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Optimal Selection of Process Controller for a Cascade Control System Using Analytical Hierarchy Process

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Abstract

Selection of Process controller is a onerous task in process industries. This paper narrowly tailors on usage of Analytical Hierarchy Process (AHP), to select the appropriate controller for a Real time cascade control system. The work starts with the identification of imperative enablers for selecting the controller with the help of experts from the process industries such as CPCL, CIPLA, PRICOL and NITC IPA lab. The AHP hierarchy tree was developed for selecting optimal controllers. Finally, questionnaire was issued to those experts for fixing the levels of scale ranging from 1-9 scale for performing the pair-wise comparison. The result of AHP has been successfully verified with the real time system software namely process analyzer. Process Analyser in control system is used to simulate the performance characteristics of Cascade control system that numerically justifies the result obtained through AHP. The empirical advantage of AHP is, it’s a pure hierarchical approach for making a pair wise comparison between the criteria, sub criteria and alternatives for selecting a optimal controller in the Integrated Level-flow cascade control system.

Keywords: P-I-D Controller, MCDM, AHP, Cascade control system

1 Introduction

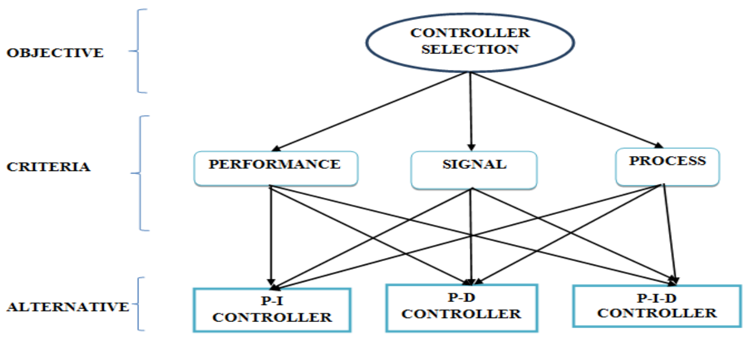
In real time, the proportional plus integral plus derivative (PID) controllers are used as the conventional controller in process control systems especially for systems with mathematical models [6]. In pragmatic applications the control systems varies in features such as nonlinearity, time-variability, and time delay, which make controller selection more tedious [3]. In peculiar cases, the system parameters and structure varies with respective to time and environment [1, 3].

These results to the complex circumstances were traditional collection methods are highly prone enough that leverages to use Multi criteria Decision making (MCDM) techniques for attaining optimal solution in ease manner [1, 4]. By using MCDM technique like AHP, the selection of suitable configuration for cascade control system can be calculated mathematically to optimize the selection of controllers.

2 Analytical Hierarchy Process

Analytical Hierarchy Process (AHP) was developed by Thomas L. Saaty in the year 1980 [1], is a concept selection tool which are highly used to help decision makers for attaining the best decision by comparing each alternatives with conflicting objectives by satisfying the determinants, criteria, and sub criteria [4,6].

Figure-1 Analytical Hierarchy Process hierarchical tree



The Figure-1 clearly shows the hierarchical structure for cascade control system using AHP. The highest level describes the goal here we are thriving for selection of optimal controller. The succeeding level in AHP hierarchy illustrates criteria's taken into consideration namely performance, signal, and process. The lowest level of the hierarchy reveals the alternative namely P-I-D, PI, PD controller.

3 Pair wise Comparisons

The Pair wise comparison was made up for criteria and alternative is done based on Saaty 1-9 scale with 1 represents equal importance,3 with moderate importance,5 with strong importance,7 and 9 with very strong and extreme importance.

A questionnaire was prepared and distributed to the experts and veterans in CPCL, CIPLA, PRICOL and NITC IPA lab who had intensify perceptual with controllers. Table 1 illustrates the pair-wise comparison from the scale values obtained from an expert's team.

Criteria	Performance	Signal	Process
Performance	1	3	2.00
Signal	½	1	1/3
Process	1/3	3	1

$a_{ij} =$

Table 1 Pairwise comparison matrix for criteria over the objective.

The normalization of matrix a_{ij} can be evaluated using below equation.

$$aij' = \frac{aij}{\sum_{i=1}^{n} aij} \quad \text{where } i, j=1,2,3,\ldots\ldots n \qquad (1)$$

The normalization matrix $a_{ij'}$ is obtained using equation 1 as shown in Table 2.

Criteria	Performance	Signal	Process
Performance	0.16	0.50	0.33
Signal	0.27	0.55	0.18
Process	0.08	0.70	0.23

$a_{ij}' =$

Table 2 Normalized comparison matrix for criteria with respect to objective.

The eighen vector W,normalized eighen vector W'and eighen value λ are evaluated using below.

$W = \frac{\sum_{i=1}^{n} aij'}{n}$ where n is the order of matrix here n=3 and $W' = \sum_{i=1}^{n} aij * W$

with i , j = 1,2,3,….n and eighen value λ is given as.

$$\lambda\max = \frac{1}{n}\left(\frac{W1'}{W1} + \frac{W2'}{W2} + \frac{W3'}{W3}\right) \tag{3}$$

The consistency test for determining the weighted sum vector or maximum value of lambda using the random index value was presented as proposed by saaty(2005)[7]. There exist a stability if consistency ratio (*CR*) value is lesser than 0.10 for matrix larger than 4*4 ,0.08 for 4*4 and 0.05 for 3*3 matrix then their exist an inconsistency in the data .The *CR,CI* is calculated through below equation

$$CR = \frac{CI}{RI}, \text{and } CI = \frac{(\lambda_{max} - N)}{(N-1)} \tag{4}$$

Where RI stands for random index (RI) the values of RI as proposed by [7] are given in table 3.

N	2	3	4	5	6	7	8	9	10
RI	0	0.52	0.89	0.11	1.25	1.35	1.4	1.45	1.49

Table 3 Random index

The value of W,W', $\lambda\max$, CI, CR are given in table as follows.

Matrix serial no.	Eigen vector	Eigen value	Maximum Eigen value = 4.06
1	0.33	2	CI =((4.06-3)/(3-1)) = 0.53
2	0.33	0.63	CR =0.53/0.52
3	0.34	1.44	=1.02<10%,

Table 4 Maximum eigen value and Consistency Ratio.

The table 4 indicates the value of *CR* is within the optimum level of 0.05,which shows that the data obtained are consistent for chosing the best alternative in cascade control system.
Similarily, the pairwise comparison was made for each alternative with respective to criteria performance.
where λ_{max} = 3.104, CI = 0.05, RI = 0.58, CR = 8.97% < 10 % (Acceptable) and Pair wise comparison matrix for alternative with respect to the process whose CR=6.8% < 10% (Acceptable) and with respect to the signal CR=1.05 % < 10% (Acceptable).

4 Result analysis and Discussion

The adjusted weight for each criteria is calculated individually
Adjusted Weight for Performance = 50.15% / (50.15% +32.57%+11.85%) =0.530
Similarly Adjusted weight for process and signal is at 0.344, 0.125.

Similarly Composite weight calculations for enablers are evaluated as:
For PI controller = (0.530) (51.05) + (0.344) (70.28) + (0.125) (12.90) = 52.44% with PID controller at 27.81 % followed by PD controller = 18.61%

The results from AHP transparently illustrate that PI as the optimal controller with additive weightage contribution of 52.44% followed by PID and PD controller. The below process analyser simulation graph have been made up for validating the results obtained from AHP.

Figure 3 Process Analyser simulation graph.

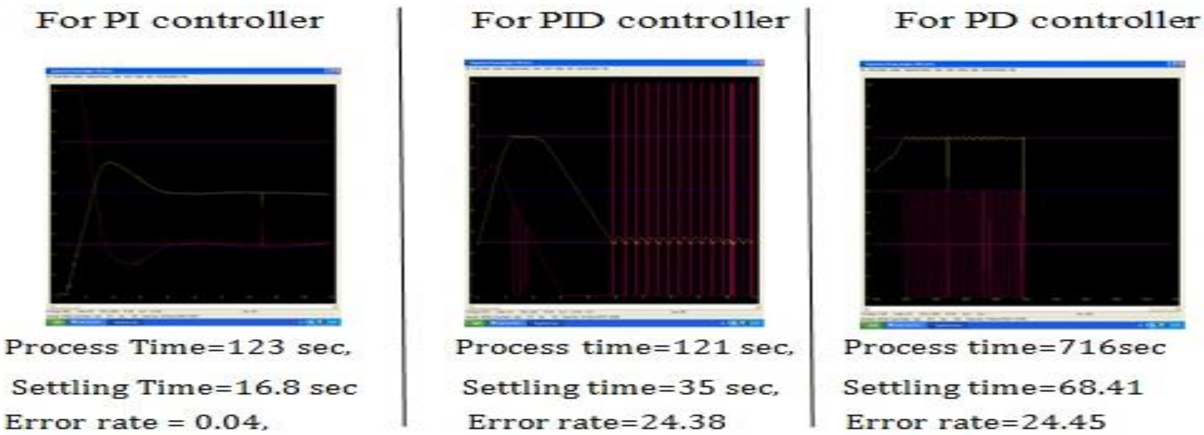


Figure 2 illustrates that the error rate of PI controller is much lesser than that of PID and PD with less settling time that urges to be chosen as an optimal controller in a manufacturing organization.

5 Conclusion

The selection of best controller for cascade control was mathematically chosen based on evaluation through AHP and justified using Process analyser. The analysis concludes Proportional plus Integral (PI) controller as a optimal controller than the PID and PD controllers.

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