ENHANCING LOAD FREQUENCY CONTROL IN DUAL AREA HYDRO-THERMAL SYSTEMS WITH FRUIT FLY ALGORITHM TUNED PIDD CONTROLLER AND HVDC INTEGRATION

Abstract

In this work, the load frequency control (LFC) of dual area conventional hydro thermal (DACHT) system is enforced under the control of fruit fly algorithm (FFA) tuned Proportional-Integral-Double derivative (PIDD) controller. Initially, the DACHT is laid with 1% step load perturbation (SLP) in area-1 to analyse its dynamic behaviour. However, the performance superiority of the FFA is validated with the artificial field algorithm (AFA), krill herd optimizer (KHO) and particle swarm optimisation. Further, the DACTH dynamic behaviour is assessed with the enforcement of high voltage DC line as the tie-line. Simulation results revealed the improvement of the system performance with the HVDC line. Finally, the DACTH is subjected with different loadings to test the robustness of the suggested control strategy.

Keywords: PIDD Controller, Fruit fly algorithm, HVDC line, 1%SLP, Load frequency control.

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I. INTRODUCTION

The installed capacity of the Indian power grid as on 31st March 2023 is 416GW of which 60.3% is of the thermal and hydro units. The generation of electric power from the thermal and hydroelectric power plants is contributing the majority part in our country. Moreover, the effective functioning and the stable operation of the hydro and thermal units in the context of interconnected nature is the crucial task. In real time environment the entire power system is the interconnected one and is termed as the interconnected power system (IPS) and for the simplicity it has been segregated in to several control regions. The benefit of operating the power system in an interconnected manner is to facilitate the power exchange between deficit and surplus control regions. The power exchange is possible through the tie-lines and hence the load demand at any deficit region can be attained from the surplus control regions.

The continuous variation of load demand on the IPS, made its operation more dynamic. The power generation must always meet the fluctuating demand including the transmission line losses. Otherwise, the frequency fluctuations arise and affect the IPS stability. The allowable frequency range in the country like India is in between the 50.2Hz to 49.8Hz and the system loses its stability when the frequency fluctuates beyond the specified range. To make the maintenance of frequency within the range, the major task is to reduce the gap between power generation and demand. For this, an automatic LFC action is to be maintained at the generation units. Considerable quantity of literature is available on the control strategies related to the automatic LFC actions over the past twenty years. The analysis on LFC was first initiated in [1] and from there a numerous methodologies and control approaches are evolved rapidly.

Too many control structures are developed by the researchers for establishing the automatic LFC actions and most of them are very difficult in adapting to the real time environment. Moreover, the developed regulators are tested on several IPS models that includes the one area hydro system, one area thermal system, one area hydro-thermal and two-area/three-area hydro-thermal systems etc. Irrespective of the models, the research community is more or less likely concentrated on the establishment of I, PI, and PID controllers [2]. These controllers performance is affected directly by their parametric values and hence soft computing algorithms are necessitated. Algorithms like naked mole rat algorithm, bacterial foraging algorithm, sinusoidal modulated PSO, JAYA algorithm, whale optimization [3], sea horse optimization, ant colony algorithm [4], donkey and smuggler algorithm, flower pollination; gravitational search technique, lion optimizer, cat swarm algorithm, harmony search method, back tracking search algorithm [5], etc. are implemented.

Furthermore, apart from the above discussed control techniques, the control approaches like fractional order control (FOC), degree-of-freedom control (DOF), and fuzzy logic control (FLC) are also available. The optimizations like artificial bee colony, spider optimizer, black widow algorithm, volley ball premier league [6] algorithm, modified grasshopper, wild horse optimizer [7], arctic wolf algorithm, snake optimizer, culinary chef algorithm, water cycle optimizer, frog leaping algorithm, genetic algorithm, differential search algorithm, stochastic fractal search [8], levy flight technique, Egyptian vulture algorithm, spotted hyena optimizer, fish schooling algorithm, atom search algorithm, selfish herd algorithm, COOT optimizer, flying squirrel algorithm, chimp optimizer, sine-cosine algorithm, cryogenic search algorithm, etc. are reported in the literature for the fin-tuning of FOC, DOF, and FLC aided controllers.

Even though, so many sophisticated controllers are put forwarded by the researchers and are available in the literature, this work performs a few modifications to the traditional PID and presented the PIDD controller. The practical implementation of FOC, DOF, and FLC aided controllers involves complexity and the handling of these regulators subjected to the realistic constraints might affect their performance. Though FFA is implemented in the domain of LFC, this paper still considers this in this work for parametric optimization owing to its operation efficacy.

The contributions of this work are as follows:

- DACHT system is developed in MATLAB/SIMULINK for assessing the dynamic analysis.
- Investigation is performed for 1%SLP in area-1.
- FFA tuned PIDD is developed and the efficacy of FFA is deliberated with AFA, KHO, and PSO.
- HVDC line as tie-line is enforced with the DACHT system and improvement in the performance is witnessed.
- Sensitivity analysis is conducted and the robustness of the implemented control strategy is validated.

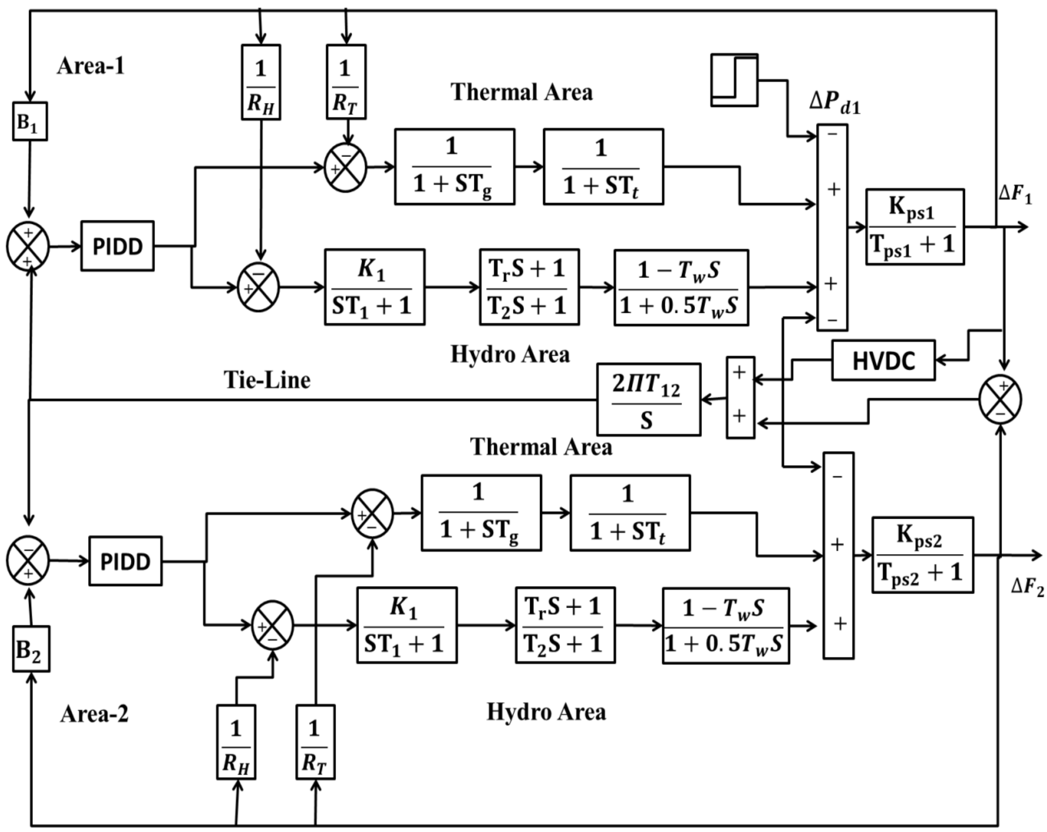


Figure 1: Model of DACHT system with HVDC tie-line.

II. POWER SYSTEM UNDER STUDY

The model of the IPS deliberated to investigate the dynamic analysis in this work is depicted in Fig.1, has two control areas of same capacity. The control areas have the thermal and hydro power generating units and the investigation is performed by subjecting the area-1 with 1%SLP. The model shown in Fig.1 is developed in (R2019a) MATLAB/SIMULINK and the necessary time and gain constants are taken directly from the [9].

The modelling of the thermal power plant is as follows:

Steam Turbine= $\frac{1}{1+sT_t}$ (1)

Governor= $\frac{1}{1+sT_g}$ (2)

The modelling of the hydro power plant is as follows:

Hydro governor= $\frac{K_1}{1+sT_1}$ (3)

Hydro turbine= $\frac{1+sT_r}{1+sT_2}$ (4)

Penstock= $\frac{1-T_w s}{1+0.5T_w s}$ (5)

III. PIDD CONTROLLER AND ITAE INDEX

The PIDD controller is the feedback type controller which has been widely implementing now days to the process and control problems. It calculates the error continuously and delivers the output proportionally, integrally, and double derivative to that of the error. The PIDD controller has the K_P, K_I, and K_{DD} are the parameters on which its performance is predominantly depended. The parametric knobs K_P, K_I, and K_{DD} help to carry put the process variable close to the set point, eliminate the steady-state errors, and counteracts the quick variations in the error respectively. The search of these parameters is one of the challenging tasks to the research community in order to make the controller best suitable for the plant model. The integral time absolute error (ITAE) in Equation (6) is taken in this work for the optimal tuning of PIDD controller as the time domain function. The PIDD optimization using FFA subjected to ITAE is shown pictorially in Fig.2.

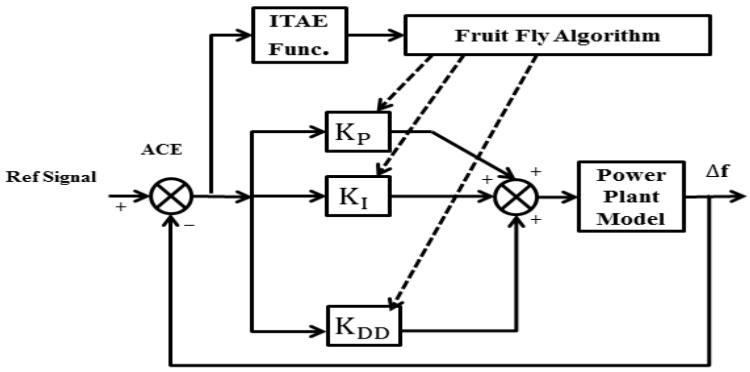


Figure 2: PIDD optimization.

$$J_{ITAE} = \int_{0}^{T_{Sim}} \left(\Delta f_1 + \Delta P_{tie12} + \Delta f_2\right) * T\,dt \tag{6}$$

IV. FRUIT FLY ALGORITHM

The behaviour of the fruit flies in locating the food sources inspired the researchers in [10], to develop the FFA. Like the other species, the fruit flies are also adopted to live as a group and the group itself is tried to locate the food locations. Of all the insects, the sensible nature for the fruit flies is more dominant and moreover they can able to detect the food even away from the 40kms. After reaching the food surroundings, through visionary glands they can exactly found the location. Among all the available optimization techniques, the FFA is one of the better in finding the global optimum solution. The initialization of fruit fly position in two-dimensional space is given in Equation (7) [11].

$$(X_{axis} \quad Y_{axis}) \tag{7}$$

Further, the movement of fruit fly position is modelled in Equation (8-9) includes the random value (RV) from [0-1].

$$X_j = X_{axis} + RV \tag{8}$$

$$Y_j = Y_{axis} + RV \tag{9}$$

The distance (D_j) of the fruit fly from food is calculated using Equation (10), the smell concentrator (S_j) as in Equation (11) and the smell index ($Smell_j$) in the objective function as given in Equation (12).

$$D_j = \sqrt{X_j^2 + Y_j^2} \tag{10}$$

$$S_j = {}^{1}\!/_{D_j} \tag{11}$$

$$Smell_j = fitness(S_j) \tag{12}$$

Furthermore, the identification of the fruit fly with best smell concentrator and the update in the position of the fruit flies according to the best concentrator is given below and the flow chart is shown in Fig.3.

$$[Best_{Smell} \quad Best_{Index}] = \min(Smell) \tag{13}$$

$$X_{axis} = X_{Best\_Index} \tag{14}$$

$$Y_{axis} = Y_{Best\_Index} \tag{15}$$

Pseudo code of FFA:

Initialize:
- Define the objective function to be optimized: f(x)
- Set the number of fruit flies (population size): N
- Set the maximum number of iterations: MaxIterations
- Initialize pheromone levels on the search space (pheromone trails)

For each iteration from 1 to MaxIterations:
For each fruit fly (i = 1 to N):
Calculate fitness of the current solution:
fitness_i = f(x_i)
Update the position of the fruit fly:
new_position_i = MoveFruitFly (current_position_i, pheromone_trails)
Apply local search (optional):
new_position_i = LocalSearch(new_position_i)
Evaluate the fitness of the new position:
fitness_new_i = f(new_position_i)
Update pheromone levels:
UpdatePheromones (current_position_i, new_position_i, pheromone_trails, fitness_i, fitness_new_i)
End loop for fruit flies
Select the best fruit fly (solution) from the population based on fitness
End loop for iterations
Return the best solution found

In this pseudo-code, the key steps of FOA are outlined, including initialization, the main optimization loop, fruit fly movement, local search (optional), fitness evaluation, and pheromone update.

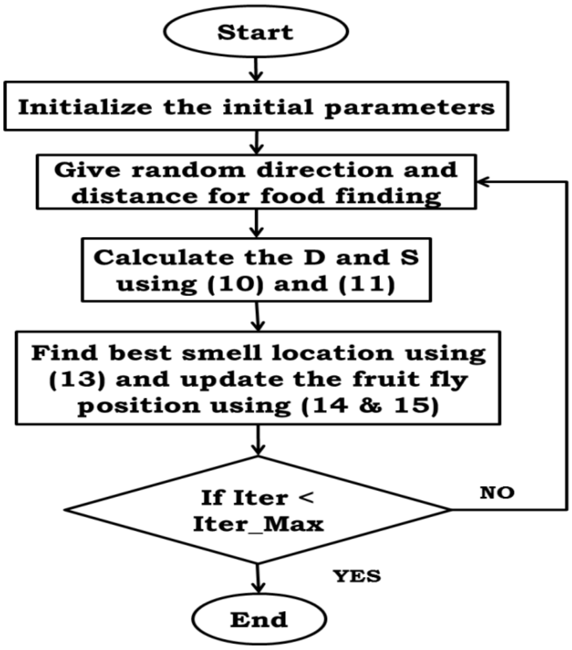
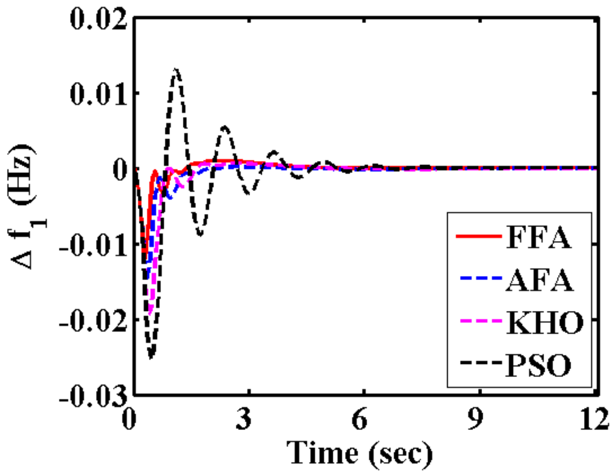


Figure 3: FFA flowchart

V. SIMULATION RESULTS

1. **Case-1: Analysis of DACHT system under PIDD controller tuned with various algorithms:** The PIDD controller is placed in area-1 and area-2 of the DACHT system and the parameters of the PIDD are individually tuned with various algorithms such as FFA, AFA, KHO and PSO for unique conditions of 100 populations and iterations. The DACHT responses under these algorithms based PIDD controller is shown in Fig.4 and are assessed in terms of settling time in seconds noted in Table 1. Observing the Fig.4, it is well cleared that the peak under shoots (PUS) of the responses under FFA algorithm are very much decreased when compared to that of AFA, KHO, and PSO. Further, the responses under FFA are quickly attained the steady state position as mentioned in Table 1. From this, it is preliminarily concluded that the FFA technique is very effectively dominated the other techniques like AFA, KHO, and PSO. The optimal parameters of PIDD that are retrieved with the FFA, AFA, KHO, and PSO are given in Table 2. Further the suggested FFA greatly controlled the ITAE over the others as shown in Fig.5 as bar chart and also as mentioned in Table 2.



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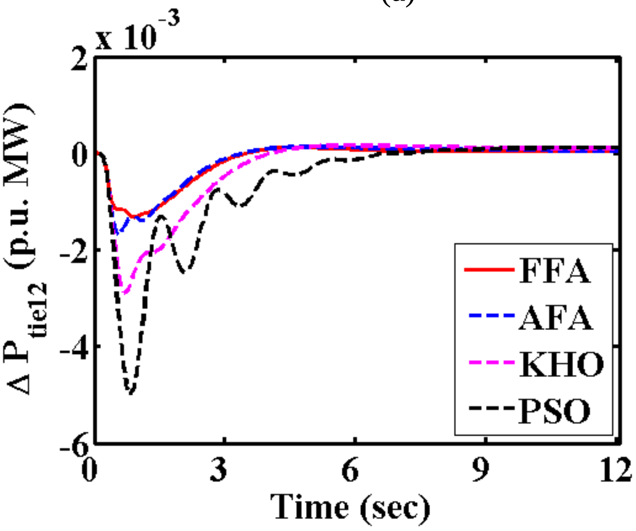

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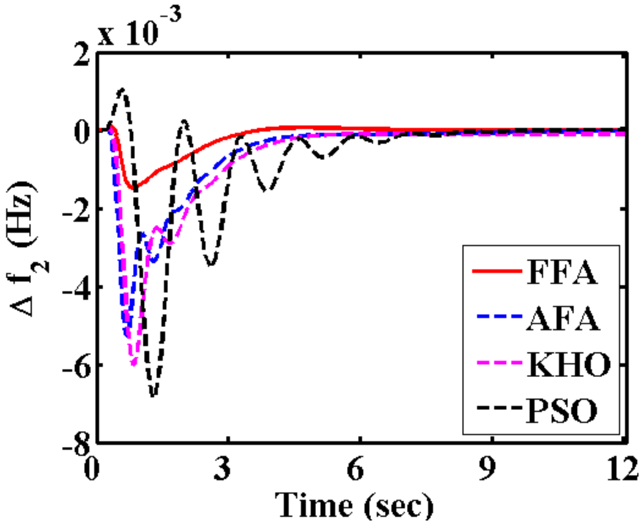

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Figure 4: Case-1 responses.

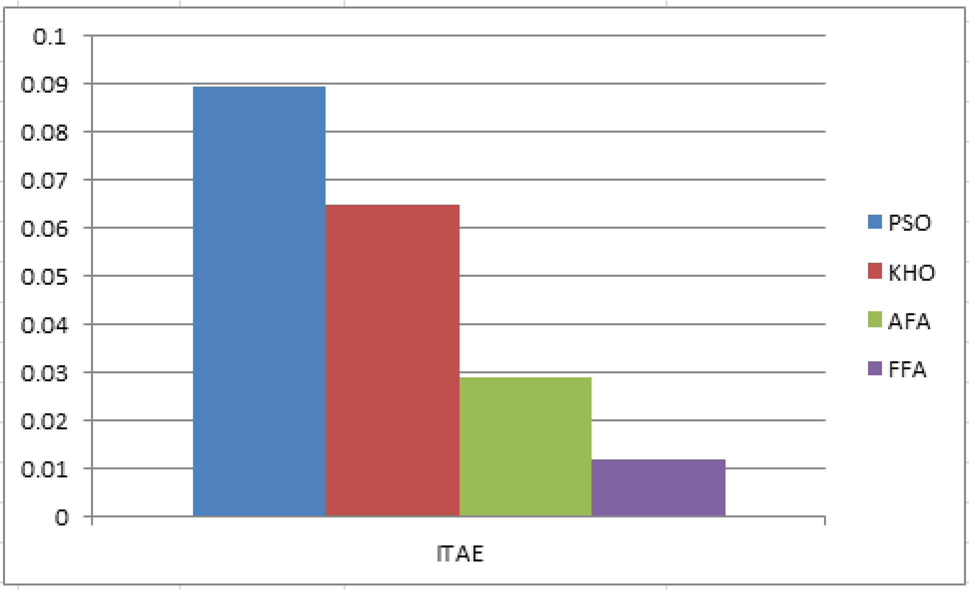


Figure 5: ITAE index under various algorithms.

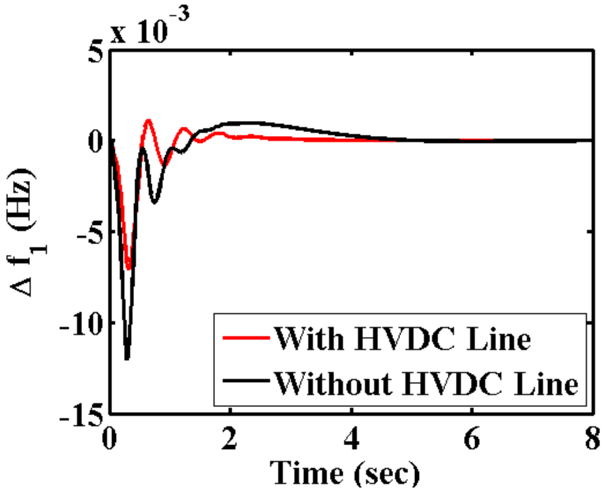
Table 1: DASHT responses settling time

Settling time (Seconds)	PIDD Controller				
	FFA	AFA	KHO	PSO	HVDC Line
Δf_1	4.98	6.34	7.72	12.17	3.62
ΔP_{tie12}	8.63	7.24	9.31	10.71	4.98
Δf_2	6.85	8.33	10.12	10.98	4.21
ITAE*10^{-3}	12.16	28.93	64.18	89.47	-

Table 2: PIDD controller optimal parameters.

Parameters	**Area-1**				**Area-2**			
	FFA	AFA	KHO	PSO	FFA	AFA	KHA	PSO
K_P	1.315	2.316	2.211	2.854	1.206	2.228	2.196	2.765
K_I	2.478	1.983	2.316	2.990	2.566	1.763	2.198	2.778
K_{DD}	1.774	0.945	1.278	1.365	1.663	1.016	1.154	1.254

2. **Case-2: Analysis of DACHT system with HVDC line:** Later, the DACHT is laid with the HVDC line as the tie-line and the analysis is continued under the operation of FFA tuned PIDD controller as the secondary regulator. The responses shown in Fig.6, compares the dynamical behaviour of DACHT under the AC and HVDC tie-line individually and is clear that the deviations, inter-area oscillations, and PUS are effectively quenched with the employment of HVDC line. Further, the settling time of the responses is decreased by far and the dynamical behaviour of DACHT is enhanced as indicated in the Fig.7 as bar chart.



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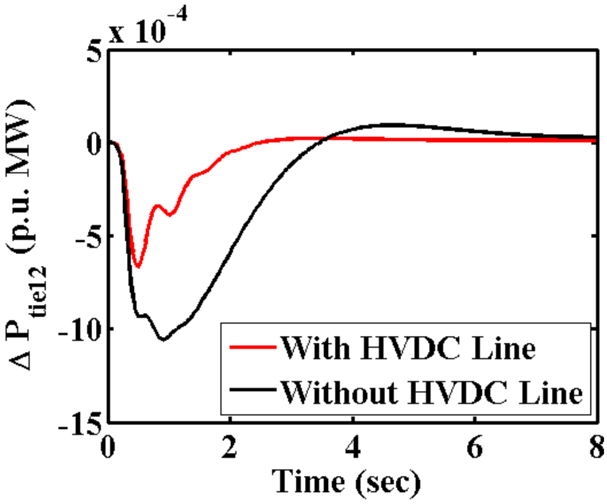

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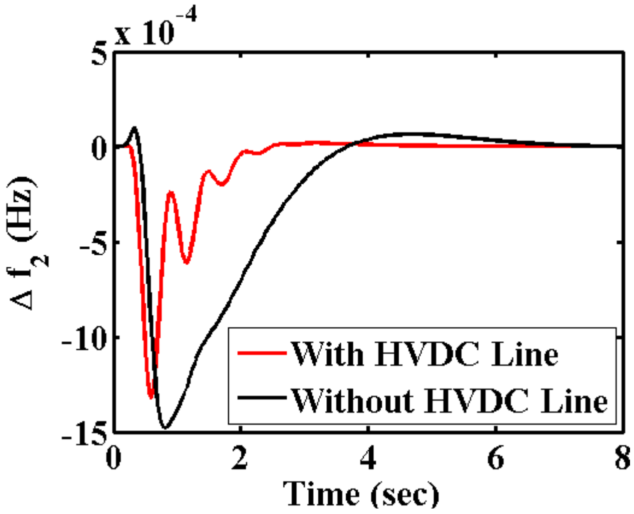

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Figure 6: Case-2 responses.

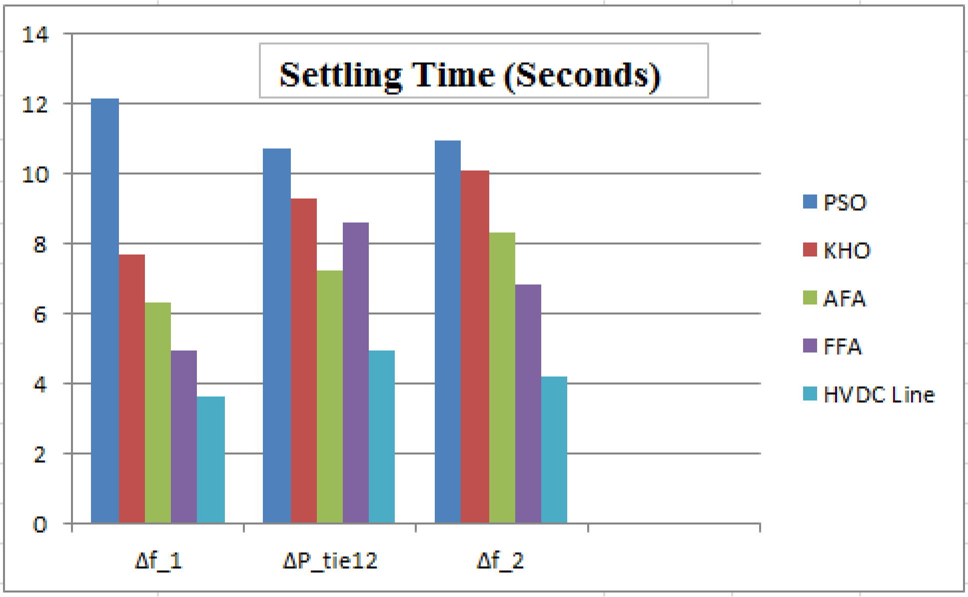
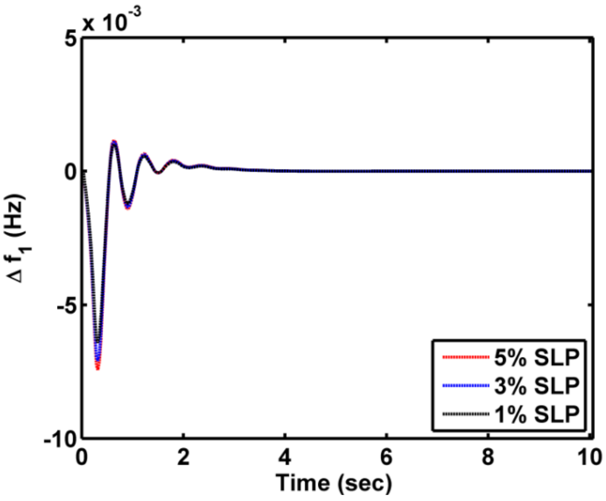


Figure 7: Bar chart represents the responses settling time (in Seconds)

3. **Case-3: Analysis of DACHT system under FFA based PIDD controller with different loadings:** In this work, the FFA based PIDD and employment of HVDC as the tie-line is enforced at the secondary and territorial levels as the controller. To test their robustness, it is required to conduct the sensitivity analysis. The sensitivity analysis is initiated by laying the 1%SLP, 3%SLP and 5%SLP in area-1 and the corresponding behaviour of DACHT is shown in Fig.8. Noticing the Fig.8, it is observed that the deviations in the DACHT behaviour is not much reported even though the system is targeted with different loadings. It is concluded that the adopted control strategies are robust.



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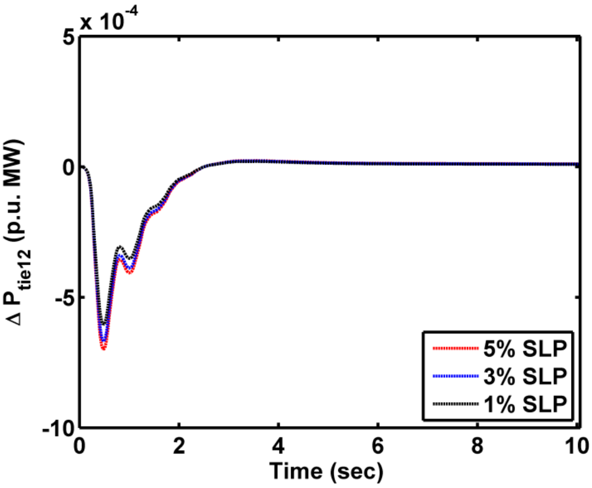

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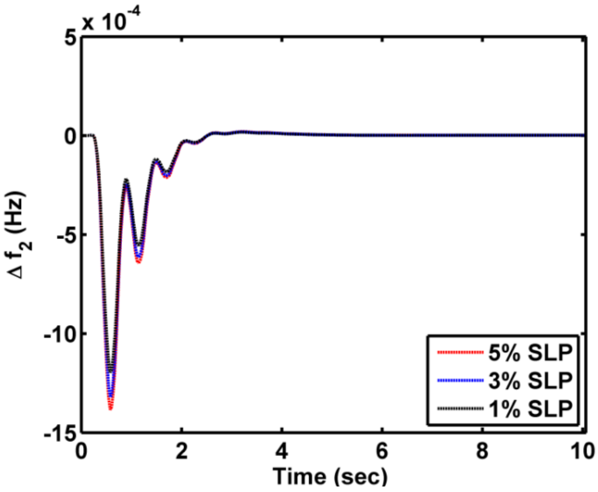

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Figure 8: Case-3 responses.

VI. CONCLUSION

The LFC of DACHT system is assessed under the regulation of FFA tuned PIDD controller in this work for the disturbance of 1%SLP in area-1. The performance of FFA algorithm is validated with the AFA, KHO, and PSO algorithm performances for the unique number of iterations and populations. In order to enhance the DACHT system behaviour further, the HVDC line is enforced as the tie-line and the simulation analysis disclosed the significant improvement in the performance. The robustness of suggested FFA tuned PIDD controller and the employment of HVDC line as the tie-line is tested by conducting the sensitivity analysis. The sensitivity analysis is conducted by laying area-1 with 3%SLP and 5%SLP along with the 1%SLP in area-1. After analysing the DACHT responses in the sensitivity test, it is concluded that the suggested control strategy is robust.

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