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Artificial Bee Colony Optimization of AGC in a Two-area Interconnected Power System

M. Elsisi, M. Soliman, W. Mansour

Electrical Power and Machines Department
Faculty of Engineering (Shoubra), Benha University
108 Shoubra St., 11241 Cairo, EGYPT

elsisimahmoud22@yahoo.com (Elsisi), msoliman_28@yahoo.com (Soliman), and wagdy_ibrhaim2010 (Mansour)

***Abstract*— Artificial Bee Colony (ABC) has recently been explored to develop a novel algorithm for distributed optimization and control. This paper proposes an ABC-based Load Frequency Control (LFC) design to enhance the damping of oscillations in a two-area power system. A two-area non-reheat thermal system is considered to be equipped with proportional plus integral (PI) controllers. The proposed design problem is formulated as an optimization problem. ABC is utilized to search for optimal controller parameters by minimizing a time-domain based objective function. The performance of the proposed controller has been evaluated with the performance of the conventional PI controller, and PI controller tuned by genetic algorithm (GA) in order to demonstrate the superior efficiency of the proposed ABC in tuning PI controller. Simulation results emphasis on the better performance of the optimized PI controller based on ABC in compare to optimized PI controller based on GA and conventional one over wide range of operating conditions, and system parameters variations..**

Index Terms - Artificial Bee Colony (ABC), Genetic Algorithms (GAs), Load Frequency Control (LFC), PI Controller.

I. INTRODUCTION

FREQUENCY control, during the load and generation imbalance, represents a very imperative issue for large-scale power systems. Automatic generation control (AGC) plays a significant role in the power system by maintaining the scheduled system frequency and tie-line power flow during normal operating conditions and during small perturbations [1-3]. This function of an AGC is always referred to as “load frequency control (LFC)” as mentioned by Kundur [2]. LFC is often considered as one of the first and foremost large-scale, decentralized, robust controllers in engineering practice. LFC is accomplished by two different control actions of the primary speed control and supplementary speed control in an interconnected power system.

Several approaches such as optimal, genetic algorithm (GAs), particle swarm optimization (PSO), imperialist competitive algorithm (ICA), bacterial foraging optimization (BFO), etc., for the design and optimization of the LFC system, have been reported in the literature [4]-[15]. Modern optimal control concept for AGC designs of interconnected power system was firstly presented by Elgerd and Fosha [4-5]. Genetic algorithms (GAs) have been extensively considered for the design of AGC. Optimal integral gains and optimal PID control parameters have been computed by GAs technique for an interconnected, equal non-reheat and reheat type two generating areas [6-7]. Parameter optimization of PID sliding-mode load frequency control used in automatic generating control (AGC) of multi-area power systems with nonlinear elements has been proposed in [8]. In [9], GA is used to compute the decentralized control parameters to achieve an optimum operating point for a realistic system comprising generation rate constraint (GRC), dead band, and time delays. The use of particle swarm optimization (PSO) for optimizing the parameters of AGC, where an integral controller and a proportional-plus-integral controller, is reported in [10]. In 2010, Gozde et al. designed the PSO based PI-controller with the new cost function and compared their results with the results of Abdel-Magid and Abido’s study [11]. In [12], a new PID controller for resistant differential control against load disturbance is introduced that can be used for load frequency control (LFC) applications. Parameters of the controller have been specified by using imperialist competitive algorithm (ICA). The authors of [13-14] have proposed bacterial foraging optimization algorithm (BFOA) for designing PI and PID-based load frequency controller for two-area power system with and without GRC. Application of BFOA to optimize several important parameters in AGC of an interconnected three unequal area thermal systems such as the integral controller gains, governor speed regulation, and the frequency bias parameters, has been reported in [15].

Recently artificial bee colony (ABC) has emerged as powerful optimization technique because colonies of bees have instinct ability known as swarm intelligence [16]. This highly organized behavior enables the colonies to solve problem beyond capability of individual members by functioning collectively and interacting primitively amongst members of the group [17-18]. This paper proposes the ABC optimization algorithm for optimal tuning of PI controllers in two area interconnected power system to damp power system oscillations. The PI control design is formulated as an optimization problem and ABC is employed to search for optimal controller parameters by minimizing a candidate time-domain based objective function. The considered objective function involves the integral time multiply the absolute error (ITAE) in the frequency and tie line power. The performance of the proposed ABC-based design is evaluated by comparison with GA-based design. Simulations results on a two-area test system are presented to assure the superiority of the proposed method in tuning controller compared with GA and conventional one.

II. ARTIFICIAL BEE COLONY OPTIMIZATION

A. *An overview*

Recently, Karaboga has proposed ABC algorithm [16] while its performance has been completely analyzed in 2007 [17-18]. In a real bee colony, there are some tasks performed by specialized individuals. These specialized bees try to maximize the nectar amount stored in the hive by performing efficient division of labour and self-organization. The minimal model of swarm-intelligent forage selection in a honeybee colony, that ABC algorithm adopts, consists of three kinds of bees: employed bees, onlooker bees, and scout bees. Half of the colony comprises employed bees and the other half includes the onlooker bees. Employed bees are responsible from exploiting the nectar sources explored before and giving information to the other waiting bees (onlooker bees) in the hive about the quality of the food source site which they are exploiting. Onlooker bees wait in the hive and decide a food source to exploit depending on the information shared by the employed bees. Scouts randomly search the environment in order to find a new food source depending on an internal motivation or possible external clues or randomly.

B. *ABC Algorithm*

The Main steps of the ABC algorithm are given below [17]:

Step 1 *Send the scouts to the initial food sources.*
Step 2 *Each employed bee produces a new food source in her food source site and exploits in the better source*
Step 3 *Each onlooker bee selects a source depending on the quality of her solution, produces a new food source in selected food source site and exploits the better source.*
Step 4 *Determine the source to be abandoned and allocate its employed bee as scout for searching new food sources.*
Step 5 *Memorize the best food source found so far.*
Step 6 *Repeat Steps 2-5 until the stopping criterion is met.*

In the first step of the algorithm $X_i\left(i=1,2,\ldots,NS\right)$, solutions are randomly produced in range of parameters where *SN* is the number of the food sources. In second step of the algorithm, for each employed bee, whose total number equals to the half of the number of food sources, a new source is produced by:

$$V_{ij}=X_{ij}+\phi_{ij}\left(X_{ij}-X_{kj}\right) \tag{1}$$

where ϕ_{ij} is a uniformly distributed real random number within the range $\left[-1 \quad 1\right]$, *k* is the index of the solution chosen randomly from the colony $k=Int\left(rand*SN+1\right)$, $j=1,2,\ldots,D$ and *D* is the dimension of problem. After producing v_i, this new solution is compared to X_i solution and the employed bee exploits the better source. In the third step of the algorithm, an onlooker bee chooses a food source with the probability

$$P_i = fit_i / \sum_{j=1}^{SN} fit_j \tag{2}$$

Where fit_i is the fitness of the solution x_i. After all onlookers are distributed to the sources, sources are checked whether they are to be abandoned. If the number of cycles that a source cannot be improved is greater than a predetermined limit, the source is considered to be exhausted. The employed bee associated with the exhausted source becomes a scout and makes a random search in problem domain by

$$X_{ij}=X_j^{\min}+rand*\left(X_j^{\max}-X_j^{\min}\right) \tag{3}$$

III. TWO AREA POWER SYSTEM

A controlled two-area interconnected power system of a non-reheat thermal plants is shown in Fig. 1 where f_i is the system frequency (Hz), R_i is the regulation constant (Hz/unit), T_{Gi} is the speed governor time constant (s), T_{Ti} is the turbine time constant (s) and T_{Pi} is the power system time constant (s), ACE_i is the area control error, ΔP_{Di} is the load demand change, ΔP_{ci} is the change in speed changer position, ΔP_{Gi} is the change in governor valve position, K_{Pi} is the power system gain, and ΔP_{tie} is the change in tie line power. The overall system can be modeled as a multivariable system in the following form:

$$\dot{x}=Ax+Bu+\Gamma d, \tag{4}$$

$$y=cx \tag{5}$$

$$x=\left[\Delta f_1 \quad \Delta P_{T1} \quad \Delta P_{G1} \quad \Delta P_{C1} \quad \Delta P_{tie} \quad \Delta f_2 \quad \Delta P_{T2} \quad \Delta P_{G2} \quad \Delta P_{C2}\right]^T$$

$$u=\left[u_1 \quad u_2\right]^T,\ y=\left[ACE_1 \quad ACE_2\right]^T,\ d=\left[\Delta P_{D1} \quad \Delta P_{D2}\right]^T$$

For the two area considered in this study, the conventional integral controller was replaced by a PI controller with the following structure:

$$K(s)=K_P+K_I/s \tag{6}$$

where K_P is proportional gain, and K_I is the integral gain, respectively. The PI controllers in both areas are considered identical. The control signal for PI controller is given by the following equation:

$$U_i(s)=K_i(s)*ACE_i(s) \tag{7}$$

IV. OBJECTIVE FUNCTION

A performance index can be defined by the Integral of Time multiply Absolute Error (ITAE) of the frequency deviation of both areas and tie line power. Accordingly, the objective function ***J*** is set to be

$$J=\int_0^{T_s} t\left(\left|\Delta f_1\right|+\left|\Delta f_1\right|+\left|\Delta P_{tie}\right|\right)dt \tag{8}$$

Where T_s is the simulation time. Based on this performance index *J* optimization problem can be stated as: Minimize *J* subjected to:

$$K_P^{\min}<K_P<K_P^{\max} \tag{9}$$

$$K_I^{\min}<K_I<K_I^{\max} \tag{10}$$

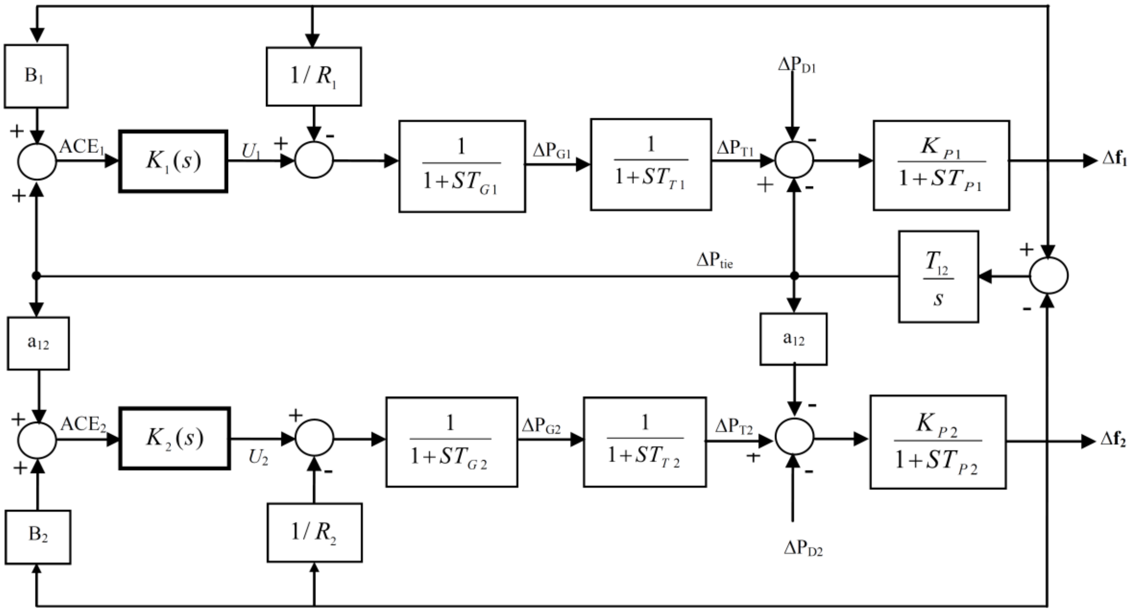

Figure 1 Two-area interconnected power system

To simplify the study, the two interconnected areas are considered identical. The optimal parameter are such that $K_{P1}=K_{P2}=K_P$ and $K_{I1}=K_{I2}=K_I$. This study focuses on optimal tuning of controllers for LFC using ABC. The aim of the optimization is to search for the optimum controller parameters setting that improve the damping characteristics of the system under all operating conditions and various loads and finally designing a low order controller for easy implementation.

V. SIMULATION RESULTS

Different comparative cases are considered to show the effectiveness of the proposed ABC method for optimizing controller parameters. The progress of the objective function (8) is shown in Figure 2. TABLE I shows the system eigenvalues, minimum damping ratio of system mode, controller parameters, performance index, and settling time. It is clear that the system with conventional controller is suffered from poor damping due to the small damping ratio of system modes (ζ = 0.021), and small damping factor (σ = -0.086). Moreover, the maximum damping factor is related to ABC. In addition, it is clear that, the proposed controller shifts substantially the system mode eigenvalues to the left of the complex plane. Hence compared to the conventional PI controller system, ABC greatly enhances the system stability and improves the damping characteristics of system modes. Moreover, the value of the performance index with the proposed controller is smaller compared to conventional controller and GA. This demonstrates that the settling time and oscillations are greatly reduced by applying the proposed controller.

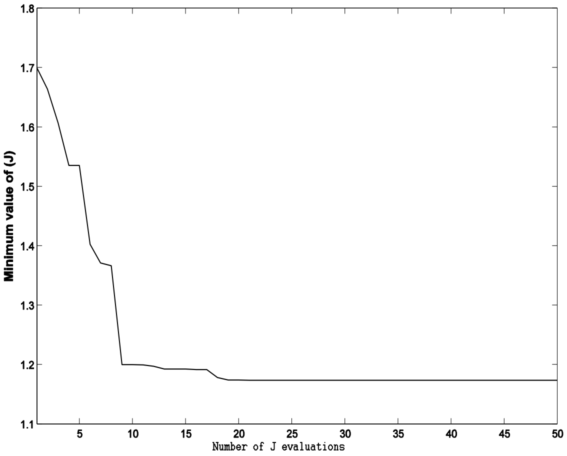

Figure 2 Progress of the objective function

TABLE I SYSTEM EIGENVALUES, MINIMUM DAMPING RATIO, CONTROLLER PARAMETERS, OBJECTIVE FUNCTION (J) , AND SETTLING TIME (TS).

	Conventional PI	**GA-PI**	**ABC-PI**
Eigenvalues	-13.7342 -13.6218 -0.086 ±*j*4.1699 -0.9568 ±*j*3.402 -1.8538 -0.2359 -0.2355	-13.1203 -13.1043 -0.5605 ±*j*3.1716 -1.1751 ±*j*1.9112 -1.1967 -0.4454 -0.4288	-13.0672 -13.0349 -0.5348 ±*j*3.0029 -0.8759 ±*j*1.6251 -0.8733 ±*j*0.5149 -1.0965
ζ_{min}	0.021	0.17	0.17
K_p, K_I	K_p=-0.7005, K_I=0.3802	K_p=-0.2346, K_I=0.2662	K_p=-0.3118, K_I=0.4585
J	3.5795	2.554	1.164
T_s	29.42 *sec*	8.56 *sec*	5.255 *sec*

A. *Step increase in demand of the first area (ΔP_{D1})*

As the first test case, a 10% step increase in demand of the first area (ΔP_{D1}) is applied as the first test point (nominal operating point). The frequency deviation of the first area Δf_1, the frequency deviation of the second area Δf_2, and tie-line power of the closed loop system are shown in Figs. 3–5. Remarkably, the response with conventional PI controller is suffered from high settling time and undesirable oscillations. Also compared with GA the proposed method is indeed more efficient in improving the damping characteristic of power system. Stability of the system is maintained and power system oscillations are effectively suppressed with the application of the proposed controller.

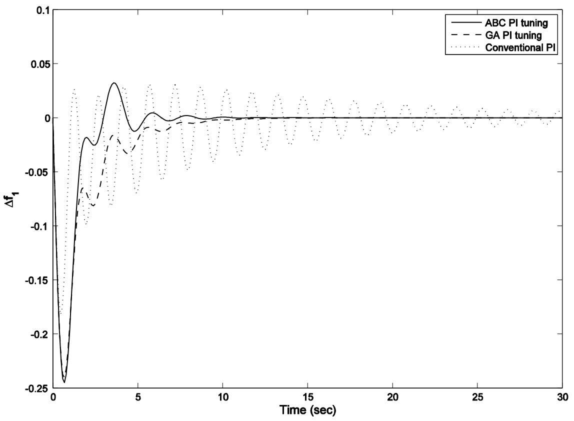

Figure 3 Change in f_1 for 0.1p.u step increment in P_{D1}.

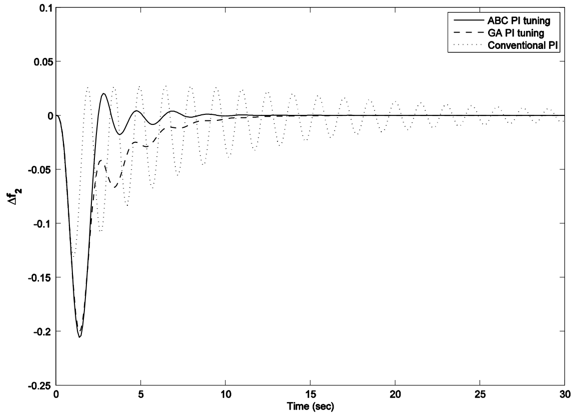

Figure 4 Change in f_2 for 0.1p.u step increment in P_{D1}.

B. *Step increase in demand of the second area (ΔP_{D2})*

In this case, the system undergoes a 10% step increase in demand of the second area (ΔP_{D2}) as the second test point. The frequency deviation of the first area Δf_1, the frequency deviation of the second area Δf_2 and tie power of the closed loop system are shown in Figs. 6–8. From these Figs. it can be seen that oscillations are sustained in the absence of the proposed controller. Moreover, the proposed method outperforms and outlasts GA in damping oscillations effectively and reducing settling time. Hence compared to the conventional controller, and GA based one, PI based ABC greatly enhances the system stability and improves the damping characteristics of power system

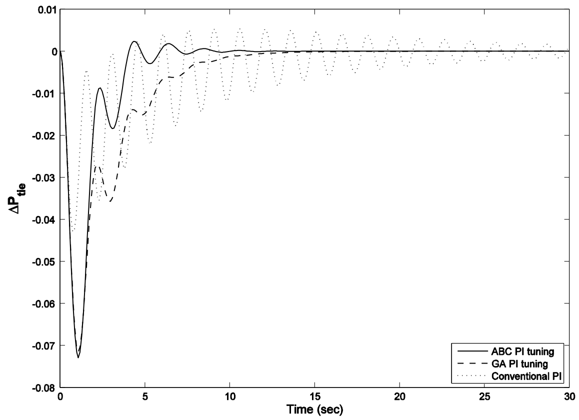

Figure 5 Change in P_{tie} for 0.1p.u step increment in P_{D1}.

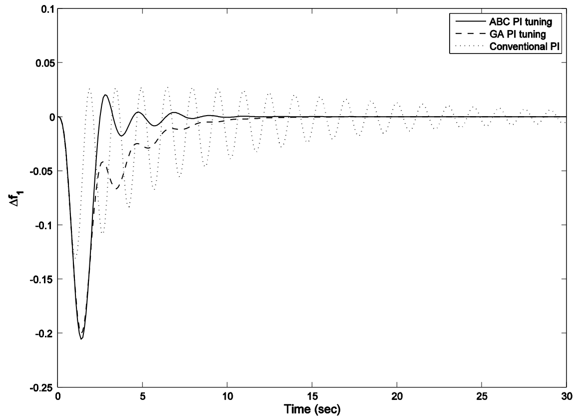

Figure 6 Change in f_1 for 0.1p.u step increment in P_{D2}.

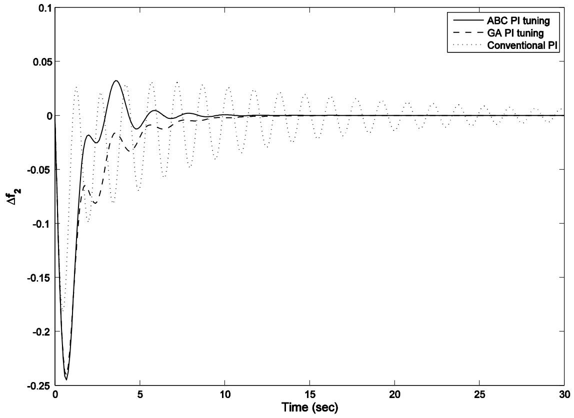

Figure 7 Change in f_2 for 0.1p.u step increment in P_{D2}.

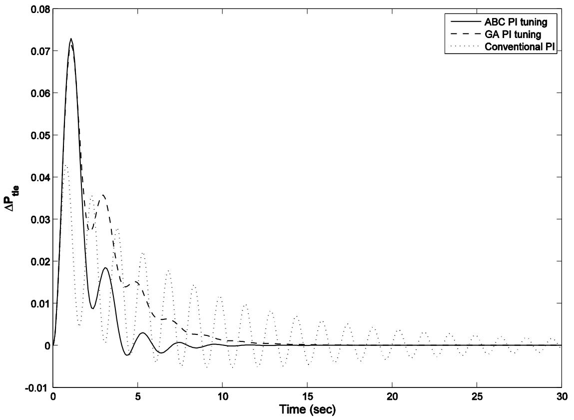

Figure 8 Change in P_{tie} for 0.1p.u step increment in P_{D2}.

C. Step increase in demand of the first and second area simultaneously

In this case, a 0.1 step increase in demand of the first area (ΔP_{D1}) and second area (ΔP_{D2}) are simultaneously applied as test point 3. The deviation in the frequency of Area 1 is shown in Fig. 9. Noticeably the ABC-based design outperforms the conventional one. Further, compared with GA the proposed method has a smaller settling time and system response is quickly driven back to zero. In addition, the potential and superiority of the proposed method over the conventional, and GA is demonstrated.

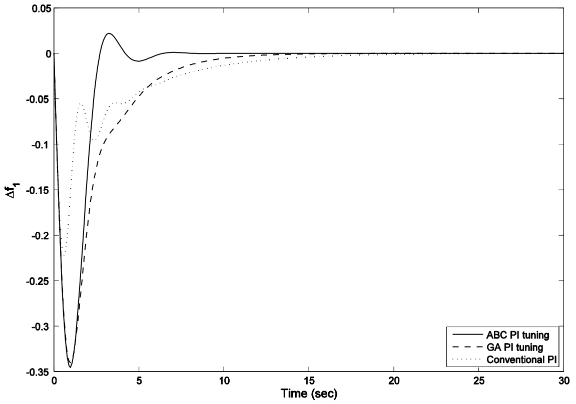

Figure 9 Change in f_1 for 0.1p.u step increment in P_{D1} and P_{D2}.

D. Parameter variation

A parameter variation test is also applied to assess the robustness of the proposed controller. Fig. 10 shows the response of frequency of first area with variation in T_{12}. Obviously, the proposed controller can ensure the system stability under parameter uncertainties, i.e. ABC-based design guarantees robustness.

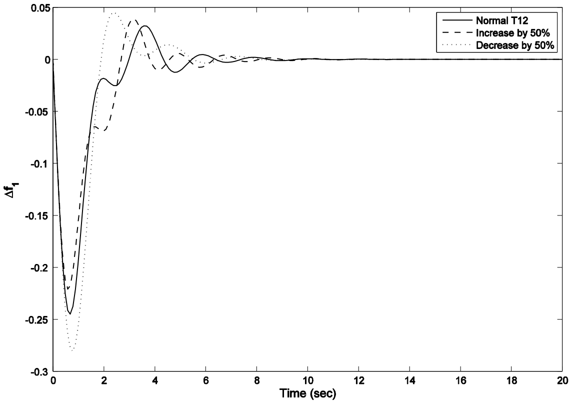

Figure 10 Change in f_1 due to ±50% perturbation in T_{12}.

VI. CONCLUSION

This paper presents the application of the ABC algorithm as a new artificial intelligence technique in order to optimize the AGC in a two-area interconnected power system. ABC algorithm is proposed to tune the parameters of PI controller. A two-area power system is considered to demonstrate the proposed method. An integral time absolute error of the frequency deviation of both areas and tie line power is taken as the objective function to improve the system response in terms of the settling time and overshoots. Simulation results emphasis that the designed ABC-based PI controller is robust in its operation and gives a superb damping performance for frequency and tie line power deviation compared to conventional PI controller, and GA tuning PI controller. Besides the simple architecture of the proposed controller it has the potentiality of implementation in real time environment.

APPENDIX

The typical values of parameters of system under study are given below: $T_{P1} = T_{P2} = 20$ s; $T_{T1} = T_{T2} = 0.3$ s; $T_{12} = 0.545$ p.u; $T_{G1} = T_{G2} = 0.08$ s; $K_{P1} = K_{P2} = 120$ Hz/p.u MW; $a_{12} = -1$; $R_1 = R_2 = 2.4$ Hz/p.u MW; $B_1 = B_2 = 0.425$ p.u MW/Hz.

Artificial Bee Colony Parameters: Number of Employed Bees+ Number of Onlooker Bees=10; Error goal in order to terminate the algorithm=$1e^{-20}$; Control parameter in order to abandon the food source limit =150;

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