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Design of Parallel 2-DOF PID Controller by Bee Algorithm for Interconnected Thermal Power Systems

***Abstract**. The article presents the design and analysis of the control of two connected thermal power generator systems by the parallel 2-degree freedom of proportional-integral-derivative (2-DOF-PID) and modified by the bee algorithm (BA). In general, power and control systems are generally characterized as non-linear, so the automatic gain controllers (AGCs) will need to be optimized for parameters, particularly the 2-DOF-PID controllers that use a large number of parameters. The bee algorithms and differential evolution (DE) have been presented to improve parameterization and compare the performance of such an algorithm while using a dynamic electric load size change approach. As a result of testing, when the bee algorithm is used to improve the parameters of the generator system, the system will be more robust to changes and have higher performance.*

***Streszczenie.** W artykule przedstawiono projekt i analizę sterowania dwoma połączonymi układami generatorów energii cieplnej poprzez równoległą dwustopniową swobodę proporcjonalno-całkująco-różniczkową (2-DOF-PID) i zmodyfikowaną przez algorytm pszczół (BA). Ogólnie rzecz biorąc, systemy zasilania i sterowania są generalnie charakteryzowane jako nieliniowe, więc automatyczne regulatory wzmocnienia (AGC) będą musiały zostać zoptymalizowane pod kątem parametrów, w szczególności regulatory 2-DOF-PID, które wykorzystują dużą liczbę parametrów. Algorytmy pszczół i ewolucja różnicowa (DE) zostały zaprezentowane w celu poprawy parametryzacji i porównania wydajności takiego algorytmu przy użyciu podejścia do dynamicznej zmiany wielkości ładunku elektrycznego. W wyniku testów, gdy algorytm pszczeli zostanie wykorzystany do poprawy parametrów systemu generatora, system będzie bardziej odporny na zmiany i będzie miał wyższą wydajność. (**Projektowanie równoległego regulatora PID 2-DOF według algorytmu Bee dla połączonych systemów elektroenergetycznych**)*

Keywords: PID controller, .Bee algorithm
Słowa kluczowe: sterownik PIDF, algorytm Bee..

Introduction

The importance of the design and control of the power system is load frequency control and power. Specifically, a power system where multiple electrical power sources are connected and each of which must have the same frequency. The core principle of controlling the load frequency in a power system is to maintain the generator frequency at each source and to manage the power flow adequately to satisfy the requirements of the load in both normal and dynamic states of change.

In general, a good power system's controller design for a generator must be able to handle changes in the load, and the voltage and frequency must be high quality [1]. In this literature study, electrical control systems for simple electrical systems are proposed [2]. Subsequently, optimal control was applied for the first time for the design and control of electrical systems within the connected power system of a power plant in order to optimize the optimal control application. This relies on the different control techniques for designing electrical automation controllers. It focuses on the development of automatic electrical controllers with the application of modern controls to improve electrical automation controllers such as neural networks [5-6], fuzzy system theory [7], reinforcement learning [8], ANFIS approach [9-10], and particle swarm optimization [11], etc. In addition to the development of the design and application of the optimization of electrical controllers, there have been advancements from basic to Parallel 2-Degree Freedom of Proportional-Integral-Derivative (2-DOF-PID) electrical controllers for electrical systems with non-linear characteristics. However, very few optimization techniques are used for the design of 2-DOF-PID controllers, especially for power systems interconnected between combined cycle power plants.

Heuristic optimization is popular for solving non-linear problems by comparing the living behaviors of organisms, such as the bee swarm method, ant swarm method, particle swarm method, and genetic method. Genetic algorithms were the first to be developed; this algorithm could always find a solution to a problem, despite the fact that the initial chromosomal randomization was far from the optimal solution and may avoid a particular solution. This is because the best chromosomes might change, increasing the likelihood of obtaining the best chromosome or the optimal solution [11]. However, the genetic process is quite complicated in order to discover the optimal solution, which requires more time and may not find the optimal solution within a specific time frame. The annealing simulation algorithm can solve any problem because it is based on the Boltzmann diffusion principle, which shrinks the size or boundary of the source. Nonetheless, a significant issue with the annealing simulation algorithm is that energy re-randomization employs only surrounding sets of ideal energy values, resulting in an inescapable local solution. Randomization is another significant issue. The initial response with a restricted number of randomizations resulted in a lengthy time to identify the optimal response when the initial response was far from the optimal response. Due to the initial randomization issue when the first response is far from the optimal answer and the initial unpredictability with a limited number of random replies, it takes a long time to discover the optimal answer, and it may not be possible to get the optimal solution. As there was no perfect solution, a heuristic optimization approach was created to connect the live behavior of an organism to its natural path by generating random beginning responses. There are an infinite number of prototypes, like the algorithm for the Bee Optimization Method, that can find solutions faster and avoid certain answers.[13-16]

This paper presents the application of the bee algorithm optimization for the parameterization of the 2-DOF PID Controller in the interconnected power system of the combined cycle power generator under non-linear features. It compares the dynamic response based on the dynamic performance, the integral of squared error (ISE), the integral of time squared error (ITSE), and the sensitivity analysis of the internal controls under abnormal conditions of the power system.

Interconnected Termal Power System

The purpose of thermal power system connections is to provide electrical stability and stability. In general, the connection between two combined cycle power plants is simulated as seen in Figure 1, with each source consisting of a generator rated at 2000 MW and supplying 1000 MW to load. Figure 1 shows a simulation of the connection of two combined-cycle power plants, each of which consists of a governor with deadband, turbine, and power system

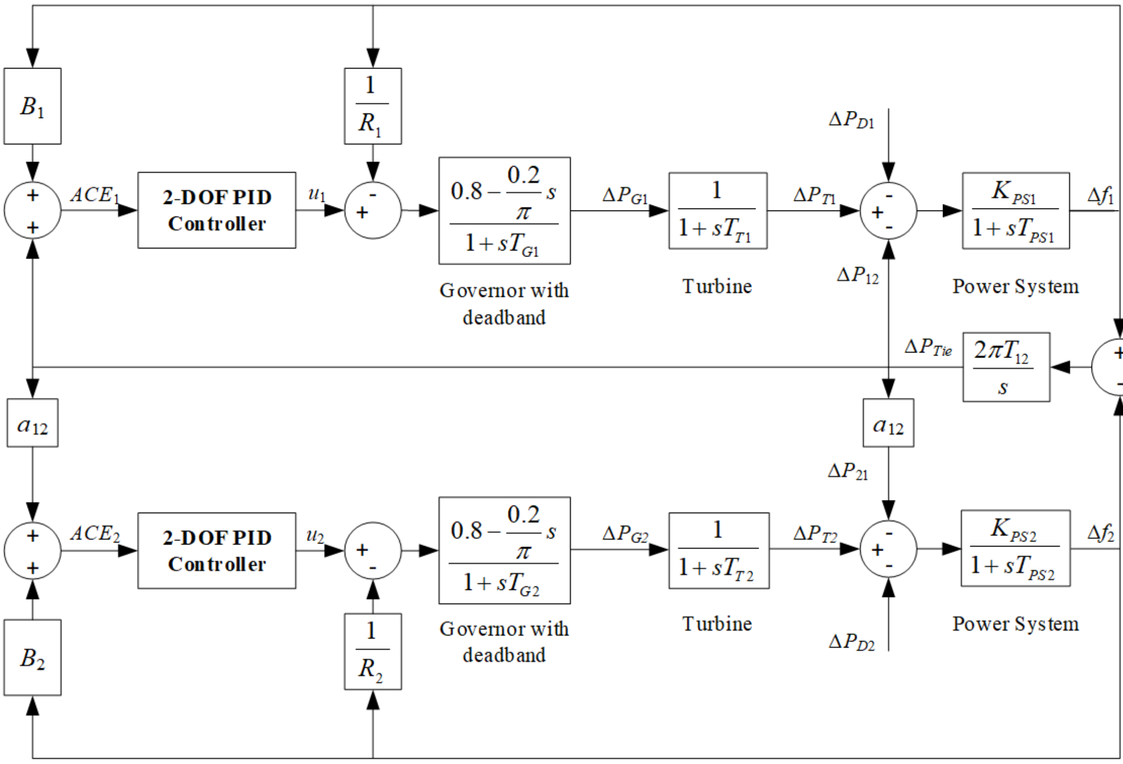

Fig.1. Transfer function model of interconnected two-area thermal system with governor dead band

THE 2-DOF PID Controller

The connection of thermal power plants to the power system increases the stability of the power system. It requires control, especially from a 2-DOF-PID controller. In this topic, controller structure and objective functions are presented, respectively.

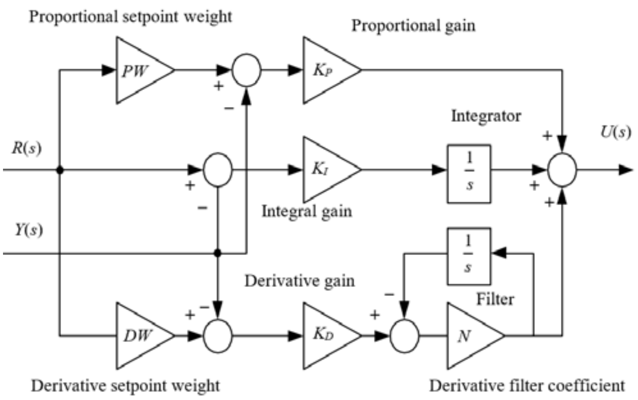

Fig.2. Two degrees of freedom (2-DOF) PIDcontroller

1. Controller structure

The structure of the parallel 2-DOF PID controller is shown in figure 2. The parallel 2-DOF PID controller consists of proportional setpoint weight (PW), proportional gain (KP), integrator gain (KI), derivative setpoint weight (DW), derivative gain (KD), and derivative filter coefficient (N), respectively. The R (s) is the reference signal and the Y (s) is the feedback signal of the system output when U (s) is the output signal of the parallel 2-DOF PID controller.

2. Objective Function

The structure of the Generally, the primary objectives of system control in power systems are:

1.) The frequency difference in each power system must approach zero when the load changes.

2.) The integral of the frequency error must be minimal.

3.) The control system characteristics should maintain the stability of the system.

4.) The power system in each source must be able to work both when the load is normal and when it changes.

From the above, control objectives can be written into equations as follow:

(1) Minimize (J_i)

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

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

The objective function must be executed under the maximum (maximum, max) and minimum (minimum, min) conditions of the parameters. In a parallel 2-DOF PID controller presented as shown in Figure 2, it consists of proportional setpoint weight (PW), proportional gain (KP), integrator gain (KI), derivative setpoint weight (DW), derivative gain (KD), and derivative filter coefficient (N) as in Equations 4 to 9 and Table 1.

(4) $K_{P\,min} \leq K_P \leq K_{P\,max}$

(5) $K_{I\,min} \leq K_I \leq K_{I\,max}$

(6) $K_{D\,min} \leq K_D \leq K_{D\,max}$

(7) $Pw_{min} \leq Pw \leq Pw_{max}$

(8) $Dw_{min} \leq Dw \leq Dw_{max}$

(9) $N_{min} \leq N \leq N_{max}$

Table 1. Minimum and Maximum Value of The Control Parameters

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

The goal of the bee algorithm (BA) is to emulate the behavior of honey bees as they forage for food in their natural environment by communicating with other bees for instructions and food sources, such as the waggle dance, which conveys the location of food sources. The bee algorithm's easy-to-understand approach to communication has led to the development of artificial intelligence algorithms for solving complex problems with a lot of variables, like building control systems with optimized parameters. The application of the bee algorithm to adjust the settings and design the parameters of the 2-DOF PID controller in order to regulate the power connection between two sources. It uses the parameters in table 2.

Table 2. Parameters of Bee Algorithm

n	Number of scout bee	10
m	Number of sites selected for neighborhood search	5
e	Number of best “elite” sites out of m selected sites	2
n_{ep}	Employed bees for e best sites	4
n_{sp}	Employed bees for m-e size	2
n_{gh}	Neighborhood search	0.1
NC	Number of iterations	30

The bee algorithm includes the following steps:

Step 1: Determine the variables in the bee algorithm as shown in Table 2.

Step 2: Pollinating bee populations (number of n) were chosen at random to find the parameters of the 2-DOF PID controls according to Table 1 under rules and conditions.

Step 3: Test the power system connection control from two sources under the parameters of the 2-DOF PID control from step 2.

Step 4: Use equations (2) and (3) to figure out the fitness value so that you can get n fitness values.

Step 5: Choose the number of m bee populations that yields the best fitness value. The m bee populations were split into e groups made up of the e bee populations with the highest fitness values. The bee population surveyed the number of n = m - e.

Step 6: Assign nep bees worker to find the parameter of the 2-DOF PID control, the surrounding bee survey e with a fixed distance of ngh, and set the nsp bee worker to find the parameter of the 2-DOF PID control. Surrounding of n = m - e survey bees with fixed spacing ngh The parameters of the 2-DOF PID controls are given in Table 1 under various nep+nsp set conditions and regulations.

Step 7: Test the power system connection control from two sources under the parameters of the 2-DOF PID control from step 6.

Step 8: Evaluate the fitness value according to equations (2) and (3) to get nep + nsp fitness values. Choose the best fitness value in this round.

Step 9: Return to step 2 until the specified number of repetitions has been completed.

Step 10: The best 2-DOF PID controller parameter is the one that makes each cycle's fitness value the best it can be.

Results And Discussion

The connection of thermal power plants to the power system increases the stability of the power system. It requires control, especially from a 2-DOF-PID controller. In this topic, controller structure and objective functions are presented, respectively.

The bee algorithm modifies the settings of the 2-DOF PID controller, which controls the connection of the power system from two sources. All processes are tested and assessed using the MATLAB R2013a program. The program runs on a CPU Corei3 of 2.40 GHz and RAM of 4.00 GB. Comparing the results of parameter tuning for 2-DOF PID controllers using the bee algorithm and the differential evolution (DE) algorithm with the same settings is shown in Table 3.

Table 3. Optimization Controller Parameters.

Objective function /Controller parameters	**Differential Evolution**		**Bee Algorithm**	
	J1 (ISE) [12]	**J2 (ITSE) [12]**	**J1 (ISE)**	**J2 (ITSE)**
K_P	0.5409	0.4935	0.6939	0.5285
K_I	0.9708	0.7619	1.0793	1.0184
K_D	0.5144	0.3007	0.5619	0.4344
N	180.6983	177.4023	152.3835	163.6528
PW	2.0832	0.5997	0.7547	1.1718
DW	0.6462	2.5641	0.3238	0.7075

Table 3 shows the best settings for the 2-DOF PID controller. These settings were made by the bee algorithm so that the integral of squared error (ISE) and the integral of time squared error would be as low as possible. The Proportional gain (KP), Integrator gain (KI), and Derivative gain (KD) parameters were found to be close to those adjusted by the differential evolution (DE) algorithm, with the exception of the Derivative filter coefficient (N), Proportional setpoint weight (PW), and Derivative setpoint weight (DW), which were less than those adjusted by the DE algorithm.

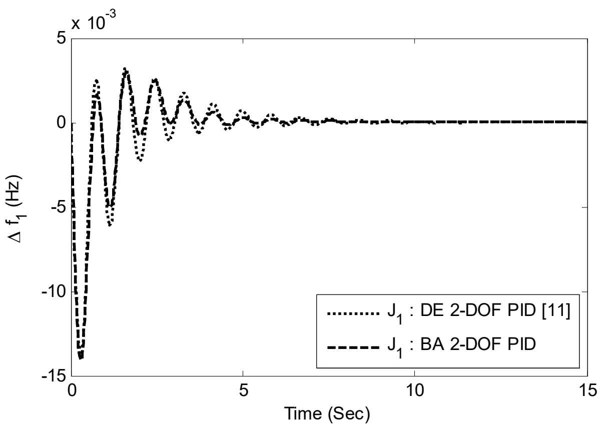

Fig.3. Frequency deviation of area-1 for 1% change in area-1 with ISE objective function.

Figures 3 and 4 compare the difference in the frequency change of the generator systems 1 and 2 in a two-source power connection control system. The parameters of the 2-DOF PID controller were designed with the integral of squared error (ISE) at its lowest value by the bee algorithm and a differential evolution (DE) algorithm. The conditional is a dynamic change by a 1% change in the load connected to the generator systems 1 and 2. Figures 3 and 4 show that the 2-DOF PID control with parametric tuning of the bee algorithm gives greatest control over both the overshoot and the transition to the steady state. Figure 5 shows the difference in electrical power in the connection of the power system from two sources. It was found that the 2-DOF PID controller parameterized by the bee algorithm had a more efficient power differential control effect than the differential evolution (DE) method

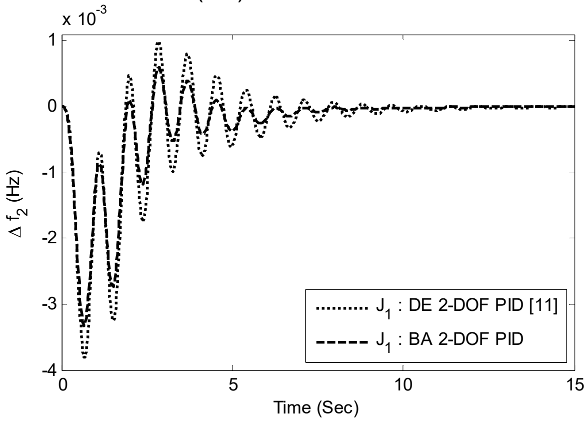

Fig.4. Frequency deviation of area-2 for 1% change in area-1 with ISE objective function.

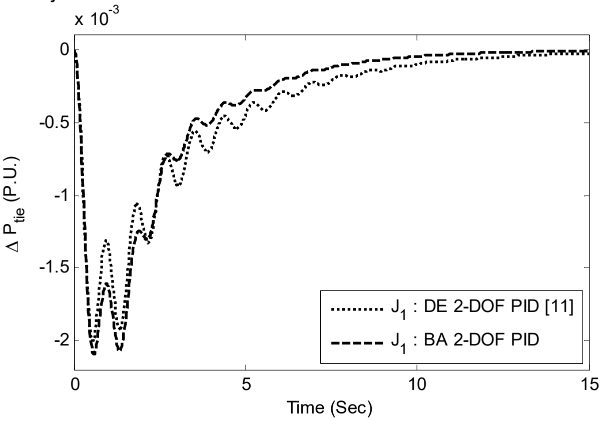

Fig.5. Tie line power deviation for 1% change in area-1 with ISE objective function

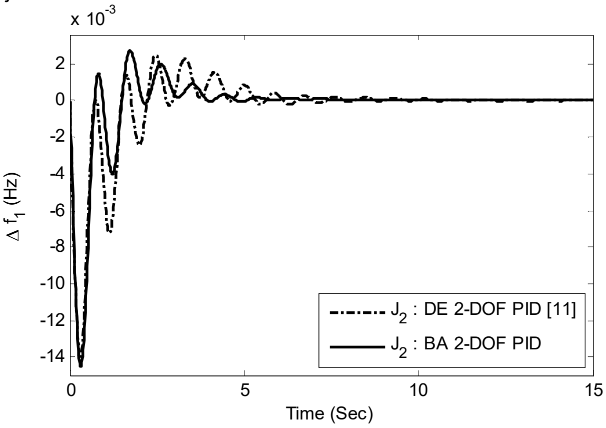

Fig.6. Frequency deviation of area-1 for 1% change in area-1 with ITSE objective function.

Figures 6 and 7 compare the difference in the frequency change of the generator systems 1 and 2 in a two-source power connection control system. The parameters of the 2-DOF PID controller were designed with the integral of time squared error (ITSE) at its lowest value by the bee algorithm and a differential evolution (DE) algorithm. The conditional is a dynamic change by a 1% change in the load connected to the generator systems 1 and 2. Figures 6 and 7 show that the 2-DOF PID control with parametric tuning of the bee algorithm gives greatest control over both the overshoot and the transition to the steady state. Figure 8 shows the difference in electrical power (〖□"P" 〗 _"Tie") in the connection of the power system from two sources. It was found that the 2-DOF PID controller parameterized by the bee algorithm had a more efficient power differential control effect than the differential evolution (DE) method.

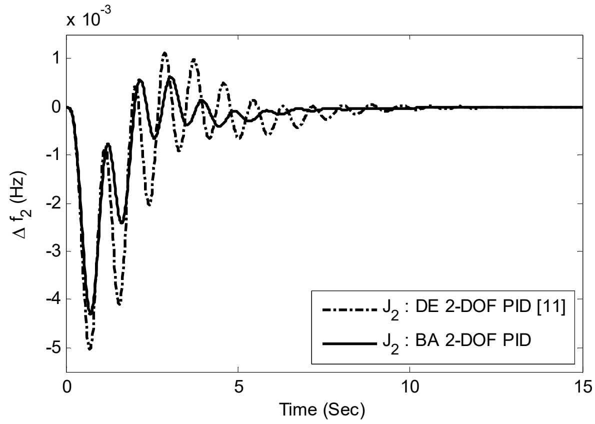

Fig.7. Frequency deviation of area-2 for 1% change in area-1 with ITSE objective function.

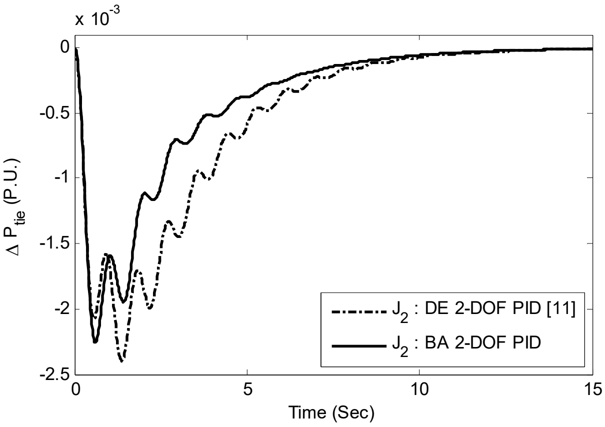

Fig.8. Tie line power deviation for 1% change in area-1 with ITSE objective function.

Also, when comparing the convergent sequence to the least differential of the integral of squared error (ISE, J1) and integral of time squared error (ITSE, J2), the parameterization of 2-DOF controls PID for controlling power connection from 2 sources. It was found that the design of the 2-DOF PID controller with the objective function integral of time squared error (ITSE, J2) has the least value by parameter tuning by the swarm algorithm showed good convergence to the answer as shown in Fig. 9.

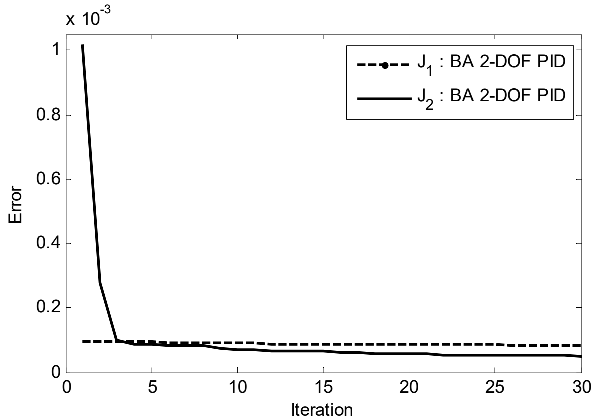

Fig.9. Convergence curves

Table 4 displays the controller performance parameterized by the bee method and the differential evolution (DE) algorithm with the objective of minimizing the integral of squared error (ISE, J1) and integral of time squared error (ITSE, J2). Table 4 displays the following performance indicators: peak undershoot, settling time and errors of Δf_1, Δf_2 and ΔP_{tie}. From Table 4, for all control purposes, controllers parameterized by the bee algorithm provided better control performance in all aspects than controllers parameterized by the differential evolution (DE) algorithm

In complicated power system management, controller design issues are a major problem. Specifically, the 2-DOF PID controller with high performance. Utilizing bee algorithms allows design by optimizing the parameters of the controller. This results in complicated power system management using a 2-DOF PID controller capable of controlling frequency and power effectively. For the goal, the integral of squared error and the integral of time squared error are the smallest, and the dynamic change conditions of the thermal power generator system are linked to two power sources.

In addition, the bee approach is used to construct and parameterize the 2-DOF PID controller. Compared to controllers configured using the differential evolution (DE) algorithm, it provides superior control over all aspects of complicated power systems.

Table 4. Values of Settling Times, Peak Overshoot,and Errors

Optimization/ Controllers	Peak overshoot (OS)			Settling times (2% band) T_s (s)			Errors
	Δf_1	Δf_2	ΔP_{tie}	Δf_1	Δf_2	ΔP_{tie}	
J_1 DE : 2-DOF PID [11]	0.0032	0.0010	0.0000	7.6676	7.6676	7.6318	8.9321×10^{-5}
J_1 BA : 2-DOF PID	0.0030	0.0006	0.0000	5.2110	6.0338	6.1814	8.4822×10^{-5}
J_2 DE : 2-DOF PID [11]	0.0025	0.0011	0.0000	7.6854	7.7748	7.6318	1.0116×10^{-4}
J_2 BA : 2-DOF PID	0.0028	0.0006	0.0000	4.7012	5.6296	6.6568	5.7807×10^{-5}

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