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Liquid Level Control Strategy using Fractional Order PID Controller Based on Artificial Intelligence

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Abstract - *At present, process control industries face serious problems related to the liquid level. These industries find it hard to maintain and regulate the liquid level so to attain efficient product quality because the level of the liquid needs to be maintained at a pre-defined rate. Without any interruption, the level of the liquid needs continuous monitoring and control that is only possible by designing a suitable controller or control system. The Proportional-Integral-Derivative (PID), Tilted-Integral-Derivative (TID) and Fractional Order PID (FOPID) controllers are designed based on artificial intelligence techniques to regulate the liquid level. This paper analyses and compares the liquid level control for a process by classical PID, TID and FOPID controllers. The simulation results show far better peak value (PV), settling time (ST), rise time (RT), steady-state error(Ess), Integral of Time Multiplied by Absolute Error (ITAE), Integral of Absolute Error (IAE) and Integral of Square Error (ISE) with FOPID controller, thus ensuring overall higher efficiency.*

***Key Words*: AI, FOPID Controller, GA, ITAE, PID Controller, PSO, TID Controller**

1. INTRODUCTION

The Control system finds numerous applications in the field of process control. Regulating the height and temperature of the liquid in a liquid tank are some of the main problems encountered by these industries [5-6]. These industries find it very hard to regulate and maintain the height and temperature of the liquid. So to overcome these problems, process control industries need to adopt a suitable controller or control system that will regulate the height and temperature of the liquid [3], [4]. This paper mainly emphasizes one such problem, the liquid level control [1], [2], [4], [6]. There are numerous methods designed in Control systems particularly to resolve such problems [5]. This paper proposes three methods: the Proportional-Integral-Derivative controller (PID), Tilted-Integral-Derivative controller (TID), and Fractional Order PID controller (FOPID). PID is feasible, robust and its concept is simple. TID resembles with PID but the tilted gain replaces the proportional gain It is easy to tune than PID [7]. FOPID being an advanced PID controller is more robust and flexible than PID and TID because it has five gain parameters [9]. Moreover, it yields better output responses. These controllers are optimized using artificial intelligence (AI) techniques, Genetic Algorithm (GA) and Particle Swarm Optimization (PSO). PSO is easy to understand, it can be easily incorporated, and it has robust parameters [2]. GA has a simple concept; better efficiency and its response are fast.

In this work, the tuning of the parameters of the three controllers is done using GA and PSO. A comparison between the three controllers is done according to the peak value, settling time, rise time, steady-state error, Integral of Time Multiplied by Absolute Error (ITAE), Integral of Absolute Error (IAE) and Integral of Square Error (ISE). The entire work is carried out in MATLAB/SIMULINK.

This work is structured as- section 2 defines the process modeling that comprises of the control valve, liquid tank, and model equation, section 3 explains the simulation results and the conclusion is discussed in section 5.

2. SYSTEM DESCRIPTION

2.1 Process Modeling

The modeling process comprises the control scheme, control valve, and liquid tank. Fig. 1 shows the basic control scheme for the process liquid level.

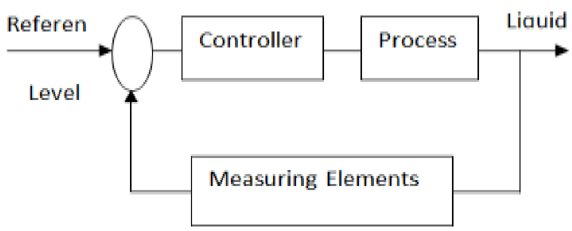

Fig -1: The Control scheme for process liquid level control

2.2 Control Valve

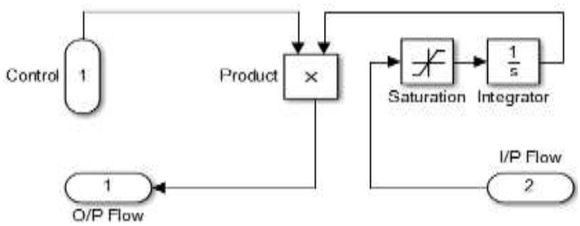

Fig -2: Simulink diagram of Control Valve

Fig. 2 shows the Matlab/Simulink diagram of the control valve. The Simulink blocks integrator and saturation are used to regulate the liquid flowing in and out of the tank.

2.3 Liquid Tank and Mathematical Modeling

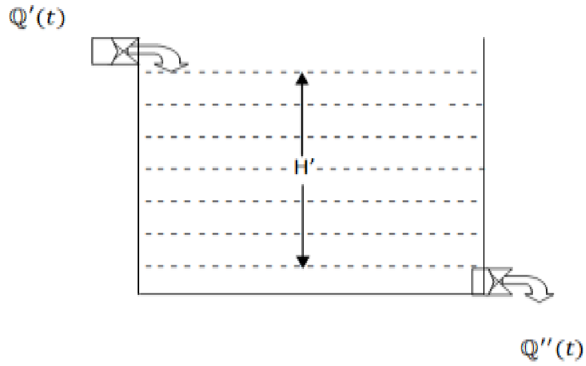

Fig -3: Schematic diagram of liquid tank

Fig. 3 shows the schematic diagram of the liquid tank. The liquid flows in and out of the tank at rates $Q'(t)$ and $Q''(t)$ respectively. The density of the liquid is assumed to be constant. The height of the liquid and output resistance are H' and R' respectively. The liquid which flows out is laminar.

For the laminar flow [2], [9]

$$Q'(t) = \frac{H'}{R'} \quad (1)$$

For the turbulent flow [2], [9]

$$Q''(t) = K'\sqrt{H'} \quad (2)$$

Where K' is the coefficient of discharge

Liquid flows in and out of the tank through an inlet valve and outlet valve. By relating the liquid in and out rates, the model of the system is obtained. Using a balance of input and output flow equations on the liquid tank [1], [2], [4], [6], [9]

$$Q'(t) - Q''(t) = A'_C\left(\frac{dH'(t)}{dt}\right) \quad (3)$$

Where A'_C is the cross-sectional area of the liquid tank

The output flow is assumed to be turbulent [2], [9]. So

$$Q''(t) = K'\sqrt{H'} \quad (4)$$

Now, equation (3) can be written as

$$Q'(t) - K'\sqrt{A'} = A'_C\left(\frac{dH'(t)}{dt}\right) \quad (5)$$

$$Q'(t) = K'\sqrt{H'} + A'_C\left(\frac{dH'(t)}{dt}\right) \quad (6)$$

For the system modeling, transfer function [1], [2], [6] is given by equation (7)

$$G'(s) = \frac{0.1553}{s}e^{-0.19s} \quad (7)$$

To tune and simulate PID, TID, and FOPID controllers, the transfer function in equation (7) is used.

The parameters of these controllers which are obtained by PSO and GA techniques in Matlab/Simulink are tabulated in Table. 1.

TABLE -1: CONTROLLER PARAMETERS

S.NO	GAIN OF CONTROLLERS	PSO-PID	PSO-TID	PSO-FOPID	GA-PID	GA-TID	GA-FOPID
01	K_P	6.8592		8.8592	10.4071		15.0230
02	K_I	2.5235	2.5232	5.5235	3.3961	2.0235	3.0176
03	K_D	0.1521	3.5213	2.5213	1.4378	3.5213	2.8664
04	K_T		10.8592			11.8592	
05	λ			0.7553			0.0884
06	μ			0.8258			0.0549

3. SIMULATION RESULTS

In this work, PID, TID, and FOPID controllers regulate and maintain the process liquid level and MATLAB/SIMULINK carries out the simulations. The figures Fig. 4- Fig. 6 show the SIMULINK models of the process with PID, TID, and FOPID controllers.

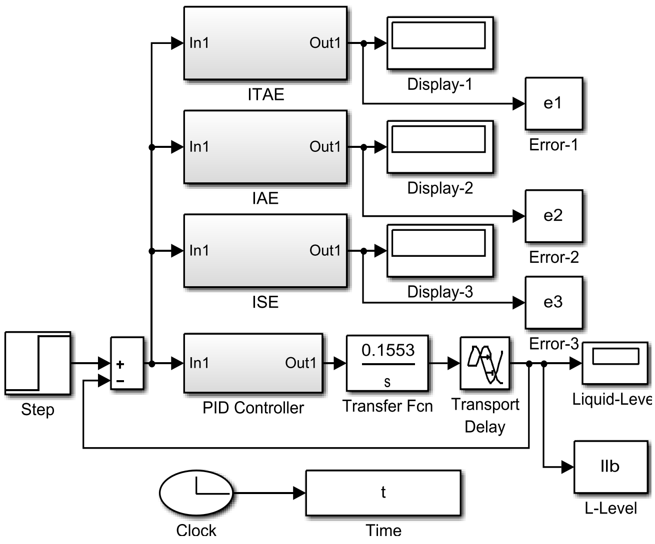

Fig -4: Simulink Model of a Process with PID Controller

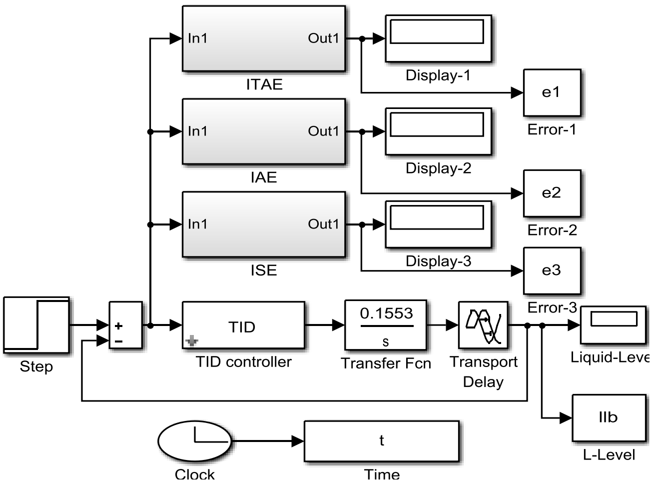

Fig -5: Simulink Model of a Process with TID Controller

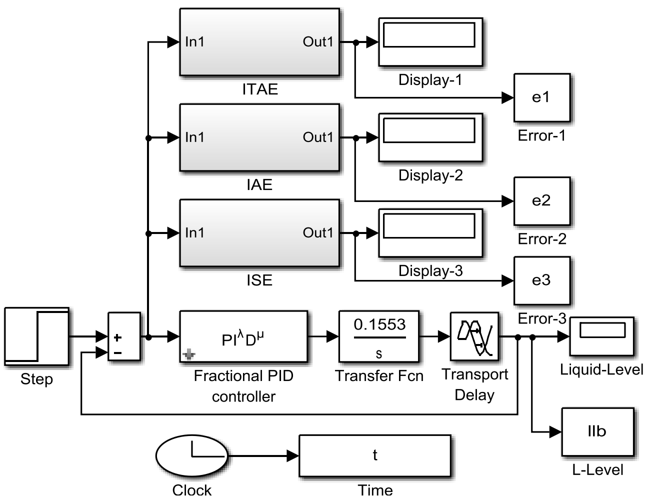

Fig -6: Simulink Model of a Process with FOPID Controller

The figures Fig. 7-Fig. 20 show the step and error responses of the process liquid level with classical PID, TID, and FOPID controllers based on PSO and GA.

The performance comparision of PID, TID, and FOPID controllers is tabulated in Table 2.

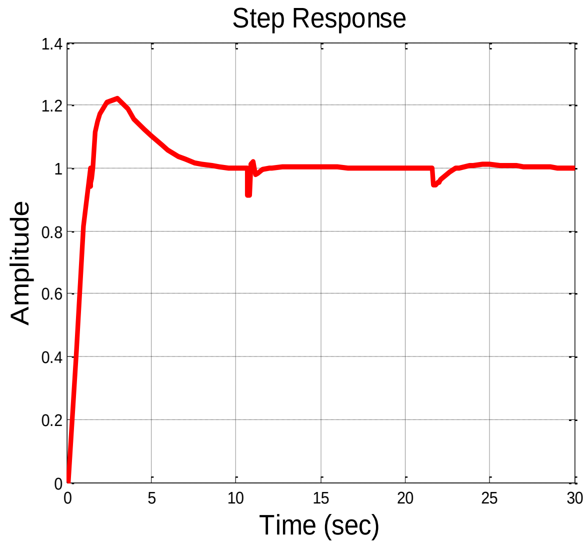

Fig -7: Step Response Based on PSO-PID Controller

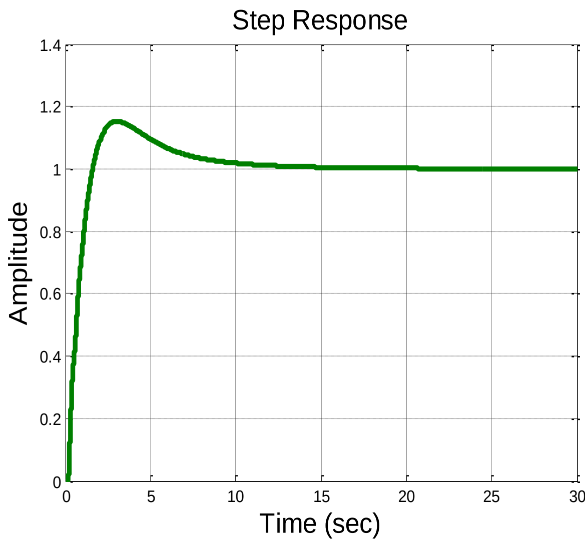

Fig -8: Step Response Based on PSO-TID Controller

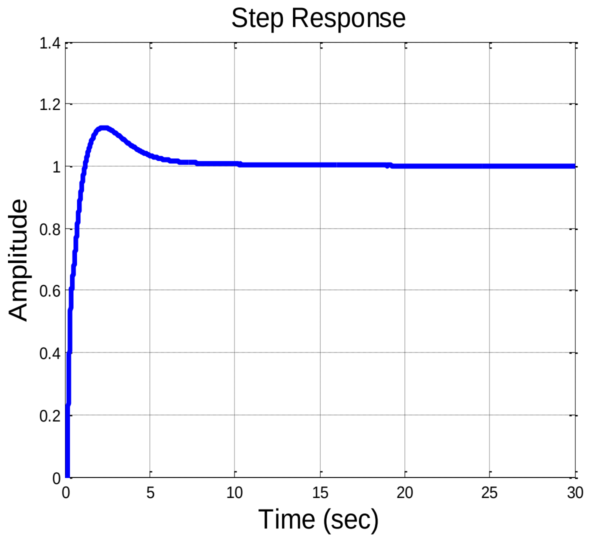

Fig -9: Step Response Based on PSO-FOPID Controller

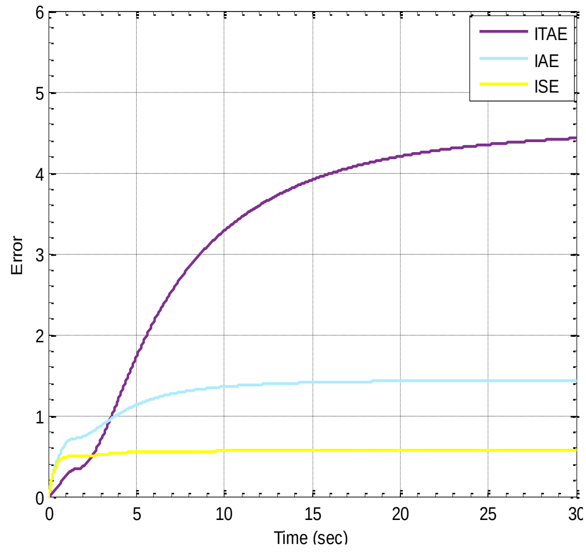

Fig -12: Error Response with PSO-TID

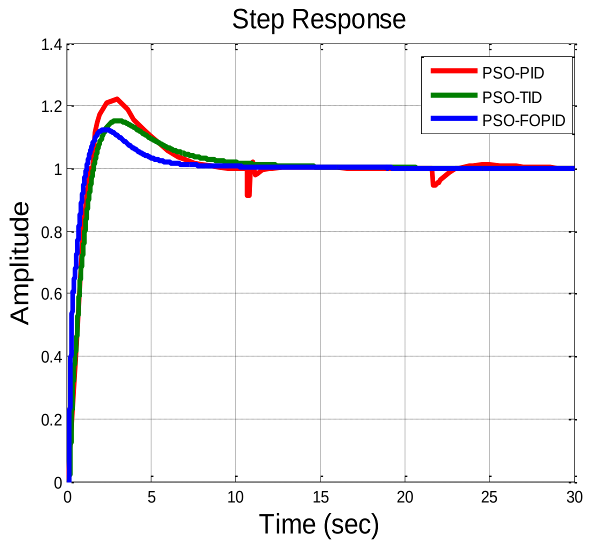

Fig -10: Overall Step Response Of The Process With PSO

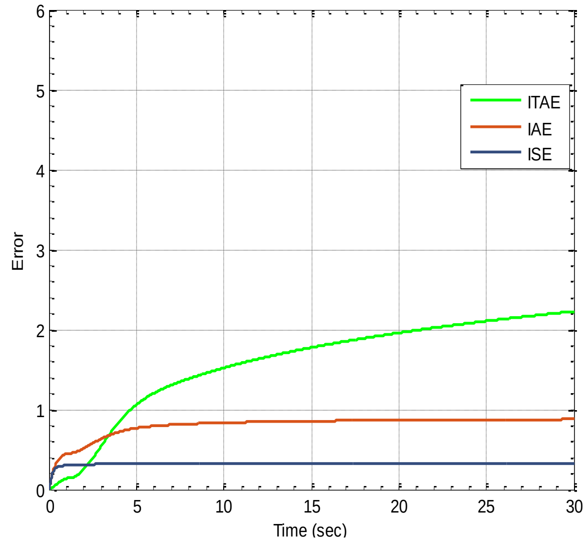

Fig -13: Error Response with FOPID

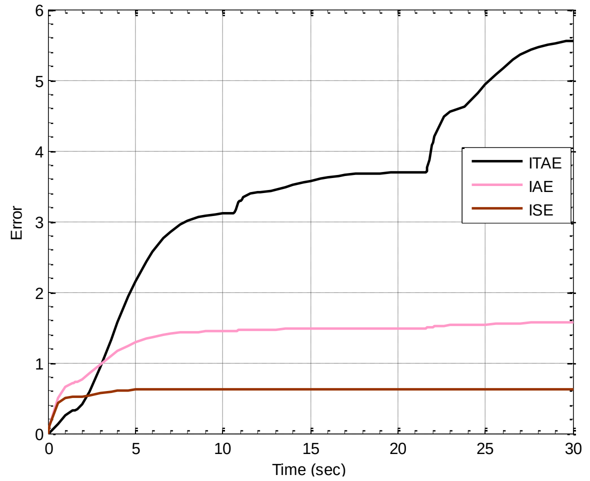

Fig -11: Error Response with PSO-PID

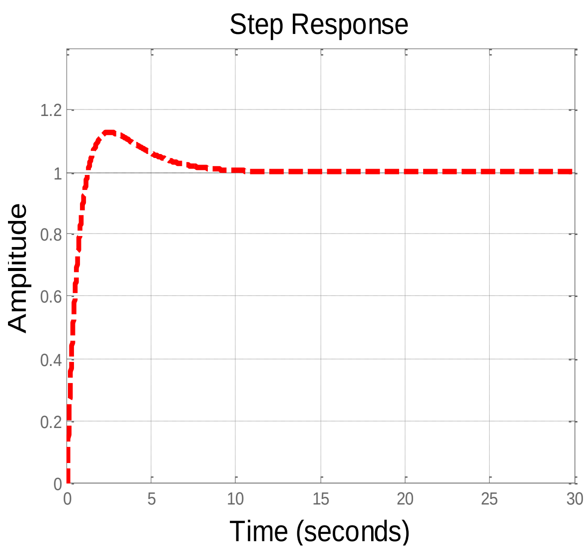

Fig -14: Step Response Based on GA-PID Controller

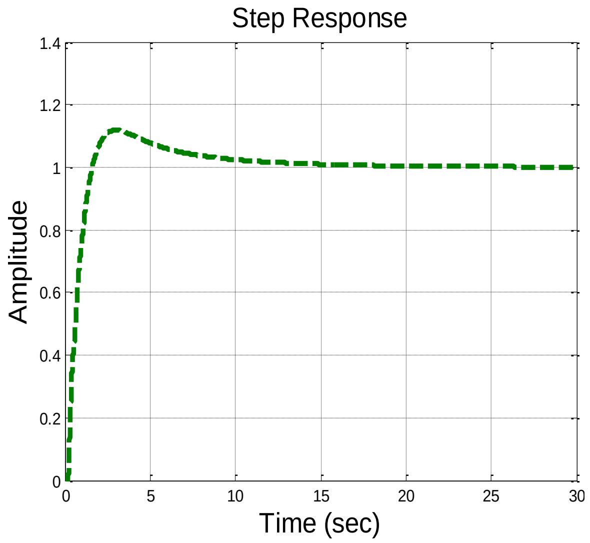

Fig -15: Step Response Based on GA-TID Controller

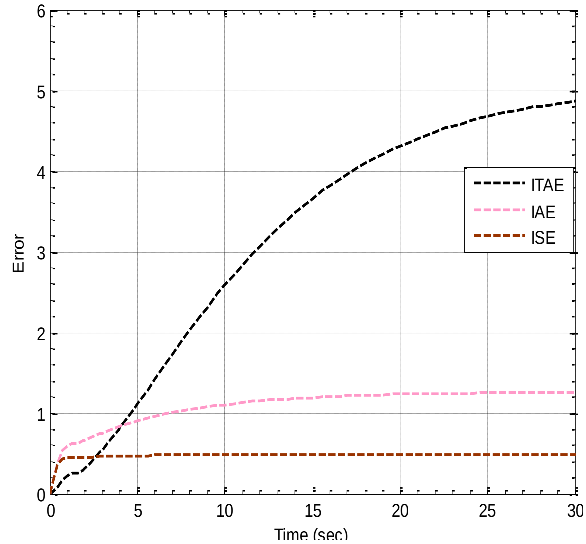

Fig -18: Error Response with GA-PID

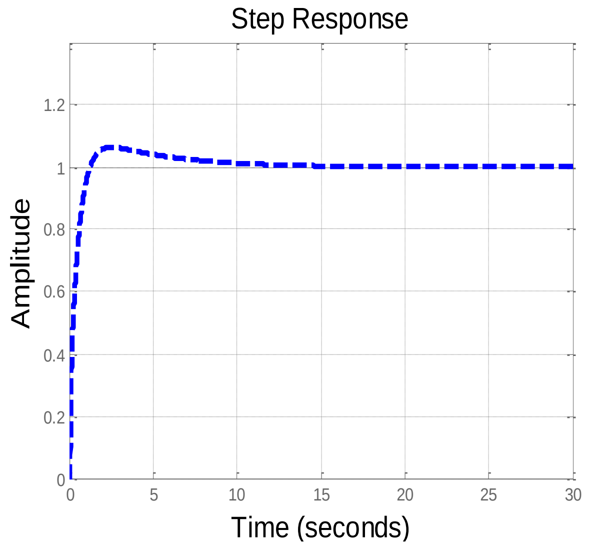

Fig -16: Step Response Based on GA-FOPID Controller

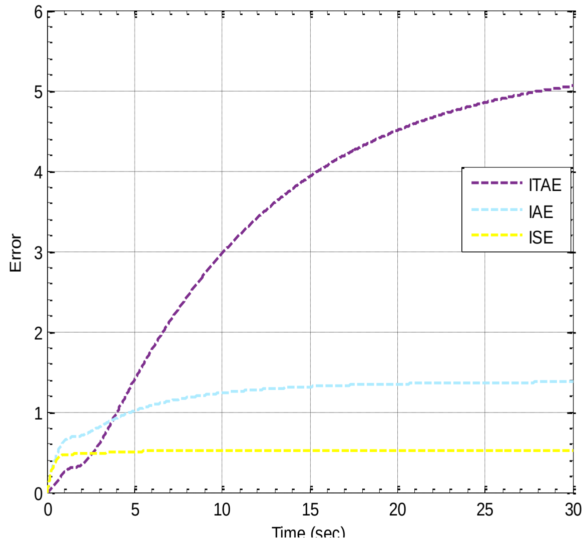

Fig -19: Error Response with GA-TID

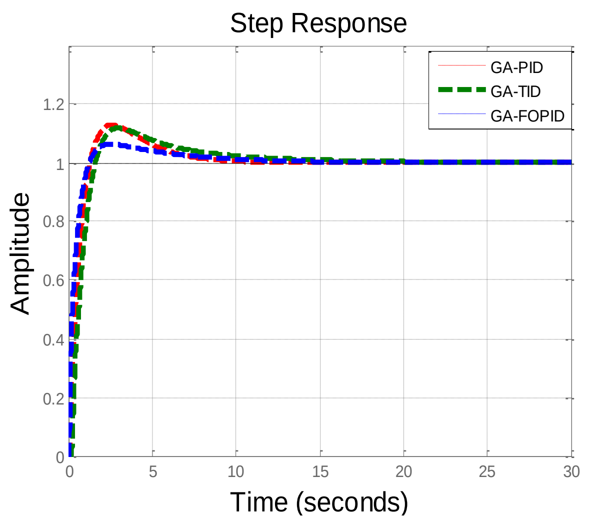

Fig -17: Overall Step Response Of The Process With PSO

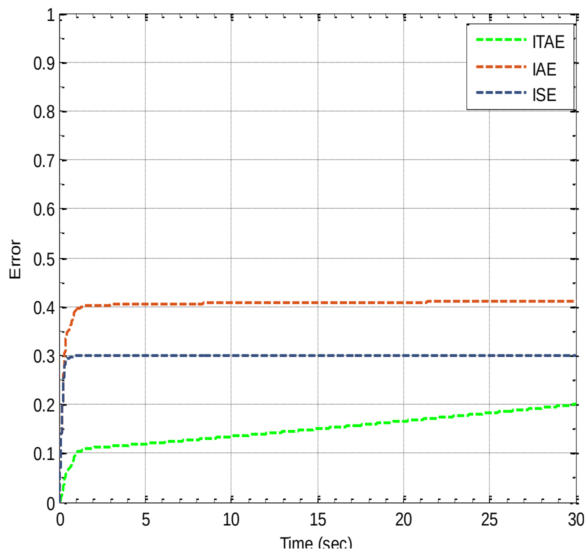

Fig -20: Error Response with GA-FOPID

Table -2: COMPARISON BETWEEN CLASSICAL PID, TID, AND FOPID

S.NO	SPECIFICATIONS	PSO-PID	PSO-TID	PSO-FOPID	GA-PID	GA-TID	GA-TID
01	PV	1.297 PU	1.258 PU	1.203 PU	1.128 PU	1.112 PU	1.063 PU
02	ST	9.697	9.242	7.421	6.939	6.931	5.563
03	RT	1.231	1.143	0.964	0.936	1.021	0.642
04	ESS	0.008	0.006	0.005	0.003	0.002	0.001
05	ITAE	5.556	4.425	2.227	4.866	5.057	0.1995
05	IAE	1.567	1.434	0.8777	1.254	1.371	0.4105
06	ISE	0.6285	0.5623	0.3312	0.482	0.519	0.2994

4. CONCLUSION

Without any interruption, the level of the liquid in the liquid tank needs continuous monitoring and control so to attain efficient product quality. In this paper, to achieve better output responses, PID, TID, and FOPID controllers with PSO and GA techniques are designed to maintain and regulate the process liquid level. Based on the output responses, the performance shown by the FOPID controller is far better than PID, and TID controllers in the case of both PSO and GA techniques. The time-domain specifications viz.- peak value, settling time, rise time, steady-state error, ITAE value, IAE value, and ISE value show superior performance with the GA-FOPID controller.

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