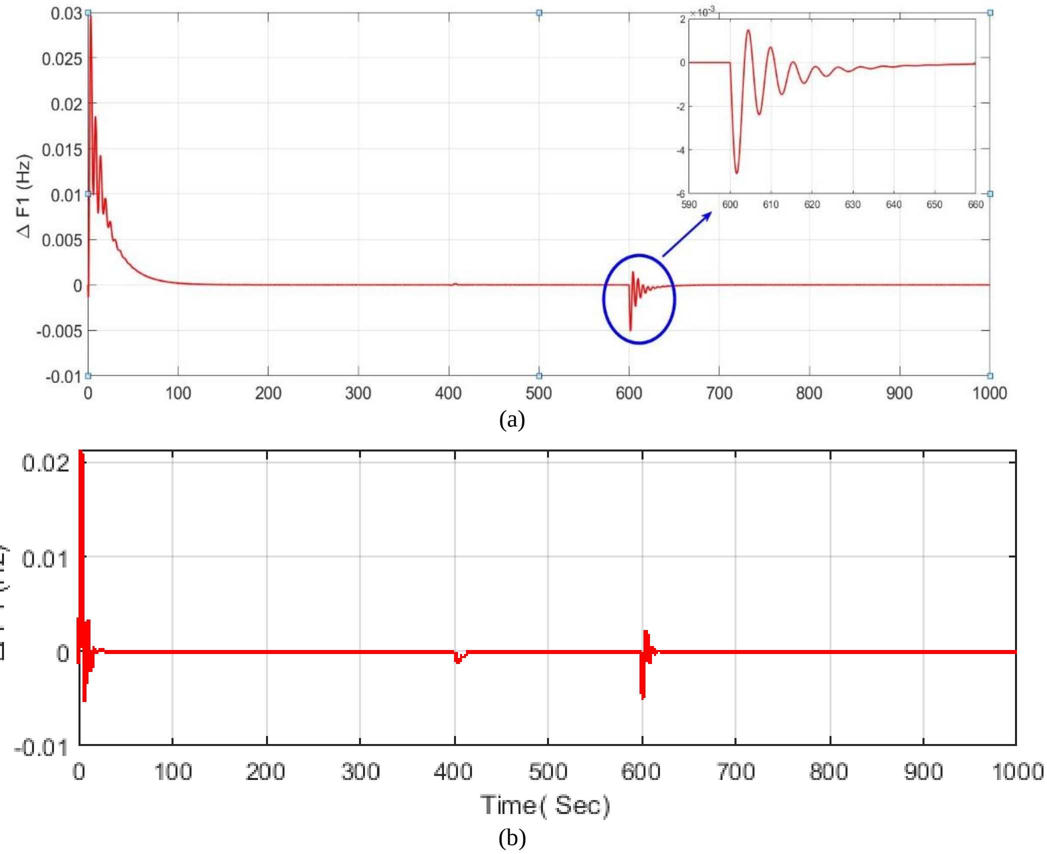


Fig. 9 The deviation of frequency at area 1 based on; (a) SCA, (b) PSO

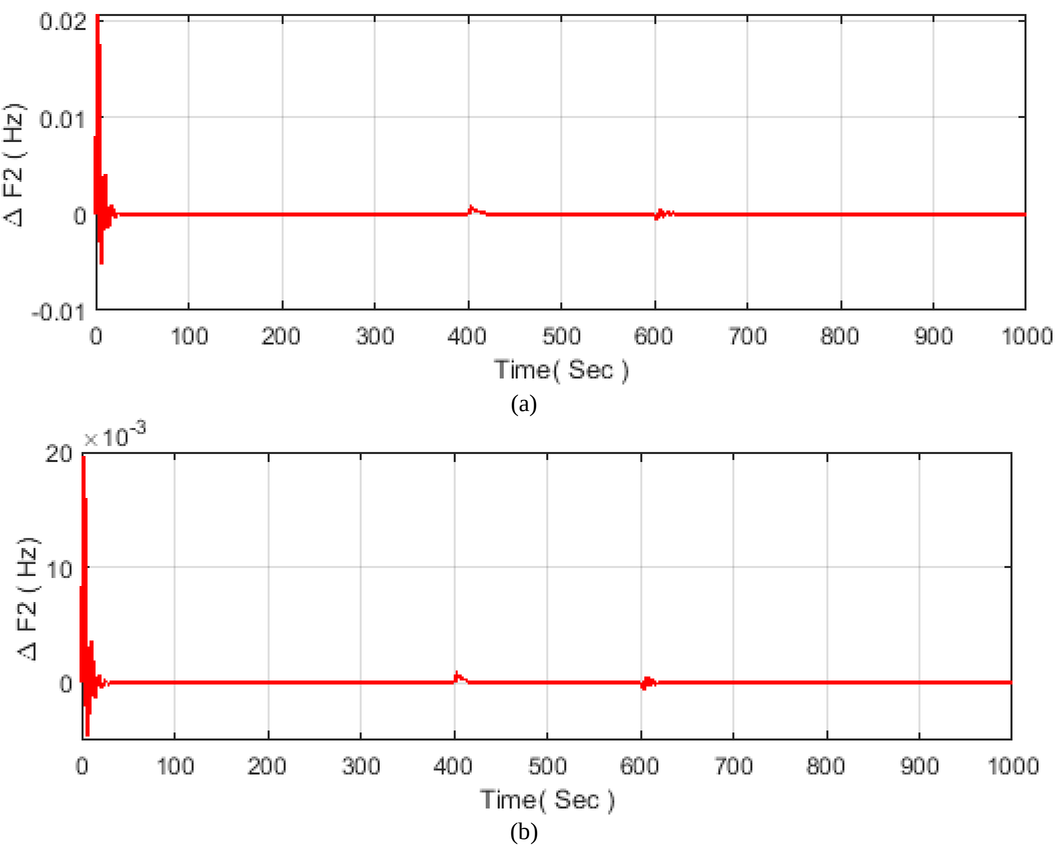
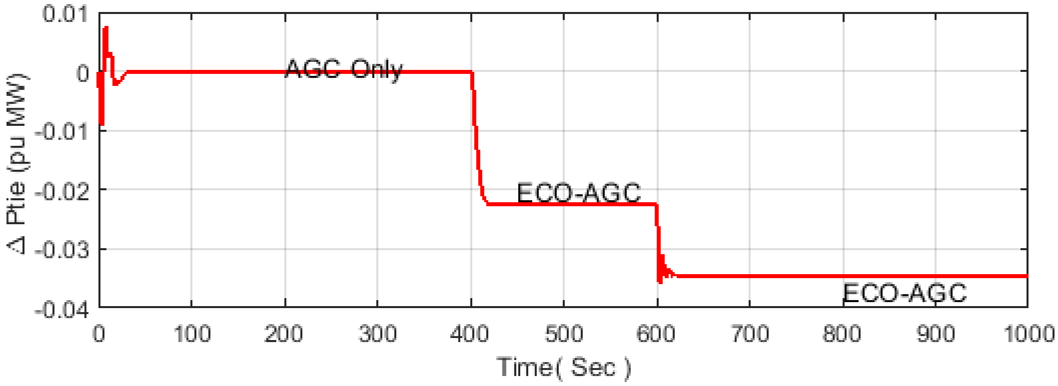
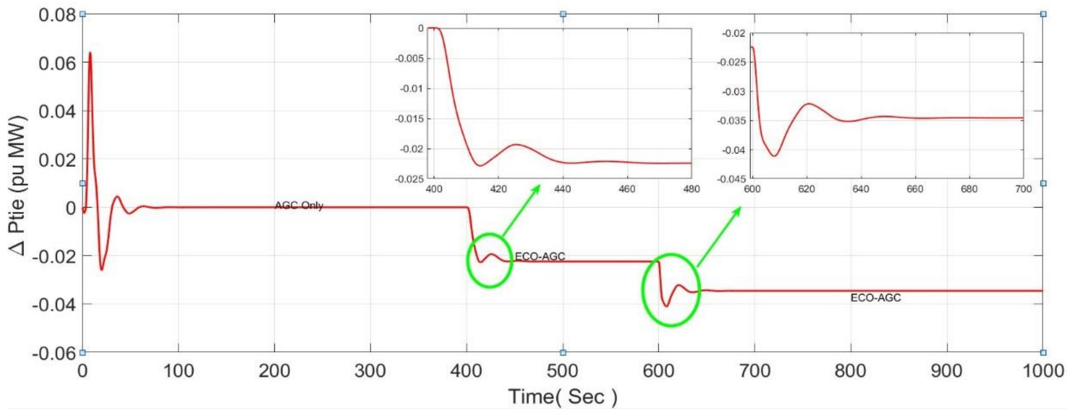


Fig. 10 The deviation of frequency at area 2 based on; (a) SCA, (b) PSO

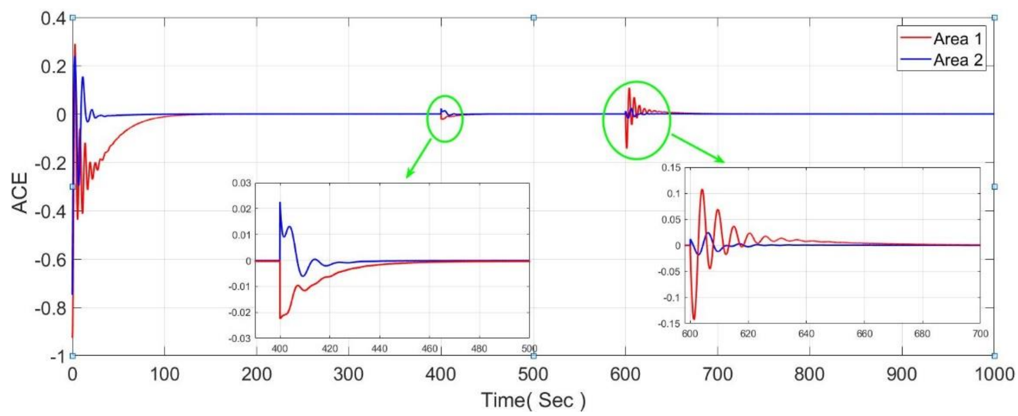


(a)

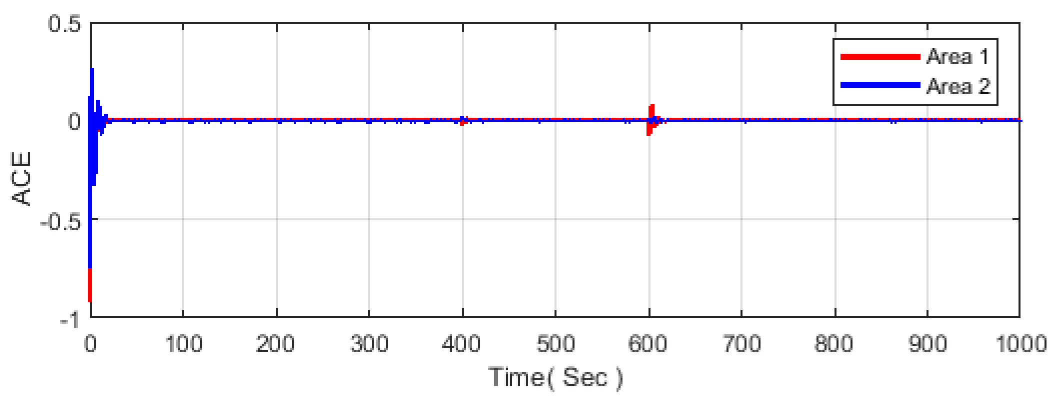


(b)

Fig. 11 Change of power tie line based on; (a) SCA, (b) PSO

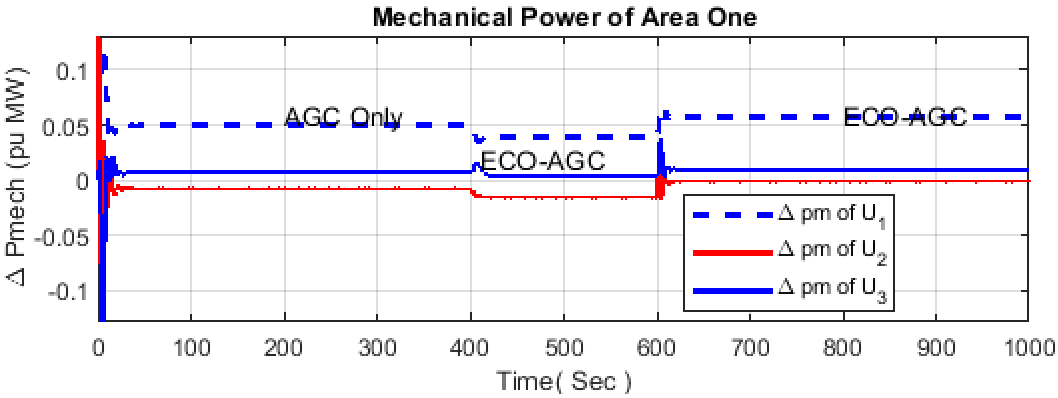


(a)

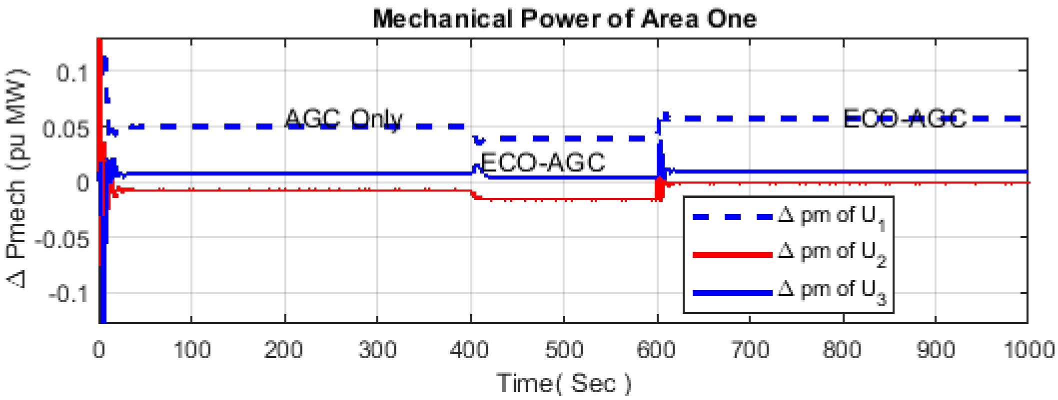


(b)

Fig. 12 ACE for two-area based on; (a) SCA, (b) PSO

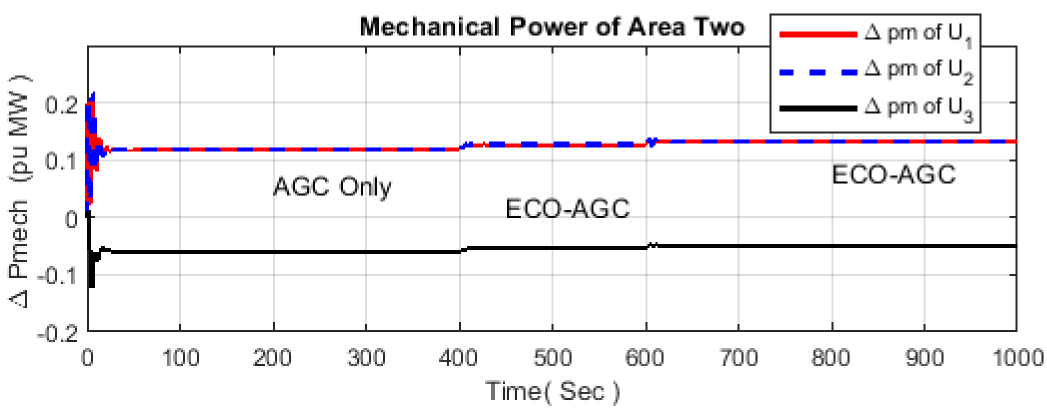


(a)

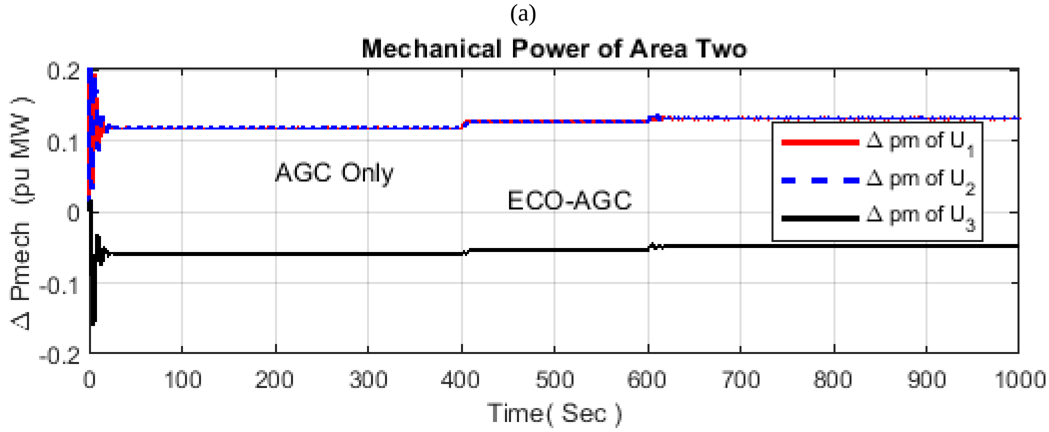


(b)

Fig. 13 Mechanical power deviation for three units in area 1 based on; (a) SCA, (b) PSO

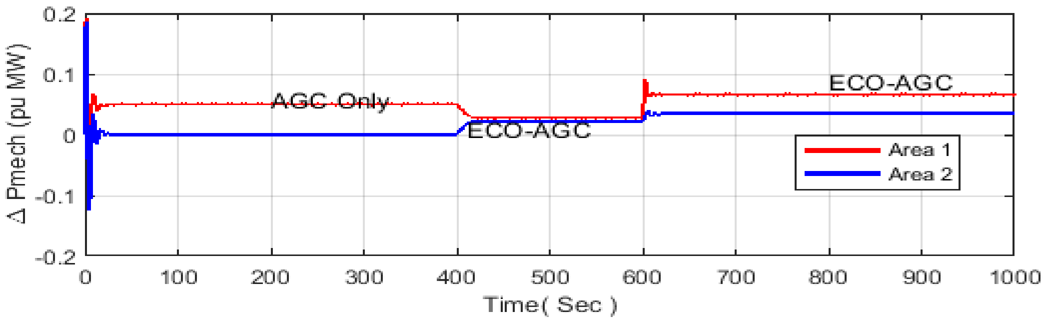


(a)

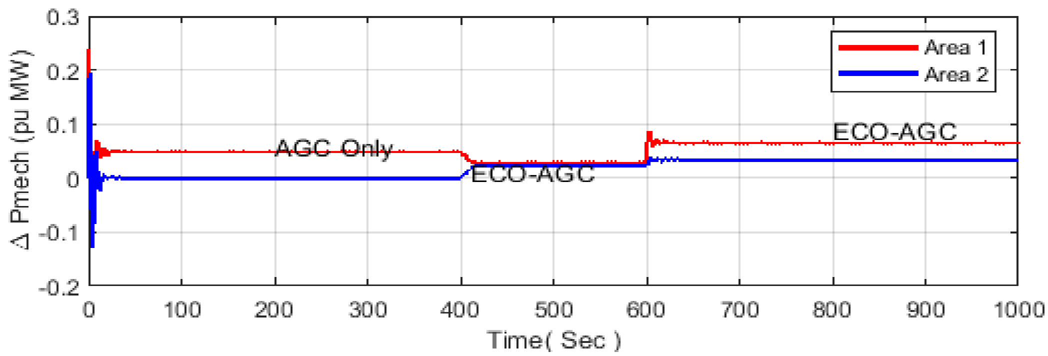


(b)

Fig. 14 Mechanical power deviation for three units in area 2 based on; (a) SCA, (b) PSO



(a)



(b)

Fig. 15 Total mechanical power deviation for two- area based on; (a) SCA, (b) PSO

8. Conclusions

Automatic generation control by regulating frequency and generation schedule plays a critical role in the successful operation of the power system. In this study a two-area sex-unit interconnected power system, power generating units which included sources of (hydro, thermal, and gas power systems) are modelled. The power system is coordinated using AGC and ELD to improve load variation by lowering frequency deviation. Each one of units shares the created load demand based on their participation variables. Mathematical formulations for the economic load dispatch are based on the system's incremental cost function relationship. The method with the lowest mistake is described as the optimal way in this situation. As a consequence, Using the proposed control system, this study established a link between ELD and AGC. The ideal gain of the simulated system's integrated controller is determined using the SCA and PSO approaches. SCA proved, through numerical results, that it is better than PSO, where it was the best cost (0.0075), while it was for PSO (0.008). Finally, the suggested controller successfully reduced frequency deviation and net tie-line power flow variance, confirming its utility. In order to optimize fluctuating load needs and increase power supply quality in diverse scenarios, this research could be expanded to include three control area power systems.

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Appendix

F_0 = 60 Hz, K_{PS} = 68.9655 Hz/puMW, T_{PS} = 0 PL 9 11.49 s, T_{12} = 0.0433, α12 = −1, β = 0.4312 puMW/Hz, R = 2.4 Hz/puMW, T_G = 0.06 s, T_T = 0.3 s, Kr = 0.3, Tr = 10.2 s, 10 T_{RH} = 28.749 s, T_R = 4.9 s, TGH = 0.2 s, T_W = 1.1 s, X = 0.6 s, Y = 1.1 s, a = c = 1, b = 0.049 s, T_{CR} = 0.01 s, T_F = 0.239 11 s, T_{CD} = 0.2 s; KT = 0.5747; K_H = 0.2873; KG = 0.1380. R_{FB}: K_{RFB} = 1.8, Kr = 0, Tr = Td = 0 s.