# Optimal AGC of a power system incorporated BESS-EHVAC/DC link using evolutionary techniques

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**ABSTRACT**

This research paper reveals the design of controller with optimization techniques for automatic generation control (AGC) in multi-area power system incorporated with diverse energy sources. The diverse sources are conventional thermal, hydro and gas power station (THG). The frequency deviations should be remains constant in modern power systems. Optimization techniques used for proposed model for proportional integral (PI) controller which is tuned for AGC with diverse energy sources. The battery energy storage system (BESS) and extra high voltage alternating current/ direct current (EHVAC/DC) link investigated with proposed model. The proposed model has been tested with 1% step load perturbation (SLP) and MATLAB/Simulink verified their results. All the simulation results justified the area control error (ACE) with frequency deviation & tie-line power flow for area-1 and area-2. The comparative study done for PI controller with GA & PSO in the proposed model. It has shown its efficacy with proposed model including BESS and EHVAC/DC-link using GA and PSO.



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## 1. INTRODUCTION

Frequency should be remained constant for the progressive power systems. Qualitative power supply can be accomplished via the support of AGC for multi-area interconnected power systems with assorted energy sources. Exigence of power supply without perturbation in frequency stands worldwide, when load perceives from its delineated extent with perturbation, the status of the system could undergo alteration from standard to aberrant situation. AGC should distinguish the digression in frequency and retained it to untiring system frequency.

As the devotion of allied power systems must be equalized amid generated powers with entire load mandate along with system deficits. If driving point swing the system frequency can departs, amassed reason exhibits biased power in the exchange of areas, outcome may detrimental consequence [1]–[3]. Study of proportional-integral-derivative (PID) done [4] with two areas AGC and operating source like hydro, gas and thermal. Genetic algorithm (GA) was used for augmenting the gain of integral squared error (ISE) in combination of integral time absolute error (ITAE). Author had worked for two area system under distinctive usual loading situations with 1% step load disruption. The genetic algorithm and PID controller optimized for various cases. Ramakrishna and Bhatti [5] worked for generation rate constraint (GRC) and governor dead band (GDB) in AGC with differential evolution algorithm-based power system thru non-linearity.

Ramakrishna and Bhatti [5] developed AGC with a proportional-integral-derivative (PID) for thermal, gas sources and hydro source including nominal loading conditions which was optimized with GA. Mohanty *et al*. [6] developed the differential evolution algorithm for AGC with non-linearity. For [7] worked for Type-1 fuzzy-PID controller (T1FPID), T2FPIDF & T2FPID and standard PID controller for AGC. Babu and Saikia [8] developed for AGC incorporated with HVDC and energy storing units in a deregulated by using of performance index HPA-ISE. Also, the justification was done [9] for AGC.

Arya *et al*. [10] utilized for THG power systems. In [11] worked the parallel combination of AC/DC links for AGC with reheat thermal turbines as optimized with GA. BESS used with AGC [12], and [13] considered for improvement in AGC. In [14] system was analyzed for a minor load disruption and the comparative outcomes were demonstrated for different power transactions also used a performance index based using a finite nonlinear optimization. Rahman *et al.* [15] developed a robust droop control scheme for BESS to hinder the deviation of frequency in multi-machine grid power system with active power supplied from PV panel. Kail *et al.* [16] proposed the effect of DFIG-based WEC in AGC also its dynamic response is reduced by area control error. The optimization techniques have been used for AGC [17]–[24] as to augment the firmness of power system also review work has done by [25].

For this research article the following objectives have been investigated with input parameter and results justified by MATLAB/Simulink: i) Design and development of mathematical model of multi-area power system with diverse energy sources; ii) Modify the proposed model with parallel EHVAC/DC-links and BESS; and iii) To investigate proposed power systems model using conventional PI controller, GA and particle swarm optimization (PSO) techniques.

## 2. SYSTEM DESCRIPTION AND MODELLING

This research article intends a multi-source based two area power systems for AGC investigation under different approaches. The conventional generating stations like thermal and hydro stations are integrated with gas power plant to form area-1 of the structure. The area-2 also comprises thermal with gas and hydro power plant to produce desired electrical power of the system. Apiece generating units are allocated with appropriate allocation factor for efficient distribution of applied load. The individual components of each generating unit are addressed through their transfer function expressions. The individual generating unit relies on separate controller to obtain secondary AGC loop of the system. The controllers are largely responsible for necessary control actions in the system.

The following equation for generator frequency Δf and ACE are given as (1).

$$ACE = B\Delta f + \Delta P_{Tie} \quad (1)$$

B stands for frequency bias parameter. For the transfer function; frequency-domain analysis is used in the model for all module of the area. The turbine is epitomized by the transfer function given as (2),

$$GT(s) = \frac{\Delta P_T(s)}{\Delta P_V(s)} = \frac{1}{1+ sT_T} \quad (2)$$

with Elgerd [2] the transfer function denoted for governor is as (3).

$$GG(s) = \frac{\Delta P_V(s)}{\Delta P_G(s)} = \frac{1}{1+sT_G} \quad (3)$$

The speed governing system has two contributions $\Delta f$ and $\Delta Pref$ with 1 yield $\Delta PG(s)$ given by [2] following:

$$\Delta PG(s) = \Delta Pref(s) - \frac{1}{R}\Delta f(s) \quad (4)$$

The load and generator are epitomized by the transfer function as [2] follows:

$$GP(s) = \frac{K_P}{1+sT_P} \quad (5)$$

where $KP = \frac{1}{D}$ and $TP = \frac{2H}{f\,D}$.

The generator load system has 2 inputs $\Delta PD(s)$ and $\Delta PT(s)$ with 1 output $\Delta f(s)$ given by [2] following:

$$\Delta f(s) = GP(s)\,[\Delta PT(s) - \Delta PD(s)] \quad (6)$$

The simulation diagram of transfer function representation for proposed two area power system is depicted in Figure 1. A brief discussion on individual generating station has been carried out and critically demonstrated in this section:

- Thermal unit: The reheat based thermal plant is developed with integrating various individual units' governor, reheat turbine and non-reheat turbine.

$$Governor\ modeling = GG(s) = \frac{\Delta P_{V(s)}}{\Delta P_{G(s)}} = \frac{1}{T_g s + 1} \quad (7)$$

$$Turbine\ (reheat)\ modeling = GT(s) = \frac{\Delta P_{T(s)}}{\Delta P_{V(s)}} = \frac{K_r T_r s + 1}{T_r s + 1} \quad (8)$$

$$Turbine\ (non-reheat)\ modeling = GT(s) = \frac{\Delta P_{T(s)}}{\Delta P_{V(s)}} = \frac{1}{T_t s + 1} \quad (9)$$

- Hydro unit: The hydro system is modelled with various individual components.

$$Governor\ modelling = GG(s) = \frac{\Delta P_{V(s)}}{\Delta P_{g(s)}} = \frac{1}{T_{rh} s+1} \quad (10)$$

$$Droop\ modelling = GD(s) = \frac{\Delta P_{V1(s)}}{\Delta P_{V(s)}} = \frac{T_R s+1}{T_{gh} s+1} \quad (11)$$

$$Turbine\ modelling = GP(s) = \frac{\Delta P_{T(s)}}{\Delta P_{V1(s)}} = \frac{-T_W s+1}{0.5 T_W s+1} \quad (12)$$

- Gas Unit: The individual components of gas unit are modelled as:

$$Valve\ modelling = GV(s) = \frac{\Delta P_{g(s)}}{\Delta P_{P(s)}} = \frac{a}{b_g s + c_g} \quad (13)$$

$$Governor\ modelling = GG(s) = \frac{\Delta P_{s(s)}}{\Delta P_{g(s)}} = \frac{X_c s + 1}{Y_c s + 1} \quad (14)$$

$$Combustion\ modelling = GC(s) = \frac{\Delta P_{R(s)}}{\Delta P_{s(s)}} = \frac{-T_c s + 1}{T_f s + 1} \quad (15)$$

$$Compressor\ modelling = GCO(s) = \frac{\Delta P_{CD(s)}}{\Delta P_{R(s)}} = \frac{1}{T_{cd} s + 1} \quad (16)$$

Figure 1 explored by [4]. The simulation model of EHVAC-DC link with AGC model is derived by Abazari *et al* [12]. Integration of battery energy storage system (BESS) to AGC model is also referred from [12]. The input data for proposed system [10]:

| | | |
|---|---|---|
| Pri = 2000 MW; | TR = 4.9s; | $T_{CR}$ = 0.01s; |
| $K_{PS}$ = 68.9655 Hz/puMW; | $T_{RH}$ = 28.749s; | $T_F$ = 0.239s; |
| $T_{PS}$ = 11.49 s; | TW = 1.1s; | $T_{CD}$ = 0.2s; |
| B = 0.4312 puMW/Hz; | $T_{GH}$ = 0.2s; | $K_H$ = 0.2873; |
| α12 = -1; | Y = 1.1s; | $K_T$ = 0.5747; |
| R = 2.4 Hz/puMW; | X = 0.6s; | $K_G$ = 0.2873; |
| $T_G$ = 0.06; | a = 1; | $T_{12}$ = 0.0433; |
| $T_T$ = 0.3s; | b = 0.049s; | Initial loading = 1740 MW; |
| Tr = 10.2s; | c = 1; | F° = 60 Hz. |
| Kr = 0.3; | | |

Also, for EHVAC/DC [4]: Tdc = 0.25; Kdc = 1; and for is BESS [12]: Tcbs = 0.2.

## 3. DESIGN CONTROLLER STRUCTURE OF AGC

Development of advanced control with conventional PI controller is fancied, as easy in configure and consistent and involves lessen user proficiencies rather others. Proportional and integral are two fashion of PI controller, the acquisition of closed loop system boosts, as it corrects transient occurrence and degrades rise time but never eradicates steady state errors. An integral controller decreases the steady state error to zero. Consequently, the outcome of the system through integral controller is sluggish throughout a transient phase. The (P+I) control does not eradicate the differ amid stagnant and vibrant precision. The tactics of PI controller has minimal digression in the former apex than the integral controller, but reduced value of settling time is attained in event of solitary the integral controller. Also, the reaction of the system is further oscillatory by PI controller judged thru solitary the integral controller.

For $\left|\frac{d(ACE)}{dt}\right| > \varepsilon.$

$$\Delta PC = KPACE\ (t) \tag{17}$$

ACE is the area control error signal.

$$\left|\frac{d(ACE)}{dt}\right| \leq \varepsilon$$

$$\Delta PC = KI\ \int ACE(t) \tag{18}$$

While designing a controller, a fitness function is first idea established on description and confines. Control tactics are ISE, ITAE, integral time square error (ITSE), and integral of absolute error (IAE). Ali and Abd-Elazim [13] deliberated ITAE as a fitness function (an objective function). Similar fitness function is appraised in this manuscript for proposed system. The constraints of PI controller can be elevated applying GA, PSO or GWO algorithm devoting as a fitness function ($J_s$) as specified in equation as below:

$$Js = \int (|\Delta f_1| + |\Delta f_2| + |\Delta P_{tie}|) \tag{19}$$

where the deviation in frequency is noted by $\Delta f_1$ and $\Delta f_2$, Also the incremental change in tie line power flow thru $\Delta P_{Tie.}$

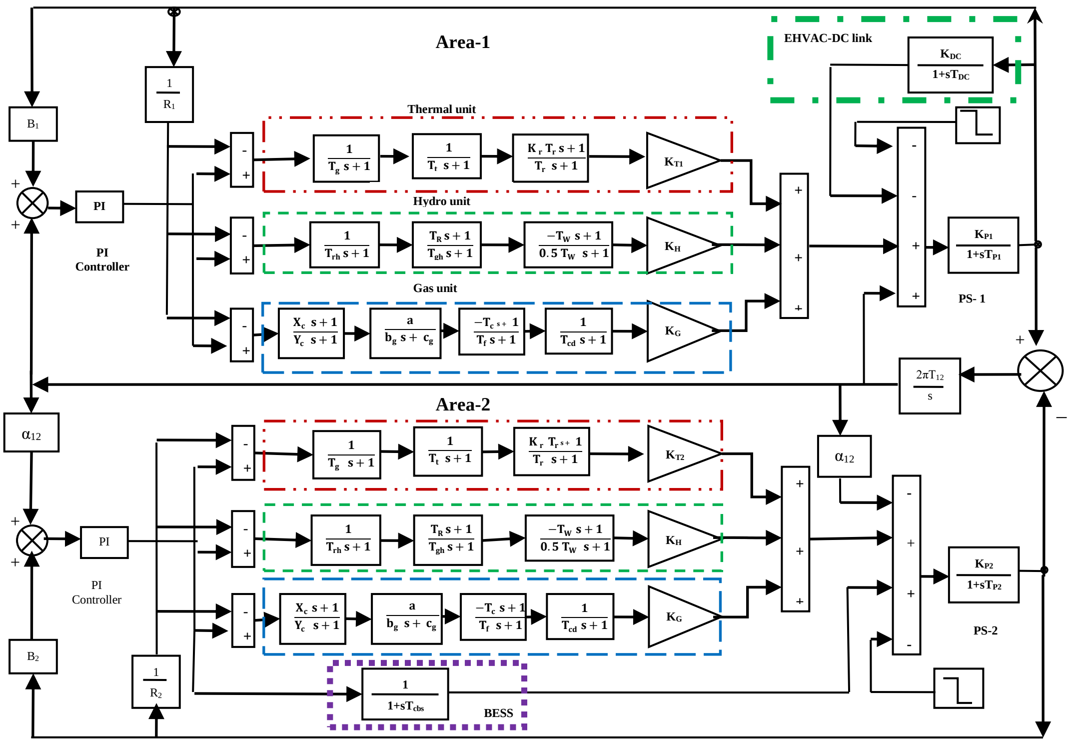



Figure 1. Multi-area thermal, hydro and gas plant (THG) model incorporating with EHVAC/DC-link and BESS

## 4. OPTIMIZATION TECHNIQUES

Optimization techniques are a dominant set of tools for solving difficult real-world problems. The application field has matured diverse in recent years, covering almost all engineering and science disciplines. Optimization problems usually have three essential basics. The main is a solitary statistical measure, or objective function, that is to be amplified or abated. Another element is a set of variables, which are sizes whose standards can be manipulated in mandate to enrich the objective. The third element of an optimization difficulty is a set of limitations, which are boundaries on the costs that the variables can take.

### 4.1. Particle swarm optimization (PSO)

This is an exploratory procedure which is known as a swarm (working with having a population) candidate solutions (called particles). Movement of particles across the hunt-space and are also directed by their individual best-known pose in the hunt-space provides swarm's best-known stance. The flow chart of PSO is given in Figure 2. Number of iterations used = 100.

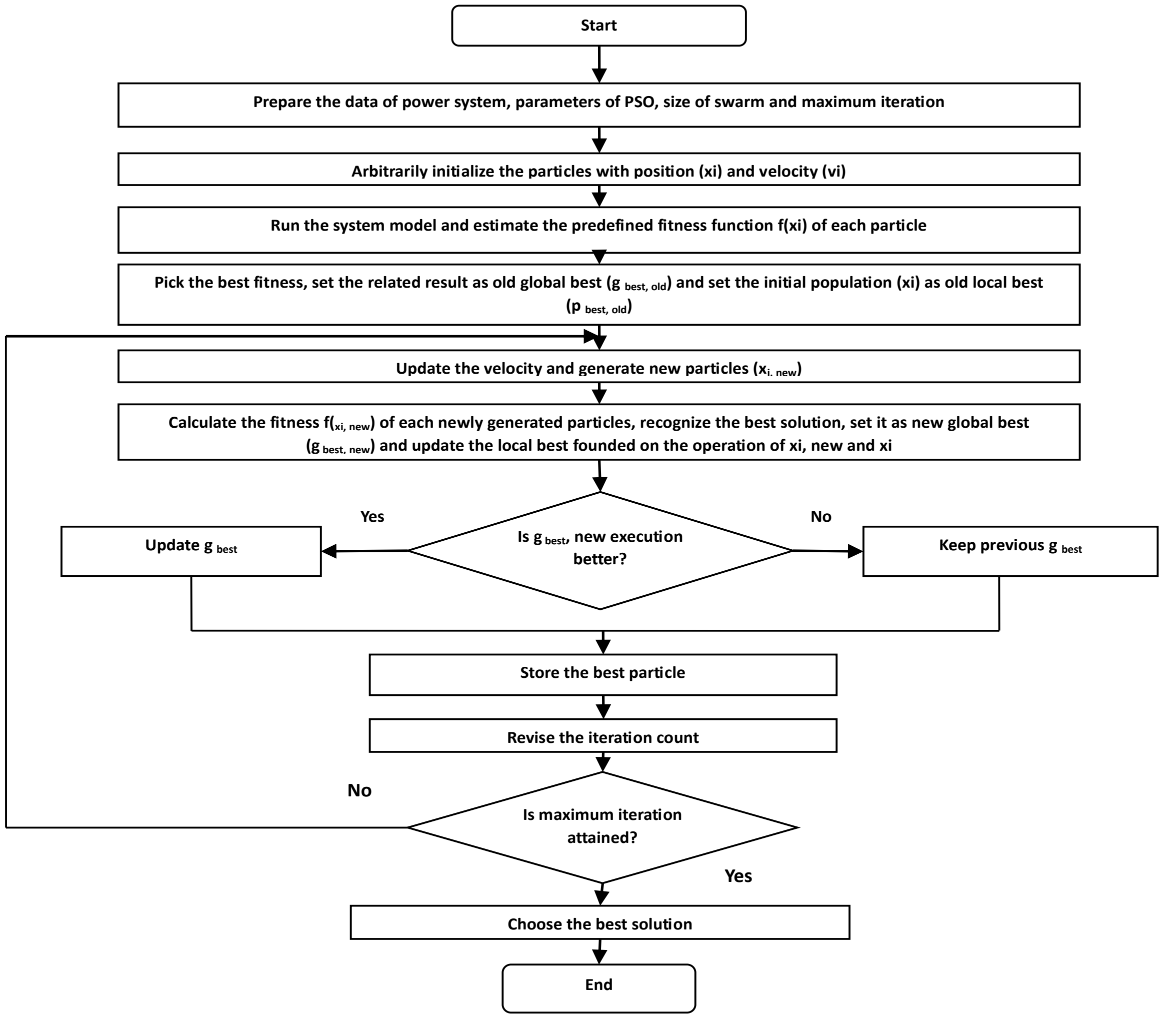



Figure 2. Flow chart of particle swarm optimization

### 4.2. Genetic algorithm (GA)

Exploration-based optimization practice is known as genetic algorithm (GA) on the ideologies of Inheritances and natural assortment. It is often exercised to acquire optimal or near-optimal results to challenging hindrances which otherwise would take a lifetime to resolve. It is utilized in this research. The flow chart of GA is given in Figure 3. Both PSO and GA are used to optimize the proposed model of AGC with PI controller. The simulation results show their suitability for optimization. All simulations have been performed for 1% SLP, in area-1. Settling time, Undershoot and Overshoot for model with inclusion of BESS & EHVAC/DC–link with 1% SLP is shown in Table 1.

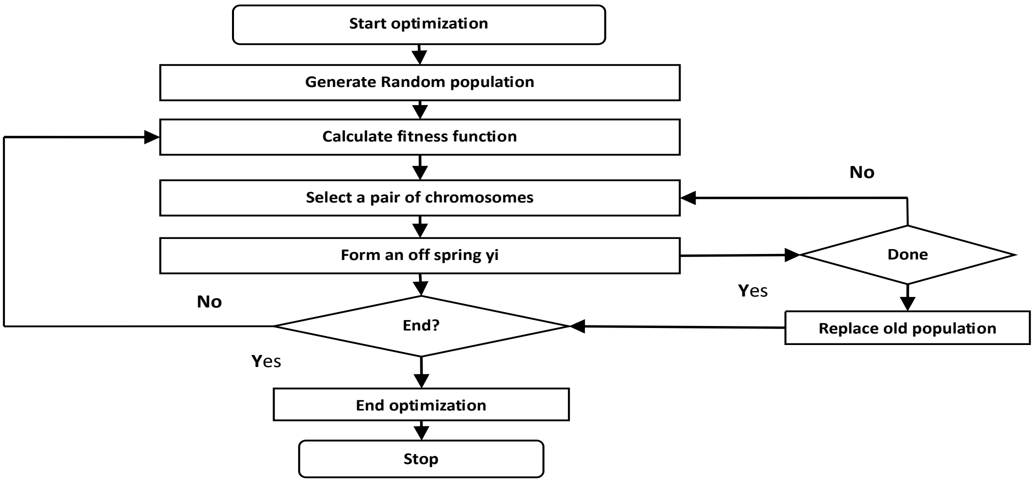



Figure 3. Flow chart of genetic algorithm

Table 1. Settling time, Undershoot and Overshoot for model with inclusion of BESS & EHVAC/DC–link with 1% SLP

| | Parameter | Settling time (sec) $S_T$ | | | Undershoot $U_S$ (-ve) | | | Overshoot $O_S$ | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | PI | GA | PSO | PI | GA | PSO | PI | GA | PSO |
| THG | $\Delta F_1$ (Hz) | 5.5 | 4 | 2.6 | 0.038 | 0.036 | 0.0365 | 0.011 | 0.009 | 0.005 |
| | $\Delta F_2$ (Hz) | 5.3 | 3.5 | 2.8 | 0.042 | 0.033 | 0.0335 | 0.0105 | 0.005 | 0.003 |
| | $\Delta P_{Tie}$ (p.u. MW) | 7.00 | 4.64 | 2.8 | 0.007727 | 0.004976 | 0.00498 | 0.0009027 | 0.001113 | 0.0009214 |
| BESS | $\Delta F_1$ (Hz) | 4.802 | 2.1 | 1.88 | 0.03779 | 0.02832 | 0.03157 | 0.007794 | 0.01441 | 0.02088 |
| | $\Delta F_2$ (Hz) | 5.082 | 2.1 | 1.9 | 0.04264 | 0.0111 | 0.02622 | 0.007542 | 0.008211 | 0.01044 |
| | $\Delta P_{Tie}$ (p.u. MW) | 6.602 | 2.997 | 2.434 | 0.007682 | 0.00333 | 0.008869 | 0.0006032 | 0.0004364 | 0.002821 |
| EHVAC/DC-link | $\Delta F_1$ (Hz) | 9.64 | 5.323 | 4.329 | 0.01356 | 0.01433 | 0.01398 | $9.512\times10^{-4}$ | 0.002049 | 0.002043 |
| | $\Delta F_2$ (Hz) | 9.624 | 5.523 | 4.329 | 0.009909 | 0.00846 | 0.01102 | $7.176\times10^{-4}$ | 0.002244 | 0.001914 |
| | $\Delta P_{Tie}$ (p.u. MW) | >10 | 5.523 | 4.329 | 0.9997 | 1 | 1 | 0.1979 | 0.2476 | 0.1182 |

## 5. RESULTS AND THEIR ANALYSIS

This paper has a detailed discussion of simulation for proposed model of AGC. Also, incorporations of EHVAC/HVDC and BESS. The simulation has been performed for given model by considering with/without GA tune PI controller and PSO tuned PI controller. Again this model is connected with BESS and then it again with GA tuned PI controller followed by PSO tuned PI controller. Similarly proposed model integrated with EHVAC/ DC-link and again with GA tuned PI controller followed by PSO tuned PI controller.

### 5.1. Test case: a (results with GA and PSO tuned PI controller)

In THG with PI model the $\Delta F_1$ (settling time = 5.5 sec) and for area-2 frequency deviation (settling time= 5.3 sec) and Tie-line power deviation $\Delta P_{tie}$ is 7 Sec. and it has compared with GA and PSO in Table 1. Also, in Figure 4 and Figure 5(a). The real simulation has been showed in Figure 5(b) with modeling for 1% SLP of THG with GA and PSO tuned PI.

### 5.2. Test case: b (result of AGC-THG for BESS & EHVAC/DC-link with PI controller)

This test has been verified with Figure 6. Which shows the frequency deviance in area-1 and area-2; also Figure 7 show the result of deviation in tie line power, for GA and PSO. Results of Ts, Us/Os and Js for test system AGC – THG-PI (with 1% SLP with PSO) has been shown in Table 2.

Table 2. Results of Ts, Us/Os and Js for test system AGC – THG-PI (with 1% SLP with PSO)

| Controller type | Ts (s) | | | \|Us\| (Hz) | | \|Us\| (puMW) | \|Os\| (Hz) | | \|Os\| (puMW) | $J_s$ |
|---|---|---|---|---|---|---|---|---|---|---|
| | $\Delta F_1$ | $\Delta F_2$ | $\Delta P_{tie}$ | $\Delta F_1$ | $\Delta F_2$ | $\Delta P_{tie}$ | $\Delta F_1$ | $\Delta F_2$ | $\Delta P_{tie}$ | |
| AGC-THG-PI with PSO | 2.6 | 2.8 | 2.8 | 0.0365 | 0.0335 | 0.00498 | 0.005 | 0.003 | 0.0009214 | 0.81 |
| DE: PID [6] | 6.87 | 6.89 | 4.40 | 0.0193 | 0.0154 | 0.0042 | $2.6\times10^{-3}$ | $1.8\times10^{-3}$ | $1.4\times10^{-4}$ | n/a |
| hBFOA-PSO: PI [17] | 14.22 | 15.32 | 11.05 | 0.0321 | 0.0330 | 0.0085 | 0.0101 | $4.2\times10^{-3}$ | $2.6\times10^{-4}$ | 0.3948 |

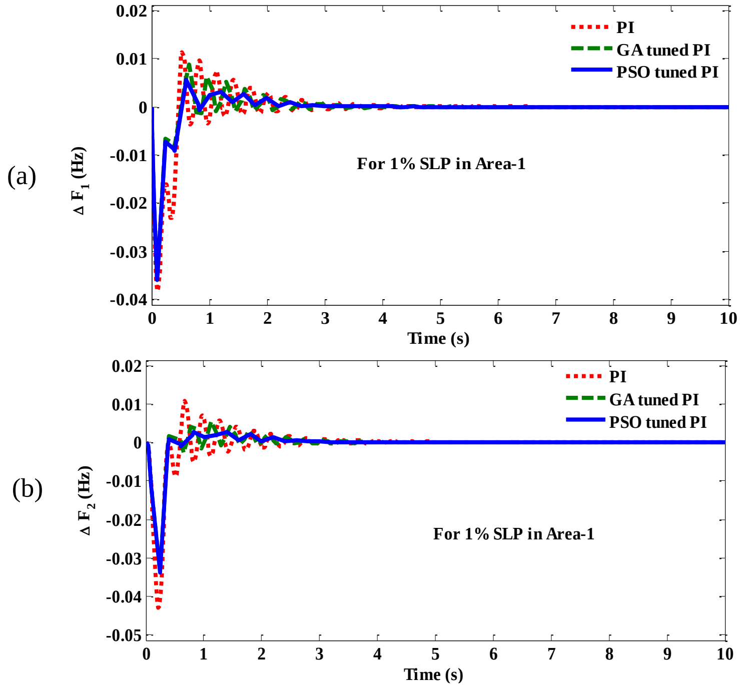
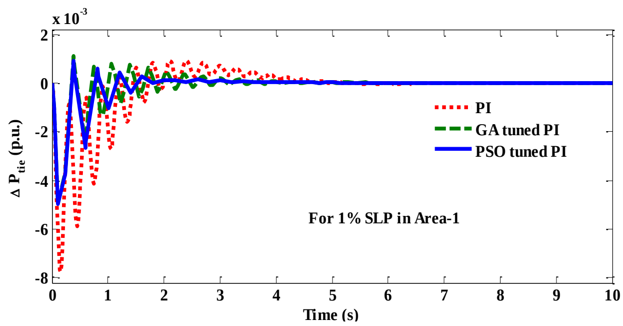
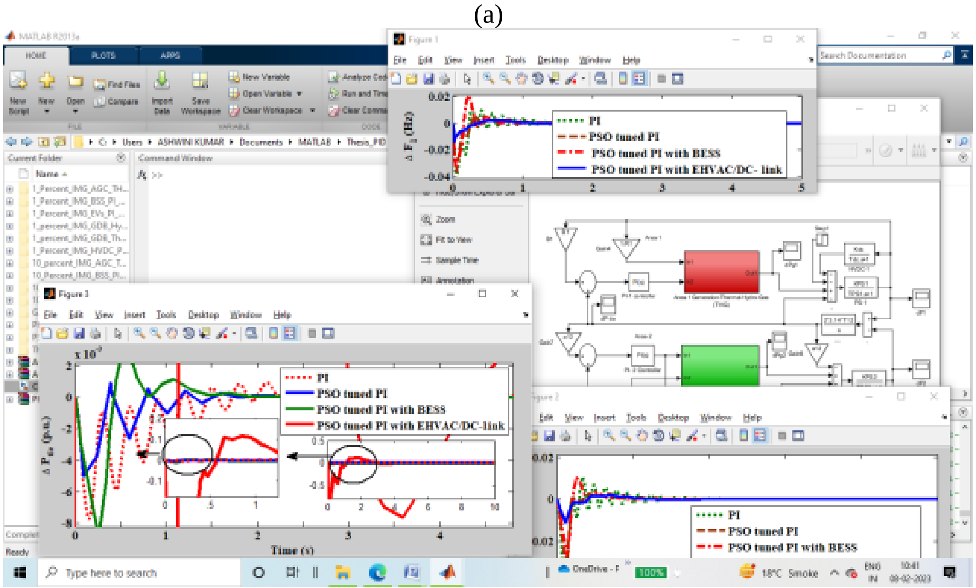



Figure 4. Frequency response for (1% SLP) in THG system with GA and PSO, (a) in area-1 and (b) in area-2




(a)




(b)

Figure 5. Tie-line power flow deviation in THG system for PI (1% SLP): (a) with GA and PSO and (b) simulation picture

(a)

(b)

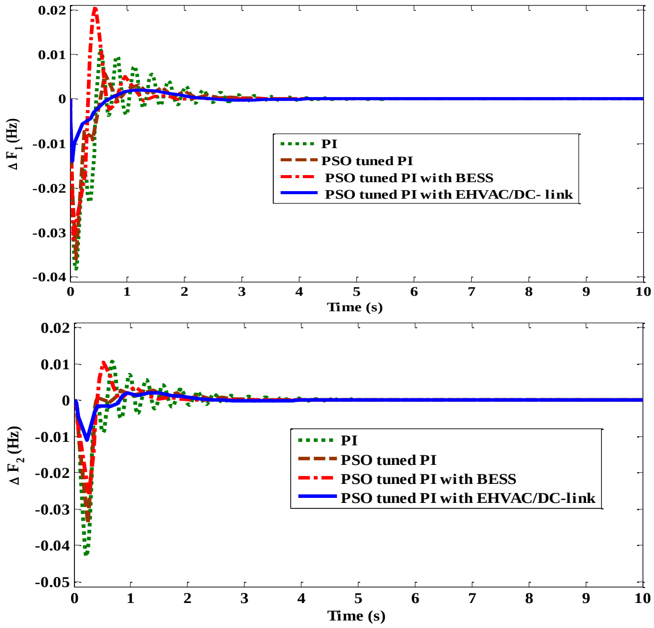



Figure 6. Frequency response of (1% SLP) in THG system for BESS & EHVAC/DC-link with PSO tuned PI: (a) in area-1 and (b) in area-2

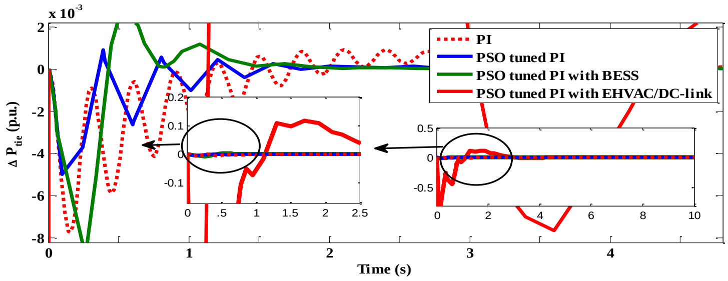



Figure 7. Tie-line power flow deviation ($\Delta P_{tie}$ p.u.MW) in THG system for BESS and EHVAC/DC-link with PSO tuned PI

## 6. CONCLUSION

A successful analysis of AGC in multi-area interconnected sundry energy sources of power system is well synthesized in this article. This work specially focused on evolutionary techniques-based PI controllers for tie-line power flow and frequency of the power system under altered operating conditions. This article also reveals the design of controllers using evolutionary techniques like GA and PSO for AGC in multi-area power system for optimal dynamic results. The utilization of BESS and EHVAC/HVDC link is also investigated and verified in the proposed model. The anticipated model has been examined with 1% SLP through MATLAB/Simulink software platform. All the dynamic results justified the ascendency of the PSO tuned PI controllers over other tested controllers in all studies.

## REFERENCES

[1] P. Kundur, *Power system stability and control*, 8th ed Tata McGraw-Hill, New Delhi, 2009.
[2] O. I. Elgerd, *Electric energy systems theory: an introduction*, 2nd ed. New Delhi: Tata McGraw-Hill Publishing Company Ltd., ch. 9, 2007.
[3] P. C. Sahu, R. C. Prusty, and B. K. Sahoo, "Modified sine cosine algorithm-based fuzzy-aided PID controller for automatic generation control of multiarea power systems," *Soft Computing*, vol. 24, pp. 12919–12936, 2020, doi: 10.1007/s00500-020-04716-y.
[4] A. K. Barisal, and S. Mishra, "Improved PSO based automatic generation control of multi-source nonlinear power systems interconnected by AC/DC links," *Cogent Engineering*, vol. 5, no. 1, 2018, doi: 10.1080/23311916.2017.1422228.
[5] K. S. S. Ramakrishna, and T. S. Bhatti, "Sampled-data automatic load frequency control of a single area power system with multi-source power generation," *Electric Power Components and Systems*, vol. 35, no. 8, pp. 955–980, 2007, doi: 10.1080/15325000701199479.
[6] B. Mohanty, S. Panda, and P. K. Hota, "Differential evolution algorithm based automatic generation control for interconnected power systems with non-linearity," *Alexandria Engineering Journal*, vol. 53, pp. 537–552, 2014, doi: 10.1016/j.aej.2014.06.006.
[7] J. R. Nayak, B. Shaw, and B. K. Sahu, "Application of adaptive-SOS (ASOS) algorithm based interval type-2 fuzzy-PID controller with derivative filter for automatic generation control of an interconnected power system," *International Journal of*

*Engineering Science and Technology*, vol. 21, pp. 465–485, 2018, doi: 10.1016/j.jestch.2018.03.010.
[8] N. R. Babu, and L. C. Saikia , "Optimal location of accurate HVDC and energy storage devices in a deregulated with PWTS considering HPA-ISE as performance index," *Engineering Science and Technology, an International Journal, Elsevier*, vol. 33, pp. 1–12, 2022, doi: 10.1016/j-jestch.2021.10.004.
[9] Y. Arya, "ICA assisted FTIλ DN controller for AGC performance enrichment of interconnected reheat thermal power systems," *Journal of Ambient Intelligence and Humanized Computing*, vol. 14, pp. 11-12, 2021, doi: 10.1007/s12652-021-03403-6
[10] Y. Arya, P. Dahiya, E. Çelik, G. Sharma, H. Gözde, and Ibraheem, "AGC performance amelioration in multi-area interconnected thermal and thermal-hydro-gas power systems using a novel controller," *Engineering Science and Technology, an International Journal*, vol. 24, no. 2, pp. 384-396, 2021, doi: 10.1016/j.jestch.2020.08.015.
[11] O. Singh, and I. Nasiruddin, "Optimal AGC regulator for multiarea interconnected power systems with parallel AC/ DC links," *Cogent Engineering, Taylor & Francis* , no. 3, pp. 1–17, 2016, doi: 10.1080/23311916.2016.1209272.
[12] A. Abazari, H. Monsef, and B.Wu, "Coordination strategies of distributed energy resources including FESS, DEG, FC and WTG in load frequency control (LFC) scheme of hybrid isolated micro-grid," *International Journal of Electrical Power & Energy Systems*, vol. 109, pp. 535–547, 2019, doi: 10.1016/j.ijepes.2019.02.029. 40
[13] E. S. Ali, and S. M. Abd-Elazim, "Bacteria foraging optimization algorithm based load frequency controller for interconnected power system," *International Journal of Electrical Power & Energy Systems*, vol. 33, pp. 633–638, 2011, doi: 10.1016/j.ijepes.2010.12.022
[14] S. A. Kumar, M. S. S. Narayana, and K. J. Gowd, "Load frequency control of thermal system under deregulated environment using slime mould algorithm," *International Journal of Power Electronics and Drive Systems (IJPEDS)*, vol. 12, no. 4, pp. 2221–2229, 2021, doi: 10.11591/ijpeds.v12.i4.pp2221-2229.
[15] S. M. I. Rahman *et al*., "Primary frequency control of large-scale PV-connected multimachine power system using battery energy storage system," *International Journal of Power Electronics and Drive Systems (IJPEDS)*, vol. 12, no. 3, pp. 1862–1871, 2021, doi: 10.11591/ijpeds.v12.i3.pp1862-1871.
[16] S. Kail, A. Bekri, and A. Hazzab, "Study of automatic generation control in two area power system with DFIG-based wind energy conversion," *International Journal of Power Electronics and Drive System (IJPEDS)*, vol. 10, no. 4, pp. 2118–2125, 2019, doi: 10.11591/ijpeds.v10.i4.pp2118-2125.
[17] S. Panda, B. Mohanty, and P. K. Hota, "Hybrid BFOA-PSO algorithm for automatic generation control of linear and nonlinear interconnected power systems," *Appl Soft Comput*, vol. 13, pp. 4718–4730, 2013, doi: 10.1016/j.asoc.2013.07.021.
[18] R. K. Sahu, S. Panda, and G. T. C Sekhar, "A novel hybrid PSO-PS optimized fuzzy PI controller for AGC in multi area interconnected power systems," *Int J Electr Power Energy Syst* , vol. 64, pp. 880–893, 2015, doi: 10.1016/j.ijepes.2014.08.021.
[19] H. Gozde, and M. C. Taplamacioglu, "Automatic generation control application with craziness based particle swarm optimization in a thermal power system," *Int J Electr Power Energy Syst*, vol. 33, no. 1, pp. 8–16, 2011, doi: 10.1016/j.ijepes.2010.08.010.
[20] B. Mohanty, S. Panda, and P. K. Hota, "Controller parameters tuning of differential evolution algorithm and its application to load frequency control of multi-source power system," *Int J Electr Power Energy Syst* , vol. 54, pp. 77–85, 2014, doi: 10.1016/j.ijepes.2013.06.029.
[21] A. K. Barisal, "Comparative performance analysis of teaching learning based optimization for automatic load frequency control of multi-source power systems," *Int J Electr Power Energy Syst*, vol. 66, pp. 67–77, 2015, doi: 10.1016/j.ijepes.2014.10.019.
[22] D. Guha, P. K. Roy, and S. Banerjee, "Study of differential search algorithm based automatic generation control of an interconnected thermal-thermal system with governor dead-band," *Appl Soft Computer*, vol. 52, pp. 160–175, 2017, doi: 10.1016/j.asoc.2016.12.012.
[23] A. Nayak, M. K. Maharana, T. Sidhu, S. Padmanaban, and G. Panda, "Frequency regulation of a maiden structured power system with integrated renewable energy source by a fuzzy - tuned fractional order controller," *Energy Sources, Part A: Recovery, Utilization, and Environmental Effects*, vol. 44, no. 3, pp. 7841–7856, 2022, doi: 10.1080/15567036.2022.2115581.
[24] V. Kumar, V. Sharma, Y. Arya, R. Naresh, and A. Singh, "Stochastic wind energy integrated multi source power system control via a novel model predictive controller based on Harris Hawks optimization," *Energy Sources, Part A: Recovery, Utilization, and Environmental Effects*, vol. 44, no. 4, pp. 10694–10719, 2022, doi: 10.1080/15567036.2022.2156637.
[25] A. Kumar, and O. Singh, "Recent strategies for automatic generation control of power systems with diverse energy sources," *IJSDA*, vol. 10, no. 4, pp. 1–26, 2021, doi: 10.4018/IJSDA.20211001.oa8.

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