International Journal of Innovative Technology and Exploring Engineering (IJITEE)
ISSN: 2278-3075 (Online), Volume-9 Issue-5, March 2020

# Design of IMC Tuned PID Controller for First Order Process with No Delay

B. Mabu Sarif, D. V. Ashok Kumar, M. Venu Gopala Rao

***Abstract:*** ***IMC tuned PID controller's present excellent set point tracking but sluggish disturbance elimination, because of introduction of slow process pole introduced by the conventional filter. In many industrial applications setpoint is seldom changed thus elimination of disturbance is important. The paper presents an improved IMC filter cascaded with Controller PID tuned by internal model principle (IMC-PID) for effective elimination of disturbance and healthy operation of non-regular first order process such as processes with no delay. The suggested filter eliminates the slow dominant pole. The present study shows that the recommended IMC filter produces excellent elimination of disturbance irrespective of where the disturbance enters the process and provides acceptable robust performance to model disparity in provisions of maximum sensitivity in comparison with other methods cited in the literature. The advantages of the suggested technique is shown through the simulation study on process by designing the IMC tuned PID controllers to maintain identical robustness in provisions of maximum sensitivity. The integral error criterion is used to estimate the performance. The recommended filter produces excellent response irrespective of nature of the process.***

***Keywords: Internal Model Control, filter form, Disturbance elimination, Robustness, Integral criteria, non-regular process.***

## I. INTRODUCTION

PID controller is the most broadly utilized controller in industries since it can give acceptable execution to a wide scope of processes with a basic calculation. It is fundamental to recollect that it is difficult for different gadgets to achieve the money saving advantage proportion gained through the PID controller [1-3].

It is discovered that the PID algorithm is used by 97 percent of regulatory controllers [4]. The Internal Model Control (IMC) offers a linear, efficient, natural, generic, distinctive, strong and easy structure for system efficiency assessment and synthesis [5, 6]. The diagnostically determined IMC tuned PID techniques grabbed the consideration of industries spread over the few tears because of the straightforwardness and enhanced proficiency of the IMC - based regulation law [14]. The trade off among execution and vigor is given by the IMC tuned PID controller, which has just lone tuning factor, which is connected to the time constant [1, 5, 7, 8]. The PID controller parameters are acquired in the IMC tuned PID methods and Direct Synthesis (DS) by calculating the controller so as to provide the preferred closed loop reaction [7-13].

Rejection of load disruption is one of the most significant control problems in process industries. IMC tuned PID controller provides excellent setpoint tracking, but the reaction to disturbance is slow, particularly if $\theta/\tau << 1$ [6, 9, 12]. Dismissal of disturbance is the significant design goal than setpoint following for most of the SISO controllers [6, 9, 14]. The goal can be achieved by designing the disturbance elimination controller, instead of designing it for setpoint performance.

A filter in series with PID controller was recommended in the literature [3, 6-8, 10, 14-16]. The IMC-PID's effectiveness is based on the IMC filter framework. The filter design was chosen in the literature to render the IMC module achievable while meeting the demands for efficiency. The resulting effectiveness of the controller PID controller is defined by the IMC controller efficiency and the IMC controller approximation to the ideal controller. It is accordingly important to choose the proper IMC filter structure not on the exhibition of the IMC controller but rather on the presentation of the subsequent PID controller. The PID tuning strategies depicted in the writing utilized first order in addition to delay time (FOPTD) and second order in addition to delay time (SOPTD) forms [11,17-24]. It is seen that the higher-order models approximated by FOPTD as well as SOPTD can likewise agreeably satisfy the control objectives [2, 17, 18, 24]. This inspired the use of model order reduction scheme for plant model.

By combining IMC-PID controller with model order reduction, the present work considers the design of an appropriate control strategy for disturbance rejection. This constructed controller is capable of eliminating the disturbances regardless of the place where it enters in the system, and it is capable of managing mismatches of model and uncertainties of variables. The objectives of the present work is to design a IMC tuned PID controller cascaded with filter to enhance the performance of first order process with no delay (FOPND) measured with integral error criteria under uniform maximum sensitivity ($M_S$).

## II. IMC-PID CONTROLLER DESIGN

Garcia and Morari launched internal model control [7,21], characterizing it as a controller in which the model of the process is clearly an inner controller component.

Revised Manuscript Received on March 30, 2020.
* Correspondence Author
**B. Mabu Sarif***, Research Scholar, Department of Electrical and Electronics Engineering, Koneru Lakshmaiah Education Foundation, Vaddeswaram, Andhra Pradesh, India *gsn.bms786@gmail.com
**D. V. Ashok Kumar**, Professor, Dept. of EEE, Rajeev Gandhi Memorial College of Engineering & Technology, Nandyal, Andhra Pradesh, India
**M. Venu Gopala Rao**, Professor & Head, Department of Electrical & Electronics Engineering, Prasad V. Potluri Siddhartha Institute of Technology, Vijayawada, Andhra Pradesh, India

IMC's structure technique incorporates factorization of the prescient plant model $G_M(s)$ as invertible $G_{M-}(s)$ and non-invertible $G_{M+}(s)$ segments as appeared in (1) through simple factorization or all transfer factorization [5, 7, 8, 10, 16, 24]. The Internal model controller (2) is the reciprocal of the invertible $G_{M-}(s)$ portion of the plant model $G_M(s)$ [17-24].

$$G_M(s) = G_{M-}(s)G_{M+}(s) \quad (1)$$

The controller of the IMC' is designed as

$$Q(s) = G_{M-}^{-1}(s)G_f(s) \quad (2)$$

The IMC controller of Figure 2 is the perfect feedback controller of Figure 3 by making small modifications to Figure1, which can be articulated mathematically in provisos of $G_M(s)$ and $Q(s)$ in (3)

$$G_C(s) = \frac{Q(s)}{1-Q(s)G_M(s)} \quad (3)$$

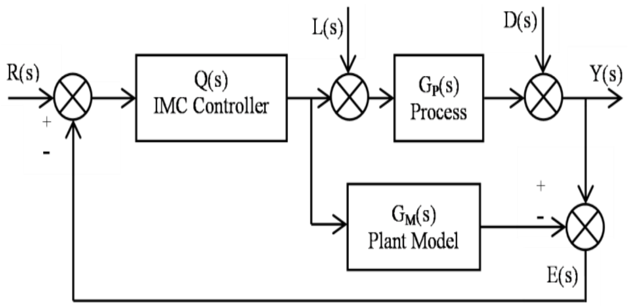


**Fig. 1. The structure of fundamental IMC**

The controller obtained in (3) does not have the regular form of PID, the PID parameters can be attained by plummeting the Eq. (3) into either the forms of Eq. (4) or Eq. (5) by incorporating suitable approximations of the process dead time.

$$G_{PID}(s) = K_P\left(1+\frac{1}{T_i s}+T_d s\right) \quad (4)$$

$$G_{PID}(s) = K_P\left(1+\frac{1}{T_i s}+T_d s\right)\left(\frac{ds^2+cs+1}{as^2+bs+1}\right) \quad (5)$$

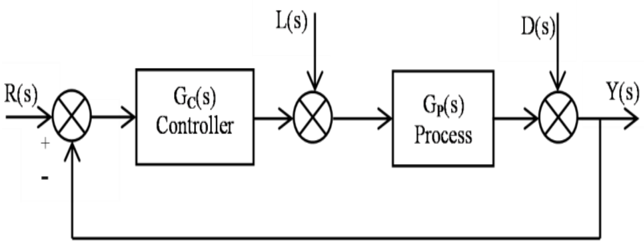


**Fig. 2. Feedback control structure**

Eq. (6) is the description of process response incorporating the controller for both set point and the disturbance input.

$$Y(s) = \frac{G_C(s)G_P(s)}{1+G_C(s)G_P(s)}R(s) + \frac{1}{1+G_C(s)G_P(s)}D(s) + \frac{G_P(s)}{1+G_C(s)G_P(s)}L(s) \quad (6)$$

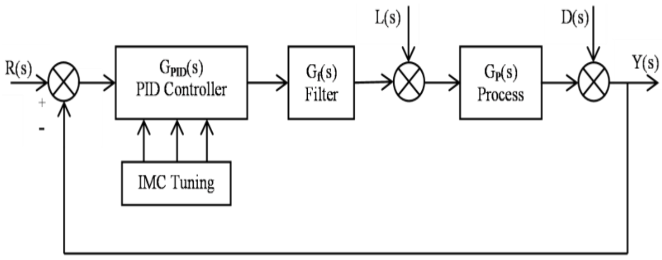


**Fig. 3. PID cascaded with filter**

## III. IMC TUNED PID REGULATIONS OF FIRST ORDER PROCESS WITH NO DELAY (FOPND) MODEL

The predictive model of the process considered here FOPRHZ is given by (7).

$$G_M(s) = \frac{K}{\tau s+1} \quad (7)$$

Separation of invertible and non-invertible parts of plant representation $G_M(s)$ is carried out incorporating all transfer factorization [Eq. (8)].

$$G_{M-}(s) = \frac{K}{\tau s+1} \qquad G_{M+}(s) = 1 \quad (8)$$

The design of PID controller using the conventional IMC filter of Eq. (9) for step disturbance input produces the output response of Eq. (10).

$$G_f(s) = \frac{1}{(\lambda s+1)^n} \quad (9)$$

$$\frac{Y(s)}{D(s)} = \frac{K\left(\lambda s^2+\lambda s\right)}{(1+\tau s)(1+\lambda s)} \quad (10)$$

It is observed that a pole of the system $s = -1/\tau$ is present in the transfer function $Y(s)/D(s)$. The effect of this, the response of the controller to disturbances becomes sluggish. To overcome this alternate filter of the structure (11) is recommended.

Alternate form of filter is

$$G_f(s)=\frac{(\alpha s+1)^n}{(\lambda s+1)^{n+1}} \qquad (11)$$

Where n = 0 to 1, with $n=1$ the filter is of the form of Eq. (12)

$$G_f(s)=\frac{(\alpha s+1)}{(\lambda s+1)^2} \qquad (12)$$

Using the optimum IMC filter of Eq. (12) with n = 1 to FOPND system design, the controller of IMC $Q(s)$ is achieved as Eq. (13)

$$Q(s)=\frac{(1+\tau s)(\alpha s+1)}{K(\lambda s+1)^2} \qquad (13)$$

IMC controller is the perfect feedback controller of the form Eq. (14),

$$G_C(s)=\left\{\frac{((\tau+\alpha)s+1)}{Ks(3\lambda-2\alpha)}\frac{(\alpha s+1)}{\left[\frac{(3\lambda^2-\alpha^2)}{(3\lambda-2\alpha)}s+1\right]}\right\} \qquad (14)$$

The ensuing PID regulation formulas and the lead/lag filter the coefficients of are obtained by comparing Eq. (14) with Eq. (5), which are presented below in Eq. (15) to Eq. (21)

$$K_P=\frac{\tau+\alpha}{K(3\lambda-2\alpha)} \qquad (15)$$

$$T_i=(\tau+\alpha) \qquad (16)$$

$$T_d=\frac{\tau\alpha}{(\tau+\alpha)} \qquad (17)$$

$$a=\frac{(3\lambda^2-\alpha^2)}{(3\lambda-2\alpha)} \qquad (18)$$

$$b=\frac{\lambda^2}{(3\lambda-2\alpha)} \qquad (19)$$

$$\hat{b}=0 \qquad (20)$$

$$c=\alpha \qquad (21)$$

The process pole $s=-1/\tau$ is cancelled by the additional degree of freedom provided by $\alpha$ , it is obtained by computation of characteristic equation of the controller $\left[1-G_M(s)Q(s)\right]_{s=-\frac{1}{\tau}}=0$.

$$\alpha=\tau\left[1-\sqrt{\left(1-\frac{\lambda}{\tau}\right)^2}\right] \qquad (22)$$

The integral criteria are generally used for evaluation of the performance the controller on the process, they are described in Eq. (23) – Eq. (25) [9, 21, 24, 25].

$$IAE=\int_0^{\infty}|e(t)|dt \qquad (23)$$

$$ISE=\int_0^{\infty}e(t)^2dt \qquad (24)$$

$$ITAE=\int_0^{\infty}t|e(t)|dt \qquad (25)$$

The maximum sensitivity $M_S$ is to be designed to be between 1.2 – 2.0 to provide compromise between performance and robustness [9, 24, 25].

## IV. SIMULATION RESULTS

The FOPND model $G(s)=\frac{1}{(s+1)}$ [26], is considered for analysis. The maximum sensitivity $M_S$ of 1.16 is utilised for calculating the variables of the controller. For nominal model, the reaction for unit step load disturbance is depicted in Fig. 4 and the Table 1. The controllers ' robustness evaluation for configuration mismatch was conducted by introducing 25 percent disruption in the all the variables of the FOPND model that has the form $G(s)=\frac{1.25}{(1.25s+1)}$.

The result analysis of Table 2 and Fig. 5 speak the performance of the controller with better IMC filter configuration. The results show the improvement in IAE by a factor of 364% and 62.87%, in ISE by factor of 945% and 155% & in ITAE by a factor of 693.78% and 70.32% in comparison to Horn et al. and Rivera et al. filter structures respectively, and the recovery to disturbance is 5.1 sec in proposed method, 5.9 sec in Horn et al. and 11.69 sec of Rivera et al. The deviation in the performance for 25% mismatch is 0.34% in IAE, 7.96% in ISE and 3.63% in ITAE, demonstrating the robustness of IMC-PID controller.

robustness of IMC-PID controller.

*Retrieval Number: D1610029420/2020©BEIESP*
*DOI: 10.35940/ijitee.D1610.039520*
*Journal Website: www.ijitee.org*



*Published By:*
*Blue Eyes Intelligence Engineering*
*& Sciences Publication*

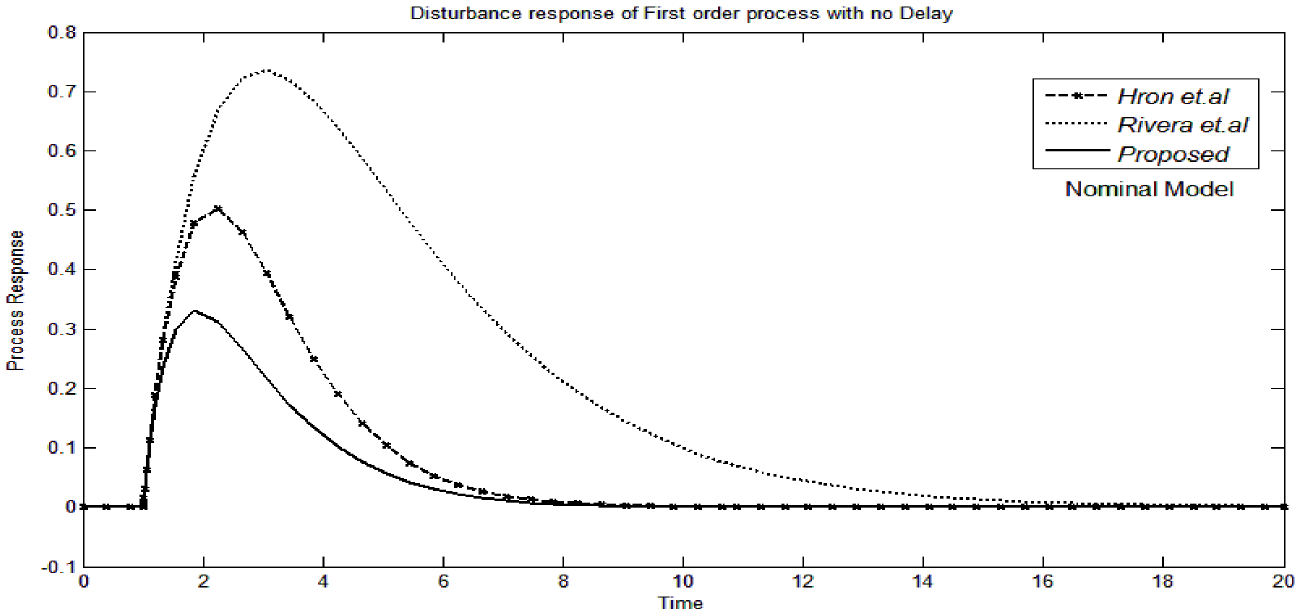


**Fig. 4. Nominal model response for instantaneous disturbance of FOPND**

**Table- 1: Presentation of IMC tuned PID controller of FOPND**

| Technique | λ | $K_P$ | $T_i$ | $T_d$ | $M_S$ | Peak | $t_{re}$ | IAE | ISE | ITAE |
|---|---|---|---|---|---|---|---|---|---|---|
| Projected | 0.95 | 2.313 | 1.99 | 0.5 | 1.16 | 0.332 | 5.1 | 0.8596 | 0.191 | 2.507 |
| Horn et al. | 1.999 | 0.251 | 1.002 | 0.002 | 1.16 | 0.503 | 5.9 | 3.992 | 1.997 | 19.9 |
| Rivera et al. | 0.7 | 0.714 | 1 | 0 | 1.16 | 0.735 | 11.69 | 1.4 | 0.487 | 4.27 |

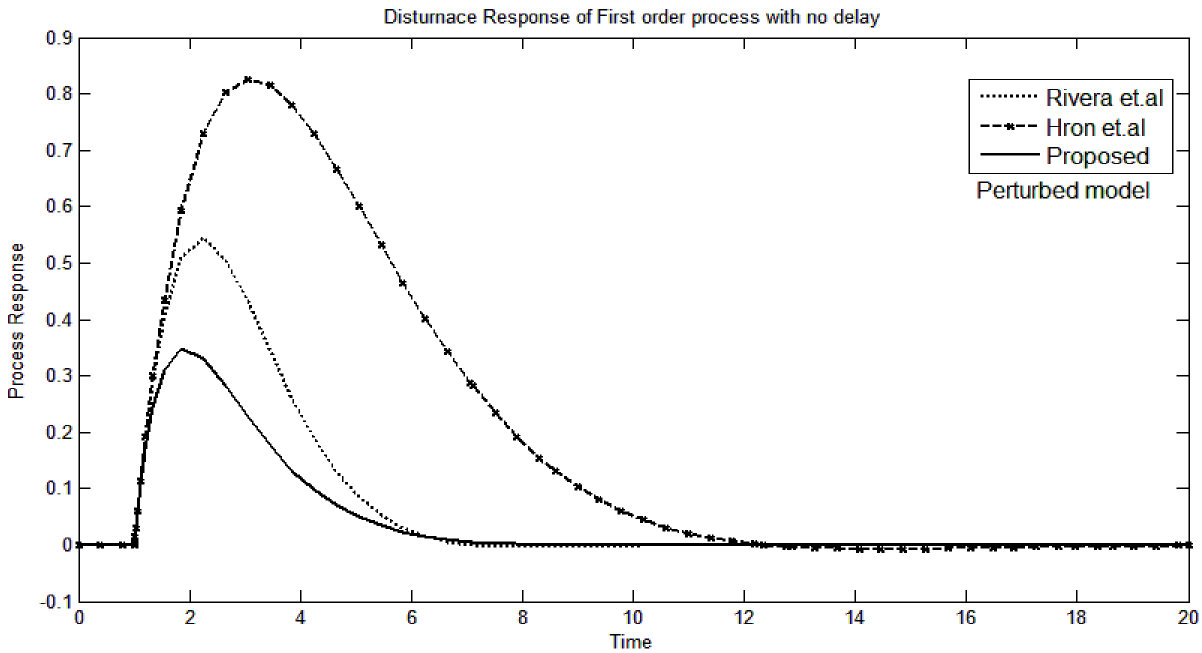


**Fig. 5. Perturbed model response for instantaneous disturbance of FOPND**

**Table- 2: Robustness Analysis FOPND process using IMC tuned PID controller**

| Technique | λ | Peak | $t_{re}$ | IAE | ISE | ITAE |
|---|---|---|---|---|---|---|
| Projected | 0.95 | 0.35 | 5.05 | 0.8625 | 0.2062 | 2.416 |
| Horn et al. | 1.999 | 0.544 | 10.1 | 4.064 | 2.396 | 18.38 |
| Rivera et al. | 0.7 | 0.826 | 5.47 | 1.417 | 0.552 | 4.095 |

*Retrieval Number: D1610029420/2020©BEIESP*
*DOI: 10.35940/ijitee.D1610.039520*
*Journal Website: www.ijitee.org*



*Published By:*
*Blue Eyes Intelligence Engineering*
*& Sciences Publication*

## V. CONCLUSION

For disruption rejection, a design approach for IMC balanced PID controller cascaded with lead / lag filter has been suggested with improved IMC filter configuration. The method suggested for first order processes provides excellent performance for disturbance rejection. The analysis was performed by tuning the PID controller in the form of a uniform contrast with various IMC filter architectures to have the identical robustness. The process mismatch robustness test was performed by adding 20 percent and 25 percent variance in FOPND's System Process Parameters for worst case scenario The suggested IMC filter provides excellent efficiency of the closed loop which was tested using integral parameters viz. IAE, ISE, ITAE and recovery time ($t_{re}$) to disturbance. The method suggested contributes acceptable answers for both nominal and agitated models. A simple approach to model inaccuracies in the midst of closed loop efficiency and robustness is achieved using a single tuning variable λ.

## REFERENCES

1. Moonyong Lee, M. Shamsuzzoha, T.N. Luan Vu, IMC-PID Approach: An Effective way to get an Analytical Design of Robust PID Controller", Intl. Conf. on Control, Automation and Systems, Oct 14-17, 2008; Seoul, 2861–2866.
2. P.V. Gopi Krishna Rao, M. V. Subramanyam, K. Satyaprasad, Model based Tuning of PID Controller, Journal of Control and Instrumentation, 4(1), 16-22.
3. M. Shamsuzzoha, M. Lee, Analytical design of enhanced PID filter controller for integrating and first order unstable processes with time delay, Che.l Engg. Sci., 63, 2008, 2717 – 2731.
4. S. Saxena, Y. V. Hote, Advances in Internal Model Control Technique: A Review and Future Prospects, IETE Technical Review, 29(6), 2012, 461–472.
5. M. Morari, E. Zafiriou, "Robust Process Control", Prentice Hall, Englewood Cliffs, NJ, 1989.
6. Rivera DE, Morari M, Skogestad S, Internal model control. 4. PID controller design, IndEngChem Process Des Dev., 25, 1986, pp.252–265.
7. Horn IG, Arulandu JR, Christopher JG, VanAntwerp JG, Braatz RD, "Improved filter design in internal model control", IndEngChem Res., 35, 1996, pp.3437–3441.
8. Seborg DE, Edgar TF, Mellichamp DA, "Process Dynamics and Control", 2nd ed. New York, Wiley, 2004.
9. Skogestad S., "Simple analytic rules for model reduction and PID controller tuning". Journal Process Control, 13, 2003, pp.291–309.
10. Dan Chen, Dale. E. Seborg, "PI/PID controller design based on direct synthesis and disturbance rejection", Ind. Eng. Chem, 41, 2002, pp.4807-4822.
11. T. Liu F. Gao, "New insight into internal model control filter design for load disturbance rejection", IET Control Theory Appl., Vol. 4, Iss. 3, 2010, pp. 448–460.
12. M. Shamsuzzoha and Moonyong Lee, "Design of Advanced PID Controller for Enhanced Disturbance Rejection of Second-Order Processes with Time Delay", AIChE Journal, Vol. 54, No. 6, , June 2008, pp.1526-1536.
13. Adian O' Dwyer, Hand book of PI and PID controller tuning rules, 2nd ed., Imperial College press, London, 2006.
14. Shamsuzzoha, M., Lee, M, "Analytical design of enhanced PID filter controller for integrating and first order unstable processes with time delay", Chemical Engineering Science, 63, pp. 2717-2731.
15. Ziegler, J. G., Nichols N. B., "Optimum Settings for Automatic Controllers", Trans. ASME, 64, 1942, pp.759.
16. Cohen, G. H., Coon, G. A., "Theoretical Consideration of Retarded Control", Trans. ASME, 75,1953, pp.827.
17. Garcia, C. E.; Morari, M., "Internal Model Controls 1. A Unifying Review and Some New Results", Ind. Eng. Chem. Process Des. Dev., 21, 1982, pp. 308.
18. R. Toscano, "A simple robust PI/PID controller design via numerical optimization approach", Journal of Process Control, Vol. 15, Issue 1, February 2005, pp. 81–88.
19. Md. Shamsuzzoha, Moonyong Lee, "PID controller design for integrating processes with time delay", Korean Journal of Chemical Engineering , 2008, 25(4), pp.637-645.
20. P. V. Gopi Krishna Rao, M. V. Subramanyam, K. Satyaprasad, "Design of internal model control-proportional integral derivative controller with improved filter for disturbance rejection," Systems Science & Control Engineering: An Open Access Journal, Taylor & Francis, 2014, Vol. 2(1), 2014, pp. 583-592.
21. P. V. Gopi Krishna Rao, M. V. Subramanyam, K. Satyaprasad, "Study on PID controller design and performance based on tuning techniques," International Conference on Control, Instrumentation, Communication and Computational Technologies (ICCICCT), 2014, pp. 1411-1417.
22. Moonyong Lee, Masum Jujuly, M., & Shamsuzzoha, M., Analytical PI/PID controller design for stable processes, Theories and Applications of Chemical Engineering, Vol. 15(1), 2009, pp. 126.
23. PVGK Rao, MV Subramanyam, K Satyaprasad, Design of cascaded IMC-PID controller with improved filter for disturbance rejection, International Journal of Applied Science and Engineering, Vol. 12(2), 2014, pp. 127-141.
24. R. Hanuma Naik, D.V. Ashok Kumar & P. V. Gopikrishna Rao (2019) Improved centralised control system for rejection of loop interaction in coupled tank system, Indian Chemical Engineer, DOI: 10.1080/00194506.2019.1647800
25. Panyam Vuppu, G.K.R., Makam Venkata, S. & Kodati, S. Robust Design of PID Controller Using IMC Technique for Integrating Process Based on Maximum Sensitivity. *J Control Autom Electr Syst* **26,** 466–475 (2015) doi:10.1007/s40313-015-0196-0
26. Gopi Krishna Rao P.V., Subramanyam M.V., Satyaprasad K. (2015) Time-Delay Approximation: Its Influence on the Structure and Performance of the IMC-PI/PID Controller, Advances in Intelligent Systems and Computing, 308.

## AUTHOR'S PROFILE

**Mr B. Mabu Sarif**, is graduated in 2010 from J. N. T. U Anantapuram, Masters in 2013 from J. N. T. U Hyderabad. He worked 6 years at ALFA College of Engineering Technology, Allagadda, A. P. in the cadres of Assistant Professor and Head of Electrical and Electronics Engineering Department. He has published 08 research papers in national and international conferences and journals. He has attended 11 National workshops. His areas of interests are Electrical Machines & Control Systems.

**Dr. D. V. Ashok Kumar**, is graduated in 1996, Masters in 2000 from J.N.T.U.C.E, Anantapuramu, and Ph. D in 2008 from the same university. He worked 12 years at R.G.M. College of Engineering Technology, Nandyal, A. P. in the cadres of Assistant Professor, Assoc. Professor, Professor and Head of Electrical and Electronics Engineering. Department. Worked as Principal at Syamaladevi institute of Technology for women, Nandyal from 2008 to June 2015. He is working as Professor of E.E.E and Director of Administration & Placements since July 2015 to till date. He has published 52 research papers in national and international conferences and journals. He has attended 15 National & International workshops. His areas of interests are Electrical Machines, Power Systems & Solar Energy. He is a Senior member of IEEE, Fellow of IE, Life Member of I.S.T.E, K.D.T.F & SESI.

**Dr. M Venu Gopala Rao** at present is Professor & Head, Department of Electrical & Electronics Engineering, PVP Siddhartha Institute of Technology, Vijayawada, Andhra Pradesh, India. He obtained M.E in Electrical Power Engineering from M S University, Baroda, India in 1999, M.Tech in Computer Science Engineering from JNTU College of Engineering, Kakinada, India in 2004 and Doctoral Degree in Electrical & Electronics Engineering from JNT University, Hyderabad, India in 2009. He published more than 42 papers in various National, International Conferences and Journals. He is Fellow of Institute of Engineers (India), Senior Member IEEE, Member ISTE and Member Solar Energy Society of India. His research interests accumulate in the area of Power Quality, Smart Electric Grid, Distribution System, High Voltage Engineering, Condition Monitoring of Electrical Machines and Signal Processing.