ELEKTROTEHNIŠKI VESTNIK 85(1-2): 42-48, 2018
ORIGINAL SCIENTIFIC PAPER

Enhancement The Dynamic Stability of The Iraq's Power Station Using PID Controller Optimized by FA and PSO Based on Different Objective Functions

Ghassan Abdullah Salman, Husham Idan Hussein, Mohammed Saadi Hasan

Department of Electrical Power and Machines Engineering, Diyala University, Diyala, Iraq.
E-mail: hishamhussein40@gmail.com

Abstract. The paper demonstrates how to improve the dynamic stability of a synchronous generator in combination with on excitation system by utilizing a Proportional Integral Derivate (PID) controller. It presents two methods of determining optimal the PID parameters to improve the power angle and terminal voltage of a synchronous generator: i.e. the Firefly Algorithm (FA) and Particle Swarm Optimization (PSO). These methods are used to determine the optimal PID controller parameters required to minimize various performance indices as objective functions. Two objective functions are considered for optimization: the Integral Absolute Error (IAE) and the Integral Error (ISE). The results obtained from conventional PID, FA-PID and PSO-PID, it shows that the FA-PID performed better than the conventional PID and PSO-PID. The result analysis demonstrates that FA-IAE better and more efficient by tune the PID parameters than FA-ISE, PSO-IAE and PSO-ISE.

Keywords: dynamic stability; excitation system; Firefly Algorithm (FA); PID controller; Particle Swarm Optimization (PSO); objective functions

Izboljšava dinamične stabilnosti sinhronskega generatorja z uporabo krmilnika PID in optimizacijskih metod FA in PSO

V prispevku smo predstavili izboljšanje dinamične stabilnosti sinhronskega generatorja v kombinaciji z vzbujevalnim sistemom z uporabo krmilnika PID. Uporabili smo algoritem obnašanja kresnic (FA) in optimizacije rojev delcev (PSO) pri določitvi optimalnih parametrov krmilnika PID za izboljšanje kota moči in priključne napetosti sinhronskega generatorja. Z obema algoritmoma smo določili optimalne parametre PID za minimizacijo različnih indeksov zmogljivosti. Za optimizacijo smo uporabili dve kriterijski funkciji. Eksperimentalno smo potrdili, da z algoritmom FA-PID dobimo boljše rezultate kot z algoritmom FA-PSO in konvencionalnim krmilnikom PID.

1 INTRODUCTION

The study of the dynamic stability of modern power systems is one of the most important challenges. The power system control is to maintain a reliable and quality supply power. The power system is stable when there is a balance between the power demand and the power generated [1, 2]. The constants needed to coordinate the operation between of synchronous generator connected to infinite bus bar and on excitation system were developed by [3] and then by [4].

Power system problems are still solved by utilizing the PID type controller. In optimal PID tuning gains is required, under different operating states, to get the desired level of robust performance. For on optimal PID tuning, a Particle Swarm Optimizer (PSO) is used in [5, 6]. In [7, 8] using the Firefly Algorithm (FA), the optimal PID tuning is implemented.

In the paper we present results of our study of the dynamic stability of a synchronous generator combined with an excitation system and utilization of FA and PSO for tuning the PID parameters to minimize two different objective functions, i.e. the Integral Absolute Error (IAE) and the Integral Square Error (ISE).

2 MODELING OF A SYNCHRONOUS GENERATOR COMBINED WITH ON EXCITATION SYSTEM

In [3] and [4], the coupling effects of the synchronous generator and the excitation system are described. The dynamic stability of the Iraqi Derbindikhan power plant combined with an AVR system is studied. Figure 1 shows the transfer function model of a synchronous generator coupled with an AVR system. The relevant parameters are presented in Table 1. According to [9, 10], the following equations are used for coupling:

$$\Delta T_e = K_1 \Delta\delta + K_2 \Delta E_q' \quad (1)$$

$$\Delta E_q' = \frac{K_3}{1+K_3 T_{do}' s} \Delta E_{FD} - \frac{K_3 K_4}{1+K_3 T_{do}' s} \Delta\delta \quad (2)$$

$$\Delta V_t = K_5 \Delta\delta + K_6 \Delta E_q' \quad (3)$$

Received 29 August 2017
Accepted 13 January 2018

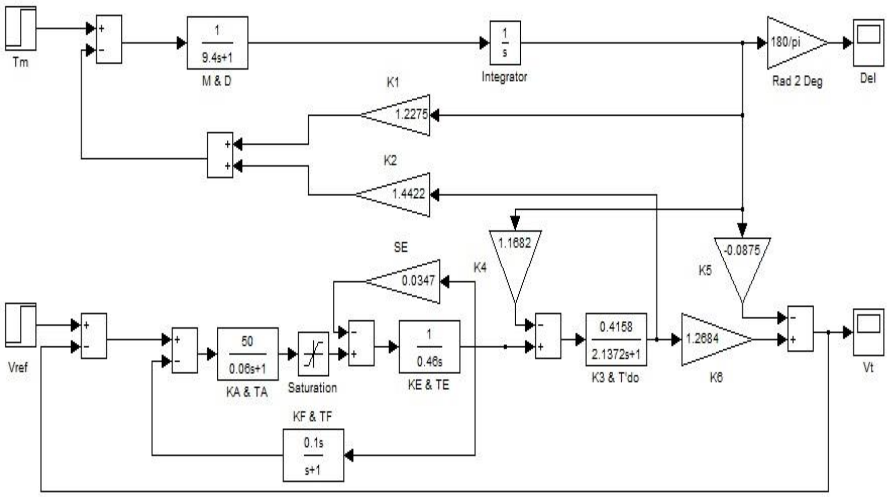

Figure 1. MATLAB/Simulink model of the Generator and AVR system.

Table 1. Parameters of the synchronous generator and AVR system.

Parameters of the synchronous generator	Parameters of the AVR system
$R_e = 0.00407$	$K_A = 50$
$X_e = 0.2037$	$T_A = 0.06$
$X_d = 1.2$	$K_E = 1$
$X_q = 0.69$	$T_E = 0.46$
$X_d^{'} = 0.38$	$K_F = 0.1$
$T_{dO}^{'} = 5.14$	$T_F = 1$
$T_m = 1.059$	$S_{E1} = 0.0039$
$M = 9.4$	$S_{E2} = 1.555$
$D = 1$	$V_{ref} = 1.0282$

Constants K_1 - K_6 are calculated using the following equations:

$$K_1 = \frac{V_\infty I_q(X_q - X_d^{'})}{R_e^2 + (X_e + X_q)(X_e + X_d^{'})}\left[(X_e + X_q)\sin\delta - R_e\cos\delta\right] + \frac{V_\infty I_d(X_q - X_d^{'})}{R_e^2 + (X_e + X_q)(X_e + X_d^{'})}\left[(X_e + X_d^{'})\cos\delta + R_e\sin\delta\right] + \frac{V_\infty E_q^{'}}{R_e^2 + (X_e + X_q)(X_e + X_d^{'})}\left[(X_e + X_d^{'})\cos\delta + R_e\sin\delta\right] \quad (4)$$

$$K_2 = \frac{1}{R_e^2 + (X_e + X_q)(X_e + X_d^{'})}\left[I_q\left(R_e^2 + (X_e + X_q)^2\right) + I_d R_e(X_q - X_d^{'}) + E_q^{'} R_e\right] \quad (5)$$

$$K_3 = \frac{R_e^2 + (X_e + X_q)(X_e + X_d^{'})}{R_e^2 + (X_e + X_q)(X_e + X_d)} \quad (6)$$

$$K_4 = \frac{V_\infty(X_d - X_d^{'})}{R_e^2 + (X_e + X_q)(X_e + X_d^{'})}\left[(X_e + X_q)\sin\delta - R_e\cos\delta\right] \quad (7)$$

$$K_5 = \frac{V_\infty V_d X_q}{V_t[R_e^2 + (X_e + X_q)(X_e + X_d^{'})]}\left[(X_e + X_d^{'})\cos\delta + R_e\sin\delta\right] - \frac{V_\infty V_q X_d^{'}}{V_t[R_e^2 + (X_e + X_q)(X_e + X_d^{'})]}\left[(X_e + X_q)\sin\delta - R_e\cos\delta\right] \quad (8)$$

$$K_6 = \frac{1}{V_t[R_e^2 + (X_e + X_q)(X_e + X_d^{'})]}\left[V_d X_q R_e + V_q\left(R_e^2 + X_e(X_e + X_q)\right)\right] \quad (9)$$

3 MODELING OF THE PID CONTROLLER

Due to its uncomplicated and simple implementation, the PID controller is one of the most successful efficient and widely used control instrument in the industry. Based on [8, 11], Figure 2 shows a typical structure of the conventional PID controller.

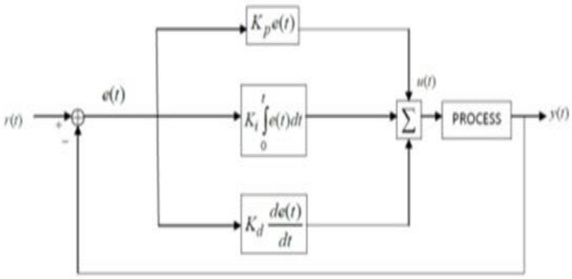

Figure 2. Block diagram of the PID controller.

The transfer function of the PID controller described with regard to the Laplace domain is:

$$G_{PID}(s) = \frac{U(s)}{E(s)} = k_p + \frac{k_i}{s} + k_d s \quad (10)$$

where $U(s)$ is the control signal and $E(s)$ is the error signal. These are the difference between the input and feedback. k_p is the proportional gain, k_i is the integration gain and k_d is the derivative gain.

The output of the PID controller in terms of the time domain is:

$$u(t) = k_p e(t) + k_i \int_0^t e(t)dt + k_d \frac{de(t)}{dt} \quad (11)$$

where u(t) is the control error signal and e(t) is the tracking error signal; both are in the form of the time domain.

The effect of the IAE and ISE objective functions on optimization parameter is studied. The IAE and ISE functions are defined as:

$$\mathrm{IAE} = \int_0^t [|e_1(t)| + |e_2(t)|]\,dt \quad (12)$$

$$\mathrm{ISE} = \int_0^t [(e_1)^2(t) + (e_2)^2(t)]\,dt \quad (13)$$

The optimization functions IAE and ISE are minimized and subjected to:

$$k_p^{min} \le k_p \le k_p^{max},\; k_i^{min} \le k_i \le k_i^{max} \text{ and } k_d^{min} \le k_d \le k_d^{max} \quad (14)$$

4 OPTIMIZATION TECHNIQUES

Our main objective is to control the power angle and terminal voltage of the Derbindikhan power plant by using modern heuristic techniques which play an important role in controlling the power system performance. Conventional by the first step is to tune the controller parameters which is, unfortunately, not applicable in practical systems. As a result, powerful mathematical optimization methods are used for PID parameters tuning. The most reliable ones, i.e. PSO and FA, are population-based optimization techniques.

4.1. Firefly Algorithm (FA)

Developed by Xin She Yang in 2007, FA is based on the natural swarming behavior of animals such as schools of fish, swarms of insects and birds. Regarding the social light-flashing ability of fireflies (or lighting bugs) in the skies of tropical regions, FA is a meta-heuristic optimization algorithm inspired by nature [12, 13]. FA has three idealized rules based on some of the main flashing abilities of fireflies. They are:

a. Being unisex, fireflies are drawn to more attractive, brighter, individuals regardless of their sex.
b. The firefly's brightness is directly related to the degree of its attractiveness. The brighter it is the more attractive it is to other fireflies. As its distance from the fireflies increases, its brightness diminishes. This is because the air absorbs its light. If no firefly shines brighter than an individual firefly in the vicinity, it will move about at random.
c. The value of the objective function of a given problem determines the brightness or the intensity of the light a firefly emits. For optimization problems, the value of the objective function is proportional to the intensity of light. The following equations describe implementation of FA:

$$X_i^{new} = X_i^{old} + \beta(X_j - X_i) + \alpha\left(\mathrm{rand} - \frac{1}{2}\right) \quad (15)$$

The firefly movement is represented by equation (15). The first term is the firefly's current position. The second term represents the firefly's attraction to the light intensity. The third term describes the firefly's motion when there are no brighter fireflies. Coefficient α is a randomization parameter determined by the problem of interest while rand is a random number generator uniformly distributed in space [0, 1].

$$\beta = \beta_0 e^{-\gamma r_{ij}^m} \qquad (m \ge 1) \quad (16)$$

where r is the distance between any two fireflies, γ is an absorption coefficient that regulates the decrease of the light intensity β_0 is the initial attractiveness at r = 0.

$$r_{ij} = \|X_i - X_j\| = \sqrt{\sum_{k=1}^{d}(X_{i,k} - X_{j,k})^2} \quad (17)$$

Term $X_{i,k}$ is the kth component of spatial coordinate X_i of the ith firefly; d is the number of dimensions. Figure 3 shows a flowchart of the FA-PID based on the IAE or ISE objective.

4.2. Particle Swarm Optimization (PSO)

Kennedy and Eberhart developed PSO, a modern heuristic algorithm in 1995 [14]. It effectively solves in the PSO method, continuous and nonlinear optimization problems. A swarm made up of individuals called particles is defined by its velocity and position [5, 15].

Every particle in the swarm knows the global best (g_{best}), i.e. the location with the best objective value in the swarm. Each particle at each point along its path, compares the objective value of its personal best (p_{best}) to that of (g_{best}). If a particle has a (p_{best}) that has a superior objective value than the current(g_{best}), the current (g_{best}) is replaced with that particle's (p_{best}). Its movement is halted when all particles approach a position in the swarm with the best objective function. By updating the positions and velocities of particles, the algorithm can search for an optimum solution in a specified search space. The following equation is what each particle utilizes to initialize its positions and velocities:

$$X_i^{k+1} = X_i^k + V_i^{k+1} \quad (18)$$

$$V_i^{k+1} = wV_i^k + c_1 r_1 \left(p_{best\,i}^k - X_i^k\right) + c_2 r_2 \left(g_{best\,i}^k - X_i^k\right) \tag{19}$$

$$w = \frac{maxiter - iter}{maxiter} \tag{20}$$

Where X_i^k is the position of a particle at a k iteration, X_i^{k+1} is the position of a particle at a k+1 iteration, V_i^k is the velocity of a particle at a k iteration, V_i^{k+1} is the velocity of a particle at a k+1 iteration, w is the inertia weight parameter, , r_1 and r_2 are a random number in the interval; c_1 and c_2 are the learning factors [0, 1]. Figure 3 shows a flowchart of PSO-PID based on AIE or ISE objective function.

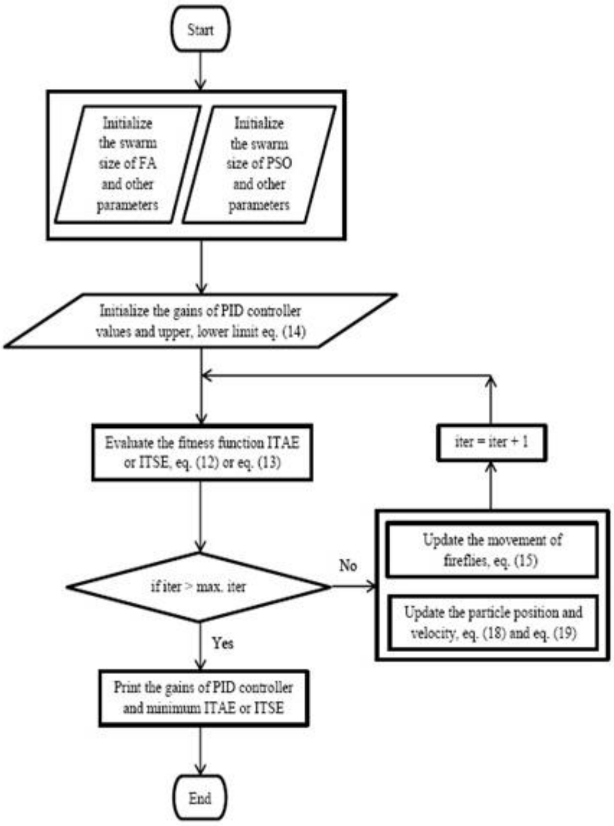

Figure 3. Flowchart of FA or PSO for the PID controller.

5 RESULTS AND DISCUSSION

Figure 4 shows a synchronous generator model connected to an AVR system and implemented with a PID controller in a MATLAB/Simulink. Figure 5 shows the results of a power angle simulation first carried out with and with no PID controller. Figure 6 shows the terminal voltage with and with no PID controller. The values of the PID controller obtained with the conventional method are shown in Table 2. The graphs are shown only for the first 50 seconds for the power angle and for 10 seconds for the terminal voltage though the simulation took 60 seconds. Table 3 shows the maximum peak, setting time, minimum peak and final value for the power angle. Table 4 shows the maximum deviation, peak time, settling time and steady state error for the terminal voltage.

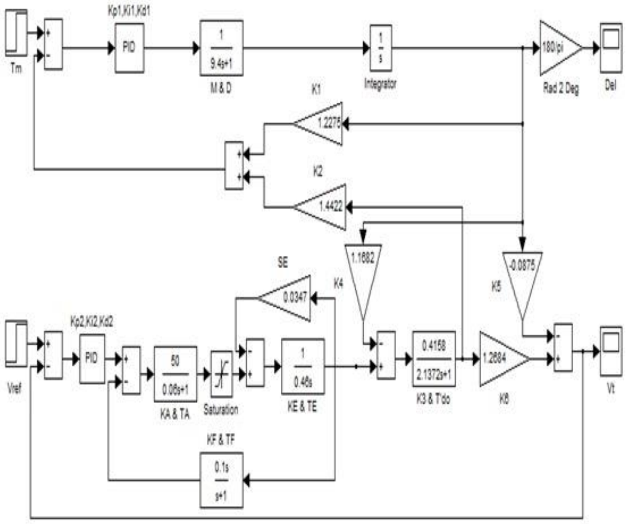

Figure 4. MATLAB/Simulink model of the Generator and AVR system with a PID controller.

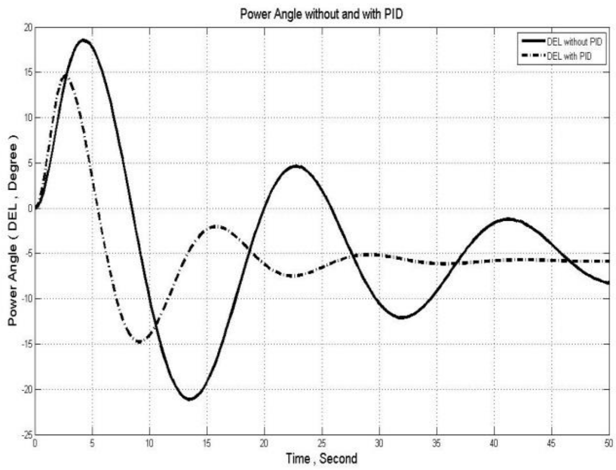

Figure 5. Power angle with and with no PID controller.

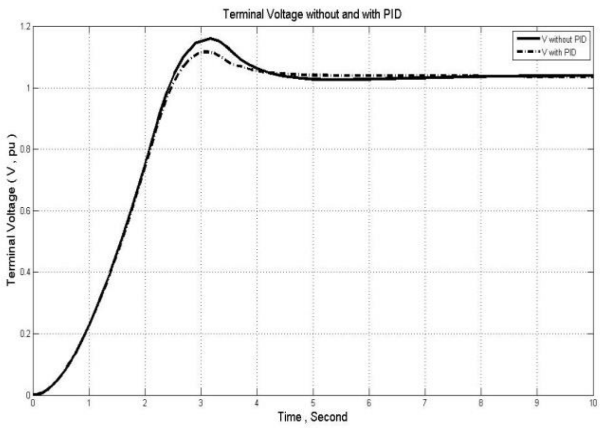

Figure 6. Terminal voltage with and with no PID controller.

Table 2. Values of the PID controller with conventional method.

PID Parameters	Conventional method
K_{p1}	1.9943
K_{i1}	0.0022
K_{d1}	1.3216
K_{p2}	2.3850
K_{i2}	0.0098
K_{d2}	0.5511

Table 3. Power angle characteristics with and with no PID controller.

	With no PID	Conventional PID
Max. peak (Deg.)	18.51	14.85
Min. peak (Deg.)	-21.12	-14.76
Settling time (sec.)	---	31.9
Final value (Deg.)	-8.256	-5.877

Table 4. Terminal voltage characteristics with and with no PID controller.

	With no PID	Conventional PID
Max. deviation (p.u)	1.16	1.117
Peak time (sec.)	3.161	3.135
Settling time (sec.)	4.041	3.934
Steady state error (p.u)	-0.0118	-0.0068

Different algorithms have been implemented for turning the k_p, k_i and k_d gains of the PID controller to improve the performance of the synchronized generator coupled with on AVR system. Three is the upper and zero is the lower limit value of the PID controller. First, the optimal value of the PID controller as an objective function is determined by using the IAE performance index value, i.e. the sum of absolute cumulative errors shown in Figure 7. Second, the ISE performance index, i.e. the sum of the square of cumulative errors, is used to determine optimal values of the PID controller as an objective function shown in Figure 8. To minimize IAE and ISE, FA-IAE, FA-ISE, PSO-IAE and PSO-ISE, i.e. optimized combinations, are used. The optimal PID controller tuning gains for the combinations sets are shown in Table 5.

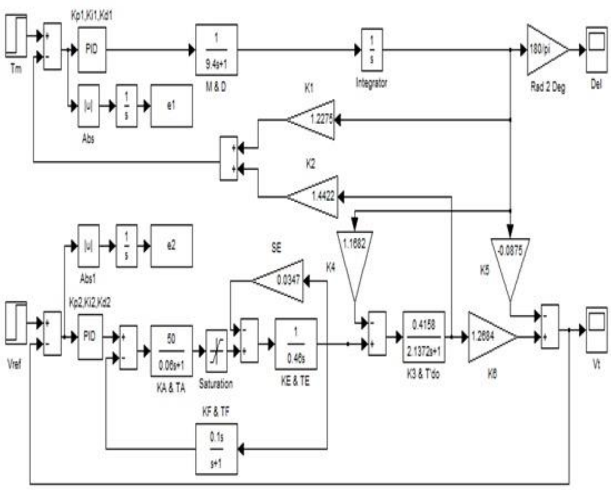

Figure 7. MATLAB/Simulink model of the Generator and AVR system based on IAE.

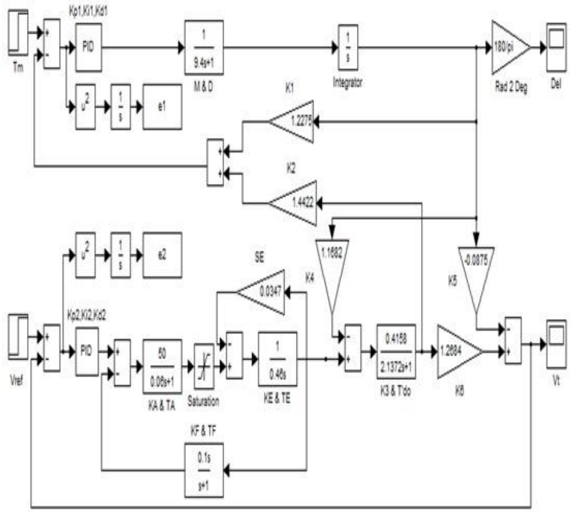

Figure 8. MATLAB/Simulink model of the Generator and AVR system based on ISE.

Table 5. Optimal PID controller gains.

PID Parameters	PSO-IAE	PSO-ISE	FA-IAE	FA-ISE
K_{p1}	2.2894	2.9838	1.8856	2.5527
K_{i1}	0.0751	0.0990	0.0521	0.0661
K_{d1}	2.7298	2.9738	2.4600	2.6150
K_{p2}	2.8285	1.9284	2.6322	1.5893
K_{i2}	0.0118	0.0121	0.0102	0.0086
K_{d2}	0.9310	0.4696	0.9156	0.3834

Figure 9 shows the response of the power angle obtained by using FA and PSO. Figure 10 shows The response of terminal voltage obtained by using FA and PSO. The graphs for the power angle are displayed for the first 50 seconds and 10 seconds for the terminal voltage though the simulation took 60 seconds. The maximum peak, minimum peak, settling time and final value of the power angle are shown in Table 6. The maximum deviation, peak time, settling time and steady state error for the terminal voltage are presented in Table 7.

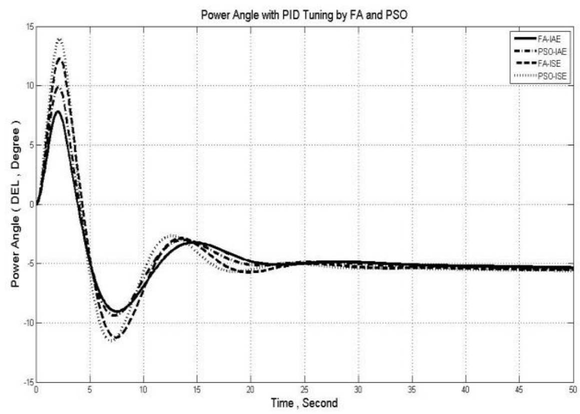

Figure 9. Power angle with PID tuning by FA and PSO.

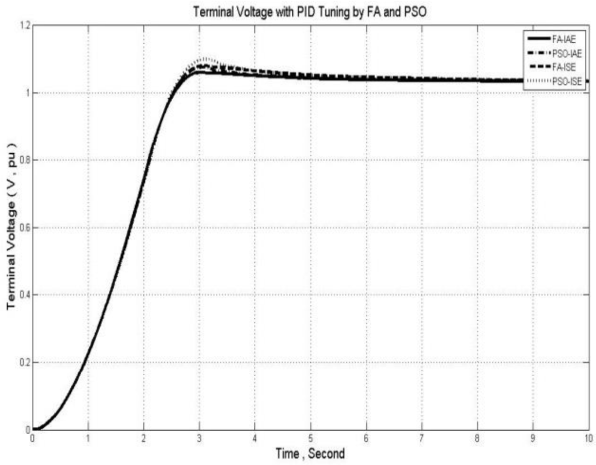

Figure 10. Terminal voltage with PID tuning by FA and PSO.

Table 6. Power angle characteristics with PID tuning by using FA and PSO.

	FA-IAE	FA-ISE	PSO-IAE	PSO-ISE
Max. peak (Deg.)	7.796	12.28	9.884	13.95
Min. peak (Deg.)	-9.062	-11.25	-9.396	-11.54
Settling time (sec.)	28.07	28.17	28.11	28.25
Final value (Deg.)	-5.357	-5.517	-5.454	-5.624

Table 7. Terminal voltage characteristics with PID tuning by using FA and PSO.

	FA-IAE	FA-ISE	PSO-IAE	PSO-ISE
Max. deviation (p.u)	1.06	1.08	1.075	1.099
Peak time (sec.)	3.025	3.064	3.068	3.071
Settling time (sec.)	3.642	3.853	3.767	3.895
Steady state error (p.u)	-0.0049	-0.0056	-0.0051	-0.0064

Figure 11 shows the minimization convergence of the IAE index by using FA and PSO to determine the optimal values of the PID controller. Figure 12 presents the minimization convergence of the ISE index by using FA and PSO to determine the optimal the PID controllers values. The FA-FID controller performed better than the PSO-PID controller as shown by the convergence curves.

The overall characteristics of the power angle and terminal voltage in the above results are reduced by FA and PSO for PID controller tuning. The power system damping characteristics compared to conventional PID controller, are more effectively improved by using FA and PSO for PID controller tuning. The power system oscillations are reduced, and its stability is preserved.

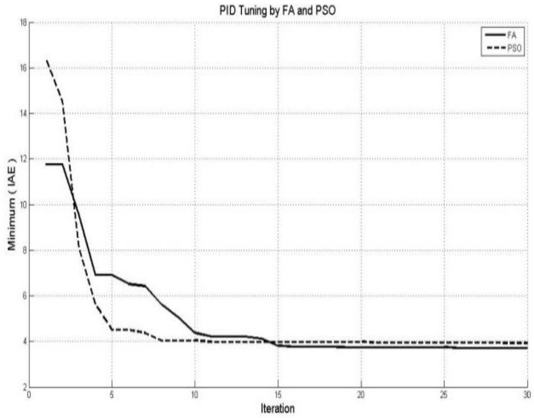

Figure 11. Convergence curve of FA and PSO based on IAE to obtain the PID parameters.

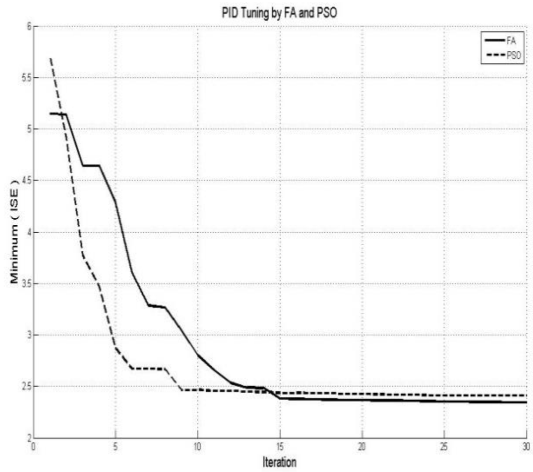

Figure 12. Convergence curve of FA and PSO based on ISE to obtain the PID parameters.

6 CONCLUSIONS

In the paper we study the dynamic stability of a synchronous generator with an excitement system whose performance is enhanced by using a PID controller. To tune the optimal values of the PID controller, the FA and PSO algorithms are used indicating effectiveness and robustness of the proposed approach for the IAE and ISE objective functions. The results are compared with FA-PID and conventional PID, PSO-PID. To determine the PID controller gains with respect to the overall performance characteristics of the power angles and terminal voltage of the Derbindikhan power plant, our comparison shows that FA is more efficient and promising for determination the PID controller gains. As to objective functions our results show that the response performance of the IAE criterion is more promising than ISE criterion.

REFERENCES

[1] P.Kundur. "Power System Stability and Control" McGraw Hill, New York, 1994.

[2] D.Das. "Electrical Power Systems" New Age International (P) Ltd., New Delhi, (2006).

[3] W. G. Heffron and R. A. Phillips. "Effects of Modern Amplidyne Voltage Regulator in Underexcited Operation of Large Turbine Generators" AIEE Trans., PAS-7l, Aug. 1952, 692-697.

[4] F. P. DeMello and C. Concordja. "Concepts of Synchronous Machine Stability as Affected by Excitation Control". IEEE Trans., PAS-88, Apr. 1969, 316- 329.

[5] Zwe-Lee Gaing. ″A Particle Swarm Optimization Approach for Optimum Design of PID Controller in AVR System". IEEE Tran. Ene. Con, vol. 19, no. 2, pp. 384-391, June 2004.

[6] Nour EL Yakine Kouba, Mohamed Menaa, Mourad Hasni and Mohamed Boudour. "Optimal Control of Frequency and Voltage Variations Using PID Controller Based on Particle Swarm Optimization". Proceedings of the 4th International Conference on Systems and Control, Sousse, Tunisia, April 28-30, 2015, pp. 424-429.

[7] K. Naidu, H. Mokhlis and A. H. A. Bakar. "Application of Firefly Algorithm (FA) based optimization in load frequency control for interconnected reheat thermal power system". 2013 IEEE Jordan Conference on Applied Electrical Engineering and Computing Technologies (AEECT).

[8] Mahmoud Reza Shakarami, Iraj Faraji, Iraj Asghari and Mohsen Akbari. "Optimal PID Tuning for Load Frequency Control Using Levy-Flight Firefly Algorithm". 3rd International Conference on Electric Power and Energy Conversion Systems, Yildiz Teclmical University, Istanbul, Turkey, October 2-4, 2013.

[9] Hadi Saddat. "Power System Analysis". McGraw Hill, New York, 1999.

[10] P. M. Anderson and A. A. Fouad. "Power System Control and Stability". John Wiley & Sons, INC., 2003.

[11] Husham I. Hussein "Neural Network Controller Based Dstatcom for Voltage Sag Mitigation and Power Quality Issue", International Journal of Engineering and Technology (IJET), Vol 8, No 1,pp.405-420, 2016.

[12] X. S. Yang. "Nature-Inspired Metaheuristic Algorithms". Luniver Press, 2008.

[13] X. S. Yang. "Firefly algorithm, Levy flights and global optimization". in Research and Development in Intelligent Systems XXVI, pp. 209–218, Springer, London, UK, 2010.

[14] J. Kennedy, R. Eberhart. "Particle Swarm Optimization". Proceeding of the IEEE International Conference on Neural Networks, Vol.IV, 1995, pp.1942-1948.

[15] Y. Shi and R. Eberhart. "A modified particle swarm optimizer". in Proc. IEEE Int. Conf. Evol. Comput, Anchorage, AK, May 1998, pp. 69–73.

Ghassan Abdullah Salman was born in Diyala -Iraq 1983. He completed his B.Sc. Electrical power and machines department Diyala University College of Engineering, Iraq in 2005, M. Sc. (Power Systems) from university of technology-Baghdad in 2011. He has three years of Industrial experience and electrical companies and has teaching experience. He has working as assistant lecturer in Electrical power and machines department, College of Engineering, Diyala University. His research interests are optimal power system, FACTS & Power Quality.

Husham I. Hussein was born in Baghdad, Iraq, in 1978, received his B.Sc. from University Technology / Iraq in 2002, M.Sc. from University Technology of Malaysia (UTM) in 2012. He is currently senior lecturer in the Department of Electrical Power Engineering, College of Engineering, Diyala University -Iraq. Professional Strength and Skills: His current research interests are optimization power system, power quality, power electronics, State estimation, and Renewable Energy. He has good experience in practice of Electrical engineering in different fields such as installation of industrial plants and other electrical design and executing works. He is teaching several basic subjects of the Electrical Engineering, Diyala University - Iraq. He is a member of IAENG

Mohammed S Hasan was born in Diyala, Iraq, in 1965, received his B.Sc. from Rajlovac Eng. Academy Sarajevo Bosnia and M.Sc. from Belgrade, Serbia, Yugoslavia, in 1986 and 1988 respectively, and the Ph.D. from the University of Northumbria, Newcastle, UK, in 2014. He is currently a lecturer in the faculty of Engineering of Diyala, Iraq. His main interests are in the areas of electrical machines and power systems.