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Original Article

Application of an Adaptive Artificial Bee Colony Algorithm for Automatic Generation Control in Interconnected Power Systems with Nonlinear Characteristics

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Abstract *- This article presents the 2-degree freedom of proportional-integral-derivative (2-DOF PID.) controller for interconnected thermal power generators and optimization through the Adaptive Artificial Bee Colony Algorithm (AABCA). Power systems are typically nonlinear, requiring the optimization of Automatic Gain Controllers (AGCs), especially the 2-DOF PID controller with numerous parameters. The AABCA enhances parameterization and evaluates the performance through dynamic electric load size changes. The test results indicate that utilizing the bee algorithm to optimize the generator system parameters leads to increased robustness to changes and improved overall performance. The ISE value and the ITSE value are improved by 11.79% and 43.79% respectively.*

Keywords *- 2-DOF, PID, The adaptive artificial bee colony algorithm, Automatic generation control, Non-Linearity.*

1. Introduction

Efficient design and control of power systems are integral to managing load frequency and optimizing power distribution. In interconnected electrical power systems, maintaining uniform frequency across all sources is crucial. The main aim of frequency control of load is to ensure the consistent frequency of each generator at every source by effectively managing power flow to meet load requirements under various operating conditions. Typically, an effective controller design for a generator within a power system should be capable of accommodating fluctuations in the load while ensuring high-quality voltage and frequency [1].

This literature review suggests electrical control systems designed for basic electrical setups [2-3]. Following that, optimal control was introduced for the regulation and initial design of electrical power systems within a link of power plants, aiming to enhance the application of optimal controllers. This involves employing various control techniques in the design of electrical automation controllers, emphasizing the advancement of automatic controllers through the utilization of modern controls, such as reinforcement learning [4], fuzzy theory [5], neural networks [6-8], particle swarm optimization [9], ANFIS approach [10-11] and bee colony algorithm [12], etc. Beyond the progress in designing and optimizing controllers, considerable progress has been made in the transition from fundamental principles to the development of a 2-DOF PID controller customized for electrical power systems characterized by non-linear attributes. Nevertheless, limited optimization techniques have been applied in this design controller, particularly in the context of interconnected power systems involving combined cycle power plants. Heuristic optimization is widely employed to address non-linear problems by drawing inspiration from the collective behaviors of living organisms, including methods such as ant swarms, the bee swarm, genetic algorithms and particle swarms. Among these, genetic algorithms served as the pioneering method. Despite an initial chromosomal randomization that might be distant from the optimal solution, genetic algorithms consistently discover solutions to problems. This robustness is attributed to the adaptability of the algorithm, as the best chromosomes can evolve over time, enhancing the probability of attaining a suitable solution [11].

Nevertheless, the genetic algorithm is intricate, demanding more time and offering no guarantee of finding the most appropriate resolution within a designated time frame. The Annealing-Simulation Algorithm (ASA), rooted in the Boltzmann diffusion principle, holds promise for solving diverse problems by contracting the dimensions or limits of the source. However, a notable drawback of this algorithm lies in its reliance on re-randomization of energy, which utilizes only the sets of optimal energy values in the vicinity, leading to the inevitable local solution. The use of randomization presents another notable challenge. Initiating the process with a limited number of randomizations prolongs the time required to recognize the most effective reaction. Particularly since the initial response is distant from the optimal answer, the protracted time required to discover the optimal solution, coupled with the uncertainty stemming from the initial randomization issue, may render it impractical to achieve the optimal solution.

Acknowledging these difficulties and the lack of an ultimate solution, a heuristic optimization was developed, leveraging the mimicry of living organism behaviors to navigate their natural paths through the generation of random initial responses. Various prototypes, such as the Bee Colony Algorithm (BCA), offer alternatives that facilitate quicker solution discovery and the avoidance of certain responses [13-14]. The BCA replicates the food-seeking behavior observed in swarms of honey bees.

Inspired by the sophisticated strategies utilized by honey bees, such as the waggle portion of the dance communication, for effective food source discovery and exploration, this algorithm is distinguished by its simplicity, robustness, and its status as a framework that keeps a set of potential solutions uses randomness in searching, and aims to find the best solution for an optimization problem.

The following manuscript introduces the Adaptive Artificial Bee Colony Algorithm (AABCA) to use for a 2-DOF PID controller to optimize an interconnected thermal power system characterized by nonlinearity.

The assessment of dynamic performance through key metrics, including the Integral of Time Squared Error (ITSE), the Integral of Squared Error (ISE), and sensitivity analysis, the investigation entails a comprehensive evaluation encompassing dynamic responses and internal control mechanisms under abnormal power system conditions.

2. Interconnected Thermal Power Systems

The objective of interconnecting thermal power systems is to ensure electrical stability and reliability. Typically, this connection power plant is depicted in Figure 1, where each source incorporates a 2000 MW-rated generator providing a load of 1000 MW. Figure 1 illustrates a simulation model of the interconnection of 2 plants utilizing combined cycle technology, encompassing governors with dead bands, turbines, and the power system.

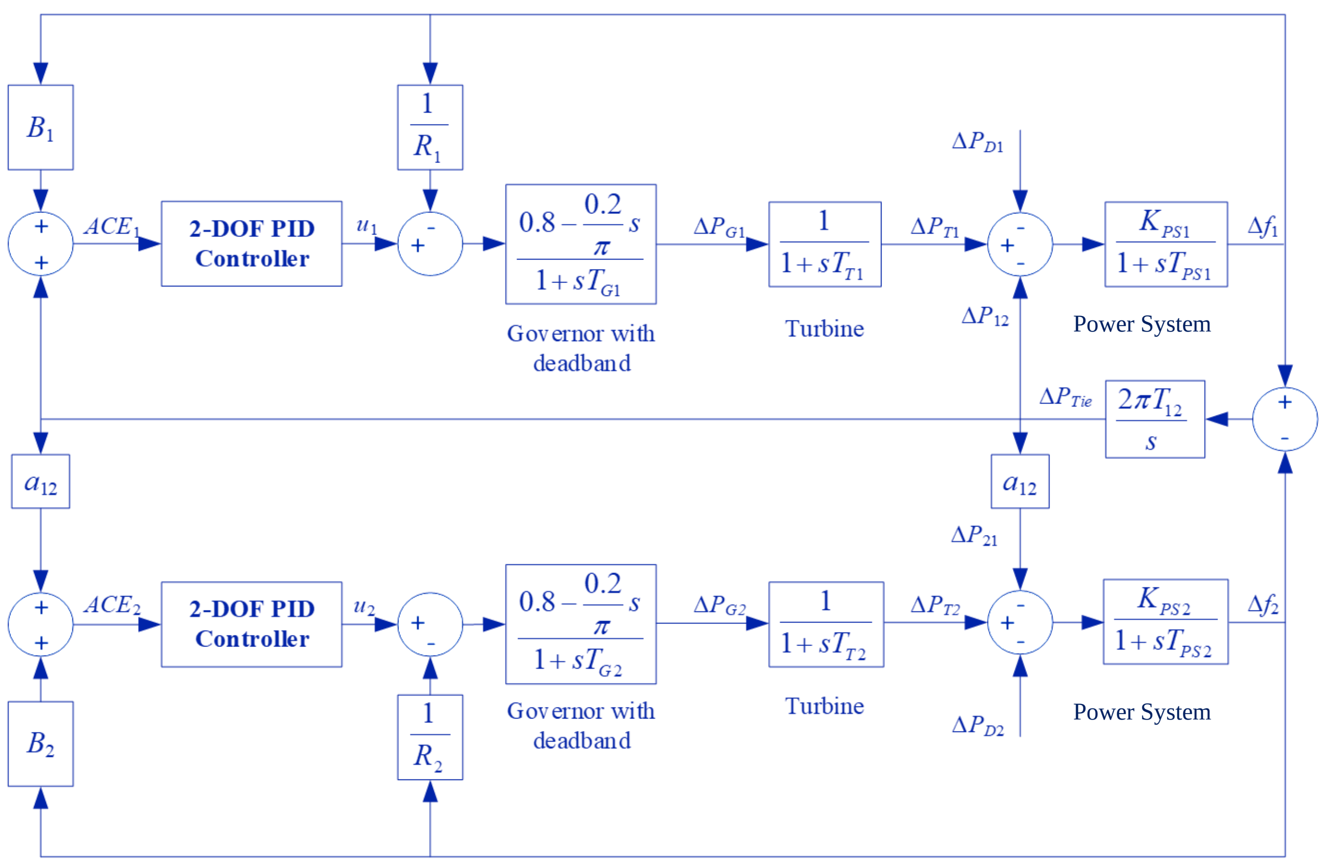

Fig. 1 Two-area interconnected thermal power systems [12]

As depicted in Figure 1, the parameter for the interconnected thermal power system consists of a tie-line coefficient constant (a_{12}) of -1 and a frequency bias constant (B_1 and B_2) of 0.425 p.u.MW/Hz, regulation constant (R_1 and R_2) of 2.4 Hz per p.u., turbine time constants (T_{T1} and T_{T2}) of 0.2s, governor time constants (T_{G1} and T_{G2}) of 0.1s, power system gain (K_{PS1} and K_{PS2}) of 120 Hz per p.u. MW, power system time constants (T_{PS1} and T_{PS2}) of the 20s and the synchronization time between the two control areas (T_{12}) of 0.0707 p.u. In the power system, the connected thermal power plant enhances the overall stability of the system. This enhancement necessitates control mechanisms, notably the implementation of a 2-DOF PID controller. This discussion will delve into the structure of the controller and the respective objective functions. Figure 2 illustrates referring to the arrangement of the 2-DOF PID. the controller in parallel. The controller comprises components such as the derivative setpoint weight (DW), the proportional setpoint weight (PW), the derivative filter coefficient (N) and controller gain. The increase comprises proportional gain (KP), integrator gain (KI), and derivative gain (KD). Here, R(s), Y(s) and U(s) denote the reference signal, the feedback signal from the system output and the output signal generated by the parallel 2-DOF PID controllers, respectively. This study outlines PID parameter limits, which are explicitly delineated in Table 1.

The configuration of system control in power systems typically aims to achieve the following primary objectives: (1) minimizing the frequency difference in each power system as the load varies, approaching zero, (2) minimizing the integral of the frequency error, (3) ensuring that the characteristics of control system contribute to the overall stability of the system, and (4) enabling the power system from each source to operate effectively under normal load conditions and adapt seamlessly to load changes. These control objectives can be expressed mathematically as follows:

$$\text{Minimize } (J_i) \tag{1}$$

$$J_1(\text{ISE}) = \int_0^{t_{sim}} [(\Delta f_1)^2 + (\Delta f_2)^2 + (\Delta P_{Tie})^2].dt \tag{2}$$

$$J_2(\text{ITSE}) = \int_0^{t_{sim}} [(\Delta f_1)^2 + (\Delta f_2)^2 + (\Delta P_{Tie})^2].t.dt \tag{3}$$

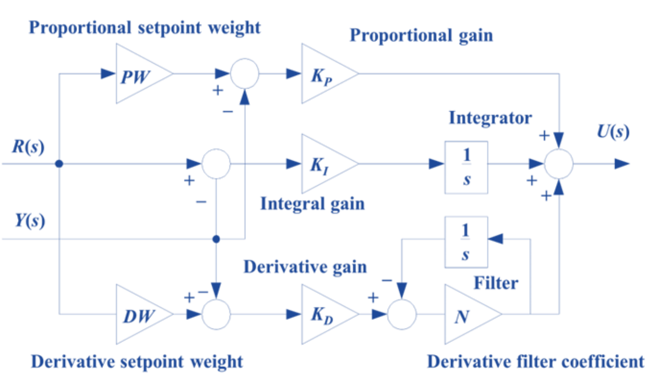

Fig. 2 The 2-DOF PID Controller [12]

Table 1. The boundaries of the PID parameters

Parameters	K_P	K_I	K_D	N	PW	DW
Minimum	0	0	0	10	0	0
Maximum	1	1	1	300	2	5

3. AABCA

The objective of the AABCA is to mimic the natural habitat foraging tendencies of honey bees. This emulation involves communication among bees, facilitated by means such as the waggle dance, which communicates information about food source locations. The simplicity of communication within the bee algorithm has paved the way for the development of artificial intelligence algorithms capable of tackling intricate problems characterized by numerous variables.

One notable application is in optimizing parameters for building control systems. In this research, the AABCA employed to settings parameters of the 2-DOF PID controller carefully, specifically aimed at regulating The two interconnected power sources. The pertinent parameters are detailed in Table 2.

The AABC encompasses the subsequent steps:

Step 1: Generate the initial-populations by random selection, quantity of n. Ensure that initial populations conform to viable candidate solutions within the stipulated conditions. Set NC=0.
Step 2: Initial populations evaluated for optimization.
Step 3: Select the m for the process of exploring nearby
Step 4: Divide the optimal m solutions into 2 groups: the 1st group comprising the optimal e solutions and the 2nd group consisting of the remaining optimal m-e solutions.
Step 5: Calculate the adaptive size of the process of exploring nearby for each of the optimal solutions (n_{gh}).
Step 6: Create solutions within the neighborhood selected solutions.
Step 7: Find a patch for the optimal solution.
Step 8: Verify the fulfillment of the stopping criterion. If met, conclude the search; else, NC=NC+1.
Step 9: Allocate the population of n-m for the purpose of generating novel solutions, then advance to Step 2.

Table 2. AABCA parameters

	Parameters	Qty
n	Bee scouts	10
m	Chosen sites for neighborhood exploration	5
e	Optimal "elite" sites from a set of m-selected sites	2
nep	Utilized bees for the e best sites	4
nsp	Utilized bees for the size of m-e	2
ngh	Exploration of the local vicinity.	0.1
NC	Iterations	30

4. Results and Discussion

In power systems, the linking thermal power plant enhances overall system stability, necessitating control mechanisms, particularly the use of a 2-DOF PID controller. This discussion outlines both the structure of the controller and its respective objective functions. The AABCA is employed to adjust the parameters of the 2-DOF PID controller, which is responsible for governing the connection of the system of power from 2 sources.

The MATLAB R2021a program is utilized to rigorously test and evaluate all processes, executing on a CPU Core i5 with 2.40 GHz clock speed and RAM DDR3 4.00 GB. A comparison of the outcomes from tuning the 2-DOF PID controller utilizing both the AABCA and the configuration of the uniform settings for the differential evolution (DE) algorithm is elaborated upon in Table 3.

Table 3 displays the optimal configurations for the 2-DOF PID controller, determined through the AABCA. These settings aim to minimize both ISE and ITSE. Notably, the gain of KP, KI and KD parameters closely align with those adapted using the DE algorithm. However, there are variations in the N, PW and DW, which are comparatively lower than those tunned by the DE algorithm.

Figures 3 and 4 present a comparative analysis of the frequency change in a power connection between two sources. The controller for 2-DOF PID parameters was meticulously crafted by the AABCA and DE algorithm to minimize ISE. The scenarios involve a dynamic load change of 1% connected to generator systems 1 and 2.

The results depicted in Figures 3 and 4 highlight that the tunning 2-DOF PID facilitated by AABCA demonstrates exceptional mastery in managing both the transition to a steady state and minimizing overshoot. In Figure 5, the variation in the power system with connection from two sources is illustrated. Notably, the controller for 2-DOF PID, parameterized by the AABCA, demonstrates a more effective control over power differentials compared to the DE method.

Table 3. Optimal controller parameters

Objective function With Controller parameters	DE [12]		AABCA	
	J1 (ISE)	J2 (ITSE)	J1 (ISE)	J2 (ITSE)
K_P	0.5409	0.4935	0.7427	0.5737
K_I	0.9708	0.7619	0.9004	0.9851
K_D	0.5144	0.3007	0.6561	0.4389
N	180.6983	177.4023	288.0342	257.5218
PW	2.0832	0.5997	0.7814	0.9480
DW	0.6462	2.5641	0.2800	0.8468

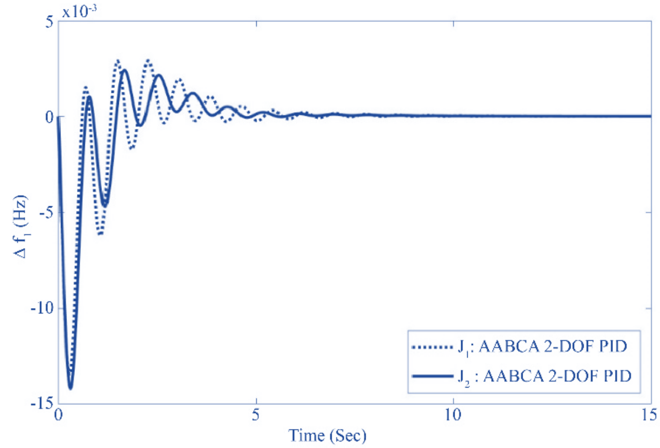

Fig. 3 Area-1 result by frequency deviation from 1% alteration in Area 1, evaluated using ISE and ITSE objective functions

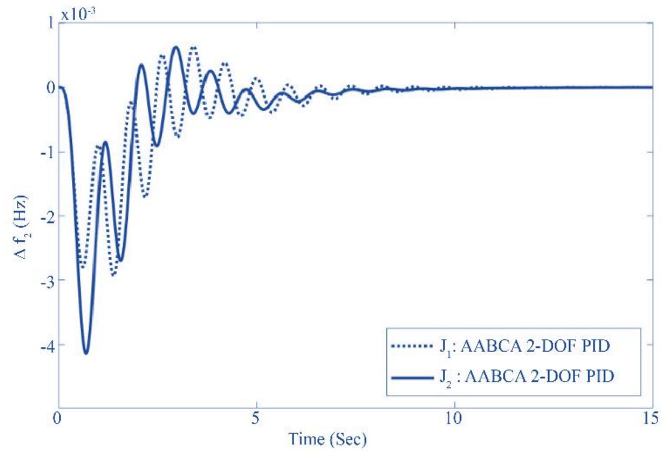

Fig. 4 Area-2 result by frequency deviation from 1% alteration in area 1, evaluated using ISE and ITSE objective function

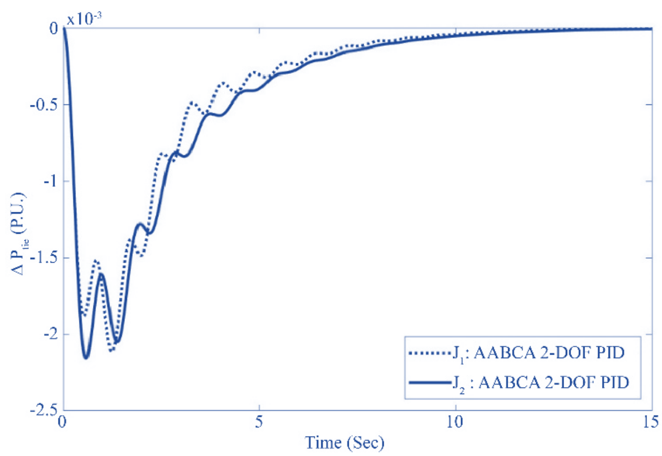

Fig. 5 Power deviation by Tie line result from 1% alteration in area 1, evaluated using ISE and ITSE objective function

Tables 4 to 6 show the performance of controllers tuned by AABCA and DE algorithm, with the objective of minimizing ISE (J1) and ITSE (J2). The tabulated data illustrates essential performance metrics, including settling time, peak undershoot and errors of Δf1, Δf2, and ΔPtie.

Table 4. Peak overshoot values

Controller for Optimization	Peak Overshoot (OS)		
	Δf_1	Δf_2	ΔP_{tie}
2- DOF PID for J_1 DE [12]	0.0032	0.0010	0.0000
2-DOF PID for J_1 AABCA	0.0027	0.0005	0.0000
2-DOF PID for J_2 DE [12]	0.0025	0.0011	0.0000
2-DOF PID for J_2 AABCA	0.0022	0.0005	0.0000

Table 5. Values of settling times

Controller for Optimization	Settling times (2% band) T_s (s)		
	Δf_1	Δf_2	ΔP_{tie}
2- DOF PID for J_1 DE [12]	7.6676	7.6676	7.6318
2-DOF PID for J_1 AABCA	5.1554	5.9351	6.0456
2-DOF PID for J_2 DE [12]	7.6854	7.7748	7.6318
2-DOF PID for J_2 AABCA	4.5685	5.5542	6.5436

Table 6. Values of errors

Controller for Optimization	Errors	% Improvement
2- DOF PID for J_1 DE [12]	8.9321×10^{-5}	11.79%
2-DOF PID for J_1 AABCA	7.8791×10^{-5}	
2-DOF PID for J_2 DE [12]	1.0116×10^{-4}	43.79%
2-DOF PID for J_2 AABCA	5.6864×10^{-5}	

From Table 4, it becomes evident that controllers parameterized by the AABCA outperform those adjusted by the DE across all control objectives. The AABCA consistently yields superior control performance in peak undershoot term, settling time, and errors for Δf1, Δf2, and ΔPtie compared to controllers tuned by the DE algorithm.

To show the superiority of the AABCA, the results are compared with a recently published approach for the same interconnected thermal power system [12]. As shown in Table 6, the ISE (J1) value is improved by 11.79%, and the ITSE (J2) value is improved by 43.79%.

5. Conclusion

In the intricate realm of power system management, the design of controllers poses significant challenges, particularly in achieving high-performance control. Specifically, the utilization of bee algorithms facilitates the design process by tuning 2-DOF PID controllers. This approach leads to the development of a sophisticated power system management system, where the 2-DOF PID controllers are adept at effectively controlling both frequency and power.

The objective is to minimize the ISE and ITSE, ensuring optimal performance under dynamic conditions in the two thermal power plants. Furthermore, the AABCA is employed for the construction and parameterization of controllers. In comparison to the other techniques, such as the DE algorithm, the AABCA demonstrates superior control across all facets of intricate power systems.

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