A Review on Control System Applications in Industrial Processes

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Abstract. Present paper attempts to review the literature related to design of P-I-D control for time delayed complex industrial process for single as well as for multivariable process with interaction considerations, their decoupler design and time delay compensators. General instrumentation of the industrial feedback control systems along with control system analysis has been covered. Also it covers, control features of some paper mill sub-processes like headbox operation, basis weight and retention. The importance of eliminating the effects of interactions, among the process control loops inside a multi input multi output industrial control system, has been discussed with the help of literature study. The importance of the process dynamics knowledge for designing a control system has also been investigated. This paper also investigates the significance and effectiveness of PID controllers through various literature studies. The problems of the classical PID controllers such as constraints, presence of disturbances etc.) can be removed by designing in combination with soft computing techniques. Moreover, possibility of further enhancements in the PID controller with the utilization of various schemes available, has been presented. The present status of control systems in industrial processes in terms of various control parameters such as stability, dead time compensation etc. has been presented and the future improvements have been stated.

1. Introduction

The For any process industry such as chemical industry, the designing of optimal control system is extremely important. The kind of automation that is being employed in such industries is not very efficient as it is based on classical approaches such as PID controllers. The undesirable effect of this is twofold. One is failure to produce appropriate product quality and second is the consumption of massive quantity of chemicals, water and other energy sources.

So, there is a need to be more focused in this direction in order to improve the productivity and economic aspect of the process industries by minimizing the requirement of more chemicals, water
and man power. This can be achieved by optimizing various design parameters by using various modern control system techniques.

2. Instrumentation and Control Status

A prominent parameter which significantly degrades the performance by delaying the response of a feedback-based control system is the dead time. Therefore, compensating this dead time is highly required. Various techniques such as Smith predictor can be used for this dead time compensation.

The response of a conventional PID control structure may be further enhanced with the use of internal model control (IMC) technique.

This approach has exhibited a remarkable betterment in the output of process industries as far as the efficient use of resources, productivity and economy is concerned.

Advanced control systems based on on-line sensors have shown a tremendous up-gradation in the performance. In general, the sub processes which are involved in any process industry are not so simple. Actually, they are complex in nature in the sense that many input and output variables are associated with them with a severe interaction among them. This results in the formation of multiple input-output loops in that process.

An efficient control system can only be designed for any process industry only when we have the knowledge about its process dynamics. But the unfortunate part is that the availability of this dynamics is very rare. It enforces the need of developing mathematical models of the considered process starting from the very basic principles based on balance of mass and energy leading to a conceptual analytical model of that process. This modeling of the processes having single input and single output (SISO) is comparatively easy but very challenging for the processes having multiple inputs and multiple outputs (MIMO). Generally, complex to solve and complicated models are provided by the basic methods, therefore determination of parameters by performing simulation on such complex models is a challenging work. Obtaining data set from the process industry, while the process is in running mode, is not possible. This leads to non-availability of any primary data to initiate the design work. Few data of abroad based mills is available in the literature but its non-reproducibility and non-practicality restricts us to apply it in the designing. So, the ultimate solution to cope up with this problem is the use of some advanced system identification technique.

3. Control System Analysis for SISO and MIMO Industrial Processes

The ‘dead time’ involvement is very common in the dynamics of any process industry. It makes the designing of control structure a very tough task. As there is a high degree of interaction between input-output variables of a MIMO process, therefore the loops need to be, first of all, decoupled.

But the unfortunate part is that the chemical industries hardly takes care of this aspect and are only dependent on the suppliers of the control systems. The chemical process industries are generally based on DCS (Distributed Control System). The customers have no knowledge of the design architecture of DCS. Classical control systems are based on tuning of all the loops in the process by hit and trial method.

The knowledge of process dynamics is a very critical parameter for an effective control system design for a process with either interactive or non-interactive input-output variables. Unfortunately, the estimation of the dead time of high value is a very challenging task. Moreover, determining the values of various parameters involved in the process dynamics, such as peak overshoot, settling time, rise time, dead time etc., cannot be determined by doing experiment in the process industry.

The estimation of performance of various process loops and the design of a robust control system is seriously not possible without knowledge of values of these parameters. Therefore, in order to design such systems, the design engineers go for using the data simulated by computers.

4. Modeling and Design of Control System
Various tuning methods for PID controllers with their applications are proposed within the literature such as tuning method given by Cohen–Coon [1], Direct Synthesis approach [2], IMC approach [3], minimization of integral error criteria based tuning rules [4], Chidambaram [5], Shinskey [6], Kinney [7], Milosawlewitsch-Aliaga M. et. al. [8] and Lengare et al. [9].

A deep study on ANN, based on knowledge base for finding practically feasible solutions of several challenging problems of linear models, has been done by Scott et al. [10]. A comparison of classical PID controllers with ANN controllers has been presented.

A detailed analysis on several sub processes involved in a paper mill and various operations (such as improvement in energy efficiency, refining efficiency of centrifugal cleaner, simulation and modeling) done on them has been performed by Banerjee et al. [11].

A detailed explanation, on consistency of properties of paper across the entire width of paper, has been given by David wood [12]. He explored the possibility of achieving this consistency of properties by locating the slice very close to parallel. This is done by stabilization of the head box and slice lip mounting against fluctuations in the temperature. He has also suggested that the control of head box can be improved by the use of adjustable slice lip.

Wei Tang et al. [14] proposed an algorithm for auto-tuning of PID/PI controller which can control large time delay processes.

Honghai Wang et al. [15] illustrated the issue of attaining the completed stabilizing set of PI controllers for SOPDT model.

Cheng-qiang Yin et al. [16] proposed a method to control a class of time delayed unstable processes through a modified version of Smith predictor.

C.B. Kadu and C.Y. Patil [17] presented PID controller tuning for FOPDT model (reduced) which is comparatively easy and reliable, and can be determined by dual locus diagram. The resultant controller obtained by this method offers effective tracking of set point and also rejection of the disturbance.

P. Juneja et al. [18] studied a suitable process model which has been governed by mass balance equations and which further corresponds to the basis weight and paper machine retention.

P. Juneja et al. [19] proposed a method of controlling and maintaining the liquor feed quality for raw materials pulp production at the time of cooking in digesters, which in turn helps the paper industry in acquiring a sustainable quality of paper production and converting this waste to wealth by minimizing the solid waste disposal problem.

M. Chaturvedi et al. [20] suggested that most of the processes of chemical industry or a process industry can be represented by FOPDT model. The errors due to delay time can be compensated by applying suitable techniques.

M. Joshi et al. [21] performed the research considering a process of order 1 containing time delay. The SOPDT & TOPDT representations were obtained from the FOPDT representation of the process by the use of Skogestad’s half rule.

M. Chaturvedi et al. [22] emphasized that the dead time is mostly viewed in the industrial processes as the energy or material is propagated frequently in such processes. The presence of dead time is entirely undesirable for the process industry. It was concluded that the system stability decreases because of effect of dead time.

J. Uniyal et al. [23] in their study suggested that a robustness based controller is required to overcome the effects of disturbances in the process industry.

S.K. Sunori et al. [13] and S. Singh et al. [24] in their research work, considered an industrial process with significant time delay. The improvement in the response has been achieved by incorporating the dead time compensation technique in the control structure.

P. Kholia et al. [25] proposed that various industrial processes can be modeled as IPDT process model. A hydraulic control, with inherent delay, implemented in application of position control, is taken to study. With the use of multiple tuning methods, PID controllers were designed for approximated process model. The stability and disturbance rejection capacity were improved by approximating the delay applying Padé approximation of first order.
S.K. Sunori et al. [26] reduced a pH control FOPDT model of 16th order to 2nd order by balanced truncation method and also designed controllers based on IMC, ZN, GA-IMC techniques for reduced model. In their results, the performance of control system is found to be upgraded using GA technique. S.K. Sunori et al. [27] designed and studied a neuro-fuzzy controller for a MIMO process with high multivariable interaction.

P Saini et al. [28] designed a classical PI controller based on PSO technique for consistency of stock in the paper making process. It was found that proposed approach, in comparison to most of the ZN-PI, Tyreus-Luyben (TL-PI), and IMC-PI, offers comparatively good optimal performance relating to the response of overshoot, relative stability, low-performance index and frequency values.

S.K. Sunori et al. [29] considered a cane carrier system. They designed and compared the ARMAX polynomial model with the ARX polynomial model for the considered process and concluded that ARMAX model more closely maintains comparatively more similarities to the initial real process than ARX.

P Verma et al. [30] considered a MIMO paper machine model and designed models with eight different methods includingZN continuous cycling, McAvoy, TL, ZN, Cohen-Coon method, IMC, quarter decay ration, Chien, Hrones and Reswich method. They concluded that for SISO loops, IMC controller is best for both the steady state and transient responses.

S.K. Sunori et al. [31] considered 2x2 MIMO system of a boiler turbine with high multivariable interaction and designed controllers for it using conventional PID and MPC technique by first investigating the stability using Niederlinski index and interaction analysis using RGA recommendations for the selected plant.

Sunori et al. [32] suggested that for sugarcane crushing mill process which is nonlinear and complex in nature, MPC technique offers fast response with absence of steady state error, very good transient response and absence of overshoot in comparison to PID and fuzzy controllers.

D K Kumar et al. [33] implemented a mixed method for system with uncertain parameters. It offers the advantages of being simple and achieving stability of ROM for the stable original system. They suggested that method of moment matching may not guarantee to be good results alone, instead obtains effective results when implemented in combination with some other method.

Sunori et al. [34] investigated the robustness of a MPC based boiler turbine process. For the testing, they used perturbed models of the system by changing time delays and time constants and suggested that the system is robust and also the performance is very much close to the actual system.

Beerten et al. [35] proposed a cable model order reduction for system interoperability literature studies. The state-space form of the presented model can be minimized without losing the accuracy of the converter interactions.

J Uniyal et al. [36] in their study, suggested that a robustness-based controller is required to overcome the effects of disturbances in the process industry.

Sambariya et al. [37] (2016), used the stability equation method for reduction of the transfer function of higher order into low order model, based on pole-zero patterns. They found the proposed method to be very simple to implement and effective in terms of preserving the stability.

P Juneja et al. [38] performed the research for a process of first order system with delay (FOPDT). The second order SOPDT and third order TOPDT models were derived, from FOPDT model of the process by the use of Skogestad’s half rule.

S K Sunori, P K Juneja [39] selected lime kiln process with high multivariable interaction. They analysed index of Niederlinski and RGA analysis for its stability consideration and interaction respectively. The comparative analysis was performed between the performances of the designed PID technique-based controllers and that of Fuzzy logic controllers. After decoupling of the system, the composite MIMO system responses were compared with the closed loop step responses. They concluded that lime kiln though an significant industrial process but offers various challenges, due to being multivariable, complex, interactive and delayed process.

P Juneja, A K Ray, R Mitra [40] stated that artificial Intelligence, an intelligent rule-based technique can be implemented to design the control system of lime kiln, which is significantly used in
various process industries viz. cement, paper, glass, sugar, and leather and ceramics etc. They presented two important artificial intelligence techniques, fuzzy logic control system-based techniques and neural network adopted to control limekiln process.

S Sunori, M C Lohani, P Juneja, G S Jethi [41] considered a lime kiln process with frequent occurrence of disturbances and complex multivariable interactions. They designed a prediction-based controller and also investigated the disturbance rejection performance, under multiple prediction horizon, control horizon and sampling interval values.

S K Sunori and P K Juneja [42] mentioned that the MPC technique is one of the popular techniques and is stated to be the finest among various other existing ones of control of the constrained multivariable dynamic plants. They utilized a linearized model obtained with the use of Taylor series expansion about the operating point to control lime kiln process using MPC technique.

For a lime kiln delayed control system, MPC can offer more stable operations. MPC strategy, if implemented can easily handle the constraints of manipulated and controlled variables [43].

P Juneja, A K Ray, R Mitra [44] reviewed a neural network approach and fuzzy logic control to control the industrial limekiln process and concluded that for industrial processes with multivariable and strongly nonlinear models like lime kiln, conventional control methods have comparatively poor performances than modern control techniques.

P Juneja, A Ray and R Mitra [45] presented the analysis of the effects of constraints for a limekiln process on manipulated variables and controlled variables. They explored the effects of control and prediction horizon variations. The comparative results were presented for various weights and rate of weights of significant variables. For the designed controllers, the disturbance rejection capabilities set-point tracking and robustness were explored.

S Sunori, P K Juneja, A K Ray [46] stated that limekiln is a tedious to operate due to multivariable nature, complex dynamics, long transportation lags and non linear kinetics. It is hazardous in nature if misoperated beyond set points. But MPC technique offers comparatively better solution for control and optimization of this process.

In control of multiple-loop, MIMO systems are considered and operated as a collective set of multiple number of single loops [47].

The area of control of distillation column, in the process industry is mostly benefitted by the Decoupling control technique [48].

Xiong [49] proposed effective relative gain array (ERGA) method for reducing interaction in MIMO processes by establishing the ratios of transmission of energy for a transfer function.

Dynamic RGA (DRGA) could possibly be utilized to analyze the plant under consideration at any available frequency yet at one single frequency at one point of time only [50].

RGA can be used by generalizing effectively for the non-square plants [51].

Partial Relative Gain (PRG) can effectively resolve the pairing issue for very large systems. Another set of RGA methods available in the literature are as follows: μ interaction index method, PRGA (Performance Relative Gain Array) [52], GI (General Interaction) measure [53], NRGA (normalized RGA) matrix.

The MIMO system stability is tested using Niederlinski Index [54]. Yang Bo et al. [55] suggested an algorithmic technique for selecting the structure of control.

The knowledge offered by RGA about the most appropriate time to use the multivariable controller is in a very limited form and also no indication is provided by it about the appropriate method of selecting the multivariable controller structures [56].

Chien et al. [57] presented simple technique for the tuning of multiloop PID controller which can be used for incomplete knowledge of process. For the processes with not only the multiple controlled outputs but also the multiple manipulated variables, one solution for selecting one of the best feasible SISO controllers out of the all the configurations available, is to attempt all possible loops one by one and then choose those pairs of input-output which reduce the quantity of interaction among the SISO controllers. Both the static as well as dynamic RGA methods attempt to reduce the interaction among the SISO loops by choosing a suitable pairing yet are unable to achieve its complete absence.
D Guhaa et al. [58] investigated a coordinated hybrid energy distributed power system for its dynamic behavior by developing the design of an optimized 3-degree-of-freedom PID controller. They concluded that the controller designed is user friendly and serves the advantages of improved stability, fast frequency active compensation and power oscillation.

Zafer Bingul et al. [59] employed the PSO and ABC approach for tuning of the PID and FOPID for the SOPDT system. From the simulation results, they concluded that the PSO algorithm is effective to improve the step response of second order process. Also, ABC algorithm exhibited better performance for the process with time delay. For the cost function variable, the simulation results revealed that ABC controller is superior.

Farshad Merrikh-Bayat [60] proposed a LMI algorithm for tuning the MIMO PI/PD/PID controller parameters. It served the advantage of eliminating the need of stabilizing controller for initializing the control. This is an important research as in some control problems, finding a stabilizing controller is not easy.

5. Summary and Conclusion

Classical PID controllers have so many shortcomings associated with them. One of them is that, with PID controllers, it is very hard to handle presence of disturbance, dead time and constraints. In order to overcome all these problems associated with the classical controllers, control systems based on soft computing techniques are designed. Some examples of soft computing techniques are GA, FLC and ANN. Some modern optimization techniques which are nowadays very frequently adopted for control system optimization SA, ACO and PSO. A combination of these techniques is also used for upgrading the response of the controller. However, role of classical PID controllers cannot be ignored as these above-mentioned techniques are applied on the existing PID controller in order to tune its parameters and optimize and its performance.

Efforts have been made for surveying literature regarding stability and control of single and multivariable FOPDT process models. Prospects of refinements in terms of quality with rise of productivity by the use of automation have also been discussed. This survey clearly indicates that the PID controllers are very effective for a variety of industrial processes; therefore, their extensive use has been carried on in various chemical industrial processes.

Finally, we conclude that there is still a wide scope of improvement in the control systems which presently exist in the industrial processes.

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