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Application of artificial intelligence techniques for LFC and AVR systems using PID controller

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ABSTRACT

Development of electrical power systems led to search for a new mathematical methods to find the values of PID (Proportional-Integral-Derivative) controller. The goal of the paper is to improve the performance of the overall system, through improved the frequency deviation and the voltage deviation characteristics using PID controller, so in this paper are proposed three methods of artificial intelligence techniques for designing the optimal values of PID controller of Load-Frequency-Control (LFC) and Automatic-Voltage-Regulator (AVR), the first is the Firefly Algorithm (FA), the second is the Genetic Algorithm (GA) and the third is the Particle Swarm Optimization (PSO), in addition to these three methods use the conventional (Ziegler–Nichols, Z-N). The FA, GA and PSO are used to obtain the optimal parameters of PID controller based on minimized different various indices as a fitness function, these fitness functions namely Integral-Time-Absolute-Error (ITAE) and Integral-Time-Square-Error (ITSE). Comparison between the results obtained show that FA has better performance to control of frequency deviation and terminal voltage than GA and PSO, so the results observed the FA is more effectual and reliable to determine the optimal values of PID controller.

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1. INTRODUCTION

Both LFC and AVR plays an important and essential role in the control of power generation systems in order to be suitable for the consumer, through the control of (active power - frequency) and (reactive power - voltage) respectively, so that the deviation values must be within acceptable limits [1, 2]. First of all influence between the mechanical and electrical parts precisely, interconnection equations between LFC and AVR have been proposed by [3, 4]. The coordination between LFC and AVR with the new model has been proposed by [5]. The oscillation of LFC and AVR are studied with PID controller in [6, 7] to improve the performance of two control loops. To more efficient results the artificial intelligence techniques was used for tuning the gains of PID controller for LFC with AVR loops, the applications of artificial intelligence technique based on optimization of PID controller for LFC are presented in [8-12], whereas the optimal design of PID controller by using artificial intelligence technique for AVR system are presented in [13-17]. The LFC and AVR control loops with tuning PID parameters by optimization technique are studied individually in [18, 19], while the interaction effect among the LFC with AVR control loops with optimized the PID controller gains are presented in [20-22].

The paper problem lies in tuning the optimal values of the PID controller on the LFC and AVR systems and thus improving the general performance of the system by improving frequency and voltage deviations, Finally, for this paper the performance of LFC with AVR loops for single area power system have been studied and it is implementation FA, GA and PSO for tuning the parameters of PID based to minimize two different fitness functions. First is ITAE and second is ITSE.

2. MODELING OF LFC AND AVR SYSTEMS

The effect of coupling and coordination between LFC and AVR are studied in this paper, a full description of the transfer function model for LFC and AVR loops are presented in [2, 6] and shown in Figure 1.

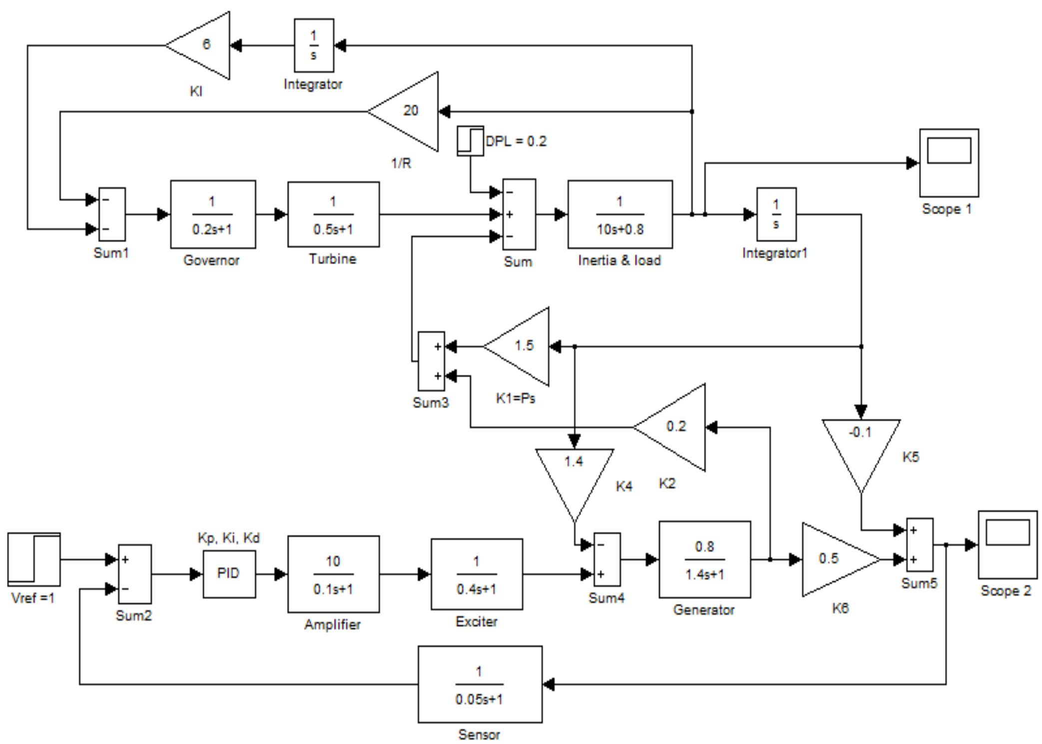

Figure 1. MATLAB/Simulink model from LFC and AVR system

According to [2, 5] from the interaction among LFC with AVR loops obtain the following equations:

$$\Delta P_e = K_1 \Delta\delta + K_2 \Delta E'_q \tag{1}$$

$$\Delta E'_q = \frac{K_3}{1+K_3 T'_{d0} s} \Delta E_{FD} - \frac{K_3 K_4}{1+K_3 T'_{d0} s} \Delta\delta \tag{2}$$

$$\Delta V_t = K_5 \Delta\delta + K_6 \Delta E'_q \tag{3}$$

3. MODELING OF THE PID CONTROLLER

The PID controller still the dominant play an important role in power systems, for ease of representation and implementation, as well as to its effectiveness in enhancement the performance of electrical power systems. According to [7, 21] Figure 2 shows the typical structure of PID controller.

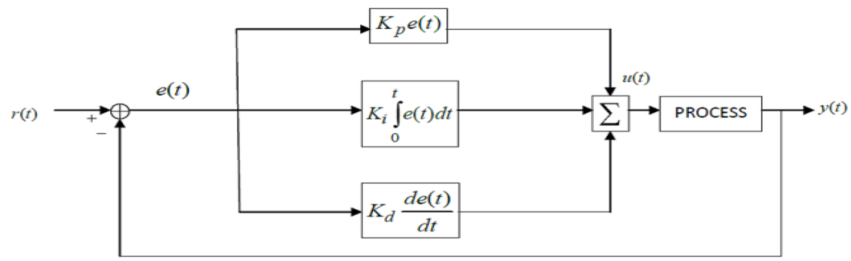

Figure 2. Block diagram of the PID controller

The PID controller transfer function model in terms of Laplace domain is qualified as follow:

$$G_{PID}(s) = \frac{U(s)}{E(s)} = k_p + \frac{k_i}{s} + k_d s \quad (4)$$

Where, E(s) with U(s) are the error signal and the control signal that represented the variation among input and feedback in expression of Laplace domain on the other; k_p represent the proportional gain, k_i represent the integration gain and k_d represent the derivative gain. The PID controller output in term of time domain is represented as follow:

$$u(t) = k_p e(t) + k_i \int_0^t e(t)dt + k_d \frac{de(t)}{dt} \quad (5)$$

Where, e(t) and u(t) are tracking error and the control signals that represent in the form of time domain.

Finally, in this paper the effect of two different objective functions is studied for optimization to determine the parameters of PID controller. First is ITAE and second is ITSE. Has been defined as follows:

$$ITAE = \int_0^t t[|e_1(t)| + |e_2(t)|]\, dt \quad (6)$$

$$ITSE = \int_0^t t[(e_1)^2(t) + (e_2)^2(t)]\, dt \quad (7)$$

Minimize ITAE and ITSE subjected to:

$$k_p^{min} \leq k_p \leq k_p^{max}, \; k_i^{min} \leq k_i \leq k_i^{max} \text{ and } k_d^{min} \leq k_d \leq k_d^{max} \quad (8)$$

4. CONTROL STRATEGY OF PID CONTROLLER

4.1. Conventional (Z-N) Method [20, 23-25]

In the fourth decade of the last century, Ziegler and Nichols presented the values of K_p, T_i and T_d according to the rules shown in Table 1.

By this method, the dynamic property of the procedure is represented by the final gain from a consistent controller and the final pulse period of the loop. The final gain and a period of actual operation are usually determined by the following process:

a. The derivative and integrated modes of the feedback controllers are turned (off) for this reason they have a relative control.
b. For the automatic control, the relative gain - relative range reduction- is increased into the loop fluctuates for a constant capacity.
c. For the help of time register for the controlled variable, the pulse period is measured and registered as the final T period.

Table 1. Z-N Tuning Rules

Type of Controller	K_p	T_i	T_d
P	T/L	∞	0
PI	0.9*T/L	L/0.3	0
PID	1.2*T/L	2 L	0.5 L

Note: $k_p = K_p$, $k_i = K_p / T_i$ and $k_d = K_p * T_d$

4.2. Intelligence techniques

The modern artificial intelligence and heuristics techniques play an important role to control of electric power system therefore, the main objective of this paper for control the frequency deviation and terminal voltage deviation of single area power system. At first controller parameters tuning is accomplished by conventional (Z-N) procedure. But, this method is not feasible in practical systems that need fast processing and this is not available in this method. Consequently, much powerful mathematical optimization techniques are utilizing to tune the parameters of PID and most reliable are population based optimization procedures especially FA, GA and PSO.

FA is a Meta heuristic search technique based on optimization algorithm; it is proposed in 2007 by Xin She Yang [26]. The FA is described in the following rules.

a. Each firefly has the ability to attract other fireflies of the same sex or of the opposite sex.
b. Firefly brightness is proportional to the attraction and inversely proportional to the distance, thus the low brightness of the firefly moves to a high-brightness firefly near it.
c. The optimum value for the fitness function represented by the brightness of fireflies.

The following equations below describe the FA:

$$X_i^{new} = X_i^{old} + \beta(X_j - X_i) + \alpha\left(rand - \frac{1}{2}\right) \tag{9}$$

$$\beta = \beta_0 e^{-\gamma r_{ij}^m} \qquad (m \geq 1) \tag{10}$$

$$r_{ij} = \|X_i - X_j\| = \sqrt{\sum_{k=1}^{d}(X_{i,k} - X_{j,k})^2} \tag{11}$$

Where (9) represents the movement of the Fireflies, where the first expression is the current position of a firefly, the next expression is applied for considering a firefly's attractions to light intensity seen by adjacent fireflies, then the third expression issued for the random movement of a firefly in case, there are no any brighter ones. The coefficient α is a indiscriminate parameter determined by the problem of interest, whilst rand is a random number generator regularly distributed in the space [0, 1].

Where β_0 consider the foremost attractiveness at r equal 0, γ is an absorption coefficient that can controls the decrease from the light intensity and r consider the dimension among any two fireflies. But $X_{i,k}$ consider the kth component of the locative X_i of the ith firefly while d is the dimensions number. GA is introduced by John Holland in 1970; it is a stochastic global search method used for optimization [27]. The GA operators are usually done by following stages [28]-[29].

a. Selection: Operator selection is applied multiple times because there are members in the population. Any individual is iterative at this step together with a eventuality proportional to the relative fitness function of the population.
b. Crossover: The crossover operator is applied to produce two new individuals, by choice and combining two individuals (parents). The collection process is done by random selection of the cut point and then dividing the parents into two parts, so that the parents are replaced by the offspring, formed in the population.
c. Mutation: The values in a site are randomly selected for individual changes by the mutation operator, after the number of iterations that the algorithm has been completed, while running the algorithm represents the best individual solution created.

In 1995 the PSO is developed by Kennedy and Eberhart, it is one of the modern heuristic algorithms used for optimization [30]. In PSO method, set of individuals that make up the swarm called particles, each particle has position and velocity. To reach the optimal values the position and velocity are update using the following equations:

$$X_i^{k+1} = X_i^k + V_i^{k+1} \tag{12}$$

$$V_i^{k+1} = wV_i^k + c_1 r_1(p_{best,i}^k - X_i^k) + c_2 r_2(g_{best,i}^k - X_i^k) \tag{13}$$

$$w = \frac{2}{\left|2-\varphi-\sqrt{\varphi^2-4\varphi}\right|} \tag{14}$$

Where X_i^{k+1} is position of particle at k+1 iteration, X_i^k is position of particle at k iteration, V_i^{k+1} represent velocity form particle at k+1 iteration, V_i^k represent velocity of particle at k iteration, w represent inertia weight parameter, c_1 with c_2 are learning factors, r_1 with r_2 are random number in the interval [0, 1].

The flowchart of FA, GA and PSO based on ITAE and ITSE as a fitness functions to determine optimal values of PID controller as shown at Figure 3, while the parameters from these technique are given in Table 2.

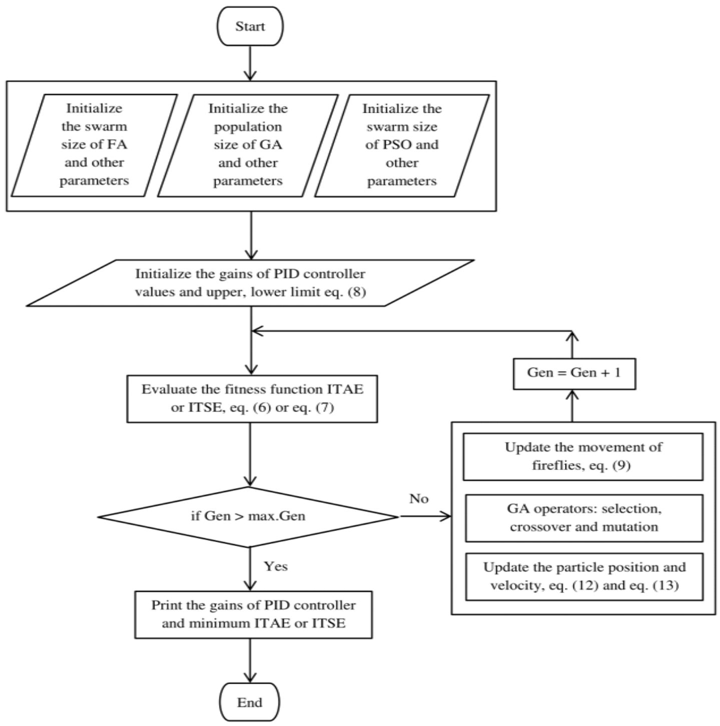

Figure 3. Flowchart of intelligence techniques for PID controller

Table 2. Parameters of FA, GA and PSO

FA	GA	PSO
Population Size (Pop) = 30	Population Size (Pop) = 30	Population Size (Pop) = 30
Absorption Coefficient (γ) = 0.5	Crossover Factor (γ) = 0.5	$\varphi_1 = 2$, $\varphi_2 = 2.1$ and $\varphi = \varphi_1 + \varphi_2$
Attraction Coefficient (β_0) = 0.2	Crossover Percentage (pc) = 0.8	Inertia Weight (w) = Eq. (14)
Mutation Coefficient (α) = 0.3	Mutation Percentage (pm) = 0.3	Personal Learning Coefficient (c_1) = $w*\varphi_1$
$m = 3$	Mutation Rate (mu) = 0.1	Global Learning Coefficient (c_2) = $w*\varphi_2$

5. SIMULATION RESULTS AND DISCUSSION

The implementation coupling between LFC with AVR loops for single area power system and PID controller that shown at Figure 4, the LFC with AVR control loops as presented individually in the papers [18, 19]. Table 3 gives the PID gain, which is set in the conventional (Z-N) method.

Then, for enhancing the terminal voltage and the frequency oscillation of single area power system, the optimal values of PID controller are obtained by FA, GA and PSO with ITAE and ITSE fitness functions, the ITAE take as a fitness function to obtained the optimal values of PID controller is shown in Figure 5, whereas Figure 6 shows the ITSE takes as a fitness function to obtained the optimal values of PID controller. The lower bound of PID gain is chosen as 0 and the upper bound is chosen as 3. Therefore, the optimal values of the PID gains to minimize the ITAE and ITSE are computed by FA, GA and PSO, also these values of PID controller are given at Table 4.

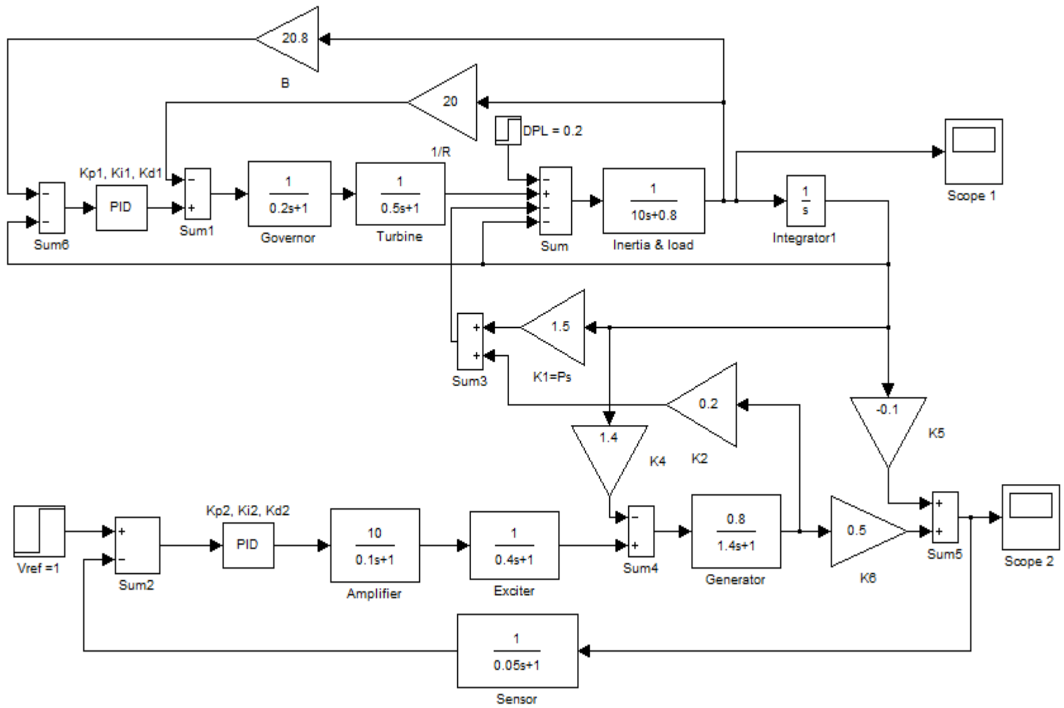

Figure 4. MATLAB/simulation model of LFC with AVR system with PID controller

Table 3. Gains of PID Controller by Z-N Method

k_{p1}	k_{i1}	k_{d1}	k_{p2}	k_{i2}	k_{d2}
1.6028	2.0254	1.3137	0.9523	0.3515	0.2018

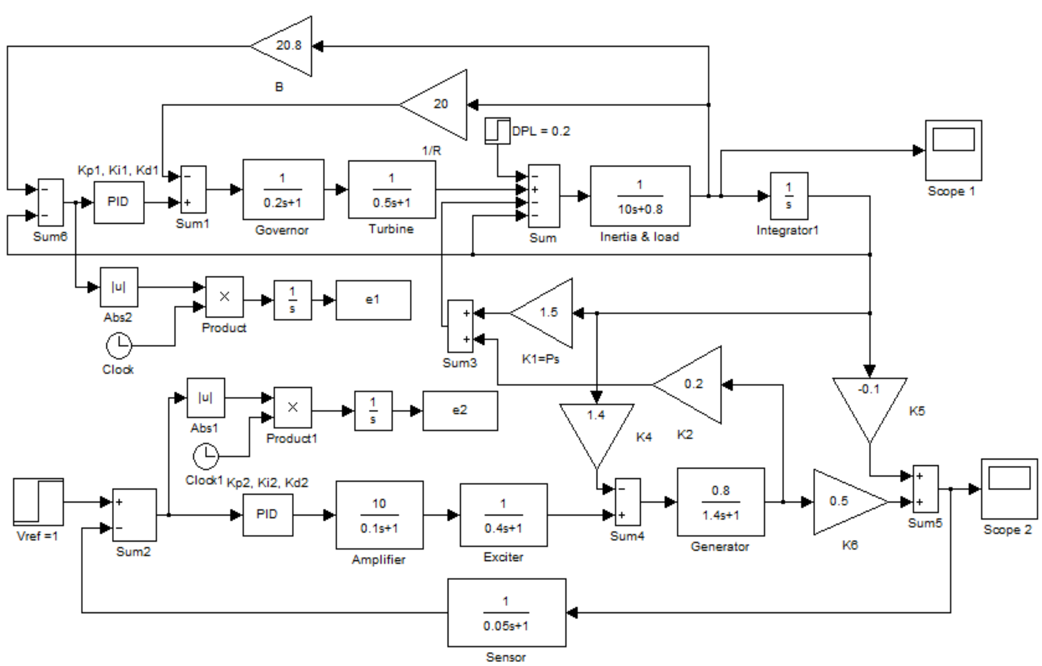

Figure 5. MATLAB/ simulation model form LFC with AVR system based on ITAE

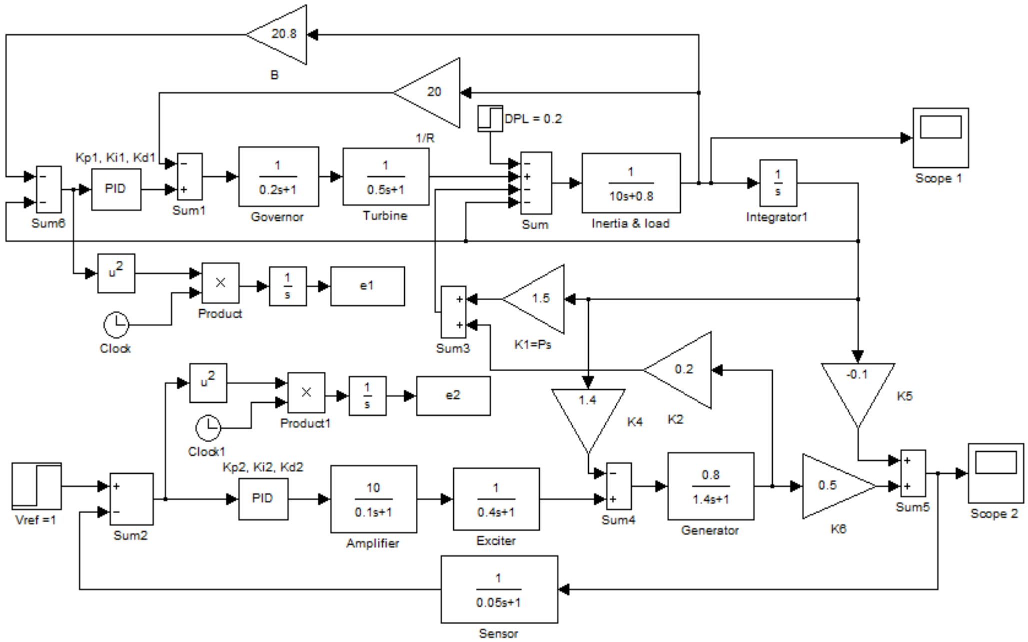

Figure 6. MATLAB/ simulation model from LFC with AVR system based on ITSE

Table 4. Optimal gains of PID controller by FA, GA and PSO

	k_{p1}	k_{i1}	k_{d1}	k_{p2}	k_{i2}	k_{d2}
FA-ITAE	2.9931	2.9972	2.4862	2.6872	0.5717	0.7283
FA-ITSE	2.9850	2.9916	2.4238	2.8715	0.5821	0.7764
GA-ITAE	2.6959	2.9638	2.2359	2.3915	0.5984	0.6293
GA-ITSE	2.6231	2.4978	2.3509	2.4868	0.6441	0.6637
PSO-ITAE	2.7789	2.9868	2.3592	2.5751	0.5803	0.6883
PSO-ITSE	2.8192	2.7951	2.4026	2.7821	0.6202	0.7518

Figures 7 and 8 shows the frequency deviation response to adjust the PID controller by FA, GA and PSO on the basis of ITAE and ITSE compared to the conventional (Z-N) method, while the characteristics of the frequency deviation (maximum-deviation, peak-time,then settling-time and finaly steady-state-error) are given at Table 5 compared with results are presented in papers [18, 19].

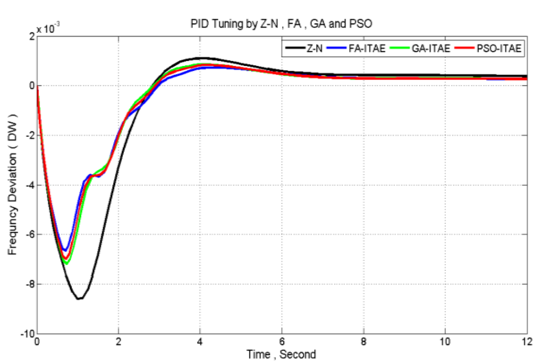

Figure 7. Frequency Deviation and PID tuning using FA, GA with PSO based on ITAE compared with Z-N

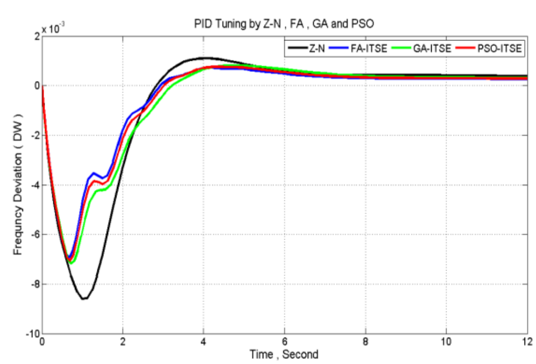

Figure 8. Represent frequency deviation and PID tuning using FA, GA with PSO based on ITSE compared with Z-N

Table 5. Frequency deviation characteristics and PID tuning using Z-N, FA, GA and PSO

	M_d (p.u)	t_p (sec.)	t_s (sec.)	E_{ss} (p.u)
Z-N	$-8.597\text{x}10^{-3}$	0.9976	9.441	$-3.816\text{x}10^{-4}$
FA-ITAE	$-6.666\text{x}10^{-3}$	0.7040	8.726	$-2.627\text{x}10^{-4}$
FA-ITSE	$-6.917\text{x}10^{-3}$	0.6893	8.671	$-2.608\text{x}10^{-4}$
GA-ITAE	$-7.194\text{x}10^{-3}$	0.7363	8.993	$-2.662\text{x}10^{-4}$
GA-ITSE	$-7.186\text{x}10^{-3}$	0.7239	9.012	$-3.151\text{x}10^{-4}$
PSO-ITAE	$-6.997\text{x}10^{-3}$	0.7166	8.695	$-2.636\text{x}10^{-4}$
PSO-ITSE	$-7.061\text{x}10^{-3}$	0.6968	8.738	$-2.825\text{x}10^{-4}$
Ref. [18]	$-7.6\text{x}10^{-3}$	None	10.42	None
Ref. [19]	$-9.3\text{x}10^{-3}$	None	9.5	None

Figures 9 and 10 shows the terminal voltage response to the PID controller adjustment by FA, GA and PSO based on ITAE and ITSE compared with conventional (Z-N) method, while the characteristics of the terminal voltage (maximum-peak, peak-time, then settling-time and finaly steady-state-error) are given in Table 6 compared with results are presented in papers [18, 19].

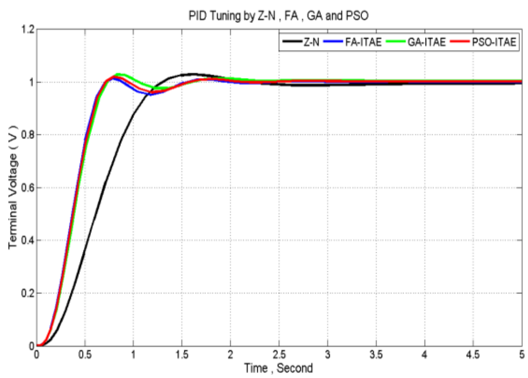

Figure 9. Terminal Voltage with PID tuning by FA, GA and PSO based on ITAE compared with Z-N

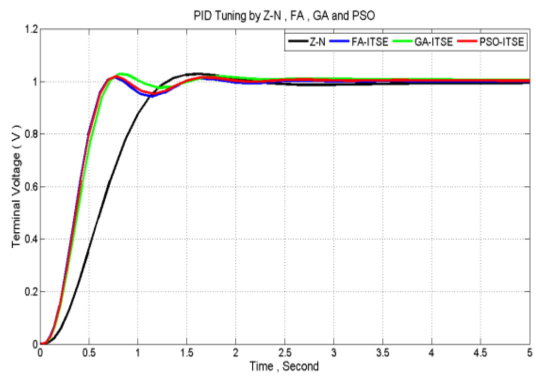

Figure 10. Terminal Voltage with PID tuning by FA, GA and PSO based on ITSE compared with Z-N

Table 6. Terminal Voltage Characteristics with PID Tuning by Z-N, FA, GA and PSO

	M_p (p.u)	t_p (sec.)	t_s (sec.)	E_{ss} (p.u)
Z-N	1.029	1.625	1.933	$5.3\text{x}10^{-3}$
FA-ITAE	1.013	0.7849	1.422	$-1\text{x}10^{-3}$
FA-ITSE	1.015	0.7679	1.383	0
GA-ITAE	1.027	0.8218	1.439	$-3\text{x}10^{-3}$
GA-ITSE	1.028	0.8085	1.396	$-5\text{x}10^{-3}$
PSO-ITAE	1.019	0.7995	1.432	$-2\text{x}10^{-3}$
PSO-ITSE	1.019	0.7766	1.385	$-3\text{x}10^{-3}$
Ref. [18]	1.204	None	9.3	None
Ref. [19]	1.0	None	4.9	None

Figure 11 illustrates the convergence in reducing the ITAE index using FA, GA and PSO to determine the optimal values for a PID controller. While, Figure 12 illustrates the convergence in reducing the ITSE index using FA, GA, and PSO to determine the optimal values for a PID controller. Therefore; these convergence curves show that FA has better performance than GA and PSO.

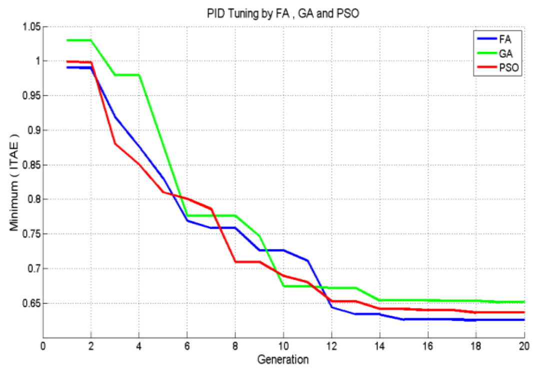

Figure 11. Convergence curve of FA, GA then PSO for optimal gains for PID with minimize ITAE

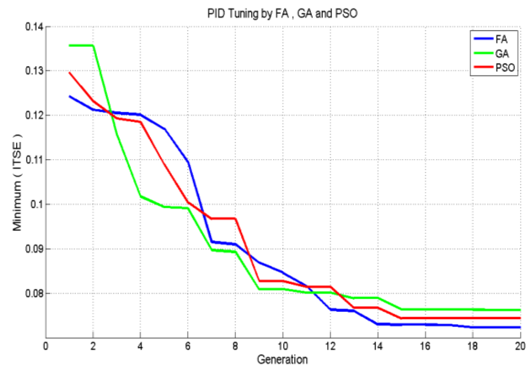

Figure 12. Convergence curve of FA, GA then PSO for optimal gains for PID with minimize ITSE

In all the results above, the overall characteristics of the frequency deviation and the terminal voltage are reduced by FA, GA and PSO for tuning of the PID controller when compared with conventional (Z-N) PID controller, the damping characteristics of single area power system with tuning the PID controller by FA are improved more effectively compared with GA and PSO. Also, stability of single area power system is conserved and reduced for power system oscillations.

6. CONCLUSION

This paper studied the PID control performance taking the coupling effect between LFC and AVR, at first using the conventional PID controller (Z-N) method to improve the performance of these loops, and then for faster tune of PID controller and for obtain the results more accurate, we used the modern intelligence techniques such as FA, GA and PSO. Demonstrated by the results that were obtained and compared between the three techniques mentioned previously, observed that FA has a clear progress over than GA and PSO for tuning the PID gains to enhanced the overall characteristics of the terminal voltage and frequency oscillation for single area power system.

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