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# Differential Evolution Based PID Controller For Three Tank Level Process

**K.Vijaya Lakshmi, P.Srinivas, Sk.Harshad**

***Abstract:** This paper recommends to employ differential (DE) evolution algorithm for obtaining the optimum tuning parameters of PID controller, three tank level process. Optimal tuning improves the performance of the process in terms of time domain specifications. DE based PID controller is simulated using MATLAB/Simulink software. To fix the initial ranges of PID parameters in DE, PID controller is designed initially for this process. The responses of PID and DE based PID controller are compared and it is evident from the simulation results that the proposed controller outcompetes over conventional PID.*

***Index Terms:** Controller, Differential Evolution, level process, tuning, MATLAB/Simulink.*

## I. INTRODUCTION

Most of the process industries consists of a very vast, sensitive and time varying processes. Every process industry has different parameters such as level, flow, pressure, temperature etc. which has to be controlled efficiently for safe and effective operation of the plant. Liquid level is the one of the process parameters which has to be controlled accurately for the safe operation. Among the different liquid level systems, three tank liquid level process plays a major role in industries for fluid storage, recovery and dispensing. Due to fluid over flow or lack of proper fluid level, explosions or instrument damages may occur depending the fluid properties. To overcome these conditions, the fluids should be maintained at the required level. It is very difficult to handle such type of processes without implementing the proper controller strategy. One of the mostly used controller strategy in industries is conventional PID controller strategy for three tank liquid level process [1].

To satisfy the process requirement's the controller has to be tuned by using suitable tuning method. Conventional tuning methods like Ziegler Nichols (Z-N), Tyerus Luyben (T-L) or Cohen-Coon (C-C) methods are not much efficient as the optimal tuning methods. The PID parameters Kp, Ki, and Kd calculated from the Z-N method are used to estimate the bounds of the tuning parameters initially in the optimization algorithm. Evolutionary-based optimization techniques such as Genetic Algorithm (GA), Ant Colony Optimization (ACO), Artificial Bee Colony (ABC) algorithm, Differential Evolution (DE), Particle Swarm Optimization (PSO), Teaching Learning based Optimization (TLBO) etc. have been successfully practiced for controller tuning. Differential evolution is a heuristic algorithm with numerous applications which gives global optimum [2,3]. This paper aims at evaluating the controller optimum parameters for three tank level process using Differential Evolution (DE).

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* Correspondence Author (s)
**K.Vijaya Lakshmi***, Department of Electronics and Instrumentation Engineering, VR Siddhartha Engineering College, Vijayawada, India.
**P.Srinivas**, Department of Electronics and Instrumentation Engineering, VR Siddhartha Engineering College, Vijayawada, India.
**Sk.Harshad**, Department of Electronics and Instrumentation Engineering, VR Siddhartha Engineering College, Vijayawada, India.



## II. THREE TANK PROCESS MODEL

The mathematical model of three tank system (3TS) is developed using Bernoulli's law for liquids [4], [5], [6]. Fig. 1 shows the schematic diagram of three tank liquid level process.

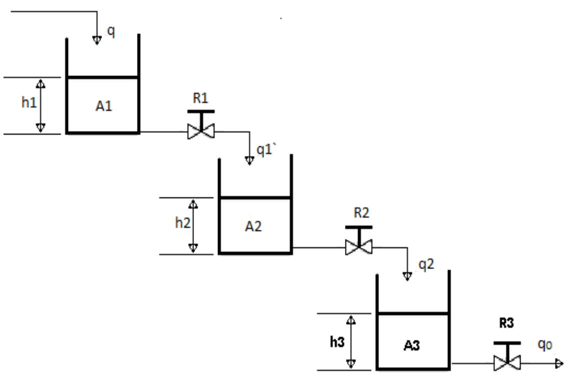


**Fig. 1. Three Tank Level Process**

Where q: Initial inlet flow rate of fluid
$q_0$: Final outlet flow rate of fluid

h1, h2, h3: Height of the fluids in three tanks respectively A1, A2, A3: Cross-sectional area of three tanks respectively. Final transfer function of three tank level process is given in (1).

$$G_p(s) = \frac{1}{(1+\tau_1 s)(1+\tau_2 s)(1+\tau_3 s)} \qquad (1)$$

Where $A_1R_1 = \tau_1$; $A_2R_2 = \tau_2$; $A_3R_3 = \tau_3$

"Equation (1) is considered as in (2) for simulation".


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$$G(s) = \frac{6}{(S+1)(S+2)(S+3)} \quad (2)$$

## III. PID CONTROLLER DESIGN

Conventional PID controllers are mostly used in process industries for controlling the different process parameters. When compared to the other controller structures it is simple to understand the PID structure. Fig. 2. shows the PID structure with a process which is to be controlled. The process considered here is three tank level process.

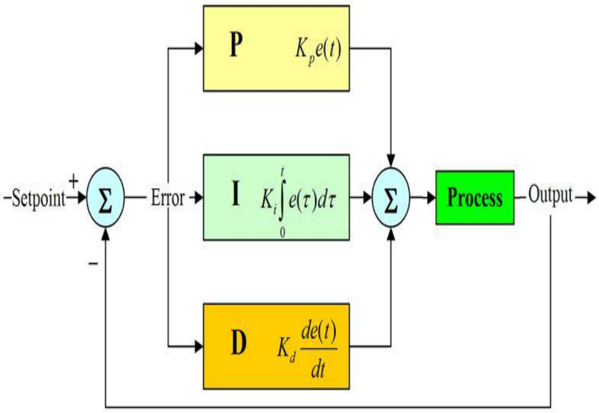


**Fig. 2. Structure of PID Controller**

There are different methods to represent PID controller. The most commonly used transfer function form of PID controller, as in (3).

$$G_c(s) = k_c(1 + \frac{1}{\tau_I s} + \tau_D s) \quad (3)$$

Where $K_C$, $T_I$ and $T_D$ are the tuning parameters of PID controller.

To obtain the optimal control action with the PID controller the PID parameters has to be tuned properly. There are different techniques available to tune the PID parameters perfectly. The most commonly used tuning method is Ziegler-Nichols (ZN) tuning method because its simplicity. It is developed based on the study of several thousand processes. According to the Z-N method, to tune the PID controller first keep the controller in P only mode and increase the gain until the sustained oscillations are exhibited by the process. The value of gain where the process exhibits sustained oscillations is known as ultimate gain *Ku* and the period of oscillations are denoted as ultimate period *Pu*. By the values of *Ku* and *Pu* corresponding parameters of the PID controller are obtained with the help of Ziegler-Nichols tuning Table I [7].

**TABLE I ZIEGLER-NICHOLS TUNING**

| Controller | $K_C$ | $T_I$ | $T_D$ |
|---|---|---|---|
| P | 0.5 $K_u$ | - | - |
| PI | 0.45 $K_u$ | 0.833 $P_u$ | - |
| PID | 0.6 $K_u$ | 0.5 $P_u$ | 0.125 $P_u$ |

For the three-tank level process, the values obtained are $K_u$=10 and $P_u$ =1.8944. By using Ziegler-Nichols tuning method the respective tuning parameters are $K_p$= 6, $K_i$ = 6.334 & $K_d$= 1.4208.

## IV. DE BASED PID CONTROLLER DESIGN

### A. Introduction

To control various process parameters like temperature, level, flow, pressure etc., most of the industries mainly focused on the PID controllers because of its advantages. Lower cost and easy maintenance are main reasons for selecting the PID controller. To exhibit the optimal control action, it is necessary to tune the controller [8]. If controller is not tuned effectively poor performance characteristics may occur like overshoot, peak time, rise time, settling time and robustness. Tuning is done only for to avoiding the difficulties in particular operating conditions

optimum PID tuning parameters need to be determined using evolutionary algorithms like GA, DE etc. or swarm intelligence based algorithms like PSO, ABC, ACO etc. These algorithms even work if there is a variation in the operating conditions [9].

### B. DE Algorithm

Differential Evolution (DE) is a recent, heuristic, population based optimization algorithm to identify a global optimum by minimizing the objective function. It is simple, fast convergence and robust. GA rely on crossover whereas DE employs mutation as main search mechanism [10]. In DE, weighted differences between solution vectors are used to deviate the population. Unlike genetic algorithms, which uses binary coding of the population, DE uses real coding [11].

The steps in the implementation of DE algorithm are as follows [12]:

Step-1 Assume the DE control parameters. Initialize the population of individuals with random positions. Target vectors in generation 0 are given as in (4).

$$X_i^{\,0} = Xmin + (Xmax - Xmin) * rand \quad (4)$$

Step-2: Evaluate the fitness function value for every particle.

Step-3(Mutation): A donor vector is generated by adding the weighted difference between two vectors to a third vector. Based on current individual's $X_i^{\,G}$, mutant vector is generated, as in (5).

$$Y_i^{\,G+1} = X_i^{\,G} + F\,((X_{r1}^{\,G} - X_{r2}^{\,G}) + (X_{r3}^{\,G} - X_{r4}^{\,G})) \quad (5)$$

Where F is mutant factor (between 0 & 1). r1 to r4 are mutually different points chosen from the population randomly and must not be equal to the mutant factor.

Step-4(Crossover or Recombination): The mutant vectors are merged with the target vector to create a trial vector, as in (6). Each generation of the ith individual is reproduced from mutant vector $Y_i^{\,G+1}$ and current individual $X_i^{\,G}$.

$$Y_{hi}^{\,G+1} = \begin{cases} X_{hi}^{\,G}, & if\ a\ random\ number > CR \\ Y_{hi}^{\,G+1}, & otherwise \end{cases} \quad (6)$$

Where CR is called crossover probability

Step-5(Selection): Every single solution in the population have an equal possibility of being chosen as a parent regardless of its fitness value.


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The fitness of offspring obtained after these two steps is calculated and compared with its parent and superior one is selected.

Step-6: Steps 2 to 5 are repeated until the desired fitness is achieved.

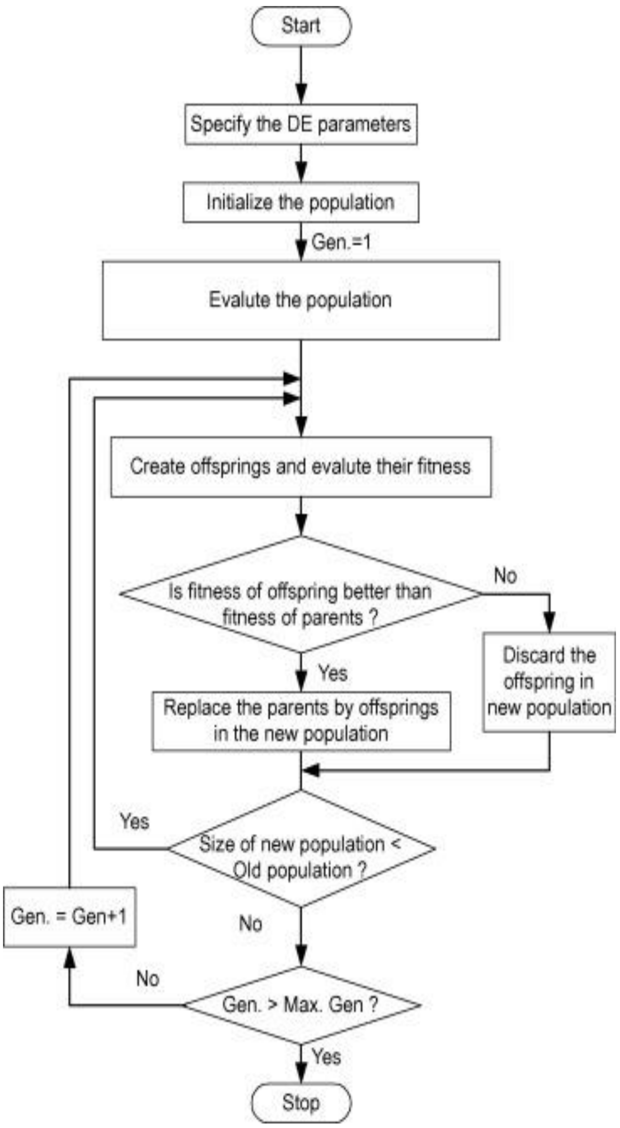


**Fig. 3. DE Flow Chart**

## C. Fitness Function

The three parameters of PID are considered as three dimensions to be optimized for best results. Each specific point in search space represents a specific value of [Kp Ki Kd] which in turn gives a specific response. Fitness function determines the performance of that point [13]. The fitness functions considered to evaluate the fitness of PID parameters for three tank level process are Integral Time-weighted Absolute Error (ITAE), Integral Squared Error (ISE) and Mean Squared Error (MSE), as in (7), (8) & (9).

$$ISE=\int e^2 dt \qquad (7)$$

$$ITAE=\int t*|e|dt \qquad (8)$$

$$MSE=\frac{\sum_0^n e2}{n} \qquad (9)$$

## V. SIMULATION RESULTS AND COMPARISON

### A. Implementation of PID Controller

By using MATLAB/Simulink software, the PID controller is designed for controlling the three-tank level process. The response of the process for unit step input is shown in Fig. 4. From the response, time domain specifications are observed and tabulated in Table II. With PID controller, huge rise time, peak amplitude and peak overshoot are observed.

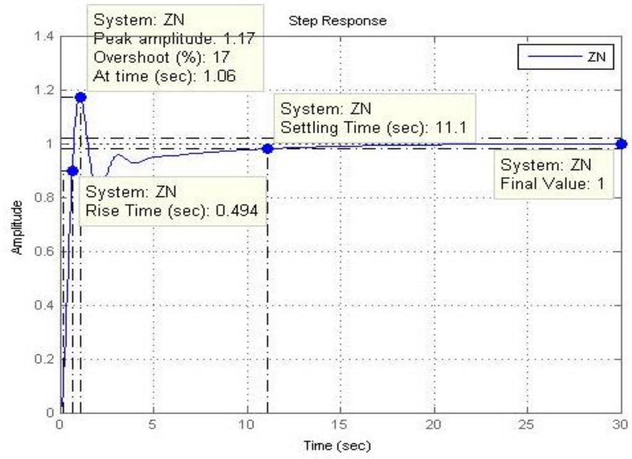


**Fig. 5. Process Response using conventional PID controller**

### B. Implementation of DE based PID Controller

By using MATLAB/Simulink software, DE based PID controller is designed for controlling the three-tank level process. The algorithm is executed for 100 iterations. The process response for unit step input with ITAE, MSE and ISE criteria are shown in Fig. 6, 7 and 8 respectively. From the response, time domain specifications are observed and tabulated in Table II.

With DE based PID controller, considerable rise time, peak amplitude and peak overshoot are observed compared to PID controller. However, peak time and settling time are the shortcomings of proposed controller when related to PID.

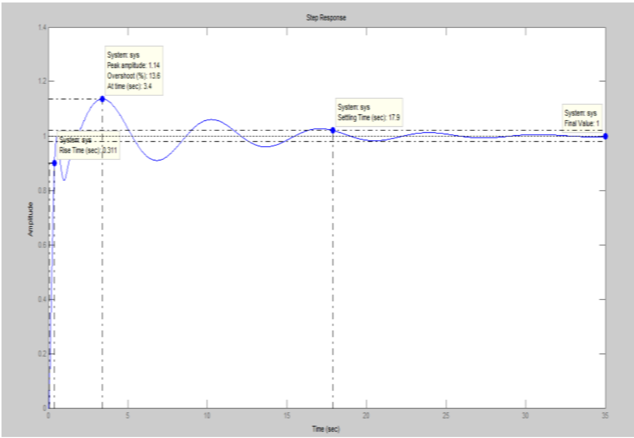

**Fig. 6. Process Response using DE based PID Controller with ITAE**


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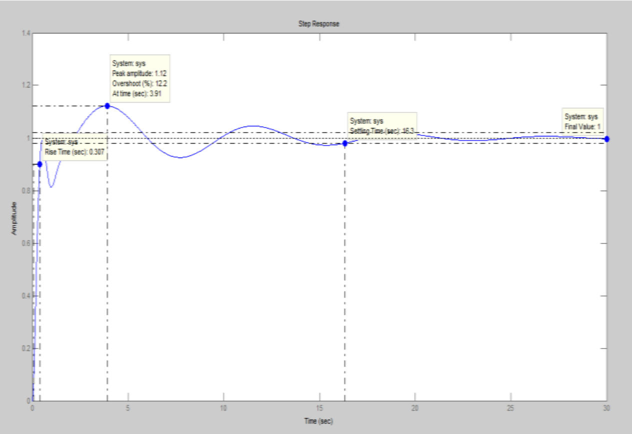

**Fig. 7. Process Response using DE based PID Controller with MSE**

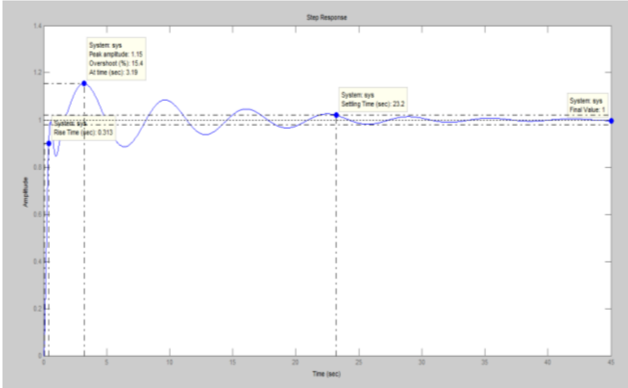

**Fig. 8. Process Response using DE based PID Controller with ISE**

### C. Comparison of Reponses of Z-N and DE based PID Controllers

The responses of Z-N and DE tuned PID controllers to unit step input for three tank level process are compared and shown in TABLE II. It is proved from the results that DE based PID controller with MSE criteria shows better performance over other controller designs.

**TABLE II COMPARISON OF RESPONSES USING PID & DE BASED PID CONTROLLERS**

| Criteria | Ki | Kd | Kp | % overshoot | Peak Amplitude | Settling Time (s) | Rise Time (s) | Peak Time (s) |
|---|---|---|---|---|---|---|---|---|
| ZN (PID) | 1.4208 | 6.334 | 6 | 17 | 1.17 | 11.1 | 0.494 | 1.06 |
| ITAE | 1.5629 | 5.8649 | 6.2886 | 13.6 | 1.14 | 17.9 | 0.311 | 3.4 |
| MSE | 1.5854 | 5.9681 | 5.1529 | 12.2 | 1.12 | 16.3 | 0.307 | 3.91 |
| ISE | 1.3064 | 5.8542 | 7.0678 | 15.4 | 1.15 | 23.2 | 0.313 | 3.19 |

## VI. CONCLUSION

An efficient method for level control of 3TS using DE-based PID algorithm is recommended in this paper. The simulated results show the superiority of DE-PID using MSE criteria over conventional PID controller with respect to rise time, peak amplitude and peak overshoot. But as the settling time is slightly increased with proposed intelligent controller, the system is slightly sluggish in nature. So in applications where initial response and stability are required, this method can be useful.

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## AUTHORS PROFILE

**Korupu Vijaya Lakshmi** was born in Visakhapatnam, India, in 1982. She received the B.Tech degree in Instrumentation Technology from VR Siddhartha Engineering College, Vijayawada, India, in 2003, and the M.Tech. degree in Industrial Process Instrumentation from the Andhra University, Visakhapatnam, India, in 2006. She is a research scholar at VIT, Vellore joined in the year 2017. She is currently working as an Assistant Professor in the Department of Electronics and Instrumentation Engineering, VR Siddhartha Engineering College, Vijayawada. She has 9 years of teaching experience and a number of technical publications in peer reviewed journals. Her current research interests include process control, process modelling and simulation, neural networks and optimization techniques.

Mrs. Korupu is a Life Member of the Instrument Society of India (ISOI) and the Biomedical Engineering Society of India (BMESI).

**Paruchuri Srinivas,** was born in Andhra pradesh, India, in 1970. He received the M.Tech. Degree in Electronic Instrumentation from NIT Warangal, India, in 1992. He is a research scholar at Andhra University, Visakhapatnam. In 1993, he joined the Department of Electrical and Electronics Engineering, VR Siddhartha Engineering College, Vijayawada, as a Lecturer and currently he is an Associate Professor in Electronics & Instrumentation Engineering in the same college. He has 20 years of teaching experience and a number of technical publications in peer reviewed journals. His current research interests include control systems and optimization techniques. He is a Life Member of Indian Society technical Education (ISTE), the Instrument Society of India (ISOI) and the Biomedical Engineering Society of India (BMESI).

**Sk.Harshad,** was born in Andhra pradesh, India, in 1996. He is currently pursuing final year B.Tech at VR Siddhartha Engineering College, Vijayawada. He worked as trainee assistant engineer at POLMON INSTRUMENTS Pvt. Ltd, Hyderabad for a period of one year. He has done a project in the area of process control at Central Leather Research Institute (CLRI), Chennai. He is a Member of Instrument Society of India (ISOI).


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