

# Design of Multi-stage Fuzzy PID Bundled Artificial Bee Colony for Multi-machine PSS

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## ABSTRACT

This paper presents a new strategy based on Multi-stage Fuzzy (MSF) PID controller based on Artificial Bee Colony (ABC) for damping Power System Stabilizer (PSS) in multi-machine environment. The recent studies in artificial intelligence demonstrated that the ABC optimization is strong intelligent method in complicated stability problems. Also, finding the parameters of PID controller in power system has direct effect for damping oscillation. Thus, to reduce the design effort and find a better fuzzy system control, the parameters of proposed controller is obtained by ABC that leads to design controller with simple structure that is easy to implement. The effectiveness of the proposed technique is applied to Single machine connected to Infinite Bus (SMIB) and IEEE 3-9 bus power system. The proposed technique is compared with other techniques through ITAE and FD

## Keywords;

Multi-stage PID, ABC, Power System Stabilizer

## 1. Introduction

The Power System Stabilizer (PSS) controller design, technique of composing the PSS with the excitation controller (AVR), research of several different input signals and the vast field of tuning methodologies are all part of the PSS topic [1]. The action of a PSS is to extend the angular stability limits of a power system by providing supplemental damping to the oscillation of synchronous machine rotors through the generator excitation. This settlement is provided by an electric torque applied to the rotor that is in phase with the speed variation [2, 3]. In the recent years, a large number of research papers have been appeared in the area of PSS. Also they directed towards obtaining such a PSS that can provide an optimal performance for a wide range of machine and system parameters [4]. Currently, many literatures used Conventional PSS (CPSS) to damped low frequency oscillations [2]. However, these controllers don't have appropriate revenue in different load conditions.

Consequently, a lot of intelligent methods have been introduced to optimal tuning of the PSSs parameters [5].

For this purpose the intelligent techniques has been proposed to solve the mentioned problem. Accordingly, in industry, Proportional Integral (PI) controllers have been broadly used for decades as the load frequency controllers. Actually, several techniques have been proposed to design PI controller [5], where the controller parameters of the PI controller are tuned using trial-and-error approach. However, it gives poor performance in the system transient response. Moreover, a Proportional Integral Derivative (PID) method is one of the techniques that used to improve the performance of the fuzzy PI controller [6]. But, it is clear that the mentioned technique needs three dimensional rule base which leads to difficult design process.

To overcome the mentioned backwards the Multi-stage fuzzy PID is proposed in this paper to solve the stability problem in multi machine power system. Actually, the proposed technique has two dimensional rules. And this method needs fewer resources to operate. In fact, best designs of the fuzzy controllers are depended to choosing appropriate membership function, rule bases inference mechanism and the defuzzification [7-8]. In these factors, exact tuning of membership function is really important to proposed controller reflex. Maybe, the tuning of the membership function by human experts is appropriate; however experts may not be available. For this purpose the intelligent techniques are proposed to find the mentioned factor.

In this paper Artificial Bee Colony (ABC) is proposed to solve the backwashes of mentioned problem. The effectiveness of the proposed technique is applied on Single-machine Infinite Bus System (SMIB) and 3 machine 9 bus IEEE standard power system in comparison of GA-PSS and CPSS [9] in first case study and PSOPSS and CPSS [9] in 3-9 bus test system through Integral of the Time multiplied Absolute value of the Error (ITAE) and the Figure of Demerit (FD) performance indices [10].

## 2. Power System Model

The complex nonlinear model related to multi-machine interconnected power system, can be described by a set of differential-algebraic equations by assembling the models for each generator, load, and other devices such as controls in the system, and connecting them appropriately via the network algebraic equations. Fig. 1 shows the main model of power system with location of controller [10].

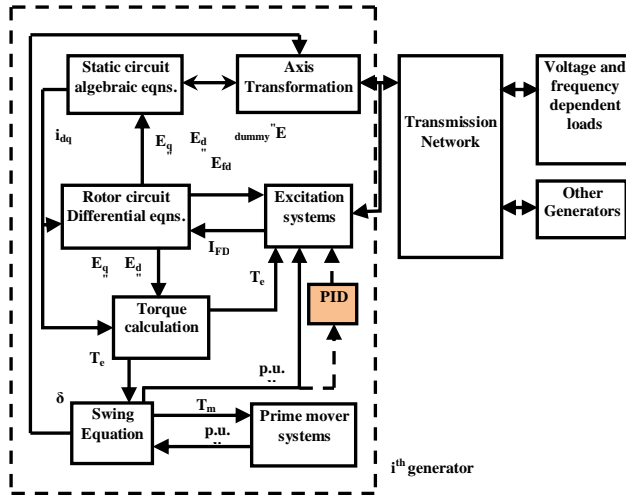


Figure 1. Structure of PSS in power systems

### A. Single-machine Infinite Bus System

The Single-machine Infinite Bus system considered for small-signal performance study which is shown in Fig. 2.

The generator is represented by the third-order model comprising of the electromechanical swing equation and the generator internal voltage equation [11-12]. The swing equations of this system are:

$$\begin{aligned} \dot{\delta} &= \omega_b (\omega - 1) \\ \dot{\omega} &= \frac{1}{M} (P_m - P_e - D(\omega - 1)) \end{aligned}$$

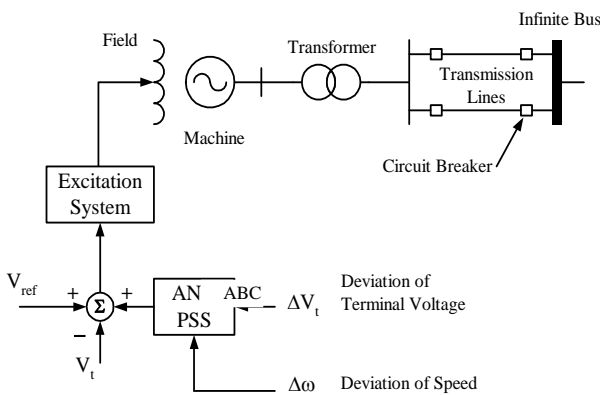


Figure 2. Schematic diagram of single machine infinite bus system

### B. 3-9 bus IEEE Power System

The proposed approach is extended to a multi-machine power system as a second case study. The widely used Western Systems Coordinating Council (WSCC) 3-machine, 9-bus system shown in Fig. 3 is considered. The simplified IEEE type-ST1A static excitation system has been considered for all three generators [13]. Also, the proposed controller is connected to all of the generators. The system data are given in [9].

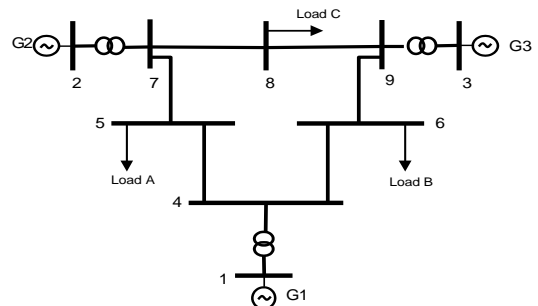


Figure 3. Three-machine nine-bus power system

### C. Multi-stage Fuzzy Controller

According to the backwards of the classic PID, this paper proposed the multi-stage fuzzy controller for LFC problem. In this controller, input values are converted to truth value vectors and applied to their respective rule base. It is clear that the output truth value vectors are not defuzzified to crisp values as with a single stage fuzzy logic controller however are passed on to the next stage as a truth value vector input.

In this structure, the membership function is defined as triangular partitions with seven segments from -1 to 1 as shown in Fig. 4. Zero (ZO) is the center membership function. For the remaining parts of the partition it can describe as: Negative Big (NB), Negative Medium (NM), Negative Small (NS), Positive Small (PS), Positive Medium (PM) and Positive Big (PB). Also in this controller there are two rule bases. The first one is the PD rule base as it operates on truth vectors from the error (e) and change in error (e) inputs. And the second one is PID switch rule base while, if the PD input is in the zero fuzzy set, the PID switch rule base passes the integral error values (Ie) that are presented in [14]. The truth value vectors are indicated in Fig. 5, by darkened lines [14-15].

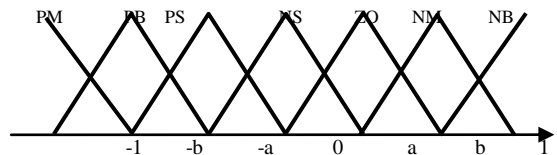


Figure 4. Symmetric fuzzy partition

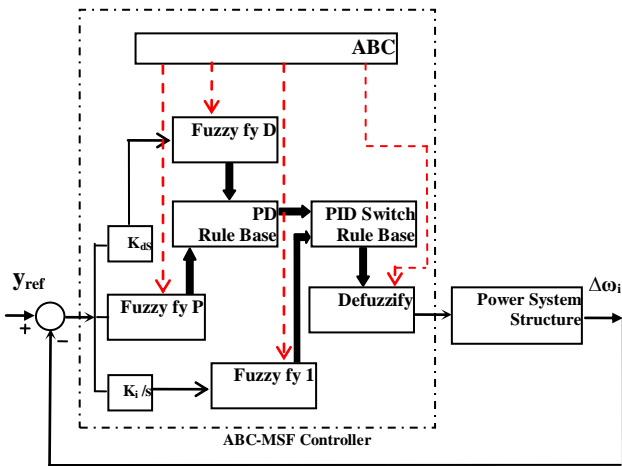


Figure 5. Structure of the proposed controller

### 3. Artificial Bee Colony

Intelligence artificial optimization techniques are receiving great interests these days. Honey bee colony structure is taking the spotlight in the field of function optimization. In this research our attention centres on the food foraging behaviour of honey bees. A behavioural model of self-organization is proposed for a colony of honey bees by Seeley (1995). Foraging bees visiting flower patches come back to the hive with nectar as well as a profitability rating of respective patches in the behavioural model. Recently, Karaboga and Basturk [16] have described an Artificial Bee Colony (ABC) algorithm based on the foraging behaviour of the honey-bees for numerical optimization problems. The algorithm resembles the intelligent foraging behaviour of the honey bee swarms. It is a very easy, robust and population based stochastic optimization algorithm [17].

All bees that are currently exploiting a food source are known as employed. The employed bees operate the food source (NFS) and they carry the information about food source back to the hive and share this information with onlooker bees. Onlookers bees are expecting in the hive for the information to be shared by the employed bees about their discovered food sources and scouts bees will always be searching for new food sources near the hive. Employed bees contribution information about food sources by dancing in the designated dance area inside the hive. The temperament of dance is proportional to the nectar content of food source just exploited by the dancing bee. Onlooker bees look the dance and choose a food source according to the probability proportional to the quality of that food source. Therefore, well food sources attract more onlooker bees compared to bad ones. Whenever a food source is abused fully, all the employed bees related with it abandon the food source, and become scout. Scout bees are able to visualize as performing the job of exploration, whereas employed and onlooker bees can be visualized as performing the job of exploitation [18].

In the ABC algorithm, the number of employed bees is equal to the number of food sources which is also equal to the number of onlooker bees. There is only one employed bee for each food source whose first position is randomly generated. Each employed bee, at each iteration of the algorithm determines a new neighboring food source of its currently associated food source by “Eq. (3)”, and computes the nectar

amount of this new food source:

$$v_{ij} = z_{ij} + \theta_{ij} (z_{ij} - z_{kj}) \quad (3)$$

Where,  $k \in \{1, 2, \dots, BN\}$  and  $j \in \{1, 2, \dots, D\}$  are randomly chosen indexes. Although  $k$  is choosing randomly, it has to be different from  $i$ .  $\theta_{ij}$  is a random number among  $[-1, 1]$ . It controls the production of a neighbor food source position around  $z_{ij}$  and the modification represents the comparison of the neighbor food positions visually by the bee. “Eq. (6)” shows that as the discrepancy between the parameters of the  $z_{ij}$  and  $z_{kj}$  decreases, the perturbation on the position  $z_{ij}$  decreases, too. If the nectar amount of this new food source is higher than that of its currently associated food source, then this employed bee goes to this new food source, otherwise it maintains with the old one [19]. After all employed bees complete the search process; they share the information about their food sources with onlooker bees. An onlooker bee calculates the nectar information taken from all employed bees and chooses a food source with a probability related to its nectar amount by “Eq. (4)”. This method, known as roulette wheel selection method, supply better candidates to have a greater chance of being selected:

$$p_i = fit_i / (\sum_{n=1}^{SN} fit_n) \quad (4)$$

Where  $fit_i$  is the fitness value of the solution  $i$  which is proportional to the nectar amount of the food source in the position  $i$  and  $SN$  is the number of food sources which is equal to the number of employed bees. Figure 6 presents the flowchart of the proposed technique [16-19]. The pseudo code for ABC algorithm looks as follows:

- Initialize
- Repeat.
- Move the employed bees onto their food source and evaluate the fitness
- Move the onlookers onto the food source and evaluate their fitness
- Move the scouts for searching new food source
- Memorize the best food source found so far
- Until (termination criteria satisfied)

### 4. Simulation Results

In this paper the considered performance indices are; Time multiplied Absolute value of the Error (ITAE) and the Figure of Demerit (FD). Where are described in literature as:

$$ITAE_i = 100 \int_0^{10} t(|\Delta\omega_i|) dt \quad (5)$$

$$FD = (OS \times 10^{-4})^2 + (US \times 10^{-4})^2 + T_s^2 \quad (6)$$

#### A. SMIB

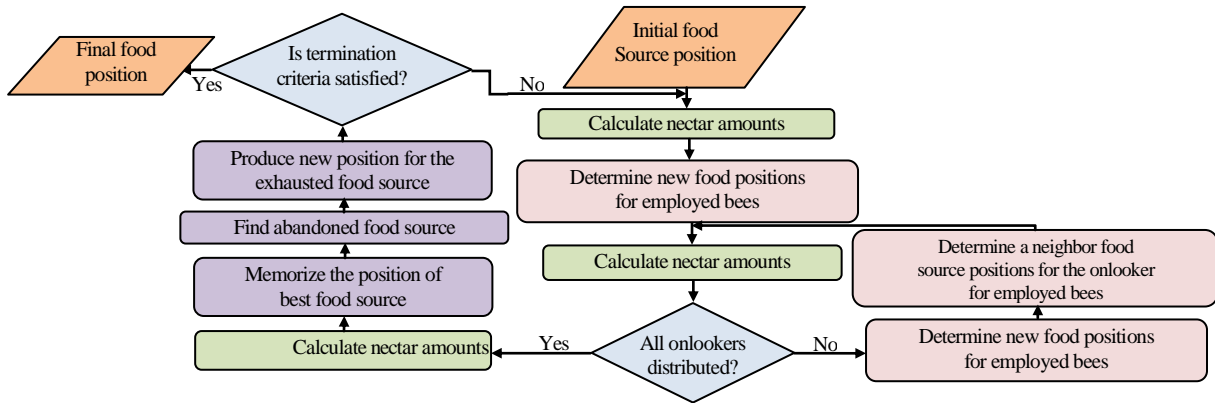
For this case study the fitness function trend of proposed technique is presented in Fig. 7. This case is compared with GAPSS and Classic PSS (CPSS) [9]. Accordingly, Fig. 8, shows the response of system against 6-cycle three-phase fault in different load condition as a first scenario. The results of the second scenario are presented in numerical results for 0.2 p.u. step increasing in mechanical torque. Also, the optimum parameters for case studies achieved by ABC are presented in Table. 1-2.

**TABLE 1. OPTIMUM PID CONTROLLER PARAMETERS IN CASE 1**

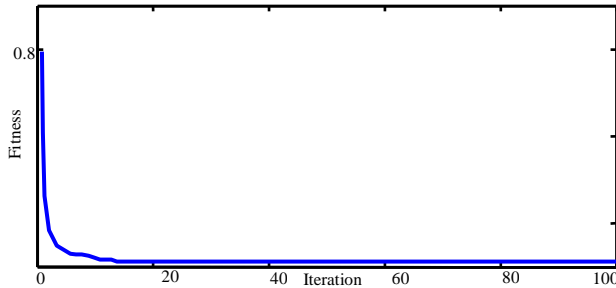
Membership Function	$\omega_i$	$\Delta\omega_i$	$\int\omega$	Output
ABC Results	a	0.22	0.0431	0.04
	b	0.14	0.18	0.3

**TABLE 2. OPTIMUM PID CONTROLLER PARAMETERS IN CASE 2**

Membership Function	$\omega_i$	$\Delta\omega_i$	$\int\omega$	Output
ABC Results	a	0.35	0.0723	0.06
	b	0.27	0.23	0.4



**Figure 6. The flowchart of artificial bee colony**

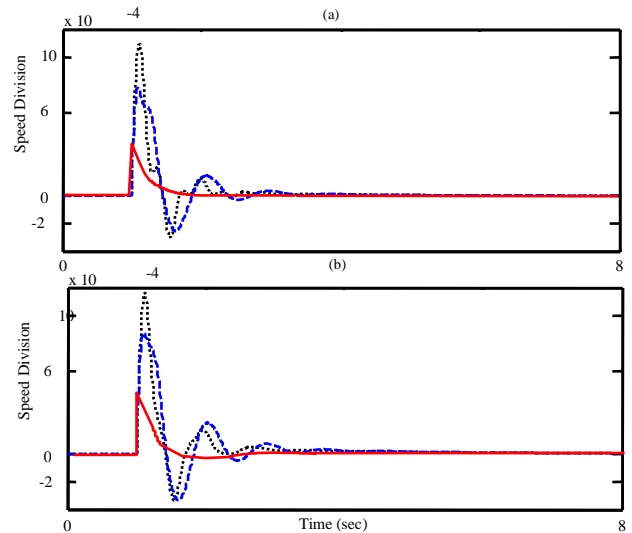


**Figure 7. Optimal trend of fitness function evaluation**

**B. 3-9 bus IEEE Power System**

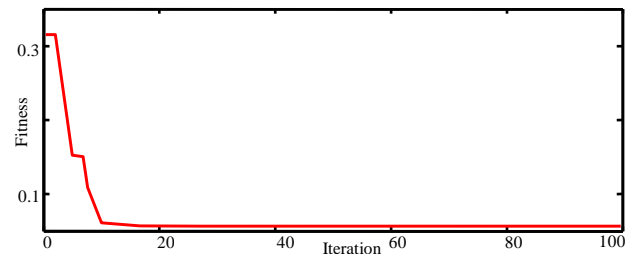
The convergence of the proposed technique over second case study is shown in Fig. 9. Actually, the performance of the proposed controller under transient conditions is verified by applying a 6-cycle three-phase fault at  $t=1$  sec, on bus 7 at the end of the line 5-7. The fault is cleared by permanent tripping the faulted line. The speed deviation of machines under the nominal loading conditions is shown in Fig. 10. This case study is compared with PSOPSS and CPSS [9].

According to the numerical results, it can be seen that the values of these system performance characteristics with the proposed controller are much smaller to other compared techniques. This demonstrates that the overshoot, undershoot settling time and speed deviations of all machines are greatly reduced by applying the proposed algorithm based fuzzy PSSs. The numerical results of ITAE and FD are listed in Table 3-4.



**Figure 8. System response by applying a 6-cycle three-phase fault at  $t=1$ : Solid (MSF-ABC-PSS), Dashed (GA-PSS) Doted (CPSS).**

a : $P=0.8, Q=0.4, X_e=0.3$  b:  $P=0.5, Q=0.1, X_e=0.3$



**Figure 9. Optimal trend of fitness function evaluation**

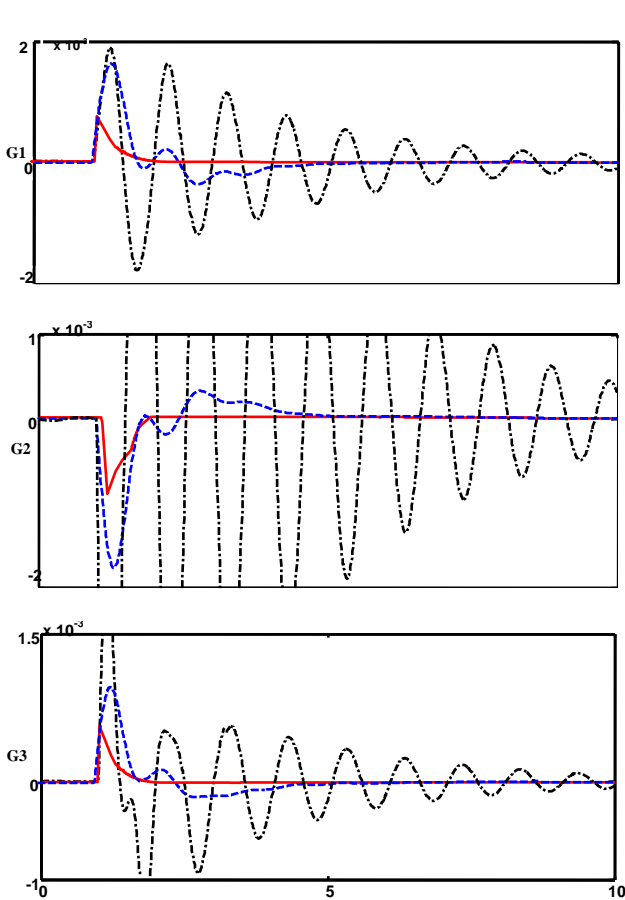


Figure 10. System response under scenario 1 with heavy loading condition: Solid (MSF-ABC-PSS) Dashed (PSOPSS) Dotted (CPSS).

For more testing, a 0.2 p.u. step increase in mechanical torque was applied at  $t=1.0$  as a second scenario. The results of system response are presented in Fig. 11.

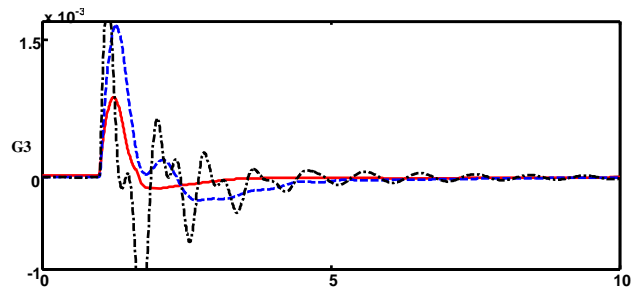
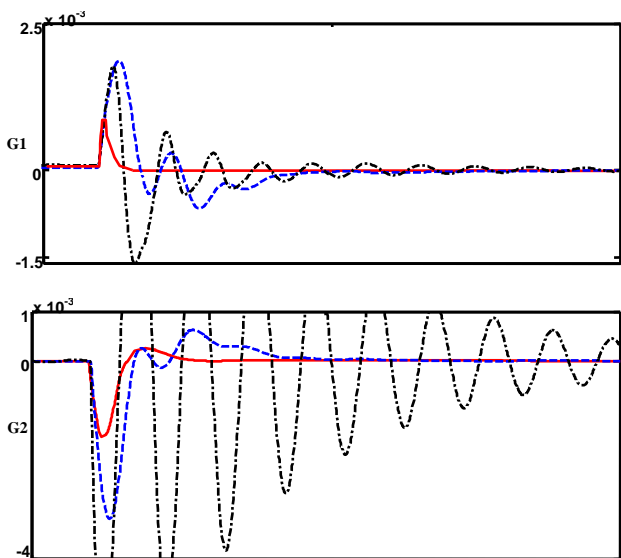


Figure 11. System response under scenario 2 with nominal loading condition: Solid (MSF-ABC-PSS) Dashed (PSOPSS) Dotted (CPSS).

TABLE 3. VALUE OF ITAE IN DIFFERENT TECHNIQUES

Method	Scenario 1			Scenario 2		
	Nominal	Light	Heavy	Nominal	Light	Heavy
MSF-ABC-PSS	0.33	0.32	0.36	0.30	0.31	0.34
GA-FPSS	0.76	0.73	0.84	0.73	0.70	0.79
CPSS	37.1	36.7	38.5	36.03	36	37.4

TABLE 4. VALUE OF FD IN DIFFERENT TECHNIQUES

Method	Scenario 1			Scenario 2		
	Nominal	Light	Heavy	Nominal	Light	Heavy
MSF-ABC-PSS	1.14	1.26	1.34	1.07	1.28	1.38
PSO-PSS	2.45	2.86	3.04	2.36	2.64	2.71
CPSS	55.4	58.6	60.4	54.1	55.4	57.7

### 5. CONCLUSION

In this paper, a new multi-stage fuzzy controller is proposed to solve the power system stabilizer problem to provide the stability of the power system in low frequency oscillation problem in multi machine. The presented controller is optimized by Artificial Bee Colony (ABC). The ABC algorithm is a search algorithm that is inspired by the intelligent foraging behavior of a honey bee swarm process and has emerged as a useful tool for engineering optimization. It incorporates a flexible and well-balanced mechanism to adapt to the global and local exploration and exploitation abilities within a short computation time. Hence, this method is efficient in handling large and complex search spaces. This control strategy was chosen because of the increasing complexity and changing structure of the power systems. Actually, the proposed technique has two dimensional rules. And this method needs fewer resources to operate. Actually, exact tuning of membership function is really important to proposed controller. For this purpose the ABC is used which is based on natural selection. The effectiveness of the proposed technique is tested over two case studies as SMIB and 3-9 bus IEEE power systems. The results are compared with Genetic Algorithm, Particle Swarm Optimization and Classic controllers through ITAE and FD. Simulation results show the effectiveness of the proposed controller strategy based on ABC which can work effectively

over a wide range of the loading conditions and is superior to other compared methods.

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