IJAREEIE

e-ISSN: 2278-8875
p-ISSN: 2320-3765

International Journal of Advanced Research in Electrical, Electronics and Instrumentation Engineering

Volume 11, Issue 1, January 2022

INTERNATIONAL STANDARD SERIAL NUMBER INDIA

Impact Factor: 7.282

International Journal of Advanced Research in Electrical, Electronics and Instrumentation Engineering (IJAREEIE)

| e-ISSN: 2278 – 8875, p-ISSN: 2320 – 3765| www.ijareeie.com | Impact Factor: 7.282|

|| Volume 11, Issue 1, January 2022 ||

DOI:10.15662/IJAREEIE.2022.1101017

Performance Analysis of Coupled Tank System using I-PD Controller

C.Ravikumar[1], M.Vinodhini[2]

Associate Professor, Department of ICE, A.V.C. College of Engineering, Mayiladuthurai, Tamilnadu, India[1]

Assistant Professor, Department of ICE, A.V.C. College of Engineering, Mayiladuthurai, Tamilnadu, India[2]

ABSTRACT: The objective of this paper is to investigate the performance of I-PD controller used to control the level of coupled tank, which is good example for an uncertain system. The variable to be controlled is the liquid level in tank2; the manipulated variable is inflow of tank1. The response of the I-PD controller is compared with PID controller designed based on Small gain theorem that will guarantee the closed loop stability. The performance of the controllers is evaluated using various parameters such as ISE, Settling time and percentage overshoot and simulation is carried out with the help of MATLAB Simulink software.

KEYWORDS:I-PD controller, Small gain theorem, Coupled Tank system, closed loop stability, uncertain system.

I.INTRODUCTION

The control of liquid level in tanks and flow between tanks is the most common control problem in the process industries such as petroleum refinery, paper and cement industry, water treatment plants and food processing industries. A common tank system required the controller to maintain the level of the liquid in desired level. A number of conventional controllers are being used in a process industry which exploits several tuning methods for obtaining appropriate control parameters.

The main objective of this paper is to determine the mathematical model of a coupled tank system which will be useful for designing and tuning the controllers. Here comparative analysis of the transient response obtained by different controllers- Robust PID controller using small gain theorem and I-PD Controller has been done using MATLAB Simulink software.

Modeling of the processes is very difficult but it is the basic requirement in the design of controller. Difficulties in modeling are due to more complex system, poorly understood phenomena, effects of reduced model order, ignorance of certain factors like non-linearity and time delay, unknown disturbance and noise input. All these factors indicate the necessity of having controller which should work even if the actual system deviates from its ideal system and also it should give a stable closed-loop system. The controller designed considering uncertainty in a process and closed-loop stability is known as robust controller.

Robust controllers can be designed using various approaches. Robust controller design using Edge Theorem is presented in [2]. The optimal control approach is used to design robust controllers in [3]. Dubravska M. and Harsanyi L. [4, 5] have proposed robust controller design procedure for uncertain system. In [6] the author presented robust controller design for uncertain plant with bounded parameters using Kharitonov theorem.

The main downside of PID controller is setpoint kick off. This will damage the final control element like control valve, motor. To eliminate such a disadvantage, the derivative action is introduced in the feedback path in I-PD controller which will improve the system response. The I-PD Control action can be used in any physical systems that uses closed loop control of output variable. It can therefore be applied for temperature, level , flow, pressure, speed, position control systems etc.

Many researchers [7-13] proposed I-PD tuning rules for various stable and non-linear Processes by different methods to improve closed loop response.

The paper is organized as follows. The modeling of the process is described in detail following the general methodology. Then the design of controllers is presented for the two tank process. The results and conclusion are

| e-ISSN: 2278 – 8875, p-ISSN: 2320 – 3765| www.ijareeie.com | Impact Factor: 7.282|

|| Volume 11, Issue 1, January 2022 ||

DOI:10.15662/IJAREEIE.2022.1101017

presented following controller design.The control of liquid level in tanks and flow between tanks is the most common control problem in the process industries such as petroleum refinery, paper and cement industry, water treatment plants and food processing industries. A common tank system required the controller to maintain the level of the liquid in desired level. A number of conventional controllers are being used in a process industry which exploits several tuning methods for obtaining appropriate control parameters.

The main objective of this paper is to determine the mathematical model of a coupled tank system which will be useful for designing and tuning the controllers. Here comparative analysis of the transient response obtained by different controllers- Robust PID controller using small gain theorem and I-PD Controller has been done using MATLAB Simulink software.

Modeling of the processes is very difficult but it is the basic requirement in the design of controller. Difficulties in modeling are due to more complex system, poorly understood phenomena, effects of reduced model order, ignorance of certain factors like non-linearity and time delay, unknown disturbance and noise input. All these factors indicate the necessity of having controller which should work even if the actual system deviates from its ideal system and also it should give a stable closed-loop system. The controller designed considering uncertainty in a process and closed-loop stability is known as robust controller.

Robust controllers can be designed using various approaches. Robust controller design using Edge Theorem is presented in [2]. The optimal control approach is used to design robust controllers in [3]. Dubravska M. and Harsanyi L. [4, 5] have proposed robust controller design procedure for uncertain system. In [6] the author presented robust controller design for uncertain plant with bounded parameters using Kharitonov theorem.

The main downside of PID controller is setpoint kick off. This will damage the final control element like control valve, motor. To eliminate such a disadvantage, the derivative action is introduced in the feedback path in I-PD controller which will improve the system response. The I-PD Control action can be used in any physical systems that uses closed loop control of output variable. It can therefore be applied for temperature, level , flow, pressure, speed, position control systems etc.

Many researchers [7-13] proposed I-PD tuning rules for various stable and non-linear Processes by different methods to improve closed loop response.
The paper is organized as follows. The modeling of the process is described in detail following the general methodology. Then the design of controllers is presented for the two tank process. The results and conclusion are presented following controller design.

II.METHODOLOGY

A. *Small Gain Theorem*
One form of uncertainty in dynamical systems is parametric uncertainty in which the parameters describing the system are unknown. A SISO uncertain system G(s) described by a family of transfer functions and being controlled by a controller C(s) as shown in Fig.1 the loop transfer function is given by,

$$L(s) = C(s)\,G(s). \quad (1)$$

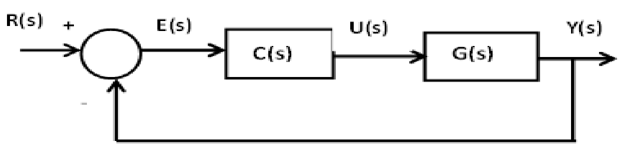


Fig.1 Closed loop control system

The Small Gain theorem states that, if the magnitude of the loop gain is less than one then, the closed loop system is robustly stable. Hence for closed loop robust stability,

$$|L(s)| < 1 \text{ for all } \omega \in [0, \infty]. \quad (2)$$

If the plant to be controlled is uncertain and described by a number of stable transfer function be $G_0(s)$. Then the perturbed system can be represented in the form of an unstructured additive uncertainty as shown in Fig (2). $W_a(s)$

| e-ISSN: 2278 – 8875, p-ISSN: 2320 – 3765| www.ijareeie.com | Impact Factor: 7.282|

|| Volume 11, Issue 1, January 2022 ||

DOI:10.15662/IJAREEIE.2022.1101017

Represents the weighting transfer function and Δ(s) represents a set of transfer functions with peak magnitudes less than or equal to one for all frequencies.

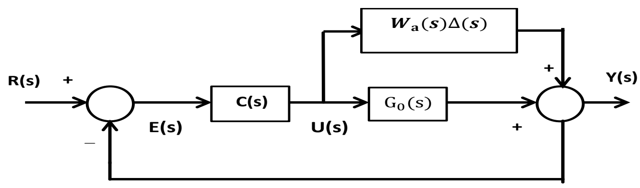


Fig. 2 Closed loop uncertain system

Following the design procedure presented in [1] the controller parameters can be determined as below,
$K_d = n_d/K$, $K_p = n_p/K$, $K_i = n_i/K$ (3)

B. I-PD Controller
It is the modified structure of PID controller that is mentioned as a brilliant PID controller which reduces peak overshoot. In I-PD controller the integral term is acting on the error e(t) and the proportional plus derivative term is acting on the process variable y(t).
The output of the controller is given by

$$u(t) = K_p\,[T_i \int e(t)dt - (y(t) + T_d \frac{dy(t)}{dt})] \quad (4)$$

Where,

K_p - Proportional gain
T_i - Integral time
T_d - Derivative time

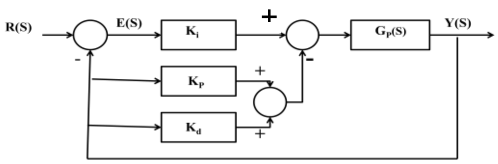


Fig. 3Block diagram of I-PD Controller

III. DESCRIPTION OF THE PROCESS

The Liquid tank process plays an important role in industrial application such as food processing, filtration, industrial chemical processing, spray coating and pharmaceutical industries. Many industrial applications are concerned with liquid level control, It may be a single loop level control or sometimes multi loop level control.
In this work coupled tank is considered as a SISO system with h_2 as process variable and q_{in1} as the manipulated variable. The apparatus consists of two tanks (Fig **(4**)), which can be coupled using valve q_{12} (the manual valve). Therefore the coupled tank process with two tanks represents a multi-input multi-output (MIMO) system for opened valve q_{12} or two independent single input single output (SISO) systems for closed valveq_{12}.

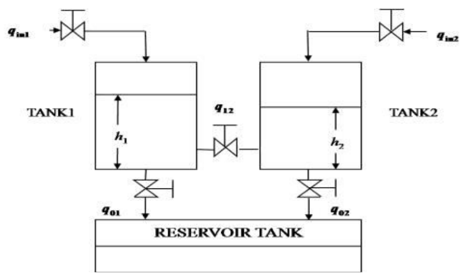


Fig. 4 Coupled Tank Process

The mass balance equation of the tank process is given by,

$$\frac{dh_1}{dt} = \frac{q_{in1}}{A_1} - \frac{a_1}{A_1}\sqrt{2gh_1} - \frac{a_{12}}{A_1}\sqrt{2g[h_1 - h_2]} \quad (5)$$

| e-ISSN: 2278 – 8875, p-ISSN: 2320 – 3765| www.ijareeie.com | Impact Factor: 7.282|

|| Volume 11, Issue 1, January 2022 ||

DOI:10.15662/IJAREEIE.2022.1101017

$$\frac{dh_2}{dt} = \frac{q_{in2}}{A_2} - \frac{a_2}{A_2}\sqrt{2gh_2} + \frac{a_{12}}{A_2}\sqrt{2g[h_1-h_2]} \quad (6)$$

Where,

q_{in1}&q_{in2} – Inflow to the tank1&2

$h_{1\&h_2}$-Height of tank1&2

A_1&A_2- Area of tank1&2

a_1&a_2- Area of the pipe outlet1&2

a_{12} – Area of the pipe connecting Tank1&Tank2

g – Acceleration due to gravity

The white box model is developed using SIMULINK software with the following specifications:

A_1andA_2 = 1130.4cm^2

$h_1$andh_2 = 25 cm

$a_1$anda_2 = 7.8cm^2

a_{12} = 1.274cm^2

Maximum q_{in1} = 100 LPH

The operating condition of the process is fixed as,

q_{in1} = 50LPH

h_1 = 11.85cm

With the area of the outlets of tank1&tank2 as

a_1 = 5cm^2

a_2 = 0.5cm^2 and

a_{12} = 1.274cm^2

The studies are carried out using three different operating conditions for the chosen process so as to understand the complete characteristics of the process and also to test the stability conditions.

For Performance analysis the following open loop responses are obtained in this work, i) Nominal model of the process is considered under normal operating condition with 50 % input, ii) open loop response with 10 % change in input in both the directions from nominal value.The nominal model of the process is obtained using step test signal under nominal operating condition as shown in fig (5).

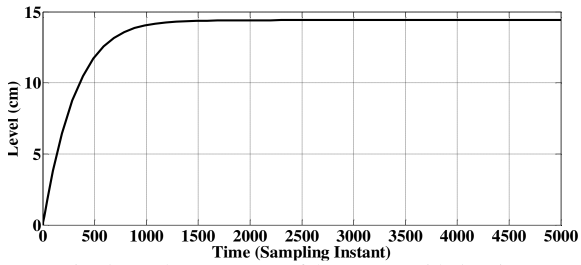


Fig. 5Open loop response of the process with 50% input

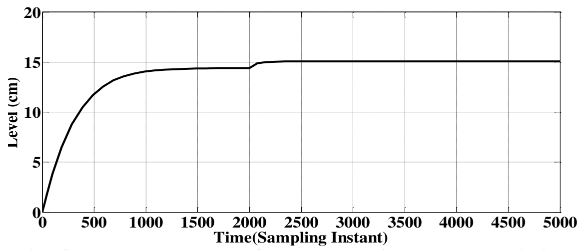


Fig. 6Open loop response of the process with 10% change in input from Nominal operating condition

| e-ISSN: 2278 – 8875, p-ISSN: 2320 – 3765| www.ijareeie.com | Impact Factor: 7.282|

|| Volume 11, Issue 1, January 2022 ||

DOI:10.15662/IJAREEIE.2022.1101017

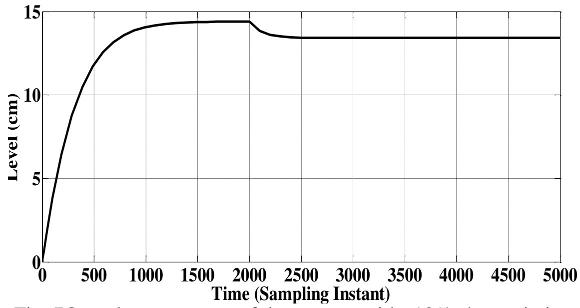


Fig. 7Open loop response of the process with -10% change in input from Nominal operating condition

Corresponding transfer functions are,

$G_0(s) = \frac{28.8}{29.6s^2+14.7s+1}$ (Nominal Model)

$G_1(s) = \frac{6.5}{609.5s^2+69.7s+1}$ (10% change in input from operating condition)

$G_2(s) = \frac{10}{627.13s^2+113.75s+1}$ (-10% change in input from operating condition)

IV.DESIGN OF CONTROLLERS

A. Robust PID Controller

From figure (2),

$G(s) = G_0(s) + Wa(s).\,\Delta(s)$ (7)

if $|\Delta(s)| \leq 1$ then, $|Wa(s)\,.\,\Delta(s)| \leq |Wa(s)|$ (8)

The weighting transfer function is chosen such that the following condition is satisfied.

$|Wa(s)| \geq \text{Max}\,|G_k(s)-G_0(s)|$ for all $\omega \in [0, \infty]$ (9)

where k = 1, 2, 3, ... n

$G_k(s)$ represents the set of n stable transfer functions describing the uncertain system.

The nominal model of the coupled tank process is given by,

$G_0(s) = G_{0c}(s)/G_{0m}(s)$ (10)

Let the PID controllerto be designed be given by,

$C(s) = C_c(s)/C_m(s) = (n_d s^2 + n_p s + n_i)/Ks$ (11)

Using the design procedure, the PID controller parameters are determined and given below,

$n_p = 88.20$; $n_i = 1$; $n_d = 1$ (12)

K=1 and suitable W_a is selected so that the stability condition said in [1] $|G_{NCL}(s)| < |G_0(s)/W_a(s)|$ is satisfied.

B. I-PD Controller

I-PD controller parameters for each condition are obtained using Ziegler Nichol's tuning method. The controller parameter values of each condition are given in the table 1.

Condition	K_p	T_i	T_d
Nominal Condition	6.94	4.44	1.11
10% change in input	7.53	19.4	4.85
-10% change in input	22.02	11.8	2.95

Table 1. Tuning parameters of I-PD controller.

V. RESULT AND DISCUSSION

The coupled tank process is represented as white box model and executed using SIMULINK software. The process is maintained at nominal operating condition and the servo and regulatory responses are obtained using robust PID and I-PD controllers for a change in setpoint of 2cm in both the directions. These responses are presented in Fig. (8-10).

| e-ISSN: 2278 – 8875, p-ISSN: 2320 – 3765| www.ijareeie.com | Impact Factor: 7.282|

|| Volume 11, Issue 1, January 2022 ||

DOI:10.15662/IJAREEIE.2022.1101017

The response for setpoint tracking in both directions are presented in Fig.(11 to 13). The performance of the process with two different controllers is evaluated using Settling time, ISE, Rise time.

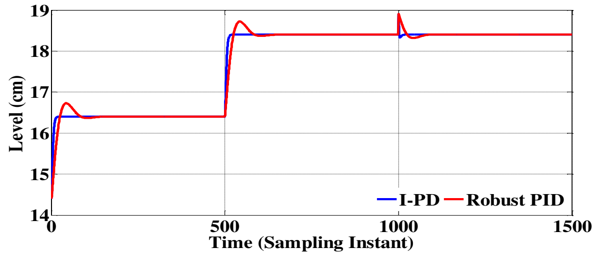


Fig. 8Servo responses of the process with I-PD and robust PIDcontrollers (Under nominal operating condition).

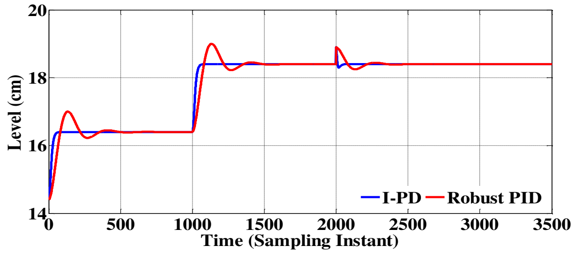


Fig. 9 Servo responses of the process with I-PD and robust PID controllers (Model with 10% change in input).

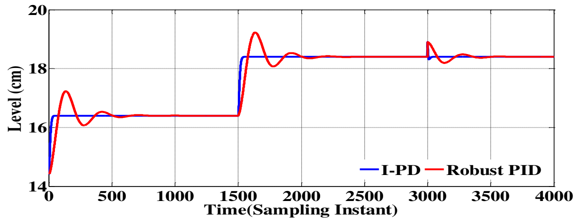


Fig. 10 servo and regulatory responses of the process with I-PD and robust PID controllers (Model with -10% change in input).

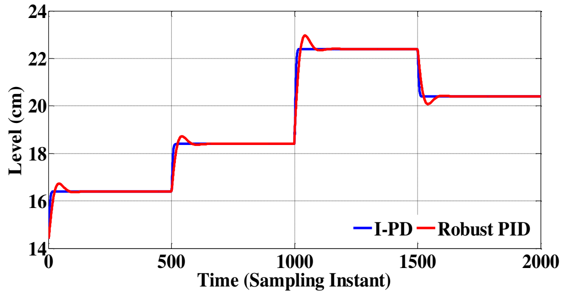


Fig. 11Set Point Tracking responseswith I-PD and robust PID controllers (under nominal operating condition).

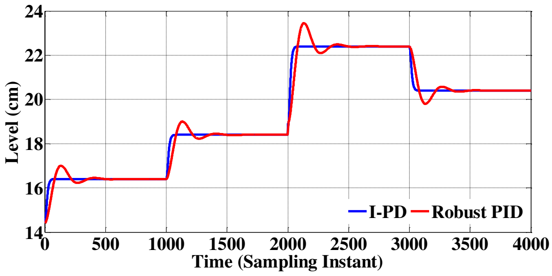


Fig. 12Set Point Tracking responseswith I-PD and robust PID controllers (Model with 10% change in input).

| e-ISSN: 2278 – 8875, p-ISSN: 2320 – 3765| www.ijareeie.com | Impact Factor: 7.282|

|| Volume 11, Issue 1, January 2022 ||

DOI:10.15662/IJAREEIE.2022.1101017

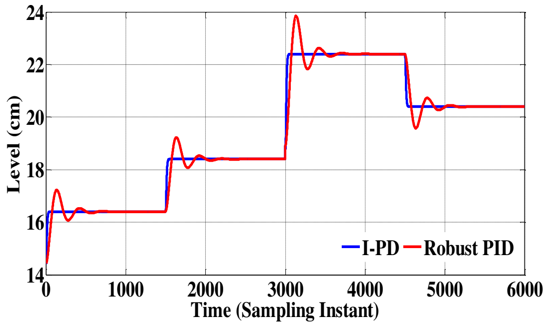


Fig. 13 Set Point Tracking responseswith I-PD and robust PID controllers (Model with -10% change in input).

	I-PD Controller			Robust PID Controller		
Condition	Settling Time	Rise Time	ISE	Settling Time	Rise Time	ISE
Nominal Operating Condition	30	24.5	11.46	260	208	33.07
10% change in input	100	95	54.29	800	635	171.1
-10% change in input	60	55	31.64	1100	800	196.7

Table 2. Performance Evaluation of the process with designed controllers.

VI.CONCLUSION

The I-PD Controller and Robust PID controller using Small Gain Theorem is designed and implemented over coupled tank process. I-PD controller performance is compared with Robust PID controller. The simulation is carried out in MATLAB SIMULINK platform. The simulation results are presented along with performance evaluation Table 2. It is observed from the results that the performance of the process with I-PD controller is better than robust PID controller in terms of settling time, in view of peak overshoot, settling time, Rise time and ISE. In I-PD Controller, the percentage overshoot is eliminated and less settling time when compared with robust PID controller.

REFERENCES

[1] SupannaS.Kumar, C. Shreesha, "Robust Controller Design for Uncertain Systems,'' International journal of scientific engineering and technology, vol. 3, no.2, pp. 207-210, February 2014.

[2] Ivan Holic, VojtechVesely, "Robust PID Controller Design for Coupled Tank Process,"18th International Conference on Process Control, June 2011.

[3] Feng Lin, "An Optimal Control Approach to Robust Control Design," INT. J. CONTROL, vol.73, no.3, pp.177-186.

[4] L. Harsanyi, M. Dubravska, "Robust Controller Design for Linear Systems with Parametric and Dynamic Uncertainties", J. Electrical Engineering, 52 No. 9-10, pp. 307-310, 2001.

[5] Maria Dubravska and LadislavHarsanyi, "Control of Uncertain systems", Journal of Electrical Engineering, Vol. 58, No. 4, pp. 228-231, 2007.

[6] Ying J. Huang and Yuan-Jay Wang, "Robust PID tuning strategy for uncertain plants based on the Kharitonov theorem", ISA Transactions 39, pp. 419-431, 2000.

[7] S.MeenaK.Chitra and R.VijayAnand,"Development of I-PD controller on embedded platform,"International conference on signal processing, communication, power and embedded system, SCOPES-2016.

[8] SisirMazumder, SusovanDutta, "Analytical study and designing of a I-PD Controller (a Practical Modified PID Controller) for a third order system using MATLAB simulation," International Journal of Engineering Research and general science, vol3, Issue 1, Jan-Feb 2015.

[9] Morimasa OGAWA, Tohru KATAYAMA, "A Robust Tuning method for I-PD controller incorporating a constraint on Manipulated Variable," Trans. of the Society of Instrument and Control Engineers, vol.E-1, no.1, 265/273 (2001).

| e-ISSN: 2278 – 8875, p-ISSN: 2320 – 3765| www.ijareeie.com | Impact Factor: 7.282|

|| Volume 11, Issue 1, January 2022 ||

DOI:10.15662/IJAREEIE.2022.1101017

[10] S. J. Suji Prasad, P. A. Balakrishnan, "PSO Based I-PD Controller for Barrel Temperature Control in Plastic Injection Molding System,"European Journal of Scientific Research, ISSN 1450-216X, vol.80, no.3 (2012), pp.351-357.

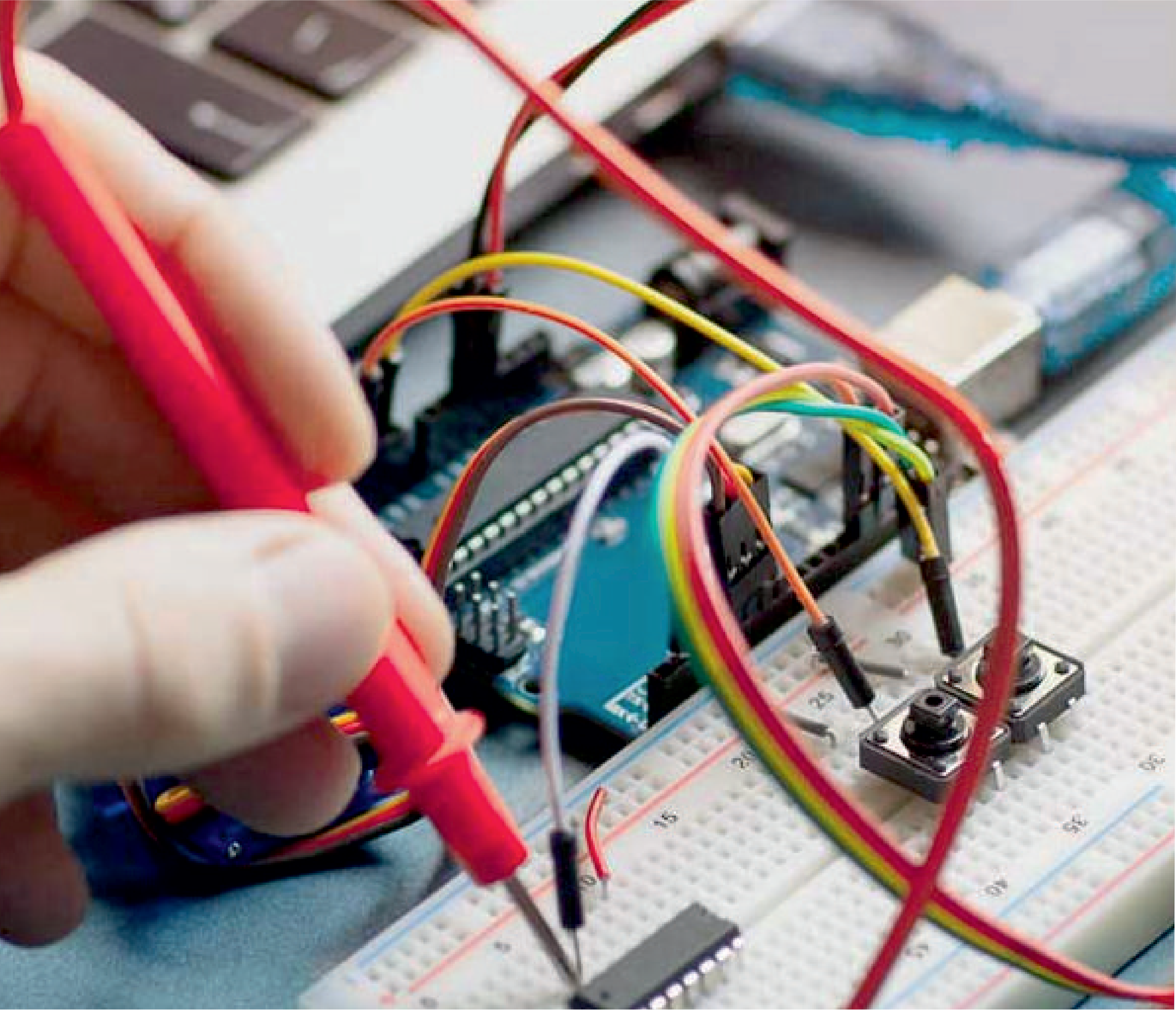
[11] Galal A. Hassaan, "Robustness of I-PD, PD-PI and PI-PD Controllers Used with Second-Order Processes," International Journal of Scientific & Technology Research, ISSN 2277-8616, vol 3, Issue 10, October 2014.

[12] V.Rajinikanth, K.Latha, "I-PD Controller Tuning for Unstable System Using Bacterial Foraging Algorithm: A Study Based on Various Error Criterion," Applied Computational Intelligence and Soft Computing, 2012.

[13] D. Dinesh Kumar, B. Meenakshipriya and S. Sakthiya Ram, "Design of PSO based I-PD Controller and PID Controller for a Spherical Tank System" Indian Journal of Science and Technology, vol 9(12), ISSN: 0974-5645, March 2016.

[14] KalyanChakravarthi M, Pannem K Vinay and NithyaVenkatesan, "Design and Simulation of Internal Model Controller for a Real Time Nonlinear Process," Indian Journal of Science and Technology, August 2015.

[15] Aidan O'Dwyer, "Handbook of PI and PID Controller Tuning Rules," 2nd edition.



INNO SPACE
SJIF Scientific Journal Impact Factor
Impact Factor: 7.282

doi crossref

ISSN INTERNATIONAL STANDARD SERIAL NUMBER INDIA

निस्केयर
NISCAIR

International Journal of Advanced Research

in Electrical, Electronics and Instrumentation Engineering

9940 572 462 6381 907 438 ijareeie@gmail.com