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A Novel Swarm Approach for Regulating Load Frequency in Two-Area Energy Systems

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ABSTRACT- One of the most important strategies for running and controlling an electric power system is the load frequency controller. LFC can be used to solve a variety of issues, such as when a generating unit is rapidly turned off by protection equipment or when a heavy load is quickly connected or disconnected. When disturbances disrupt the natural power balance, the frequency deviates from what it should be. LFC is in charge of balancing the load and restoring the natural frequency to its proper level. In this case, load frequency control optimization techniques are used in the Multiple Connect Area System to provide reliable and quality operation on frequency and tie line power flow. The purpose of this paper is to demonstrate how optimising LFC in a two-area interconnected energy system with hydro, thermal plants, and a particle swarm optimization (PSO) method may improve power system stability and save revenue on power generation. A standard (PID) controller is used to control the system. The PSO optimization approach is utilised to determine the optimal gain values of the controllers *kp*, *ki*, and *kd*.

Keywords: ACE, Load Frequency Control, Two Area System, PSO.

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1. INTRODUCTION

Based on the literature survey most of the authors are focused on the power system operating state and generation's problems, and they are tending to overcome the problems on it to overcome the issues on state of operation and to maintain normal state operation, have to control the real and imaginary powers. The control system's model parameters are very useful for doing this[1].

Variations of true power leads to frequency down falls or gets changes, however the reactive power is less sensitive to changes in frequency, moreover mainly depends on variations in voltage. Therefore, the actual & reactive forces have to be controlled separately [2].

Under steady-state conditions, total power produced by power plants equals to system load and losses. Frequency might wander off from its nominal value due to sudden advancement of generation-load irregularities, and this is referred to as off-nominal frequency. The power and frequency are under the control of load frequency control methods. Reactive power and voltage magnitude are controlled by automatic voltage regulator technology. Load frequency control is becoming more and more significant now a days. [2], [3].

1.1 Mathematical Modelling

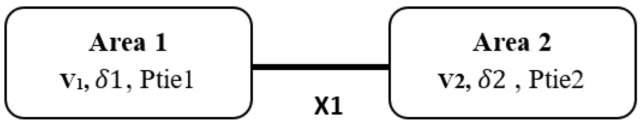

Figure 1: Two interconnected control areas

Power transmitted from area -1 is given by[4]

$$Ptie1=\frac{|V1||V2|}{X12}\sin(\delta 1-\delta 2). \quad (1)$$

Where,
$.\delta 1, .\delta 2$ are power angles of the two areas

For the changes in $\delta 1$ *and* $\delta 2$, the tie line power can be expressed as

$$\Delta Ptie1(pu) = T12\ (\Delta\delta 1 - \Delta\delta 2) \quad (2)$$

Where,

T12 = $\frac{|V1||V2|}{X12|Pr1|}\cos(\delta 1-\delta 2)$ is synchronizing coefficient
Pr1 is rated capacity of area1

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The incremental change in angle can be expressed as

$$\frac{d\delta}{dt} = \omega = 2\pi f = speed$$

$\delta = \int 2\pi f$ $\qquad$ $\Delta\delta = 2\pi \int \Delta f$

Change in angle can be expressed as the integral of changes in the frequency

$$\Delta Ptie1 = T12(\int 2\pi f1 - \int 2\pi f2)dt \qquad (3)$$
$$= 2\pi\ (\int \Delta f1dt - \int \Delta f2dt)T12 \qquad (4)$$

Here $f1$, $f2$ are gradual frequency deviations of area 1 & 2
Similarly, power transmitted from the area2 is given by

$$\text{Ptie2}=\frac{|V2||V1|}{X21}\sin(\delta 2 - \delta 1) \qquad (5)$$

For changes in $\delta 2$ & $\delta 1$ the incremental .tie line power can be expressed as:

$$\Delta Ptie2(pu) = T21\ (\Delta\delta 2 - \Delta\delta 1)$$

Change in angle can be expressed as the integral of changes in the frequency of area 2 is given by

$$= 2\pi\ (\int \Delta f2dt - \int \Delta f1dt)T21 \qquad (6)$$

Where,

$$\mathbf{T21} = \frac{|V2||V1|}{X21|Pr2|}\cos(\delta 2 - \delta 1)$$
$$= \frac{Pr1}{Pr2}T12 \qquad = a12\,T12$$

In general load model, Area 1's ongoing power balancing equation can be expressed as:

$$\Delta Pg1 - \Delta Pd1 = \frac{2H1}{fo}\frac{d(\Delta f1)}{dt} + B1\Delta f1 + \Delta Ptie1 \qquad (7)$$

Taking the Laplace transform for this equation

$$\Delta Pg1(s) - \Delta Pd1(s) = \frac{2H1}{fo}s\Delta f1(s) + B1\Delta f1(s) + \Delta Ptie1(s)$$

$$\Delta Pg1(s) - \Delta Pd1(s) - \Delta Ptie1(s) = \frac{2H1}{fo}s\Delta f1(s) + B1\Delta f1(s)$$

$$\Delta Pg1(s) - \Delta Pd1(s) - \Delta Ptie1(s) = \Delta f1(s)\left(\frac{2H1}{fo}s + B1\right)$$

$$\Delta Pg1(s) - \Delta Pd1(s) - \Delta Ptie1(s) = \Delta f1(s)B1\left(\frac{2H1}{foB1}s + 1\right)$$

$$(\Delta Pg1(s) - \Delta Pd1(s) - \Delta Ptie1(s)) * \frac{Kp1}{1+sTp1} = \Delta f1(s) \qquad (8)$$

Where,
$\text{Kp1}=\frac{1}{B1}$, $\text{Tp1}=\frac{2H1}{foB1}$

Where

$$\Delta Ptie1 = T12(\int 2\pi f1 - \int 2\pi f2)dt$$

Apply Laplace transform on both sides

$$\Delta Ptie1(s) = \frac{2\pi T12}{s}(\Delta f1(s) - \Delta f2(s)) \qquad (9)$$

For control area2

$$\Delta Ptie2 = T21(\int 2\pi f2 - \int 2\pi f1)dt \qquad (10)$$

Apply Laplace transform on both sides

$$\Delta Ptie2(s) = \frac{2\pi T21}{s}(\Delta f2(s) - \Delta f1(s))$$
$$\Delta Ptie2(s) = \frac{2\pi T12a12}{s}(\Delta f2(s) - \Delta f1(s))$$

$$\Delta Ptie2(s) = \frac{-2\pi T12a12}{s}(\Delta f2(s) - \Delta f1(s)) \qquad (11)$$

Where T21=a12*T12

A single integrating block is defined as the linear combination of progressive frequency and tie line power.

For area 1
$$\text{ACE1}=\Delta Ptie1 + b1\Delta f1 \qquad (12)$$

Where b1 is area frequency bias

Apply Laplace transforms ACE1(s) = $\Delta Ptie1(s) + b1\Delta f1(s)$

For area 2

$$\text{ACE2} = \Delta Ptie2 + b2\Delta f2 \qquad (13)$$

Apply Laplace transforms ACE2(s) = $\Delta Ptie2(s) + b2\Delta f2(s)$
The basic block diagrams of the two-control area system corresponding to *figure 2.*

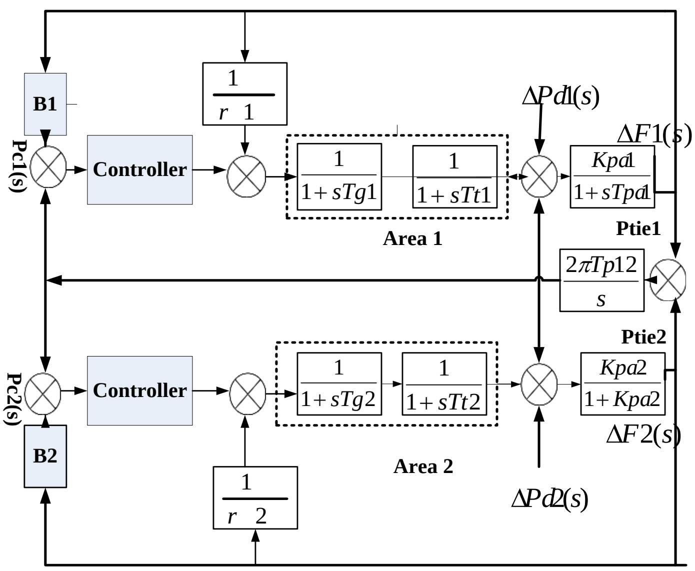

Figure 2: Block diagram of two area system

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2. PARTICLE SWARM OPTIMIZATIONS TOPOLOGY

2.1 Introduction

This particle swarm optimization is developed by using different features of natural evaluation. So, it has different components velocity, position of the particle as well as it includes local best of the each particle of the swarm[5].

PSO is developed using two methodologies
1. Artificial life (mimicking bird flocking, fish schooling, swarming theory)
2. Evolutionary computation.

In artificial life, swarm searches for food in cooperative way.in the sense in swarm has lot of birds and fishes are there, so they work in cooperative manner. In general observations lot of birds are flying in the sky and they are move in one direction, in this scenario any bird see the food ,then rest of the birds also follow the particular bird or searching food .hence the same concept is follow is borrowed and PSO have been developed[6], [7].

While doing this process, each member in the swarm learns from its experience and also from other members for changing the search pattern to locate the food. Based on this process in swarm theory, if any particle moving from one position to another, means the particle started from one position after that generation or iteration and it reaches to another position[6], [8]. In swarm theory each particle will know what was its best position, hence they keep a track of the position as well as their task is search for food or in end optimization of solution. Therefore, in swarm theory particle knows their best position, work individually as well as they see the pattern of other members, so that we can find optimal solution for given problem[7].

PSO is developed using the simple concepts and primitive operators. This is computationally inexpensive both in memory and speed and also can be easily implemented using computer programming. And one more PSO does not involve probability calculations[6].

2.2 Working

PSO starts with initializing population randomly similar to genetic algorithm. Unlike genetic algorithm operators, solutions are assigned with randomized velocity to explore the search space. Each solution in PSO referred as particle[9], [10]. *Figure 3* focuses on flow chart of working scenario.

Three distinct features of PSO[11]
- Best fitness of each particle.
- Best fitness of swarm.
- Velocity and position update of each particle

PSO is developed using two methodologies
1. Artificial life (mimicking bird flocking, fish schooling, swarming theory)
2. Evolutionary computation.

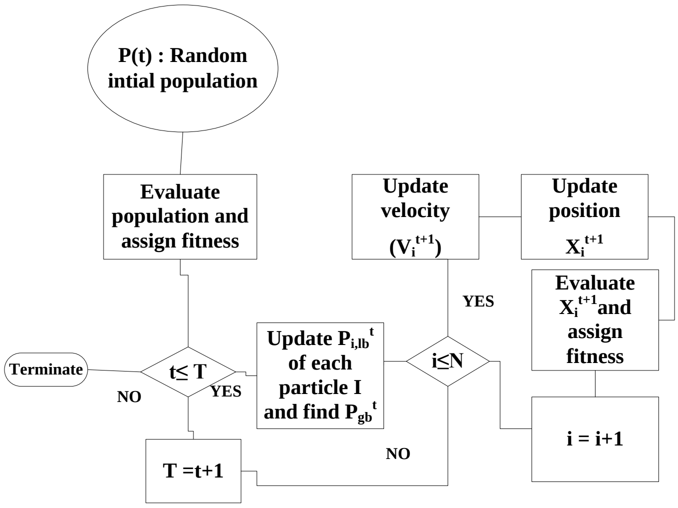

Figure 3: Flow chart for PSO

In artificial life, swarm searches for food in cooperative way.in the sense in swarm has lot of birds and fishes are there, so they work in cooperative manner. In general observations lot of birds are flying in the sky and they are move in one direction, in this scenario any bird see the food, then rest of the birds also follow the particular bird or searching food hence the same concept is followed is borrowed and PSO have been developed.

In swarm theory each particle will know what was its best position, hence they keep a track of the position as well as their task is search for food or in end optimization of solution. Therefore, in swarm theory particle knows their best position, work individually as well as they see the pattern of other members, so that we can find optimal solution for given problem.

2.3 Basic Algorithm for PSO [5]

Step 1: solution representation **% genetics**
Step 2: Input t: =1 (generation counter), maximum allowed generation =N
Step 3: initialize random swarm (P(t));
%swarm
Step 4: Evaluate (p (t)); **evaluate objective, constraints and assign fitness**
Step 5: While t ≤ N do
Step 6: update P $_{(I\ lb)}$(t) of each particle 'i' and find P_{gb}(t); **%new step**
Step 7: for (i = 1; i ≤ N, i++) do **%for eachone 'i'**
Step 8: update velocity V_I (t+1);
Step 9: Update position X_i (t+1);
% variation
Step 10: Evaluate X_i (t+1) and include it in P (t+1);
Step 11: End for
Step 12: =t+1;
Step 13: End while

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3. LOAD Frequency with PSO

Abnormal frequency deviations may cause system failure. Therefore, these necessities a perfect and fast acting controller to maintain the stable frequency. The limitations of the conventional controls in the sense integral, P and PID are giving good results in handling system non linearities[12], [13].

For optimum response of LFC control scheme must be applied at both generation side and load side using modern algorithm and techniques[14].

Problems with the generator if any changes occur in the load, means shaft speed falls down from the pre-set value and the system frequency falls from the nominal value results in fall over of frequency [14].

Many control areas are presented In an interconnected system, Each can maintain its load frequency control with objectives and adequately manage the size of the ACE close to "0" using various schemes[15].

Because the power system is not linear, the parameters of the system are simplified around the operating point. The unit's response time is based on the dynamics of the turbine, such as constant and non-linearities.[15], [16]

3.1 ACE (Area Control Error)

High deviation of system frequency may lead to system collapse. In such a case, load frequency control optimization approaches are employed to ensure the reliability and quality of operation in a system of frequency, tie line power flow and calculate net changes means Area Control Error[14], [17].
Finally

- Control the value settings of the generators to keep the ACE to a minimum value.
- AGC drives ACE to zero, thus automatically frequency and tie line power flow will gets to zero

3.1.1 Objective Function Formulation [14], [16]

The mostly used objective functions as follows

- Integral .Square .Error
- .Integral of .Time. multiplied absolute error
- .Integral of time .multiplied square error
- Integral of absolute .error

Consider F1 and F2 are frequency variations in area1 and area2 J is objective function

Table 1: Simulink parameters

No of iterations	75
Population size	10
Step time	0.0001
PID Controller parameters	
$K_p$mn	0
K_p mx	100
K_i mn	0
K_i mx	40
$K_d$mn	0
K_d mx	40

J= $\oint_0^t (\Delta square\ of\ F1 + \Delta square\ of\ F2 + \Delta square\ of\ tie\ line\ power) dt \ldots.$ (16)

This objective is the function to minimize "J" during load disturbance.

Integral of Time multiplied absolute error

J= $\oint_0^\infty t(|\Delta F1| + |\Delta F2| + |\Delta\ tie\ line\ power|)dt \ldots.$ (3.2)

This objective is composed of tie line power and frequency fluctuations of given areas.

Integral of time multiplied square error

J= $\oint_0^t (\Delta square\ of\ F1 + \Delta square\ of\ F2 + \Delta square\ of\ tie\ line\ power) dt \ldots.$ (17)

Integral of absolute error

J= $\oint_0^\infty (|\Delta F1| + |\Delta F2| + |\Delta\ tie\ line\ power|)dt$ (18)

In which objective functions most and widely used function is Integral Square Error.

4. RESULTS AND DISCUSSION

4.1 Requirement of Design Model Parameters

Table 2: Requirement of design model parameters

S.no.	Quantity	Area 1	Area 2
1	Speed Reg	0.05	0.06
2	Frequency Load Co-efficient	0.6	0.9
3	Base Power	1000MVA	1000MVA
	Constant values		
4	Inertia	5	4
5	Governor Time	0.2 sec	0.3 sec
6	Turbine Time	0.5 (sec)	0.6 sec
7	Kp=0.54, ki= 0.71, kd= 0.8		

Consider that the two interconnected sections operate in parallel on a common frequency. The synchronising the power coefficient is calculated from the initial operating condition *i.e.* 2.0 percentage. If the load change occurs in area 1 due to frequency drop, to get nominal operation in this article used PSO with PID controller-based optimization technique. Simulink model and algorithm have done and produced results here[18], [19].

The Simulink model of hybrid power system is simulated and optimized using the parameters of the proposed multi-stage PSO-PID for LFC against various load disturbances[20]. The load frequency control, created using the self-tuning PSO-PID for the two-area system, keeps the system frequency, two-area powers, and tie line powers at their rated levels [21]

In simulation & optimization studies, it is presumable that the system will experience step variations in the input power as well as step load disturbances of 0.01, 0.02, 0.03, and 0.05 in pu. The

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responses of the scheme approach to variations in frequency, delPm1, delPm2, and tie line power are shown in *figures 4 and 13.*

Table 3: Settling Time of variant schemes for LFC

Load	PID		FOPID		FLC-PID		PID-PSO	
	Freq	Power	Freq	Power	Freq	Power	Freq	Power
1	5.8	5.6628	5.79	5.69628	5.4	5.6228	2.9334	3.6802
2	5.9	5.791	5.91	5.791	5.42	5.691	2.9376	4.7851

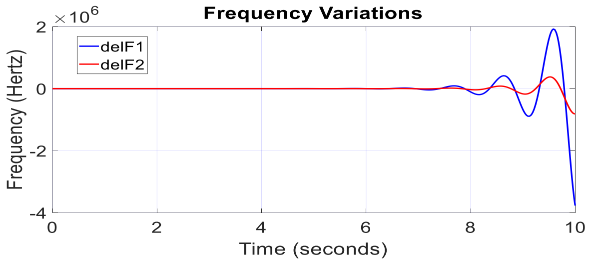

Figure 4: Frequency variations without PID scheme in two area system

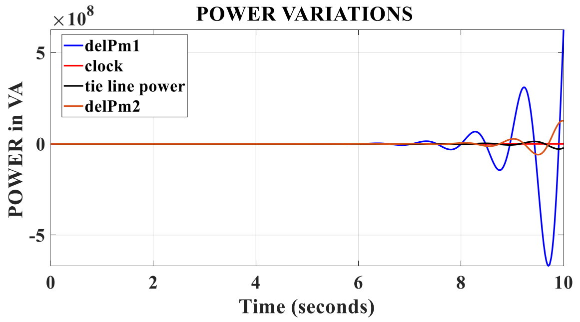

Figure 5: Power variations without PID scheme in two area system

The frequencies and power variations of two area systems in *figures 4* and *5* at 1000MVA loads, represents without any control technique, here power system cannot be stable. Therefore, in multi area system, frequency and power variations are more when load changes or may be turned-off.

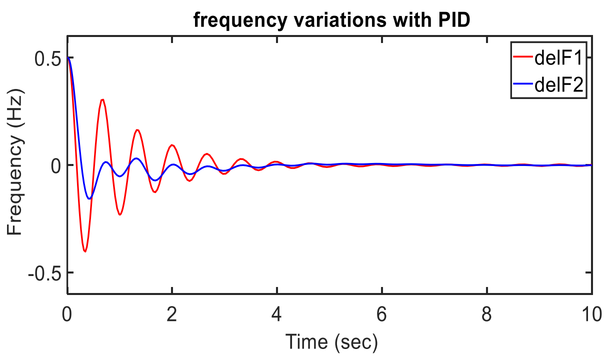

Figure 6: Frequency variations with PID scheme in two area system

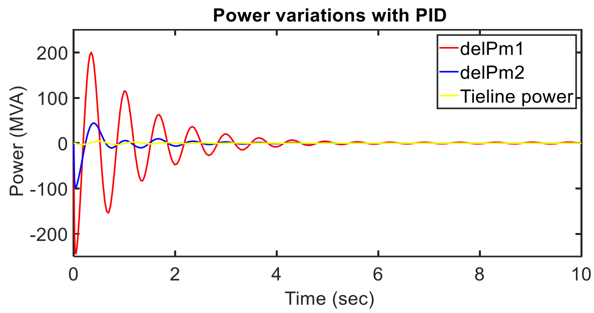

Figure 7: Power variations with PID scheme in two area system

Figures 6 and 7 represents load frequency control with PID scheme, in which frequency of two area systems settled after 5.8-5.9 sec at 1000 MVA load, while the powers settled after 5.6628 and 5.791 seconds, respectively. At 5.8 sec, the tie-line power became stable.

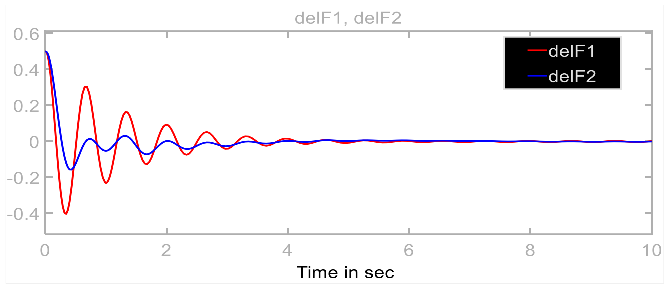

Figure 8: Frequency variations with FO-PID scheme in two area system

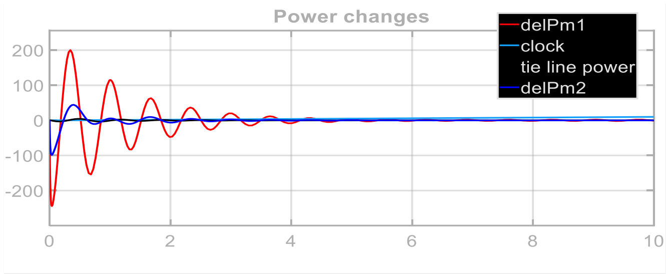

Figure 9: Frequency variations with FO-PID scheme in two area system

Figures 8 and 9 represents load frequency control with FO-PID scheme, in which frequency of two area systems settled after 5.79-5.9 sec at 1000 MVA load, while the powers settled after 5.69628 and 5.791 seconds, respectively. At 5.78 sec, the tie-line power became stable

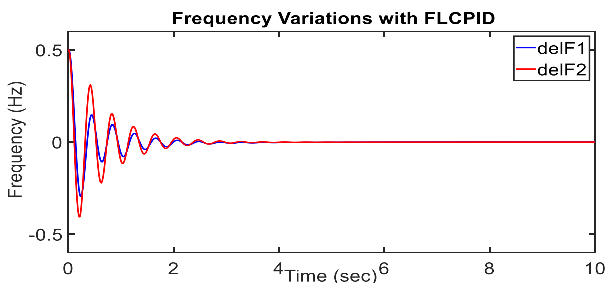

Figure 10: Frequency variations with PID FLC scheme in two area system

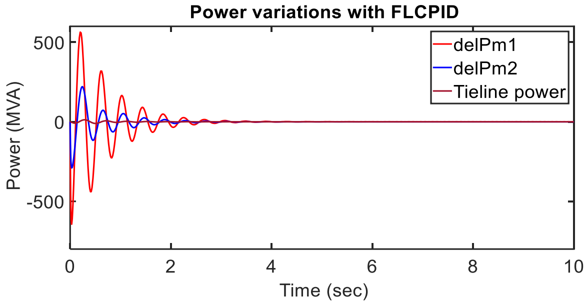

Figure 11: Power variations with PID FLC scheme in two area system

Figures 10-11 represents load frequency control with PID-FLC scheme, in which frequency of two area systems settled after 5.3-5.4 sec at 1000 MVA load, while the powers settled after 5.6228 and 5.691 seconds, respectively. At 5.76 sec, the tie-line power became stable.

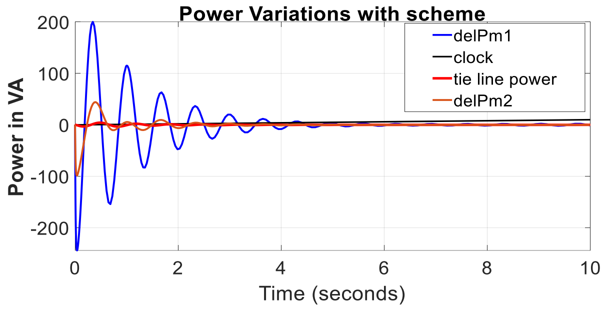

Figure 12: Frequency variations with PSO driven PID scheme in two area system

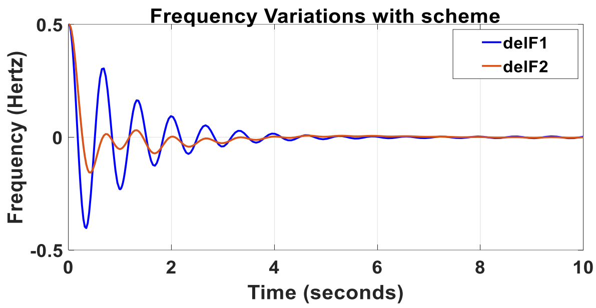

Figure 13: Power variations with PSO driven PID scheme in two area system

Figures 12-13 represents load frequency control with PID-PSO scheme, in which the frequencies of two-area systems had a settling time of 2.9334 seconds and 2.9376 seconds from at 0.01 p.u. load, and the powers had a settling time of 3.6802 seconds and 4.7851 seconds. Tie-line strength stabilised at 3.9931 seconds. The PID-PSO method is therefore more efficient.

5. CONCLUSION

The linearization mistakes are treated as parametric uncertainties and unmodeled dynamics in this research, which investigates a two-area power system. In multi area inter connected power systems load frequency control is major issue and which can be workout from particle swarm optimization technique with PID controllers and which can be optimize the tie line power values. From these techniques get optimize response of load frequency control scheme must be applied to generation side and destination side. According to the simulation results, the proposed controller has a faster response time and fewer undershoots than other controllers.

REFERENCES

[1] "Renewable and Sustainable Energy Reviews," ResearchGate. https://www.researchgate.net/journal/Renewable-and-Sustainable-Energy-Reviews-1364-0321 (accessed Mar. 19, 2022).

[2] A. Soundarrajan, S. Sumathi, and C. Sundar, "Particle swarm optimization based LFC and AVR of autonomous power generating system," IAENG Int. J. Comput. Sci., vol. 37, no. 1, pp. 37–1, 2010.

[3] A. Soundarrajan, S. Sumathi, and C. Sundar, "Particle swarm optimization based LFC and AVR of autonomous power generating system," IAENG Int. J. Comput. Sci., vol. 37, no. 1, pp. 37–1, 2010.

[4] L. Bhukya, A. Annamraju, and S. Nandiraju, "Robust frequency control in a wind-diesel autonomous microgrid: A novel two-level control approach," Renew. Energy Focus, vol. 36, pp. 21–30, 2021.

[5] B. Jana, S. Mitra, and S. Acharyya, "Repository and mutation based particle swarm optimization (RMPSO): A new PSO variant applied to reconstruction of gene regulatory network," Appl. Soft Comput., vol. 74, pp. 330–355, 2019.

[6] K.-L. Du and M. N. S. Swamy, "Search and optimization by metaheuristics," Tech. Algorithms Inspired Nat., pp. 1–10, 2016.

[7] Y. Del Valle, G. K. Venayagamoorthy, S. Mohagheghi, J.-C. Hernandez, and R. G. Harley, "Particle swarm optimization: basic concepts, variants and applications in power systems," IEEE Trans. Evol. Comput., vol. 12, no. 2, pp. 171–195, 2008.

[8] A. Kaveh, Advances in metaheuristic algorithms for optimal design of structures. Springer, 2014.

[9] A. Salman, I. Ahmad, and S. Al-Madani, "Particle swarm optimization for task assignment problem," Microprocess. Microsyst., vol. 26, no. 8, pp. 363–371, 2002.

[10] L. dos Santos Coelho and V. C. Mariani, "A novel chaotic particle swarm optimization approach using Hénon map and implicit filtering local search for economic load dispatch," Chaos Solitons Fractals, vol. 39, no. 2, pp. 510–518, 2009.

[11] "Venkata Anjani Kumar G and M. Damodar Reddy (2023), Fuzzy and PSO tuned PI controller based SAPF for Harmonic Mitigation. IJEER 11(1), 119-125. DOI: 10.37391/IJEER.110116.".

[12] C. MJ and R. Jayapal, "Performance analysis of FL, PI and PID controller for AGC and AVR of a Two-Area Power System".

[13] M. Moafi, M. Marzband, M. Savaghebi, and J. M. Guerrero, "Energy management system based on fuzzy fractional order PID controller for transient stability improvement in microgrids with energy storage," Int. Trans. Electr. Energy Syst., vol. 26, no. 10, pp. 2087–2106, 2016.

[14] H. H. Alhelou, M.-E. Hamedani-Golshan, R. Zamani, E. Heydarian-Forushani, and P. Siano, "Challenges and opportunities of load frequency control in conventional, modern and future smart power systems: a comprehensive review," Energies, vol. 11, no. 10, p. 2497, 2018.

[15] K. Naidu, H. Mokhlis, and A. A. Bakar, "Multiobjective optimization using weighted sum artificial bee colony algorithm for load frequency control," Int. J. Electr. Power Energy Syst., vol. 55, pp. 657–667, 2014.

[16] A. M. Jadhav, K. Vadirajacharya, and E. T. Toppo, "Application of particle swarm optimisation in load frequency control of interconnected thermal-hydro power systems," Int. J. Swarm Intell., vol. 1, no. 1, pp. 91–113, 2013.

[17] C. Fu, C. Wang, and D. Shi, "An alternative method for mitigating impacts of communication delay on load frequency control," Int. J. Electr. Power Energy Syst., vol. 119, p. 105924, 2020.

[18] M. Shiroei and A. M. Ranjbar, “Supervisory predictive control of power system load frequency control,” Int. J. Electr. Power Energy Syst., vol. 61, pp. 70–80, 2014.

[19] H. Shabani, B. Vahidi, and M. Ebrahimpour, “A robust PID controller based on imperialist competitive algorithm for load-frequency control of power systems,” ISA Trans., vol. 52, no. 1, pp. 88–95, 2013.

[20] N. Nireekshana, R. R. Chandran, and G. V. Narayana, “Frequency Regulation in Two Area System with PSO Driven PID Technique,” J. Power Electron. Power Syst., vol. 12, no. 2, pp. 8–20, Nov. 2022.

[21] A. Annamraju, L. Bhukya, and S. Nandiraju, “Robust frequency control in a standalone microgrid: An adaptive fuzzy based fractional order cascade PD-PI approach,” Adv. Control Appl. Eng. Ind. Syst., vol. 3, no. 3, p. e72, 2021.