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TIDF Controller for Load Frequency Control of Interconnected Power System using a Hybrid WOA and PS

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Abstract

This paper provides a robust control scheme known as Tilt Integral Derivative with Filter (*TIDF*) for the design of a secondary control loop in the Automatic Generation Control (*AGC*) problem. Investigations have been carried out on a three area reheat-thermal system with appropriate Generation Rate Constraint (*GRC*) and Governor Dead-Band (*GDB*) for more realistic study. The Optimal controller settings are determined via a new optimization algorithm known as Whale Optimization Algorithm (*WOA*) and the hybridization of *WOA* and Pattern Search (*PS*) by evaluating the Integral of the Squared Error (*ISE*). The performance of the suggested controller is compared with the classical Proportional Integral Derivative with Filter (*PIDF*) controller. Finally, the efficiency of the proposed controller is confirmed through two severe tests such as Parametric Variation (*PV*) and Random Load Pattern (*RLP*).

Key words: Automatic Generation Control; Whale Optimization Algorithm; Pattern Search; Integral of the Square Error; and nonlinear constraints.

Résumé

Cet article fournit le schéma d'un régulateur robuste appelé Tilt Intégrale Dérivé avec Filtre (*TIDF*) pour la conception d'une boucle de réglage secondaire dans le problème de la commande automatique de la génération (*AGC*). Des études ont été menées sur un système thermique de réchauffage à trois zones en prenant en considération le *GRC* et le *GDB* pour une étude plus réaliste. Les paramètres optimaux du contrôleur sont déterminés via un nouvel algorithme d'optimisation nommé *WOA* (*Algorithme d'optimisation des baleines*) et l'hybridation du *WOA* et *PS* (*Recherche de motifs*) en évaluant *ISE* (*Intégrale de l'erreur carrée*). Les performances du contrôleur proposé sont comparées avec le régulateur classique Proportionnel Intégrale Dérivé avec filtre (*PIDF*). Enfin, l'efficacité du contrôleur proposé est confirmée par deux rigoureux tests tels que la variation paramétrique (*PV*) et le modèle de la charge aléatoire (*RLP*).

Mots-clés : Commande Automatique de la Génération ; Algorithme d'optimisation des baleines ; Recherche de motifs ; Intégrale de l'erreur carrée et contraintes non linéaires.

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1. Introduction

The main objective of a power system is to generate and deliver the electrical energy as economically and reliably as possible while maintaining the frequency and the voltage within permissible limits. Therefore, it's obligatory for the operator to ensure a permanent equilibrium between the total generated power with the total load demand through the optimal frequency value [1, 2]. For this reason, the AGC have been introduced, whose role is:

- to regulate the frequency to its specified nominal value;
- to maintain the interchange power between control areas at the scheduled values;
- to distribute the required change in generation among units to minimize the operating costs.

For this purpose, several control strategies have been suggested in the literature such as *PI*, *PID*, *PIDF*, etc [3-5].

The objectives of the present paper are summarized as follows:

- to design and implement the different control strategies such as *PIDF* and robust fractional order *TIDF* for the Load Frequency Control (*LFC*) problem in an interconnected power system ;
- to elaborate a program using a novel method of optimization;
- to verify the robustness of the suggested regulator with obtained optimal values, through two severe tests such as Sensitivity Analysis (*SA*) and Random Load Pattern (*RLP*) .

2. Investigated power system

The proposed and the investigated control scheme are tested on three areas reheat-thermal non-linear system as presented in Fig.1. Each area composed by speed governing system, turbine, generator, *GDB*, and *GRC*. The nominal system parameters are taken from [6] and are offered on the Appendix.

3. Controllers Structure

3.1 Proportional Integral Derivative with Filter Regulator

A *PID* controller consists of three terms: Proportional (*P*), Integral (*I*), and Derivative (*D*) [6]. Its behavior can be roughly interpreted as the sum of the three previous actions:

- *P*: gives a rapid control response;

- *I*: eliminates the steady state error;
- *D*: improves the behavior of the control system during transient.

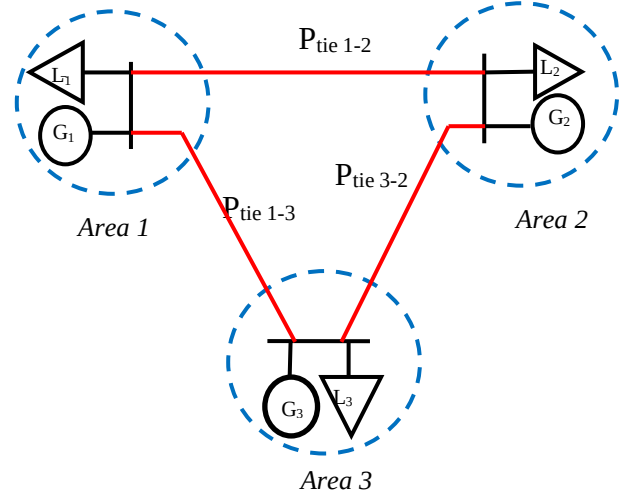


Figure 1. Three areas AGC test system.

The transfer function of the *PIDF* controller is described as follows:

$$U_{PIDF}(S) = K_P E(S) + \frac{K_I}{S} E(S) + K_D \frac{S+N}{S+N} E(S) \quad (1)$$

$$E(S) = \sum_{i=1}^n ACE_i \quad (2)$$

Where K_P is gain of the proportional action, K_I is gain of the integral action, K_D is Gain of the derivative action, N is derivative filter gain, and ACE_i is area control error of i^{th} area.

A schematic block diagram of a *PIDF* controller is shown in Fig.2

3.2 Tilt Integral Derivative with Filter Regulator

The *TIDF* controller is a type of Fractional Order Controllers (FOCs) originated from fractional order calculus. *TIDF* controller is used in each area as it offers simple tuning, better disturbance rejection ratio and have less effects of plant parameter variations on closed loop response [7].

The transfer function of the *TIDF* controller is given by:

$$U_{TIDF}(S) = K_P * S^{-\frac{1}{n}} + K_I * S^{-1} + K_D \frac{S+N}{S+N} \quad (3)$$

Here n is non-zero real number.

A representation of a *TIDF* control scheme is shown in Fig.3

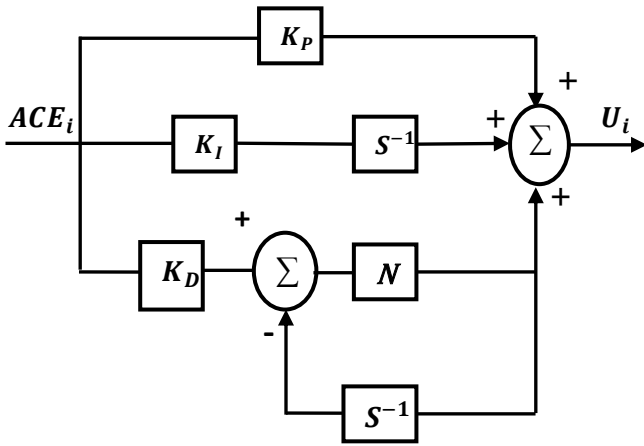


Figure 2. PIDF controller block diagram.

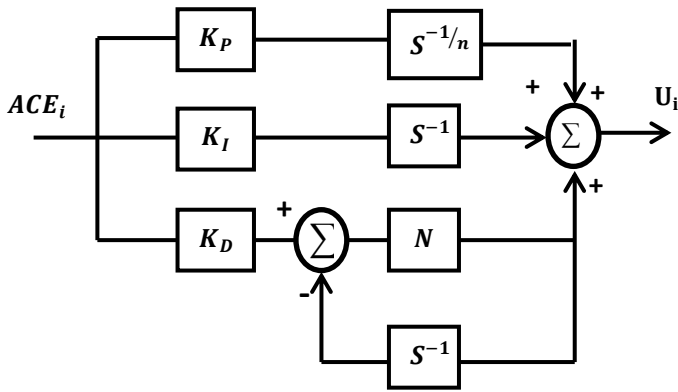


Figure 3. TIDF based controller

4. Problem formulation

In this article, the Integral of the Squared Error (ISE) based criterion has been used as a performance index and is written as follows:

$$J = \int_0^{+\infty} e^2(t) dt \quad (4)$$

In our work, the error which is needs to be minimized is $e(t)$. For n areas power system, the error $e(t)$ is represented by

$$e(t) = \sum_{i=1}^n ACE_i \quad (5)$$

The optimization problem can be formulated as follows:

Minimize $J(K_P, K_I, K_D, N \text{ and } n)$

$$\text{subject to } \begin{cases} K_P^{\min} \leq K_P \leq K_P^{\max} \\ K_I^{\min} \leq K_I \leq K_I^{\max} \\ K_D^{\min} \leq K_D \leq K_D^{\max} \\ N^{\min} \leq N \leq N^{\max} \\ n^{\min} \leq n \leq n^{\max} \end{cases} \quad (6)$$

In this study, the gains bounds limits are fixed between 0 and 10, the non-zero real number limits are fixed between 0 and 10 and the filter gain limits are chosen between 40 and 300 [5].

The performances of the hybridization of the Whale Optimization Algorithm and Pattern Search algorithm have been implemented in this paper to find the optimal controller settings and is described by the following Algorithm [8]

Initialize the whales population X_i ($i = 1, 2, \dots, n$)

Calculate the fitness of each search agent

X^* = the best search agent

while ($t < \text{maximum number of iterations}$)

for each search agent

 Update a , A , C , l , and p

if1 ($p < 0.5$)

if2 ($|A| < 1$)

 Update the position of the current search agent by the following equation

$$D = |C \cdot X^*(t) - X(t)|$$

else if2 ($|A| > 1$)

 Select a random search agent (X_{rand})

 Update the position of the current search agent by the following equation

$$X(t+1) = X_{rand} - A \cdot D$$

end if2

else if1 ($p > 0.5$)

 Update the position of the current search by the following equation [9]:

$$X(t+1) = D' \cdot e^{bl} \cos 2\pi l + X^*(t)$$

end if1

end for

 Check if any search agent goes beyond the search space and amend it

 Calculate the fitness of each search agent

 Update X^* if there is a better solution

$t = t + 1$

end while

return X^*

Where A , C are the coefficient vector, t is the current agent, a is linearly decreased from 2 to 0 over the course of iterations, p is a random number in $[0, 1]$, b is a constant for defining the shape of the logarithmic spiral

5. Simulation and Results

The proposed and the investigated control schemes are tested on three areas reheat-thermal non-linear system as

presented in Fig.1. In all the study, we consider ($\Delta P_{L1} = 1\%$ p.u.) load variation in the first area. The WOA and PS are executed to define the optimum controllers parameters, evaluating the *ISE* criterion. After the optimization process, the optimal controllers parameters are tabulated in Table 1. Fig.5 presents the *ISE* criterion with the proposed *TIDF* and *PIDF* controllers with different methods.

Table 1. Optimal controllers' settings using *ISE* criterion

Controllers Gains		K_P	K_I	K_D	n	N
Area 1	<i>PIDF</i> (WOA)	7.259	9.370	2.648	109.73	/
	<i>TIDF</i> (WOA)	6.928	4.897	2.231	81.260	4.708
	<i>TIDF</i> (WOA+PS)	6.521	4.897	2.231	249.97	4.958
Area 2	<i>PIDF</i> (WOA)	9.999	5.752	4.692	272.27	/
	<i>TIDF</i> (WOA)	9.999	4.677	4.654	116.62	3.315
	<i>TIDF</i> (WOA+PS)	9.999	3.146	3.623	249.97	2.378
Area 3	<i>PIDF</i> (WOA)	7.778	9.997	2.971	278.79	/
	<i>TIDF</i> (WOA)	6.811	9.999	4.230	133.62	6.357
	<i>TIDF</i> (WOA+PS)	9.998	7.374	4.355	249.97	3.919

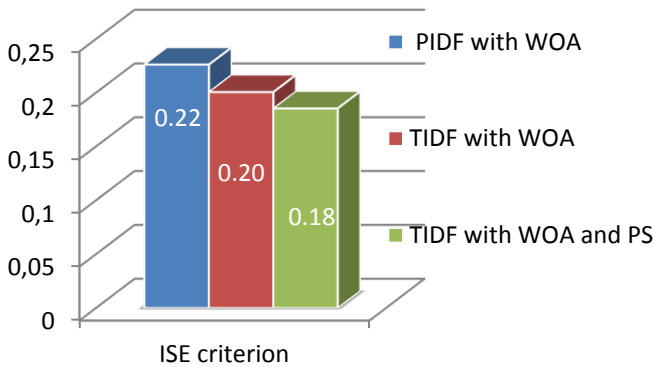
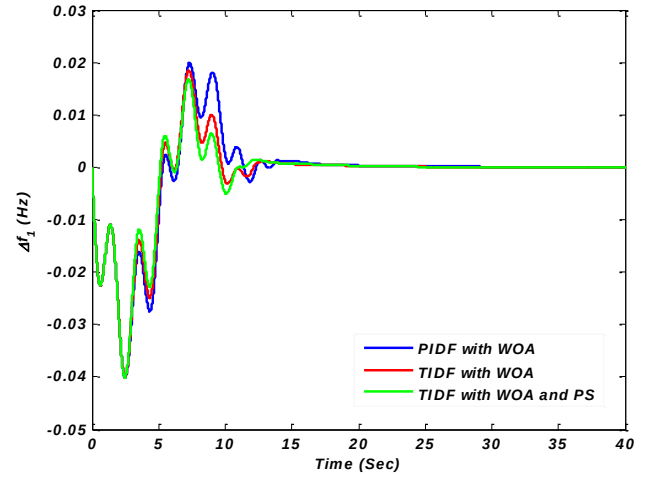


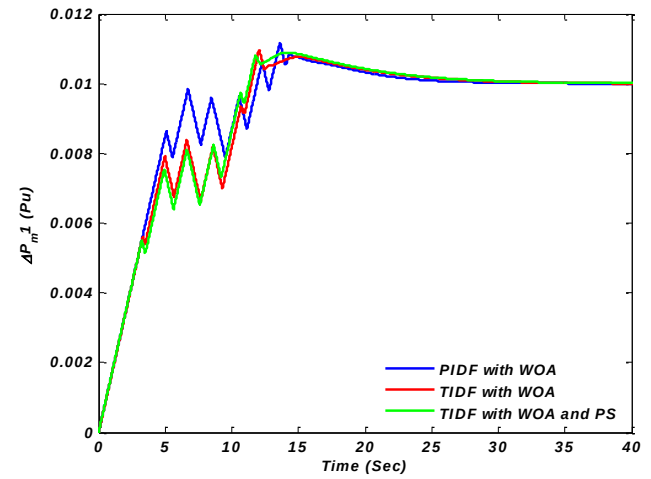
Figure 5. Comparison of *PIDF*, *TIDF* with WOA and *TIDF* with WOA+PS controllers with *ISE*

From Fig.5 it is clearly observed that the *ISE* value is reduced by 18.01% in the case of the proposed *TIDF* with WOA +PS regulator compared to the *PIDF* regulator with WOA.

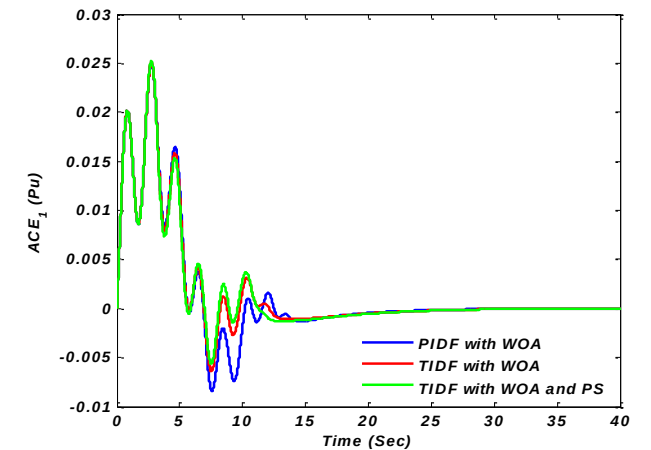
All areas dynamical responses of frequency deviation, area control error, mechanical power deviation and tie line power deviation obtained by *ISE* criterion are displayed in Fig.6(a, b, c, and d)



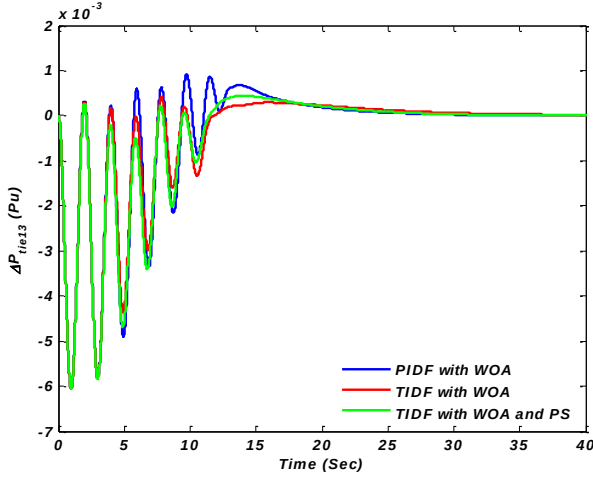
(a)



(b)



(c)



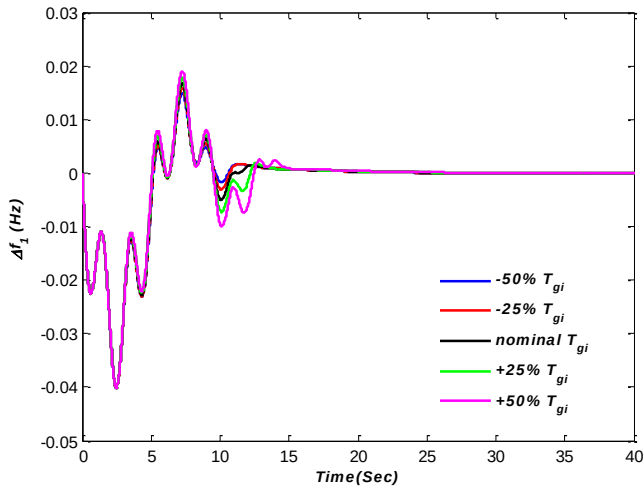
(d)

Figure 6. Dynamic response of (a): Δf_1 , (b): Δp_{m1} (c): ACE_1 , (d): $\Delta t_{tie\ 13}$, according to 1% load disturbance in area 1 for different regulators using *ISE* criterion

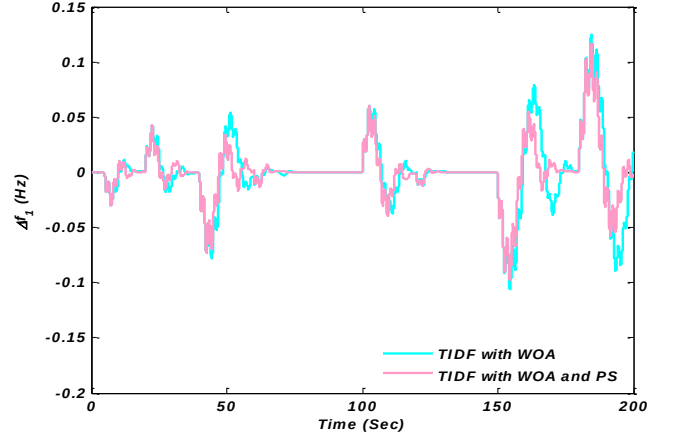
From these results, it is clearly observed the superiority of the proposed *TIDF* controller with *WOA* and *PS* compared with *TIDF* using *WOA* and the investigated *PIDF* controller from different view of points such as Settling Time (*S.T*), Peak overshoot (*P.O*), and Peak undershoot (*P.U*).

5.1 Robustness Analysis

In order to verify the robustness of the proposed *TIDF* controller, two severe tests have been performed such as Sensitivity Analysis (*SA*) is considered by changing the turbine governor time constants (T_{gi}) from their nominal values within the range of +50%,+25% to -50%,-25%, the frequency deviation response of those variations are presented in Fig.7(a), and Random Load Pattern (*RLP*) is applied in the first area, the dynamical response of Δf_1 according to this disturbance is presented in Fig.7 (b)



(a)



(b)

Figure 7. Dynamic response of Δf_1 according to (a): 1% change in area 1 with varying the turbine governor time constant (T_{gi}), (b): *RLP* in the first area with *TIDF* using *WOA* and the *TIDF* using *WOA* and *PS*.

From these tests, it is clearly revealed that the proposed approach *TIDF* regulator is more performing with the hybridization of *WOA* and *PS* compared to only using *WOA*.

6. Conclusions

In this article, for the secondary control we have investigated the classical *PIDF* and we have proposed the fractional *TIDF*, the determination of the gains of controllers are determined using a novel meta-heuristic technique known as Whale Optimization Algorithm (*WOA*), by evaluating the Integral of the Squared Error (*ISE*). The result proved the efficiency of this method for reduction of *ISE* based criterion.

From the obtained results, the proposed Fractional Order Tilt Integral Derivative (*TIDF*) is more performed compared with the investigated Integer Order Proportional Integral Derivative (*PIDF*) from different view of points such as Peak Overshoot, Peak Undershoot, and Settling Time. Sensitivity analysis has also been considered to demonstrate the efficiency of the proposed control scheme.

Appendix

The nominal system parameters under study are given below:

$$f=60 \text{ Hz}, Tg_i = 0.08s, Tr_i = 10 \text{ s}, H_i = 0.0833, Tt_i = 0.3 \text{ s},$$

$$K_r = 0.5, D_i = 0.00833 \text{ p.u}, R = 0.05 \text{ Hz/P.u MW}, B = 0.425$$

$$\text{Hz/P.u, MW/Hz}, Tp_i = 20 \text{ s}, Kp_i = 120 \text{ Hz/p.u MW},$$

In this study, the GDB and GRC limits taken into account are given below:

$GDB = \pm 0.036$ Hz and $GRC = \pm 10\%$ per minutes = 0.0017 Pu MW/min.

The WOA settings:

Number of whales = 40

Number of iterations = 200

The iteration numbers of $PS=200$

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