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VERIFICATION OF DE OPTIMIZED PD-PID CASCADED CONTROLLER FOR LFC OF INTERCONNECTED TWO AREA POWER SYSTEM

Rakesh Kumar Pattanayak, Assistant Professor Department of Electrical Engineering
rakeshkumarpattanayak@gietbbsr.edu.in GIET,Ghangapatana, BBSR
Rakesh Roshan Swain, Assistant Professor Department of Electrical Engineering
rakeshroshanswain@gietbbsr.edu.inGIET,Ghangapatana, BBSR

ABSTRACT :
In order to operate power systems in real time, intelligent systems that integrate knowledge, techniques, and methodologies from multiple sources are required due to the growing complexity and size of contemporary electric power systems as well as the rise in power consumption. A modern power system network is made up of several utilities that are connected to one another. The utilities exchange electricity through a tie-line that connects them. Constant frequency and constant tie-line power exchange are both necessary for power systems to operate steadily. To maintain the time average of the ACE at a low value, a Load Frequency Controller (LFC) in each area keeps an eye on the tie-line flows and system frequency. It also modifies the generators' fixed positions within the region [1]. Therefore, the controlled output of LFC is typically assumed to be ACE, which is defined as a linear combination of power net-interchange and frequency deviations. Both frequency and tie-line power faults will be forced to zeros when the LFC drives the ACE to zero [2]. In order to keep the system frequency and tie line flow at their scheduled values both during normal operation and under disturbance conditions, researchers worldwide are attempting to implement a number of solutions for LFC of power systems. The thesis's goal is to design a model of a two-area interconnected power system with governor dead band nonlinearity. The PD-PID controller structure is used in the power system model to minimize frequency deviation and tie line power deviation, and the controller's parameters are optimized using the differential evolution (DE) algorithm. The outcomes of the suggested method are then compared with those of the Craziness based Particle Swarm Optimization (CPSO) technique [12, 17, 18] for the same interconnected power system.

INTRODUCTION :

Numerous control factors pertaining to the LFC problem have been examined in the critical literature review on the LFC of power systems that was published in [3]. Proposals for improved LFC control systems based on contemporary control theory [4], neural networks [5,6], fuzzy system theory [7], reinforcement learning [8], and the ANFIS approach [9] have been the subject of extensive investigation. Recently, new methods based on artificial intelligence have been put forth to develop a controller. For demonstrated that an optimal controller based on the Bacterial Foraging Optimization Algorithm (BFOA) outperforms both traditional and Genetic Algorithm (GA) based controllers.

The literature on power system load frequency control (LFC) and the need for frequency control is reviewed in Section 1. A brief overview of the work is given, along with the motivation and goal, and a review of the literature on several algorithms for adjusting the controller gains. The load frequency control (LFC) of a two-area linked power system is explained also in Section 1. Mathematical modelling is used to describe the main parts of the power system. In Section 2, the PD-PID controller is explained along with the issue formulation. The DE method is described in Section 3 and also covers the findings and discussions. Section 4 concludes the research and outlines the work's future directions.

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Section –I

System Modelling :

A. LFC :

When the load in a system varies, the frequency and bus voltages are also impacted. As the name suggests, LFC maintains a constant frequency while modifying the power flow between various regions. In reality, LFC is a loop that controls output within the generator's megawatt and frequency range [23]. The LFC's operational goals are to control the tie line interchange schedules, distribute the load across generators, and maintain a fairly constant frequency. The change in rotor angle that needs to be adjusted is measured by the change in frequency and tie-line real power.A real power command signal, Δp_v, is created by amplifying, combining, and transforming the error signal, Δf and Δp_tie, and sending it to the prime mover to request an increase in torque. As a result, the prime mover modifies the generator output by Δp_g, which modifies the values of Δf and p_tie within the given tolerance. Fig. 1 shows the schematic diagram. A control system's mathematical modeling is the initial stage of its design and analysis. The following components' transfer function models are produced by linearizing the mathematical equations defining the system using the appropriate assumptions and approximations.

B. Turbine Model :

The model for the turbine, which is the source of mechanical power, links changes in steam valve position (ΔP_D) to changes in mechanical power (ΔP_m). Reheat, hydraulic, and non-reheat turbines are the three types of turbines that are typically utilized. The non-reheat turbine is the most widely used type and is taken into consideration here, which links the turbine's output to the valve's position. The generator unit will accelerate if the power difference, or ΔP_m - ΔP_D, is positive; if not, it will decelerate. Increases in valve power and the turbine's reaction characteristics determine the increase in turbine power, or ΔP_T.

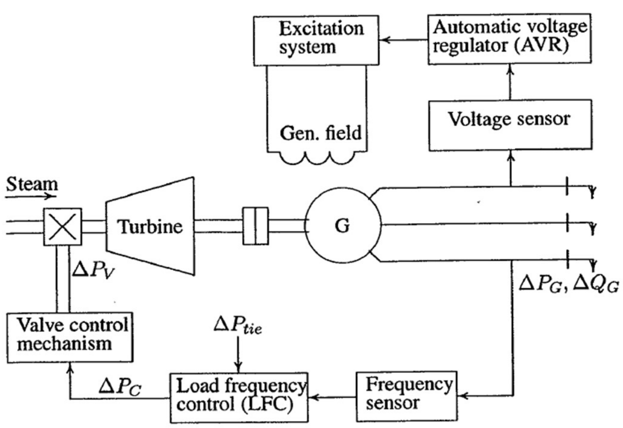

Fig 1: LFC and AVR schematic diagram for a synchronous generator

Mathematically, transfer function of turbine is:

$$\frac{\Delta P_T(s)}{\Delta P_D(s)} = \frac{1}{1+ST_T}$$

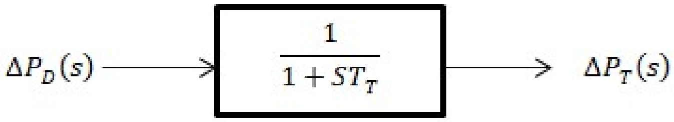

Fig.2: Block diagram of turbine

C. Generator Model :

A balance between power generation and load demand must be maintained since large-scale electrical power storage is both challenging and expensive. The power produced by the generator will not equal the mechanical power if the load changes. The variations in turbine power ΔP_m and generator power increment ΔP_G are solely dependent on each other.The generator constantly modifies its output to accommodate variations in demand ΔP_D. In terms of mathematics,

$$\frac{\Delta P_G(s)}{\Delta P_m(s)} = \frac{1}{1+ST_G}$$

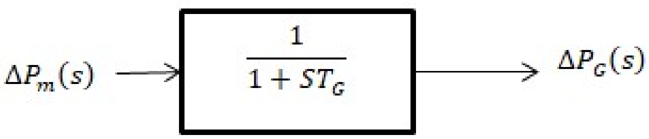

Fig.3: Block diagram of generator

D. Generator Load Model :

A range of electrical devices make up the power system's loads; some are solely resistive, while others are motor loads, which make up the majority of all electrical loads. Variations in the load that the generator is feeding determine how much power the generator can increase. Given $\Delta F(S)=G_P(S)[\Delta P_T(S) - \Delta P_D(S)]$, the generator load system has two inputs, $\Delta P_T(s)$ and $\Delta P_D(s)$, and one output, $\Delta F(s)$.

The transfer function created by combining the generator and load is provided by

$$G_P(S) = \frac{K_{PS}}{1+ST_{PS}} \qquad (2.5)$$

Where $K_{PS}=1/D$ and $T_{PS} = 2H/FD$.
D=Droop
H=Inertia constant

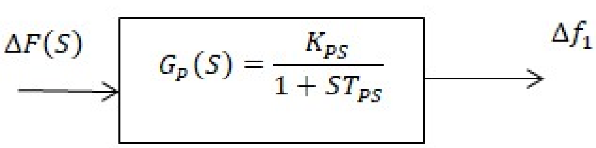

Fig.4: Block diagram of generator load

A governor, often known as a speed limiter, is a machine speed adjustment and limitation device. In power systems, governors are helpful because they control the turbine power's speed and aid in frequency regulation. Additionally, it aids in starting the turbine and shields it from damaging

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working circumstances [2]. The load fluctuates based on customer demand rather than staying constant. Generation must be adjusted as a result of frequency changes brought on by the discrepancy between generation and load demand. When frequency fluctuates, power quality is impacted. The most basic type of governor, known as an isochronous governor, modifies or controls the input valve until the frequency returns to its nominal value. In terms of mathematics,

$$\Delta P_G(S) = \Delta P_{ref}(s) - \frac{1}{R}\Delta F(S)$$

$\Delta P_G(S)$= governer output
ΔP_{ref}= the reference signal
$\Delta F(S)$= frequency deviation due to speed
$\frac{1}{R}$ = regulation constant or droop

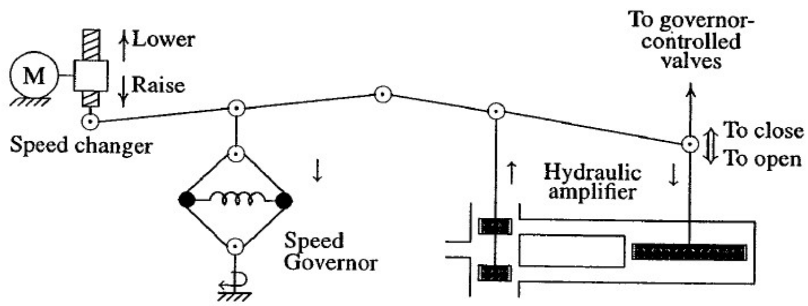

Fig.5: Functional diagram of real power control [23]

1. GOVERNER OF SPEED

The crucial component is centrifugal fly balls, which are driven either directly or via gearing by the turbine shaft mechanism to produce vertical movements that are proportionate to changes in speed.

2. LINKAGE MECHANISM: These linkages translate the fly ball movement to the turbine valve and offer feedback from the turbine valve movement using a hydraulic amplifier.

3. **AMPLIFIER HYDRAULIC:**

The steam valve requires extremely high mechanical forces to operate. The governor movements are thus transformed into high-speed power forces by a series of hydraulic amplifier stages.

4. CHANGER OF SPEED

It is made up of a servomotor that can be manually turned to schedule a load at a predetermined frequency.

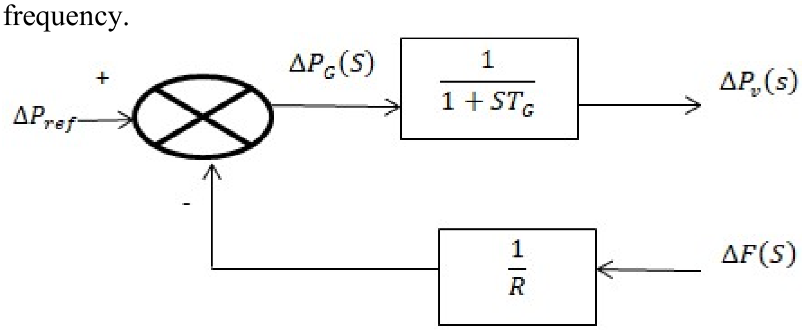

Fig.6: Block diagram of speed governing system [23]

The dynamic performance of the electric energy system is significantly impacted by the speed governor dead band. The system is non-linear since the governor dead band must be considered for a

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more realistic analysis. The whole amount of a continuous speed shift during which the valve position remains unchanged is known as the governor dead band. A large portion of this seems to take place in the rack and pinion that turns the camshaft that controls the valves. A speed increase or drop may occur prior to a change in the valve's position because of the governor dead band. The system oscillates because of the speed-governor dead band. The governor dead band nonlinearity is incorporated via a descriptive function technique. Long-term sinusoidal oscillation with a natural period of around T0 = 2 seconds, or an oscillation frequency of f0 = 0.5 Hz, is caused by the governor dead-band nonlinearity [12]. According to [12], the governor's transfer function G_g with dead-band nonlinearity can be written as:

$$G_g = \frac{0.8 - \frac{0.2}{\pi}S}{1 + T_G S}$$

Section –II

A. Problem Formulation :

The goal function is initially established in accordance with the intended specifications and restrictions for the construction of a contemporary PID controller based on heuristic optimization. Typically, performance criteria that rely on system responsiveness are used to choose the objective function to optimize the controller parameters. Peak overshooting, rising time, settling time, and steady-state error are the ideal parameters for time domain systems. Integral of Time multiplied Absolute Error (ITAE), Integral of Squared Error (ISE), Integral of Time multiplied Squared Error (ITSE), and Integral of Absolute Error (IAE) are performance metrics that are typically published in the literature. It has been demonstrated that when compared to other criteria, the ITAE yields superior results.[13]. The objective function J tries to minimize the settling times and overshoots of Δf_1, Δf_2 and ΔP_{Tie}, maximize the damping ratio (f) and minimize an error criteria given by

$$J = ITAE = \int_0^{t_{sim}} (|\Delta F_i| + |\Delta P_{Tie-i-k}|).t.dt$$

Minimize J subject to*:*

$$K_{P\,min} \leq K_P \leq K_{P\,max}, \quad K_{I\,min} \leq K_I \leq K_{I\,max}, \quad K_{D\,min} \leq K_D \leq K_{D\,max},$$
$$K_{P1\,min} \leq K_{P1} \leq K_{P1\,max}, K_{D1\,min} \leq K_{D1} \leq K_{D1\,max},$$

The choice of parameter for PID controller is K_P ranges from 0.2 to 0.3,K_I from 0 to 1,K_D from 0.1 to 0.2 . For PD controller parameter ranges for KP1 is 3 to 3.5 and for KD_1 is 0.1 to 0.3.

B. Differential Evolution Algorithms:

An effective and well-liked optimization technique for handling challenging issues in a variety of domains, including machine learning, engineering, and economics, is differential evolution (DE). DE, which was first put up by Storn and Price in 1995, works especially well for continuous optimization issues.

The method uses a straightforward but reliable approach based on the ideas of recombination and mutation. A population of potential solutions is first created, each of which is represented as a vector in a multidimensional space. Among the crucial phases in DE are:

1. Initialization: Within predetermined boundaries of the solution space, a population of

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vectors is produced at random.

2. Mutation: By adding the weighted difference between two randomly chosen vectors from the population to a third vector, DE generates a modified vector for every target vector.

3. Recombination: To create a trial vector, the target vector and the modified vector are mixed. This stage introduces new qualities while preserving the old information.

4. Selection: The goal vector and the trial vector are compared. It takes the place of the target vector in the following generation if it produces a higher fitness value (based on a predetermined goal function). This guarantees that over iterations, the population will progress toward better options.

DE's simplicity, ease of use, and resilience to different optimization environments make it very beneficial. Compared to other algorithms, it is less likely to experience convergence problems and can successfully avoid local minima. DE is also flexible, enabling users to modify its parameters—like the crossover rate and mutation factor—to fit certain issues.
In general, Differential Evolution is a dependable optimization method that exhibits effectiveness in a variety of applications while striking a balance between exploration and exploitation.

5. Flow Chart of DE Algorithm:

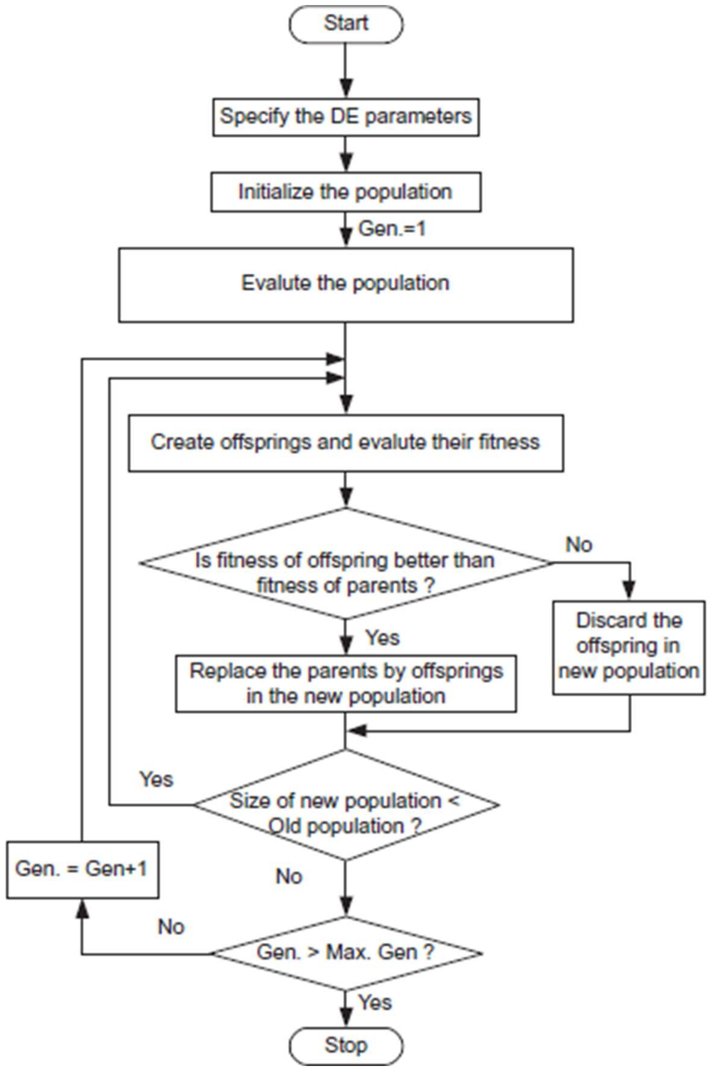

Fig 7.: Flow chart of DE algorithm

Section –III

RESULTS AND DISCUSSION:

The DE algorithm's control parameters are step size F = 0.9, crossover probability of CR = 0.9, population size NP = 10, D = 5 (the dimensionality of the control vector), and these values were chosen for the current investigation based on [14]. DE/best/1/exp is the method used. The predetermined number of generations—100 in this case—ends optimization. An Intel dual-core machine with a 2.4 GHz CPU and 2 GB of RAM was used for the simulations, which were run in the MATLAB 7.10.0.499 (R2010a) environment. For objective function J, the optimization was carried out ten times, and Table 1 displays the best final solution from the ten runs.

The system model considering 1% step load perturbation in area2 only is tested using the same optimized PD-PID controller parameter using 1% SLP in area1 as indicated in Table 1 to determine the technique's performance. The dynamic response is displayed in Figures 17 to 19. The figure's observations support the superiority of this strategy.

Table1: CONTROLLER PARAMETER FOR 1% SLP IN AREA1

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OBJECTIVE FUNCTION	KP1	KD1	KP	KI	KD
J:PD-PID	3.23	0.21	0.20	0.66	0.18
J2:CPSO PI[12]	-	-	-0.57	0.19	-
J1:CPSO PI[12]	-	-	-0.40	0.30	-

Table2: ITAE VALUE FOR 1% SLP IN AREA1

OBJECTIVE FUNCTION	ITAE
J PD-PID	**0.0204**
J2 CPSO PI[12]	0.5451
J1 CPSO PI[12]	0.5659

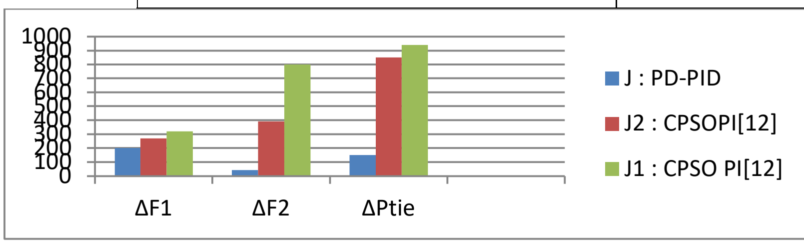

Fig 8: Comparision of overshoot for 1% SLP in area 1

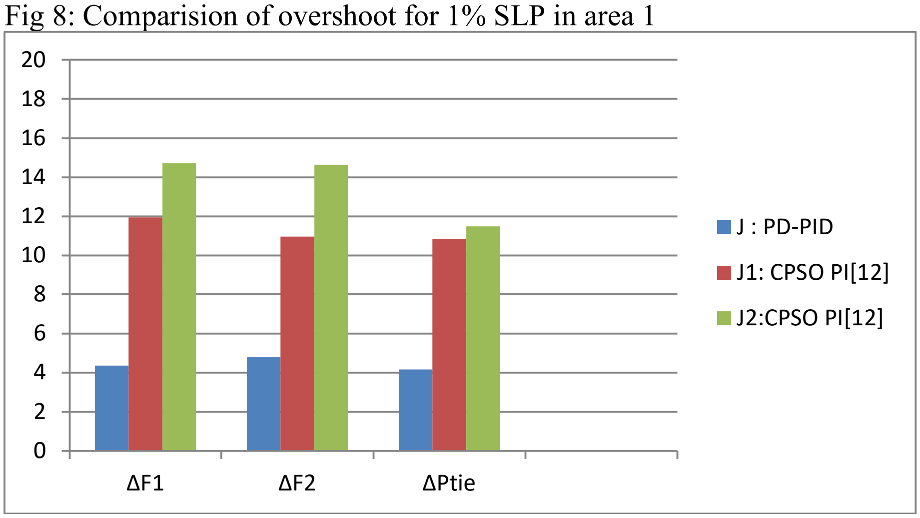

Fig.9: Comparision of settling time (in sec) for 1% SLP in area 1

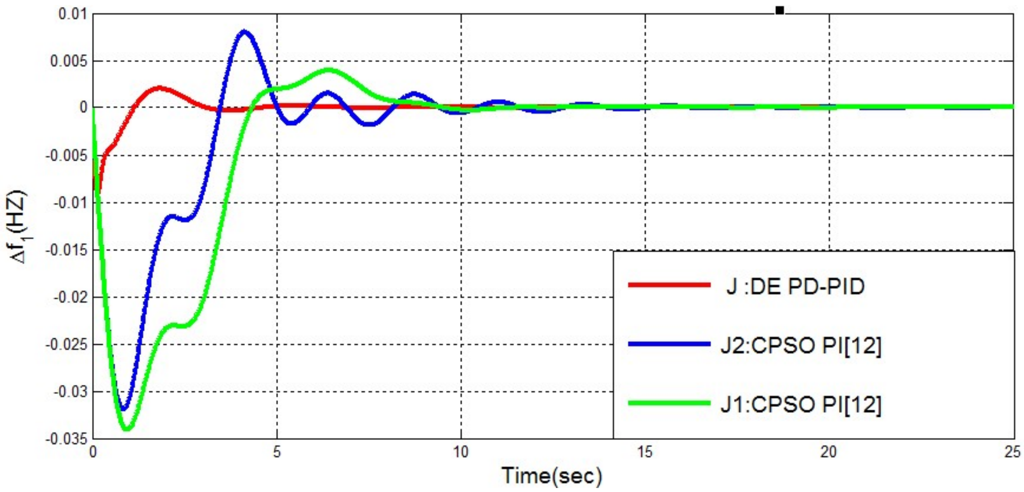

Fig.10: Frequency deviation in area1 for 1% SLP in area1

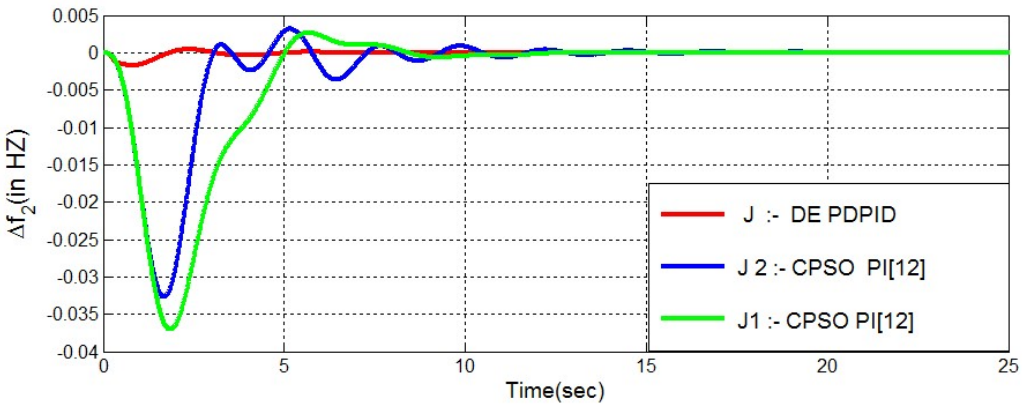

Fig.11: Frequency deviation in area2 for 1% SLP in area1

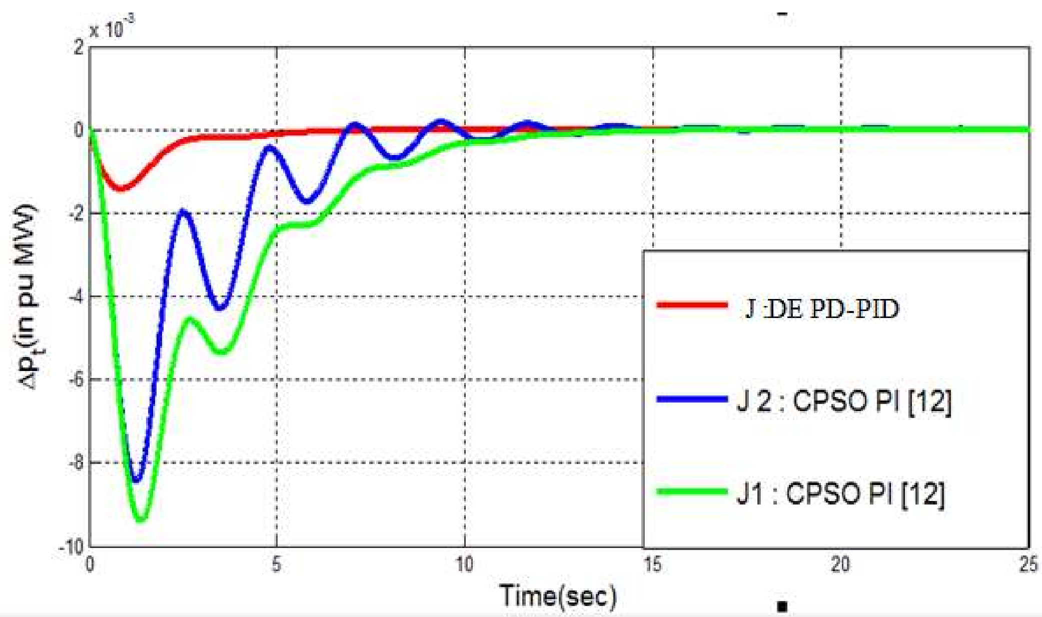

Fig.12: Tie line power deviation for 1% SLP in area1

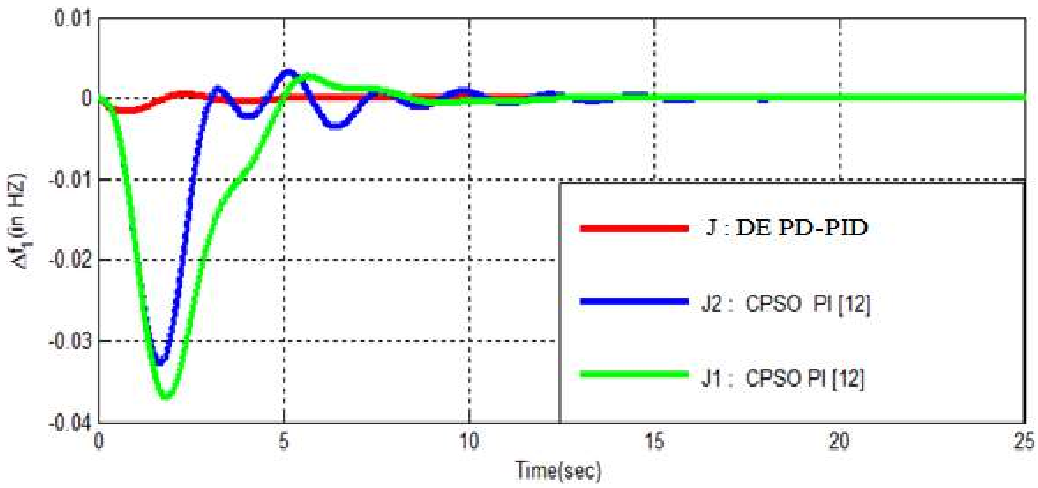

Fig.13: Frequency deviation in area1 for 1% SLP in area 2

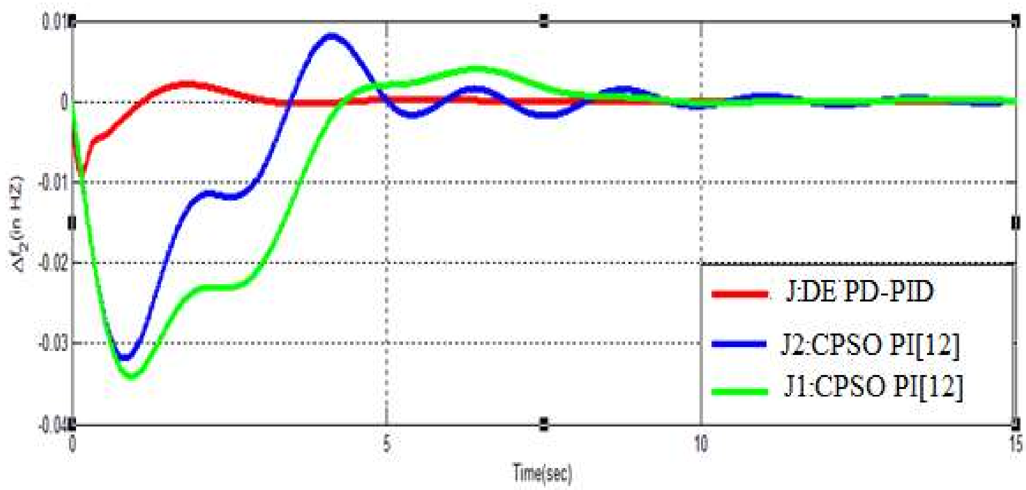

Fig.14: Frequency deviation in area2 for 1% SLP in area 2

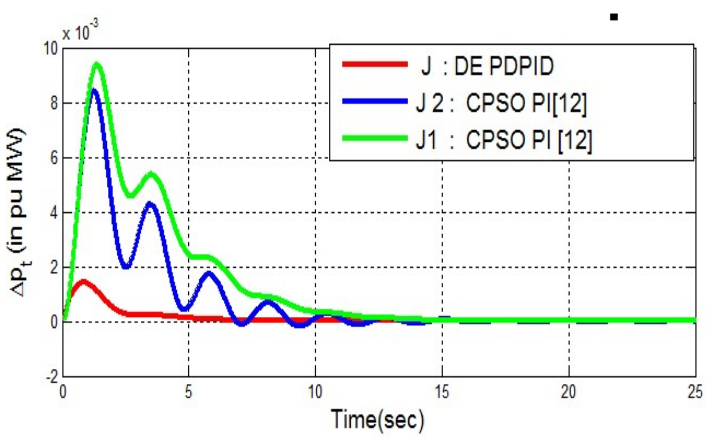

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Fig.15: Tie line power deviation for 1% SLP in area2

Section - IV

CONCLUSION:

The basics of LFC with modelling of different component of a power system are studied in section1 and section2 .The PD-PID controller with DE algorithm is briefly described in section 2 and section 3 .This study presents the performance analysis of DE optimized PD-PID Cascaded controller for Load Frequency Control (LFC) of interconnected power system. For design and analytical purposes, a popular standard test system—a two-area thermal system with governor dead-band nonlinearity—is taken into consideration.

The analysis done in the study is concluded as follows:

1) DE optimized PD-PID controller shows better performance than CPSO based PI controller in terms of oscillation, settling time, over shoot.
2) The dynamic response for both is compared for step load perturbation of 1% for area1 from which the superiority of DE optimized PD-PID cascaded control approach is verified.

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