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FO-PID CONTROLLER DESIGN WITH SCA FOR COMMUNICATION TIME DELAYED LFC

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Abstract-In this paper, Sine Cosine Algorithm (SCA) is proposed and applied to load frequency control (LFC) of different type single area power systems. Reheat turbine system without communication time delayed is considered for the first system. Power systems have communication time delays because of far remote units (FRUs'), communication channels (CCs'), delays between plant units and etc. Communication time delays (CTDs) have negative affect on reliability and stability of power systems. For this reason, non-reheat turbine system having communication time delayed is considered. Both systems are controlled by fractional order proportional-integral-derivative controller (FO-PID). This controller has five controllable parameters. Thus, it is very flexible and very effective controller. Analyzed single area power systems for LFC are compared with recent literature studies. Founded outputs are examined according to settling time (%0.005 band width), overshoot, undershoot and peak to peak values of frequency deviation signals. These outputs are demonstrated that system performances highly enhanced with proposed FO-PID controller and SCA method.

Keywords: Load Frequency Control, Sine Cosine Algorithm, Single Area Power Systems, Communication Time Delay, Fractional Order Controller.

1. INTRODUCTION

Today, most of the electrical energy needs are met by fossil-based electrical power plants. Mechanical energy generated in these power plants is converted into electrical energy through synchronous generators. The increase or decrease in the load on the system affects the rotation speed of the generators. This situation affects the output frequency of the system. Load frequency control is very important for the safe operation of the plant and for the users to reach uninterrupted quality electricity. The main mission of the LFC is to monitoring the frequency deviation of the system and make this deviation to 0 for the steady state [1, 2]. Thus, system frequency keeps specified limits and the stability of the entire system is ensured.

There are a lot of proposed and applied methods for load frequency control systems. Gravitational Search Algorithm (GSA) [3], Particle Swarm Optimization (PSO) [4], Linear Matrix Inequality (LMI) [5], Internal Model Control (IMC) [6], Salp Swarm Algorithm (SSA) [7], Non-Linear Sliding Mode Control (SMC) [8], Quadratic Regulator Approach with Compensating Pole Technique (QRAWCP) [9] etc. are examples of these methods. Communication time delayed LFC systems have been studied in recent years. CTDs can disrupt the stability of the system and even cause the system to collapse. Analytico-Graphical Approach [10] Stability Boundary Locus [11], and Genetic Algorithm [12] etc. are of some techniques considered CTDs on LFC systems. PID controllers frequently used for LFC of the power systems because of simple, inexpensive and good stability ability. On the other hand, it may not be able to tolerate changes in the system. Moreover, even if the PID parameters are set very well, it may not exhibit the desired system performance because it has three parameters. For this reason, effective FO-PID controller is chosen. This controller has five controller parameters so it is very flexible. FO-PID controller parameters are tuned with SCA method because this method has good approximation by avoiding local minimums.

The other parts are organized as follows: Communication time delayed load frequency model and mathematical terms are given in Section 2. FO-PID controller is mentioned in Section 3. Mathematical definitions and based equations of SCA are given Section 4. Graphical and numerical results of proposed controller and method are shown in Section 5 and Section 6 is Conclusions.

2. COMMUNICATION TIME DELAYED LOAD FREQUENCY CONTROL

Generated active power from energy systems and demanded active power from consumer must be equal. When analyzed in terms of power system, this balance should be achieved due to reasons such as economic

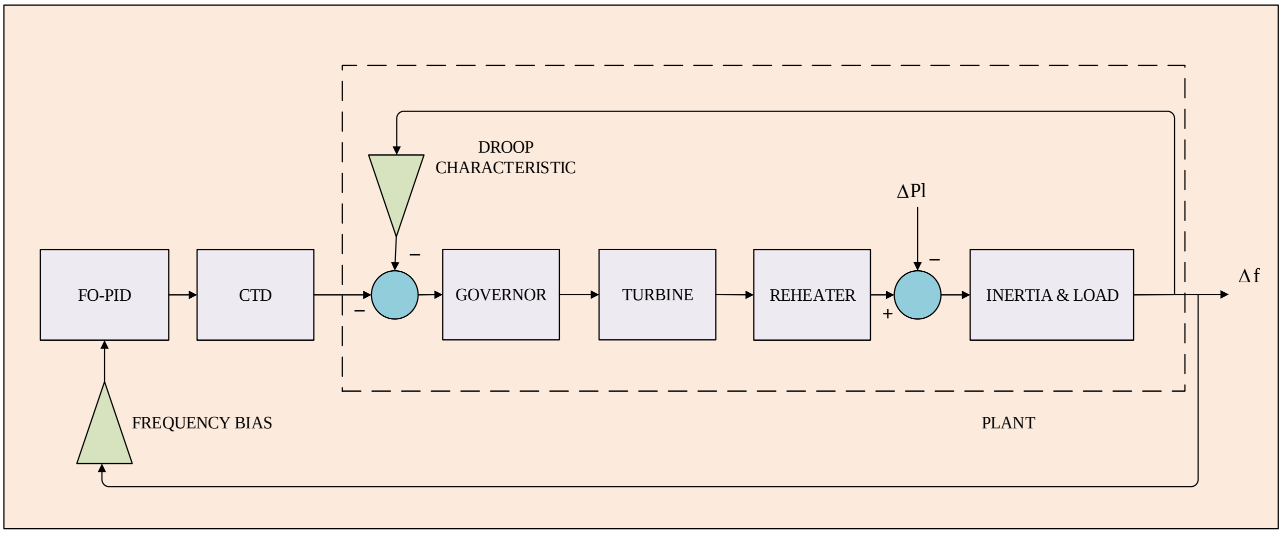

Figure 1. Considered LFC model

operation and environmental factors. When analyzed in terms of the consumer, this balance should be provided for reasons such as uninterrupted and quality energy. If this balance cannot be achieved, fluctuations occur in system frequency. These fluctuations affect the power system and consumers negatively. In order to make the fluctuations in the system frequency at steady state close to 0, the process of controlling the system is called "Load Frequency Control".

The general LFC model for the systems used in this study is shown in Figure 1. This model consists of eight system blocks. These are governor, turbine, reheater, inertia and laod, controller (FO-PID), time delayed (CTD), droop characteristic and frequency bias factor. Mathematical equations represented by these blocks are as follows:

- Governor:

$$G_g(s) = \frac{1}{1+T_g s} \tag{1}$$

where, T_g is time constant of governor.

- Turbine:

$$G_t(s) = \frac{1}{1+T_t s} \tag{2}$$

where, T_t is time constant of turbine.

- Reheater:

$$G_{reh}(s) = \frac{1+T_{reh}K_{reh}s}{1+T_{reh}s} \tag{3}$$

where, T_{reh} is reheater time constant and K_{reh} is reheater gain.

- Inertia and load:

$$G_h(s) = \frac{K_h}{1+T_h s} \tag{4}$$

where, T_h is time constant and K_h is gain of system respectively.

- Droop characteristic:

$$G_r(s) = \frac{1}{R} \tag{5}$$

where, R is droop characteristic coefficient.

- Frequency bias:

$$G_\beta(s) = \beta \tag{6}$$

where, β is frequency bias factor coefficient.

- CTD:

$$G_{CTD}(s) = e^{-s\tau} \tag{7}$$

where, τ is total communication time delay value of the system.

After all the definitions about the considered system model are made, system transfer function from ΔPl to Δf is given as Equation (8).

$$\frac{\Delta f(s)}{-\Delta Pl} = G_h(s)/[1+G_g(s)G_t(s)G_h(s)G_r(s)+ +G_g(s)G_t(s)G_h(s)G_c(s)G_{CTD}(s)G_\beta(s)] \tag{8}$$

In this equation $G_c(s)$ represents FO-PID controller block. This controller block is explained and mathematical expression is given in next section.

3. FO-PID CONTROLLER

FO-PID controller is an extension type of PID controller. This controller has two more parameters than the PID controller. I and D operators have fractional order coefficients. Therefore, it is efficient, flexible and effective compared to a conventional controller. Some advantages of FO-PID controllers than PID controllers are given below [13]:

- For higher order systems, FO-PID shows better performances than classical PID [14],
- For time delayed systems, FO-PID gives better results than classical PID [15],
- FO-PID controller provides more robust stability than classical PID [16].

FO-PID controller allows to search the PID plane continuously. This is illustrated in Figure 2. FO-PID controller scheme is shown in Figure 3.

Mathematical expression of FO-PID controller is defined as follows:

$$G_c(s) = k_p + \frac{k_i}{s^\lambda} + k_d s^\mu \tag{9}$$

In here k_p represents proportional gain, k_i represents integral gain and k_d represents derivative gain of the controller. In addition to this, λ is fractional order of I operator and μ is fractional order of D operator of FO-PID controller.

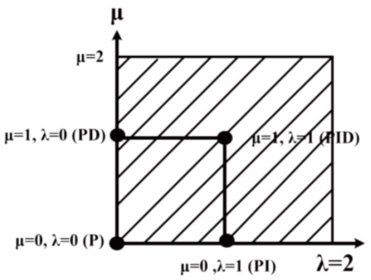

Figure 2. Search of PID plane according to λ and μ [13].

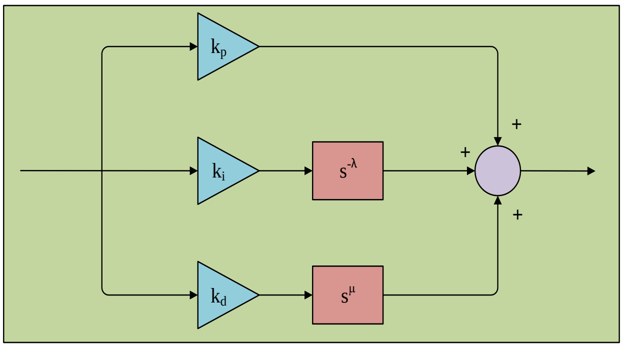

Figure 3. Structure of FO-PID controller

4. SINE COSINE ALGORITHM

Sine Cosine Algorithm is population based optimization technique. In SCA, initial candidate solutions are generated randomly. After than these are fluctuated by using sine and cosine algorithms to the best solution [17]. Different random and changeable parameters are used for enhanced exploration and exploitation behavior of this algorithm [17]. This fluctuation to the best solution is represented in Figure 4.

SCA mainly uses two different functions for updated the positions of candidate solutions. These functions are given as Equations (10) and (11).

$$X_i^{t+1} = X_i^t + r_1 \sin(r_2)\left|r_3 P_i^t - X_i^t\right| \text{ , } r_4 < 0.5 \tag{10}$$

$$X_i^{t+1} = X_i^t + r_1 \cos(r_2)\left|r_3 P_i^t - X_i^t\right| \text{ , } r_4 \geq 0.5 \tag{11}$$

For these equations, X_i^t represents current solution position, X_i^{t+1} represents next iteration position and P_i is destination point position. The r_1, r_2, r_3 and r_4 are random numbers used in the algorithm. Detailed information about SCA method and mathematical modeling can be learned from [17].

In this study, objective function for tuning of FO-PID controller is selected integral time square error (ITSE) to use in SCA method. ITSE is expressed as following equation:

$$ITSE = \int t.e(t)^2\, dt \tag{12}$$

5. RESULTS AND ANALYSIS

In this study two different single area power system are performed. The system having reheat turbine is analyzed for first case and the system having communication time delayed is analyzed for second case. These systems are examined according to settling time (ST) for %0.005 band width, overshoot (OS), undershoot (US) and peak to peak (PtP) values of output frequency deviation signal.

5.1. LFC having Reheater Turbine

Reheater turbine power system is analyzed for this case. Settling times of compared methods are calculated for %0.005 band width. System parameters are given in Table 1. Obtained FO-PID controller and literature studies controller parameters are given in Table 2. System frequency deviation graphic is illustrated in Figure 5.

Table 1. Reheat turbine system parameters

T_g	T_t	K_{reh}	T_{reh}	K_h
0.08	0.3	0.35	4.2	120
T_h	R	ΔPl	β	τ
20	2.4	0.01	1	0

Table 2. Reheat turbine system controller parameters

	Tech.	k_p	k_i	k_d	λ	μ
Prop.	SCA	26.3177	29.997	23.2575	0.7141	1.4269
[18]	EHO	7.8321	3.5559	3.2172	-	-
[19]	IMC	2.7900	1.2700	0.7870	-	-
[20]	LS	6.1600	1.9300	1.1600	-	-

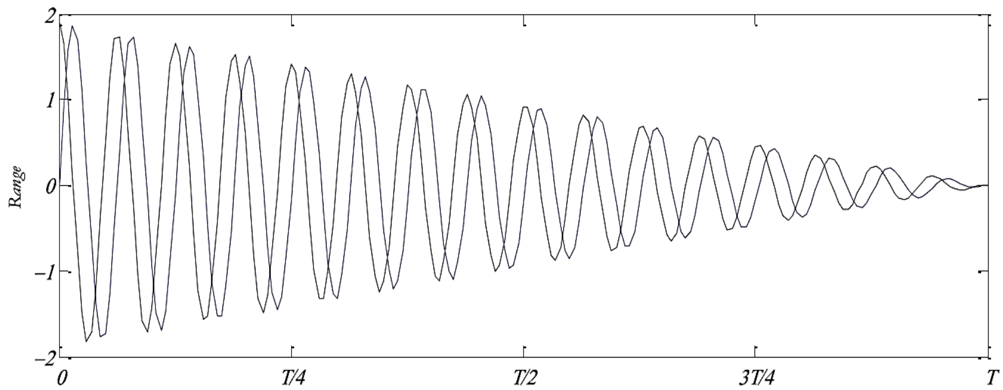

Figure 4. Fluctuating graphic for sine and cosine range to the optima [17]

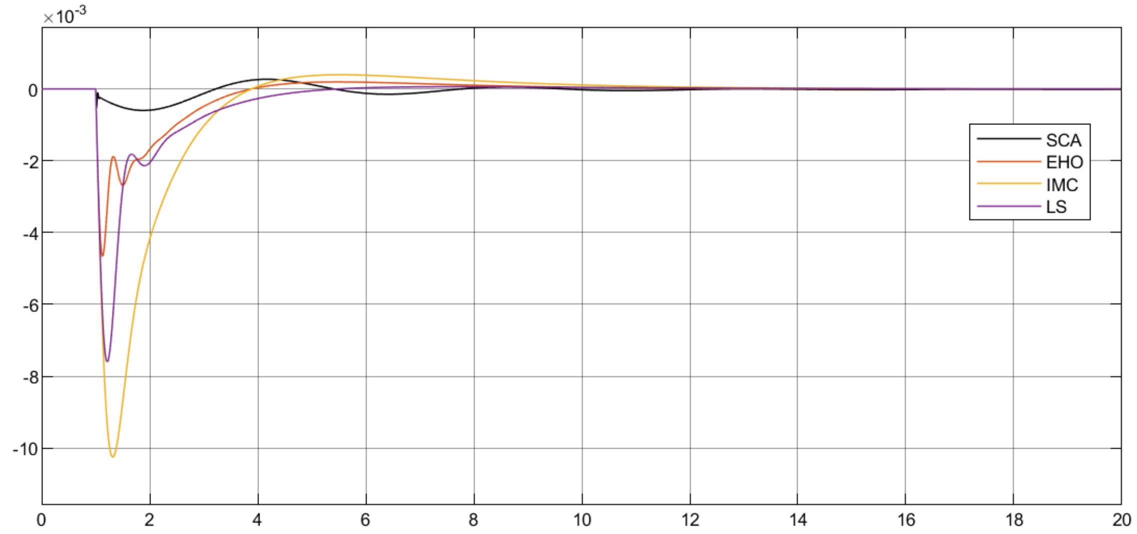

Figure 5. Frequency deviations of the reheat turbine system

Comparative system performances results are given in Table 3.

Table 3. Reheat turbine system performance results

	Method	ST	OS	US	PtP
Prop.	SCA	**8.645**	2.679e-4	**-5.996e-4**	**8.675e-4**
[18]	EHO	9.718	1.945e-4	-4.662e-3	4.857e-3
[19]	IMC	11.978	3.944e-4	-1.025e-2	1.065e-2
[20]	LS	9.195	**6.037e-5**	-7.600e-3	7.661e-3

When examined obtained results from Figure 5 and Table 3, minimum settling time, undershoot and peak to peak values are founded via proposed SCA and FO-PID controller.

5.2. LFC having CTD

Communication time delayed system is analyzed for this case. Settling times of compared methods are calculated for %0.005 band width.

System parameters are given in Table 4.

Table 4. Delayed system parameters

T_g	T_t	K_{reh}	T_{reh}	K_h
0.1	0.3	0	0	1
T_h	R	ΔPl	β	τ
10	0.05	0.1	21	2.28

Determined FO-PID controller and literature studies controller parameters are given in Table 5.

Table 5. Delayed system controller parameters

	Tech.	k_p	k_i	k_d	λ	μ
Prop.	SCA	0.3958	0.3016	0.0127	0.9999	0.0548
[10]	AGA	0.2900	0.1090	---	---	---
[11]	SBL	0.5500	0.5500	---	---	---

Delayed system frequency deviation graphic is illustrated in Figure 6. Comparative system performances results are given in Table 6.

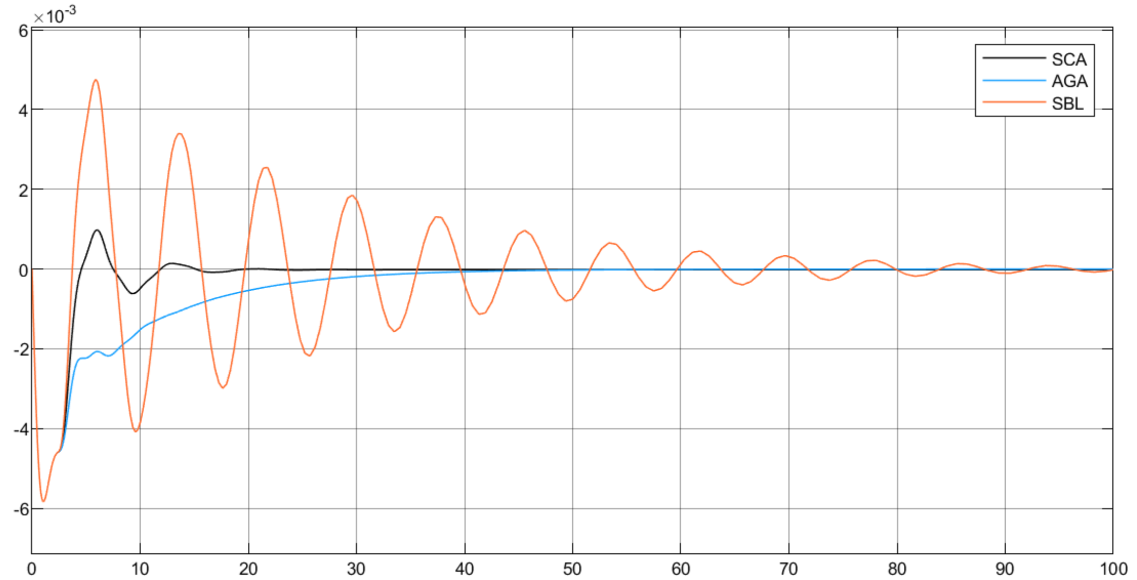

Figure 6. Frequency deviations of the time delayed system

Table 6. Delayed system performance results

	Method	ST	OS	US	PtP
Prop.	SCA	**18.261**	9.833e-4	**-5.830e-3**	6.814e-3
[10]	AGA	42.572	**0.000e0**	**-5.830e-3**	**5.830e-3**
[11]	SBL	103.102	4.760e-3	**-5.830e-3**	1.059e-2

When analyzed to obtained results from Figure 6 and Table 6, AGA found minimum OS and PtP values. However, SCA found same US value together with AGA and SBL. Moreover, settling time is obtained 2.33 times lower than [10] and 5.65 times lower than [11] with proposed SCA technique.

5. CONCLUSION

In this paper proposed Sine Cosine Algorithm and FO-PID controller for load frequency control of single area power systems. This method and controller are applied to reheat turbine LFC system and communication time delayed LFC system. The results clearly show that minimum settling time is obtained for both power systems. Moreover, system performances are considerably improved.

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