

Load Frequency Control Investigation with Optimum PD-PID Controller with Derivative Filter

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Abstract

Novel cascaded PD-PID controller with derivative filter (PD-PIDF) is projected in the present research work to investigate automatic generation control (AGC) in a dual area power system model comprising various generating sources. Each area of this dual area model consists of three different sources of generation namely hydro, gas and thermal unit. Moth Flame Optimization (MFO) technique is used as tuning tool for the projected PD-PIDF controller considering an abrupt power disturbance of 0.01p.u. in area 1. During the optimization process integral time absolute error is taken as cost/fitness function. The dynamic performance of the model is examined with three types of controllers namely, PID controller, cascaded PD-PID controller and cascaded PID controller with derivative filter. Also the supremacy of the projected PD-PIDF controller is validated over existing PD-PID and PID controller in view of various response based performance factors. Finally the robustness of the scrutinized model is verified by augmenting the nominal power loading of the control areas.

Keywords: Cascaded PD-PID controller; Moth Flame Optimization; automatic generation Control; Multi-generation system; Optimal Control.

1. Introduction

Maintaining frequency stability is the prime intension of the automatic generation control (AGC). It also helps in regulation of inter-area power exchange [1]. The objective of automatic generation control is to produce and dispense electric energy with tolerable system constraints during perturbation. The speed of the generator starts to decrease as when the total generation shows lesser amount from the demand power and vice versa. Synchronous generator sense the fluctuation in frequency in order to keep the system in synchronism by making zero steady state error. The variations in power demand due to increasing load may unsettle the equilibrium between generation and demand [2].

Till now a large number of research work has been made by researchers for AGC analysis. Cascaded control system was introduced by Yongho Lee et al. [3] for solving AGC problem. Many researchers modified the existing PID controller to extract better control action for AGC problem. The 2DOF-PID and 2DOF-IDD controller was applied in AGC analysis for unified power system model in articles [4-5]. Then various non-PID type controllers were also applied in different control problem. Model predictive control is one of the non-PID type control mythologies used in AGC problem in papers [6-7]. Different nature inspired tuning algorithm like cuckoo search algorithm was also used for optimum controller design in the field of AGC [8-9]. Dipayan Guha, Provas Kumar Roy and Subrata Banerjee presented an efficient QOGWO optimization technique in unified power system models for tuning the controller gains in better way [10]. To sustain the stability in a two area non-reheat thermal generating system a hybrid firefly algorithm and pattern search (hFA-PS) is introduced to tune the control parameters of PID controller [11]. AGC analysis was also investigated in multi generation type unified system using PID

[12] and cascaded PD-PID [13] controller. The performance analysis of teaching learning based optimized proportional-integral-double-derivative (PIDD) controller is employed for AGC in interconnected power system model [14]. In article [15] minority carrier inspired algorithm (MCI) was used to tune PI and integral controller gains for AGC in hydro-thermal generating models considering nonlinearities. Fuzzy logic based controller was employed in article [16] for examining AGC in hydrothermal unified models. A Khodabakhshian and R.Hooshmand [17] introduced vigorous PID controller for regulation of frequency for automatic generation control (AGC). Fractional calculus was used to develop fractional order proportional-integral-differential (FOPID) to enhance the behavior of conventional PID controller for frequency control application in different model with improved PSO technique [18]. The paper [19] refers to the metaheuristic optimization technique like backtracking search optimization algorithm (BSA) and fruit fly optimization algorithm (FFA) employed over a inter-act power system to get the optimal parameter of traditional PID controller.

It is observed from the literature survey that Proportional/Integral/Derivative controller is used by many researchers for different control process. Here a combination of Proportional/Integral/Derivative is taken to form cascaded PD-PID controller with derivative filter for AGC application in multi-generation model. Moth Flame Optimization [20] method is employed to get the optimum controller gains of the suggested PD-PIDF controller.

2. System Investigated

The present analysis considers a two area power system model comprising multiple sources of generation. In each area of the scrutinized model three different types of source are used for power generation. The sources include a hydro unit, a gas unit and a

thermal unit with reheat turbine. To control the frequency and tie-line power oscillation due to abnormalities, a novel optimum controller (PD-PIDF) is employed with each generating unit. Here Fig.1 depicts the transfer function based block diagram of the

power system model. For simulation purpose, the values of the parameters of the model are taken from the paper [12]. The power disturbance of magnitude 0.01p.u. is applied in area 1 to examine the system dynamic response.

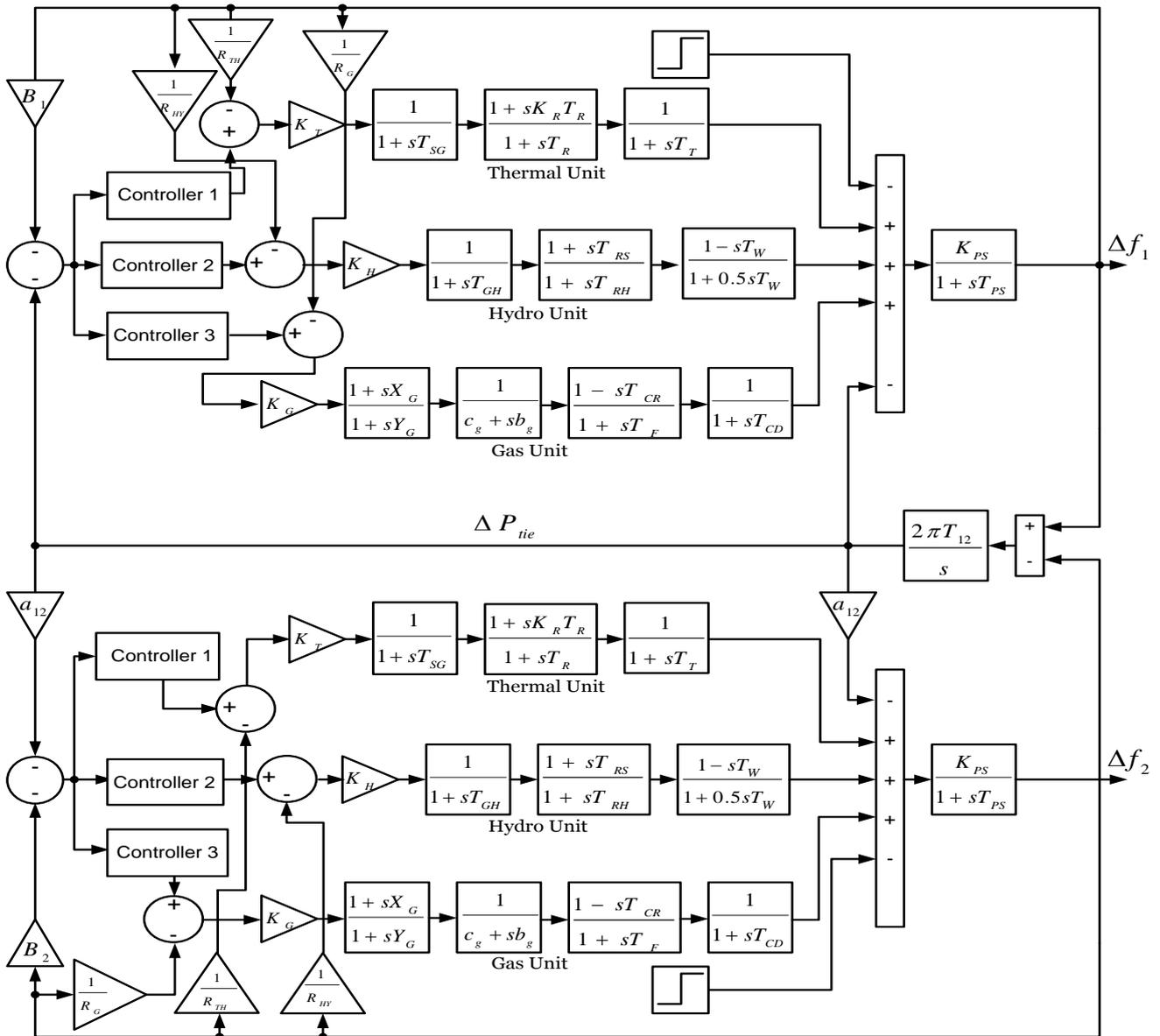


Fig. 1: Two area multi-generation power system model.

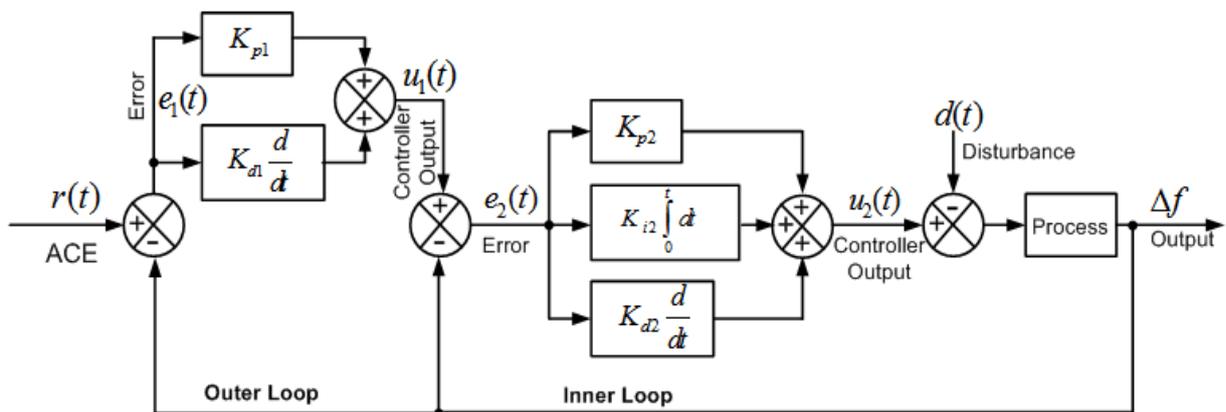


Fig. 2: Architecture of cascaded PD-PID Controller

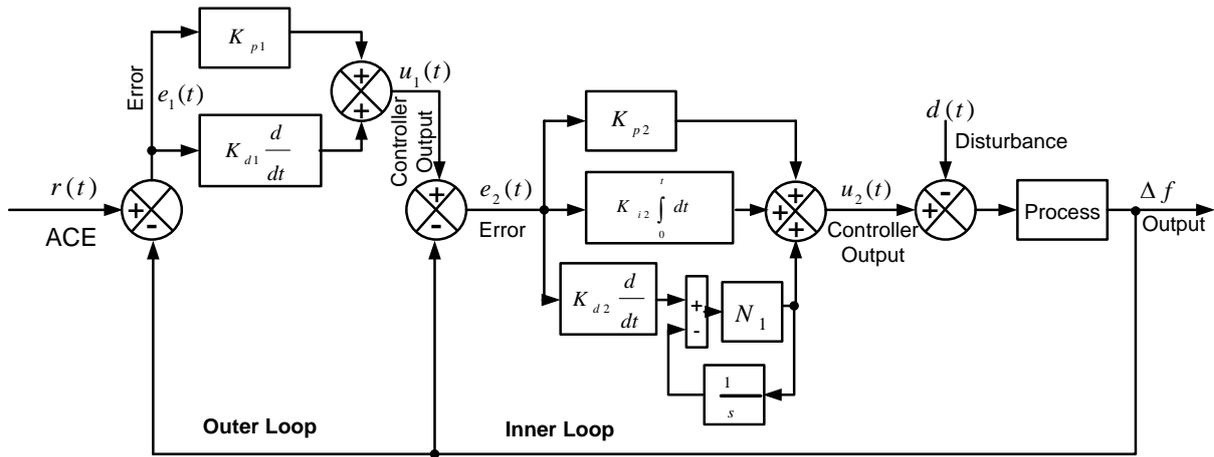


Fig. 3: Internal configuration of cascaded PD-PID controller with derivative filter.

3. Recommended Technique

3.1. Controller Configuration (PD-PID/PD-PIDF)

The PID controllers perform the control action by suitably adjusting its gain values. To augment the control action the PID controller is modified in article [13] named as cascaded PD-PID controller. The cascaded PD-PID controller has double loop control action where PD controller is in outer loop and PID controller is inner loop. The architecture of PD-PID controller is depicted in Fig.2. Again to attenuate some noise signal from the input here a first order filter is added in the derivative part of the PD-PID controller. This PD-PIDF controller organization is shown in Fig.3. The projected PD-PIDF controller has two gains (K_{p1} & K_{d1}) associated with outer PD controller and four gains (K_{p2} , K_{i2} , K_{d2} & N_1) associated with inner PIDF controller. The two step control action along with filter is designed properly for damping the oscillation caused due to power mismatch. The gains of the projected PD-PIDF controllers are tuned by Moth Flame Optimization technique.

3.2. Moth Flame Optimization (MFO) Technique

3.2.1. Characteristic of MFO:

This optimization technique was developed by Mirjalili back in November 2015 [20]. Transverse orientation in the navigation of moths in nature is the principle behind this algorithm. During this methodology the moths hover during night-time by upholding the permanent angle corresponding to the moon. Specifically as soon as the light source is at a very far distance, this methodology is useful in travelling in a conventional straight line but once the source of light is near, the moths fly spirally around it while finally converging towards it as illustrated in the Fig. 4.

3.2.2. MFO Algorithm:

Two key components in this algorithm as the name comprises are Moths along with Flames, both are regarded as solutions while the search individual (moths) travel from place to place in the search space while the flames are regarded as the best positions of the moths that are obtained. Hence flames can also be considered as flags which are dropped by moths while searching the search space. A moth never loses its flag or the best solution because each single moth explores around a flag along with it updates itself if it finds a better solution. The set of moths can be epitomized as:

$$M = \begin{bmatrix} m_{1,1} & m_{1,2} & \dots & m_{1,d} \\ m_{2,1} & m_{2,2} & \dots & m_{2,d} \\ \vdots & \vdots & \ddots & \vdots \\ m_{n,1} & m_{n,2} & \dots & m_{n,d} \end{bmatrix}$$

For the storage of the fitness values, there is an array for all the moths as follows;

$$OM = (OM_1 \ OM_2 \ \dots \ OM_n)^T$$

Where, n characterizes the dimension of moths, d symbolizes the variables of the problem and T is transpose.

Similarly, flames can be characterized as:

$$F = \begin{bmatrix} F_{1,1} & F_{1,2} & \dots & F_{1,d} \\ F_{2,1} & F_{2,2} & \dots & F_{2,d} \\ \vdots & \vdots & \ddots & \vdots \\ F_{n,1} & F_{n,2} & \dots & F_{n,d} \end{bmatrix}$$

A vector is formed to store the fitness values as follows:

$$OF = (OF_1 \ OF_2 \ \dots \ OF_n)^T$$

The MFO process basically consists of three approximated functions as follows:

$$MFO = (I, P, T)$$

Where, I represents the arbitrary population of search agent(moths) initialized randomly and its fitness value is depicted below:

$$M(i, j) = (ub(i) - lb(i)) * rand() + lb(i)$$

$$OM = FitnessFunction(M)$$

Here, ub & lb are higher and lower limits of the variables respectively.

MFO is based upon the transverse orientation of moths therefore; in this algorithm the function plays a very important role as its function is to move the moths around the search spaces. The main updated mechanism for the position of each of the moths considering the corresponding flames is chosen by the logarithmic spiral function. This P function is operated after the initialization or I function. The updated position of moths to their respective flames is represented by the following equation:

$$M_i = S(M_i, F_i)$$

The equation for the logarithmic spiral flying pattern of the MFO algorithm is:

$$S(M_i, F_j) = D_i \cdot e^{bt} \cdot \cos(2\pi t) + F_j$$

Where, M_i & F_j represents the i^{th} moth & j^{th} flame respectively. S , D_i & b is the spiral function, distance of the i^{th} moth for the j^{th} flame & a constant for defining the shape of the logarithmic spiral respectively along with t is a random number in $[r, 1]$. The value of D is evaluated according to the following equation:

$$D_i = |F_j - M_i|$$

The lesser is the value of t , the distance to the flame is very near. During the final steps of the iteration, the moths (individual) update their positions in accordance to the finest solution (flame). As depicted in the below equation, the flame numbers adaptively lowers with respect to the iterations so as to maintain a balance between exploration & exploitation.

$$flame\ no = round\left(N - l \times \frac{N-1}{T}\right)$$

In the above expression l represents the present iteration. The maximum number of flames and iterations are represented by N & T respectively.

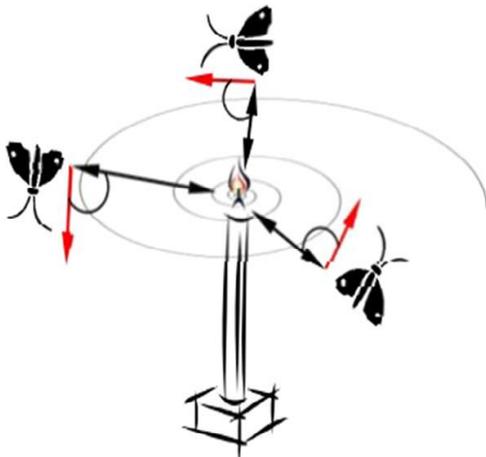


Fig.4: The movements of moths surrounding the light.

4. Result And Analysis

Here for AGC analysis Moth Flame Optimization Algorithm is applied for tuning the projected PD-PIDF controller implemented in each generating unit. As each PD-PIDF controller has six gains, total eighteen gains (three controllers) are tuned with the aforesaid optimization method considering ITAE as cost/fitness function which is shown in equation (1). In the initial investigation the system response are examined with 1% power disturbance in area 1. The optimum gains of the projected PD-PIDF controllers are tabulated in Table 1. The System response in terms of frequency and inter line power oscillations are depicted in Fig.5-7. The obtained results are compared with existing results such as PD-PID controller [13] and PID controller [12] to show the supremacy of the projected control technique (PD-PIDF controller). The response indices like undershoots, settling time and peak overshoots are tabulated in Table 2 for different control techniques. The supremacy of the PD-PIDF control technique can be clearly judged from Fig.5-7 and Table 2.

$$ITAE = \int (|\Delta f_1| + |\Delta f_2| + |\Delta f_3|) t . dt \tag{1}$$

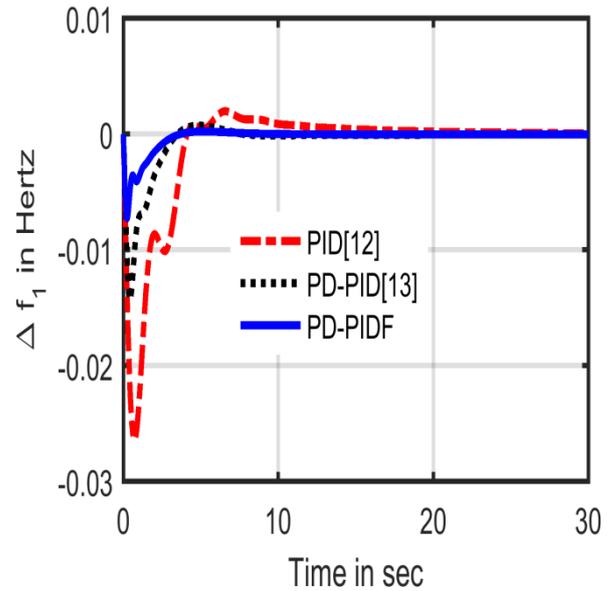


Fig.5: Frequency oscillations in area 1.

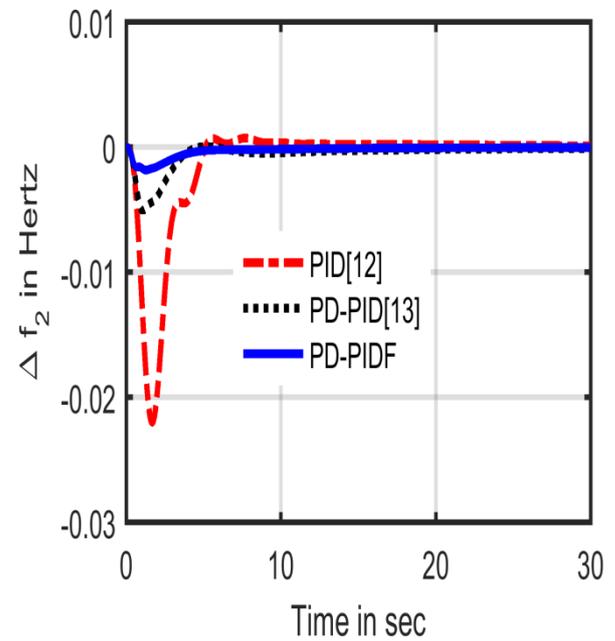


Fig.6: Frequency oscillations in area 2.

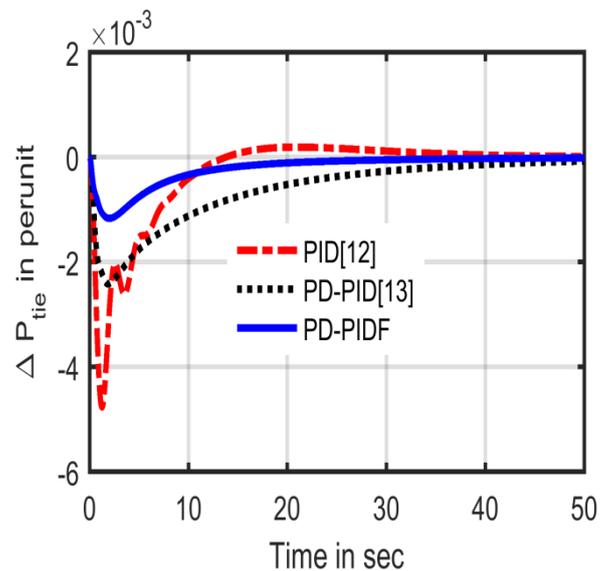


Fig.7: Interline power oscillations.

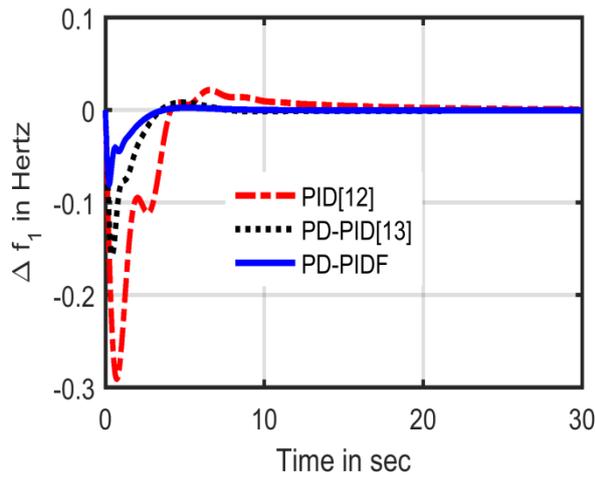


Fig.8: Frequency oscillations in area 1(Load incremented).

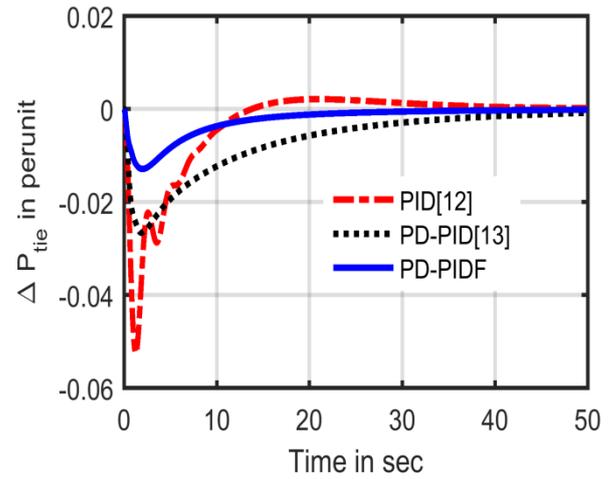


Fig.10: Interline power oscillations (Load incremented).

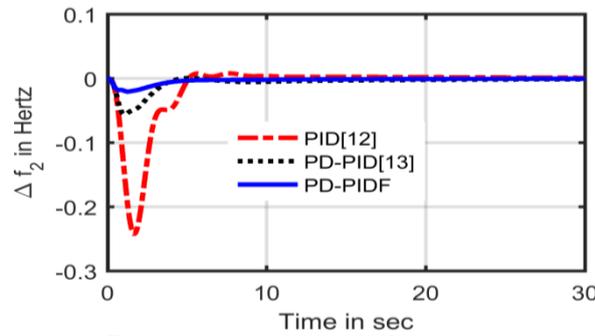


Fig.9: Frequency oscillations in area 2(Load incremented).

The system is said to be stable if it is able to maintain the deviations of response within tolerable limits during load variations. So to validate the robustness of the projected model an investigation is performed by amplifying the power loading in control area 1 by 10%. With tis augmented loading condition the system response oscillations (frequency and interline) are show in the Fig. 8-10. From these figure it can be concluded that the projected control technique is robust as it successfully manage the deviations during abnormal conditions. Also it can be judged from Fig.8-10 that projected PD-PIDF controller exhibits dominance behavior over PD-PID[13] and PID[12] controller during this abnormal situations.

Table 1: The gain values of optimal PD-PIDF controller achieved by MFO technique.

Parameters	Thermal Unit			Hydro Unit			Gas Unit		
	PD-PIDF	PD-PID[13]	PID[12]	PD-PIDF	PD-PID[13]	PID[12]	PD-PIDF	PD-PID[13]	PID[12]
K_{p1}	1.758	0.808	-	0.598	0.680	-	0.928	0.724	-
K_{d1}	1.964	2.000	-	1.998	2.000	-	-0.100	-0.10	-
K_{p2}	3.7787	2.000	0.779	-0.100	-0.10	0.5805	0.5931	0.116	0.5023
K_{i2}	0.117	-0.10	0.2762	0.006	0.050	0.2291	2.975	2.000	0.9529
K_{d2}	-0.100	-0.10	0.6894	-0.100	-0.10	0.7079	1.028	0.542	0.6569
N_1	99	-	-	197	-	-	298	-	-

Table 2: Response based performance factors

Deviations	System Response Indices	PID [12]	PD-PID[13]	PD-PIDF
Δf_1	T_s in sec	13.8981	5.9020	2.8346
	Overshoots(Hz)	0.0020	0.0007352	0.0002378
	Undershoots(Hz)	-0.0264	-0.0143	-0.0073
Δf_2	T_s in sec	8.3757	3.8154	3.9616
	Overshoots(Hz)	0.0007	0.0000574	0
	Undershoots(Hz)	-0.0220	-0.0051	-0.0018
ΔP_{tie}	T_s in sec	9.3314	10.4177	7.3476
	Overshoots(Hz)	0.0002	0	0
	Undershoots(Hz)	-0.0048	-0.0024	-0.0012

5. Conclusion

Cascaded PD-PID controller with derivative filter was successfully implemented in the examined multi-generation model for AGC analysis. The tuned value of the projected controller was obtained with Moth Flame Optimization Algorithm considering a power disturbance of 0.01 per unit in area 1. The frequency deviations and interline power variations of the examined model are studied with existing PID controller & PD-PID controller and projected

PD-PIDF controller. The superior behavior of the projected PD-PIDF controller is verified over other two controllers considering time response evaluative factors like undershoots, settling time and peak overshoots. At the end the robustness of the projected control technique is also validated by amplifying the power loading in one of the control areas.

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