Tuned Fuzzy Approach for Designing of PID Controller

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Abstract: Tuning is the first process in installing the Proportional-Integral-Derivative (PID) controller. PID controllers are used in almost every area due to its advancement and stability. More than 90% of the controllers are of PID type. The basic idea behind using the proposed technique is the use of adaptive fuzzy logics. In the conventional systems, the fuzzy logics are not capable enough in providing error free parameters. Thus, the proposed adaptive technique provides a more effective fuzzy logic based PID controller. The Proposed system uses a control loop with updating Fuzzy rules to get optimized results for the stability at output

Keywords: PID controller, Tuning, Response method, freqyency method, Fuzzy Logic Controller, Gain parameters

Introduction

In PID controllers, there are mainly three control parameters that need to be adjusted in obtaining the output. The obtained Output is the combination of Proportional, Integral and Derivative parameters. PID controllers must be tuned to provide the installation of the controllers. Thus tuning is performed on the dynamic behavior of the system.

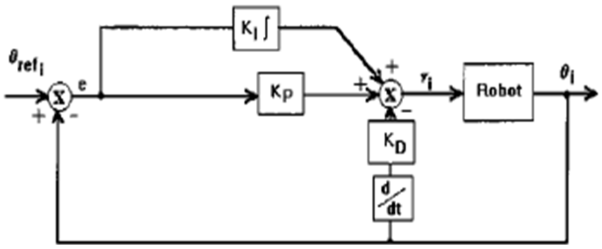


Figure 1. Conventional PID Controller system design

It is used in Industrial Control Systems. A PID controller find error value as the difference between a required set point and a measured process variable.

In the above figure three control parameters are used to obtain the output. The first parameter is Proportional control which increases gain. The second parameter is integral control which reduces steady state error. And the last one is Derivative control which improves transient response. Input is taken from the world and produces output to the world.

The Mathematical equation for PID controller is :

$$u\,(t)= K_p\,[e(t) + 1/T_i\int_0^t e(t')dt` + T_d(de(t)/dt)] + b\text{……………………..}(1)$$

Where,

u defines the control signal, e shows the difference between the current value and the set point, k_p is the gain for a proportional controller, t_i integral controller scales through this parameter, t_d derivative controller can be scale through this parameter, t defined the total time taken by the error measurement, b defines the set point of the given or taken signal which is also considered as bias or offset value.

Transfer function of the controller can be expressed as:

$$C(s) = K_p\,(1 + \tau_d s + 1/\tau_i s)\text{……………………………………….. }(2)$$

Where K_p shows proportional gain, τ_d describes Derivative time and τ_i defines integral time.

Proportional term of the controller defines proportional to the generated error given as:

$$P_{out} = K_p\,e\,(t)\text{………………………………………………}(3)$$

Proportional control value depends upon the error rate which means that higher the error higher the proportional control explained in the equation above.[5] Thus it can be concluded that proportional control brings the system into fast set point.

On the other hand, it produces steady state error which leads to an overshoot when the system gets to the set point. There is another possibility of increasing the proportional gain but that can lead to a system unstable.

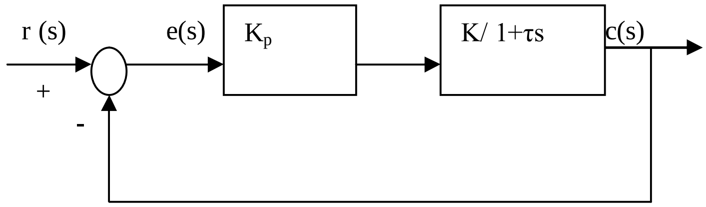


Figure2. Proportional control

Tuning a control loop means to change control parameters like Proportional gain, integral gain, derivative gain to the optimum values for the required control response.
Proportional control can expressed as closed loop transfer function like:

$$\frac{c(s)}{r(s)} = \frac{\frac{KK_p}{1+\tau s}}{1+\frac{KK_p}{1+\tau s}} = \frac{KK_p}{1+KK_p+\tau s} = \frac{KK_p}{1+KK_p}\frac{1}{1+\tau' s}$$

Where $\tau' = \frac{\tau}{1+KK_p}$

Step input $r(s) = \frac{A}{s}$

$$c(s) = \frac{KK_p}{1+KK_p}\frac{A}{s(1+\tau' s)} \text{ or } c(t) = \frac{AKK_p}{1+KK_p}(1-e^{-st}/_{\tau'})$$

Figure 1 shows system response.
From above given equation (5), it is declared that:

(1) Factor $\frac{1}{1+KK_p}$ can be used for improving time which means that time constant can be decreased by this.

(2) Difference between desired response and output response steady state offset is

$$A\left(1-\frac{KK_p}{1+KK_p}\right) = \frac{A}{1+KK_p}$$

Integral part of the controller influence with the variations of the error on time given as:

$$I_{out} = K_i \int_0^t e(T)\, d_T \text{...} (4)$$

It helps in eliminating the problem of proportional term which was steady state error but it has a disadvantage too i.e. it affects the stability of the system. [3] Thus it can be concluded that integral term depends on pass values of the error.

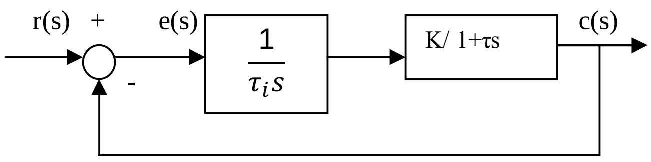


Figure 3. Integral control action

Above figure obtain following equation like:

$$\frac{c(s)}{r(s)} = \frac{\frac{KK_p}{\tau_i s(1+\tau s)}}{1+\frac{K}{\tau_i s(1+\tau s)}} = \frac{K}{K+\tau_i s+\tau\tau_i s^2}$$

Where step input $r(s)=\frac{A}{S}$,

$$e(s) = \frac{1}{1+\frac{k}{\tau_i(1+\tau s)}}\frac{A}{S} = \frac{\tau_i s(1+\tau s)}{\tau_i s(1+\tau s)+K}\frac{A}{S}$$

$$e_{ss} = \underset{s\to 0}{Lt}\, se(s) = 0$$

Unlike other terms Derivative control is relative to the rate of changes of the error defined as per the equation below:

$$D_{out} = K_d\, d/dt\, e(t) \text{...} (5)$$

The above equation helps in estimating the future error which leads to increase or decrease the speed of correction. This term

helps in taking decision soon which provides detection of any changes on the error and system remains stable. [3] This term is very sensitive to disturbances. If there is no change in the error then derivative influence will not be generated.
Transfer function of PD controller expressed as:

$$C(s) = K_p\,(1+\tau_d s) \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad (6)$$

Derivative controller cannot be used alone due to its some drawbacks thus Proportional Derivative controller has been used to provide stability to the closed loop system. To prove this fact process transfer function can be explained as

$$P(s)= \frac{1}{js^2} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad (7)$$

Therefore resultant closed loop transfer function is:

$$\frac{c(s)}{r(s)} = \frac{\frac{K_p(1+\tau_d s)}{js^2}}{1+\frac{K_p(1+\tau_d s)}{js^2}} = \frac{K_p(1+\tau_d s)}{js^2+K_p(1+\tau_d s)} \quad \ldots\ldots\ldots\ldots\ldots \quad (8)$$

Where $js^2 + K_p\tau_d s + K_p=0$ represents characteristics equation which will provide stable closed loop response.

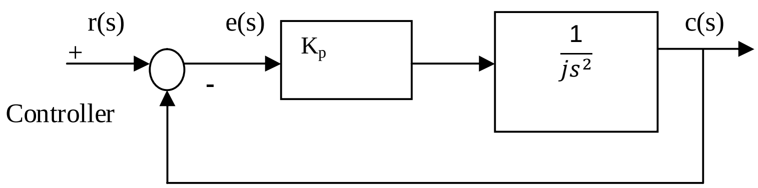


Figure 4. Control action with a higher order process.

With the use of P and P-D controller step response will be compared represent in above figure.
In this research paper, fuzzy logic controller is used to control a plant with the help of human knowledge with linguistic variables. The main advantages of using this system are good popularization as well as high fault tolerance. It can also apply to non linear systems due to which it is famous for years.

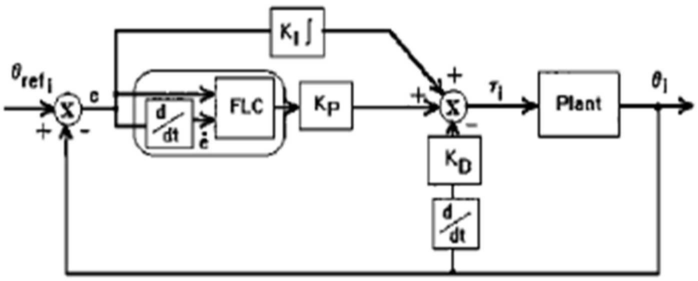


Figure 5. Fuzzy based PID controller system design

Performance of the controller can be enhanced by the hybrid fuzzy controller i.e. combination of P and ID controller shown in figure 5 where proportional term is replaced with incremental FL controller and integral and derivative term will remain same.

$$\Delta T_i\,(K_i)= K_{Pi}\,\Delta u_i\,(k) + K_{Ii}\,Te_i(k) - K_{Di}\,\frac{\theta i\,(K)-2\theta i(k-1)+\theta i(k-2)}{T}$$

From above equation, Δu_i (k) shows output of incremental FL controller.

Related Work

Wei Li, (1998) did propose a new PID controller that is considered to be better than the traditional used PID controller. This controller is designed by using the Fuzzy logic. This is basically a hybrid system in which the fuzzy logic with the conventional integral derivates controller that is an incremental form (fuzzy P+ID controller). Various approaches have been used for designing this hybrid system. The Ziegler and Nichols' approach is modified, the small gain theorem is used that will provide the stability of this controller. It was observed that without altering the original parameters the stability of the system remain the same when the conventional PID controller is replaced with the fuzzy P+ID controller. This controller designed can be determined by using an optimization algorithm. Form the experiments performed the results are obtained that depicts the performance of the system. It is concluded that the proposed fuzzy P+ID controller are more efficient and better than the traditional used PID controllers. These are used for controlling the non-linear systems.

Li Wang, (2013) presented a damping improvement for an offshore wind farm (OWF) for multi machine system. A STATCOM is used for this purpose. To provide the damping characteristic to the designed STATCOM a PID damping controller is used. Along with this a hybrid PID +fuzzy logic controller is also used. in this linear and non-linear system are made . Root –loci technique a frequency domain approach is used for the linear model and a time domain based approach is used for the non –linear system to examine the performance of the proposed system. A hybrid approach proposed using the STATCOM and the hybrid PID+ fuzzy is much efficient as the stability of the system is increased that will in turn increase the performance of the system. The disturbance that occurs in the PID controller is also removed by using proposed hybrid system.

Isaac Chairez (2013) presented that the controller design is an active research area for most of the researchers. Mostly the non –linear controller that are based on the fuzzy logics have been used till date by using such controllers the stability of the system is increased up to some extent. The author in this paper has proposed a solution to various problems that occur while designing the controller. The proposed method is advancement in controlling the non-linear systems like PID. The system is based on the behavior of the controller and to reconstruct the various states. In this proposed system a two link manipulator are used that depicts the efficiency of the proposed system. The fuzzy and the PID controller show the effective results in both the conditions. In this the conditions are also estimated using the differential neural network .For anaerobic digestion this system is used to test the controller. The results obtained are demonstrated.

Ronald S. Rebeiro (2012), describes two controllers for the controlling the interior permanent magnet synchronous motor. This is a closed –loop vector controller. The first controller designed is used for the minimizing the torque that are present by changing the hysteresis band in this the Mamdani type FLC is used. The second controller designed is used for the improving the speed as it sis primary speed controller it is an FLC –based tuned PI the Sugeno type FLC is used. In this the drawbacks of the conventional PI controller are removed so that the performance of the system is increased. The operating speed of the drive is improved that will enable the use of the torque. This proposed system is much efficient; A comparison is performed between the proposed and the conventional controller. On the basis of the comparison it is concluded that the proposed method is better. The result depicts that the dynamic response in torque and speed of the proposed drives.

Teo Lian Seng (1999) has designed the controller by using the optimization algorithm. The conventional used Neuro –fuzzy logic controller is improved by using the Genetic algorithm. The NFLC are tuned by using the GA. The Gaussian membership function is used for the NFLC that is based on the radial based function. The rules of the fuzzy systems are updated by using the Genetic algorithm that will decrease the rules of the system. In genetic algorithm the crossover and mutation process are performed that will increase the performance of the controllers more optimized results are obtained. The proposed system is finally compared with the traditional fuzzy controller and the PID system that is tuned using the genetic algorithm. Various experiments are performed and the results are obtained. The simulation results obtained concludes that the performance of the proposed system is better and efficient than the conventional controllers the stability of the system is more.

F. Karray (2002) presented that this soft computing based PID controllers are designed to improve the conventional controllers. The hierarchical tuning is used for controlling the control loop of the non-linear systems. The basic need of the system is to meet the increasing need of the industries for such a highly reliable and efficient system is designed .so in this the soft computing techniques are used for the will improve the performance of the conventional controllers. The designed controller have modified features of learning that will increase the performance of the system and stability of the system too .finally the results is calculated that is compared with the PID controller that shows that the proposed controllers is much efficient than the traditional controller.

Ya Lei Su (2004) present a hybrid approach for designing the controller for the robotic system. In this approach the fuzzy gain scheduling method and fuzzy proportional–integral-derivative (PID) controllers are combined to form a hybrid system. The designed system is divided in the two layers. In the upper layer the gain scheduling method is used and in lower layer the fuzzy PID controller is used by replacing the conventional PI controller. The linear fuzzy logic controller is used that have different types of gains .The gain of the controller is optimized using the genetic algorithm. Form the simulations results it is concluded that this controller will demonstrate the effective and robust results.

Conventional Approch

Proportional-Integral-Derivative controllers or PID controllers have been using for long period of time. Basically it is used in the field of industry as well as education. PID controllers are tuned on the basis of the dynamic behavior of the system. In this behavior, only critical gain and critical period value is considered. Thus, it does not provide the good tuning. Due to which conventional PID controllers are not being used. It has become the standard tool for process control. Most of the control loops are of PID types or PI control. PID controllers are used for various purposes. It can also use as a dedicated or special purpose control systems or can be combined with other parts. Thus it can be used to build complex systems that can be used in transportation, manufacturing etc.

Conventional PID controllers are not capable enough to provide stability. Thus, proposed PID controllers are used to provide effectiveness and robustness to the system. PID controller design is done through the tuning. Tuning is the first process in installing the PID controller. PID controllers are used in almost every area due to its advancement and stability. . More than 90% of the controllers used in industry are of PID type. The basic idea behind using the proposed technique is the adaptive fuzzy logics. In the conventional systems, the fuzzy logics are not capable enough in providing error free parameters. Thus, the proposed techniques provide fuzzy logic based PID controller more effective.

Proposed System

Proposed system is based on the fuzzy logic controller which provides more stabilize system. It is also helpful in providing more effective system than the conventional PID controller. in other words, Fuzzy logic Controller or FLC able to stabilize the system more efficiently as compared to classic PID controller. Thus, to increase the performance of the classic PID controller several approaches are used. Advancements have been performed to conventional methods for better performance as well as tuning purposes. Fuzzy logic controller provides good popularization as well as used in non linear systems. Proposed system works in four parts. Basically it consists of four components i.e. fuzzifier, rules, inference engine and the last one is Defuzzifier. The whole system works in IF THEN rule set and produces results accordingly.

Fuzzy PID controller

Fuzzy logic is based on the natural language due to which it has been used in number of applications. In the basic fuzzy logic controller, four modules has been utilized which acquires input from the environment, choose an alternative from given set of alternatives, obtain rules and then produces output to the plant. Below a figure represents the basic block diagram of Fuzzy logic controller where fuzzification module takes input, controller parameters generates rules and corresponding member function, interference engine applies necessary control actions and lastly defuzzification that generates modulated data into original values.

Fuzzy PID controller follows conventional PID controller standards along with simple fuzzy controllers design.

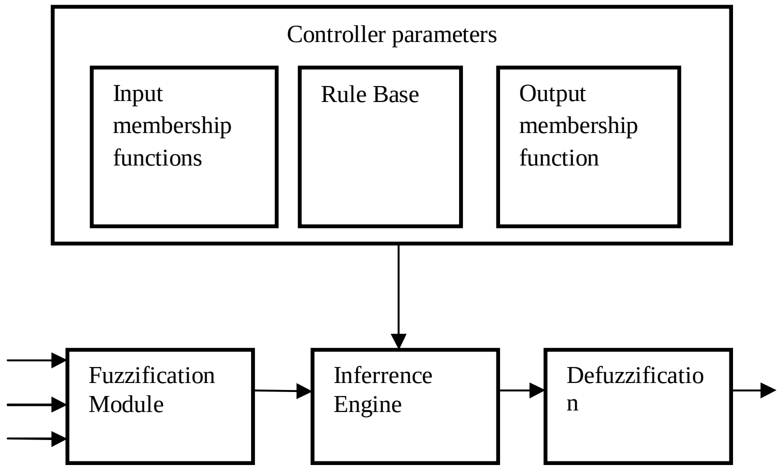


Figure 6: Block diagram of FLC

1. **Fuzzification:** It is a process of converting crisp values in fuzzy values for the implementation of PID controller. Here crisp values are defined as input vector x which contains values from x_1 to x_n and mapped into fuzzy set of U.
2. **Knowledge Base:** Conversion of crisp values into fuzzy values has been done through membership function which has been stored in knowledge base. Control rules of IF-THEN have also retains in the knowledge base.
   IF THEN rules can be shown as:
   $R^{(t)}$: IF x_1 is $A_1^{(t)}$ ….. And x_n is $A_n^{(t)}$ THEN y is $B^{(t)}$
   Where y in the equation belongs to V which is the output of FLC, $A_i^{(t)}$ and $B^{(t)}$ are fuzzy sets in U_i and V where is varies from 1 to n. t ranges from 1 to T where T denotes total number of rules in the process.
3. **Interference Engine:** Composition rules of interference are defined with the help of interference engine which map sets in U into sets in V. Most commonly used interference engine is MAX-MIN method.
4. **Defuzzification:** It is a process of converting the fuzzy set of V into crisp values of input vector V.
   Output of the fuzzy controller into crisp vales defined as:

$$y^* = f(x) = \frac{\sum_{l=1}^{L} \beta^{(t)} \left(\Pi_{i=1}^{n} \mu Ai(t)\,(xi)\right)}{\sum_{l=1}^{L} \left(\Pi_{i=1}^{n} \mu Ai(t)\,(xi)\right)} \quad \ldots\ldots\ldots.(9)$$

Where $\mu Ai(t)$ defined as membership function of the fuzzy sets and i =1, 2, 3 …n, l varies from 1,2,…..L.
Π and Σ denotes fuzzy t-norm and t-conorm operations and $\beta^{(t)}$ belongs to R. $\beta^{(t)}$ considered as the output fuzzy sets and if it describes as single tone $\beta^{(t)}$ that is:

$$\mu_B^{(t)}(y) = \begin{cases} 1, & \text{if } y = \beta^{(t)} \\ 0, & \text{otherwise} \end{cases}$$

This method will help the FLC to perform on nonlinear function with accuracy.
Fuzzy logic is a process of obtaining fuzzy values by applying rules based on the degree of membership function. Below section describes rule base and membership function.

5. **Membership Function:** Membership function is a curve that defines a value to fuzzy variables. It also defines individual point in an input space that shows degree of a membership. For instance in a system temperature and humidity are two variables where there values can be varied and one can define the range between o and 1 which will help to initialize the mapping between them and based on their degree rule will be applied accordingly.
Membership function can be represented through triangles, trapezoids, bell curves, Gaussian and sigmoidal. MATLAB uses membership function editor that provides flexible MF which can be easily varied by dragging. MF can be also added by simply clicking on the edit option and select add MF whose set will be shown in the editor represented below.

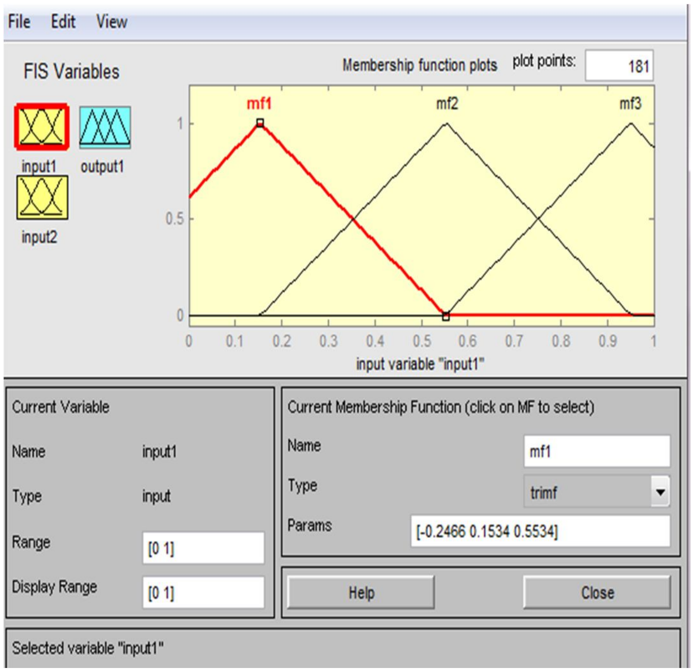


Figure 7. Shows membership function editor

6. **Rule base:** This property of fuzzy logic has been defined under the knowledge base that describes on the basis of some criteria which shows how the system will work. MATLAB has the toolbox that defined under the fuzzy section will help in obtaining rules by adjusting membership function. Below representation of the figure shows rule viewer after manipulation of the membership function and obtained rules are shown in the output.

For instance mentioned above two variables of the system, now further rules can be applied like if temperature increases or decreases from the given membership function then correspondingly switch will be on alternatively off.
Nine rules have been defined for instance where if e (k) and e'(K) is equal to Negative and Positive correspondingly then output Zero will be obtained and so on.
Rule 1: If e (k) =N and e' (k) =P then $\Delta u_f(k)$ =Z
Rule 2: If e (k) =Z and e' (k) =P then $\Delta u_f(k)$ =P
Rule 3: If e (k) =P and e' (k) =P then $\Delta u_f(k)$ =P
Rule 4: If e (k) =N and e' (k) =Z then $\Delta u_f(k)$ =N

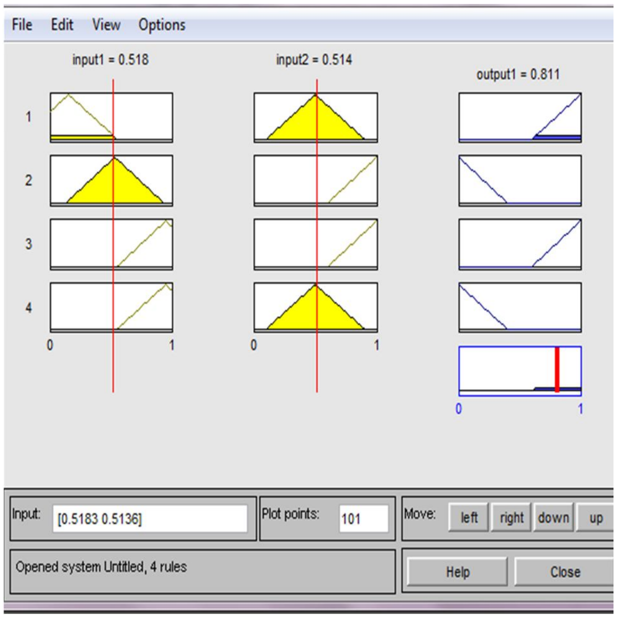
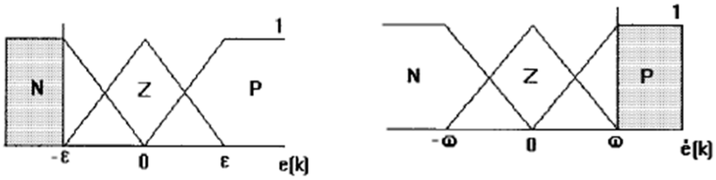


Figure 8. Rule viewer

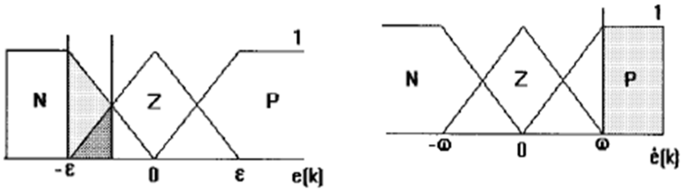
Rule 5: If e (k) =Z and e' (k) =Z then $\Delta u_f(k)$ =Z
Rule 6: If e (k) =P and e' (k) =Z then $\Delta u_f(k)$ =P
Rule 7: If e (k) =N and e' (k) =N then $\Delta u_f(k)$ =N
Rule 8: If e (k) =Z and e' (k) =N then $\Delta u_f(k)$ =N
Rule 9: If e (k) =P and e' (k) =N then $\Delta u_f(k)$ =Z
By using the below Formula one can drive related output $\Delta u_f(k)$ parameter as:

$$\Delta u_f(k) = \frac{\Sigma\begin{Bmatrix}\textit{membership value of input}* \\ \textit{output corresponding to the} \\ \textit{membership value of input}\end{Bmatrix}}{\Sigma\{\textit{membership value of input}\}} \quad .... (10)$$

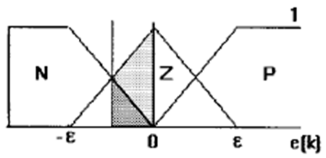
Following represents some of the rules that are obtained after implementation of given rules above.



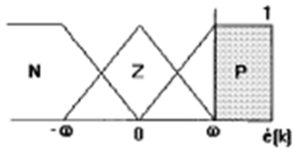
(a) (b)



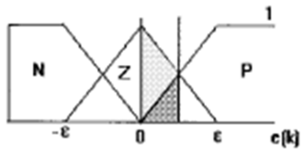
(c) (d)



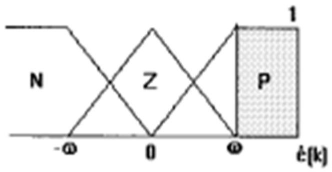
(e)



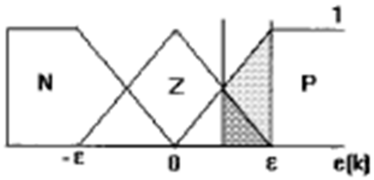
(f)



(g)



(h)



(i)

Figure 9. Shows output of rules given above as an example. (a-i)

Methodology

PID controllers have been used for various purposes and in various fields. Due to the problems occur in the conventional approach, proposed PID controllers came into existence. In the proposed technique, methods follow like figure [4]:

1. Initialize the input value to the adder. Then derivative 1 is performed on the input value.
2. Output produced will be send to the fuzzy logic controller i.e. FLC. Then output produced from this controller will give to the adder number 2 along with the derivative 2.
3. The produced output from the adder is given to the product and sends it to the plant.
4. Plant then produces the output to the environment.

Results and Discussions

In this section of the paper, results are obtained from the old and proposed controllers. Proposed controller performs better as compared to the old controller. Evaluation has been performed and results are shown below. According to the ideal scenario, Overshoot value reduced in the proposed technique. Which means it is more stable than old technique.

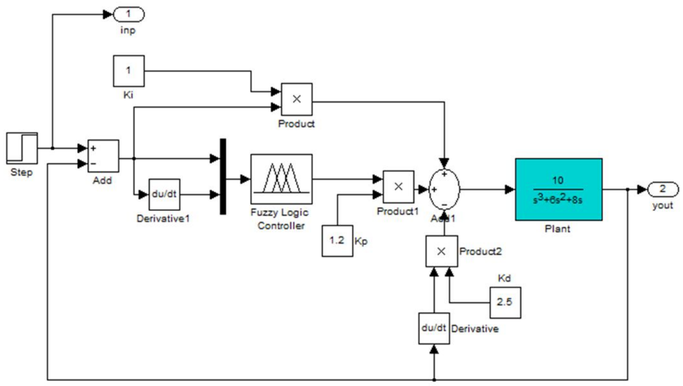


Figure 11. Traditional Simulink Modal for PID controller

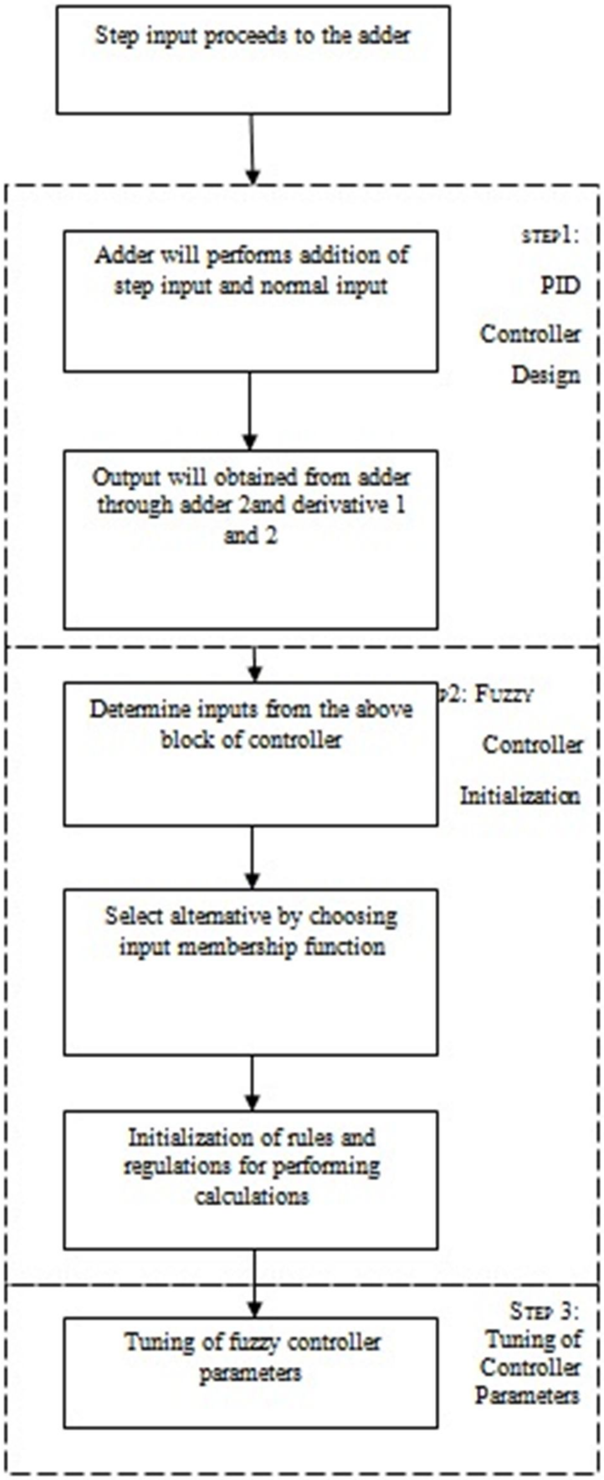


Figure 10. Block diagram of fuzzy PID controller

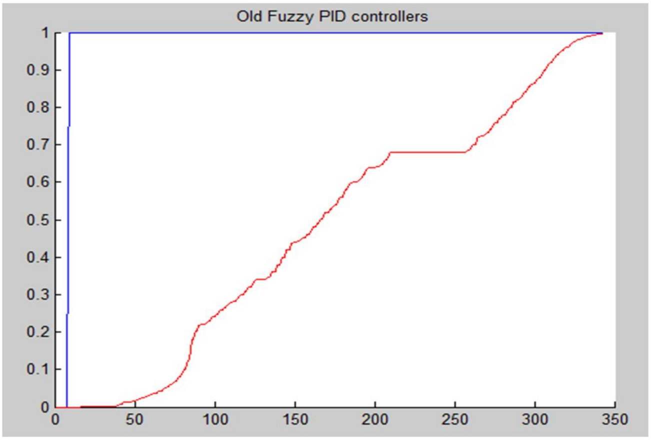


Figure 12. Results obtained by traditional fuzzy logic PID controller

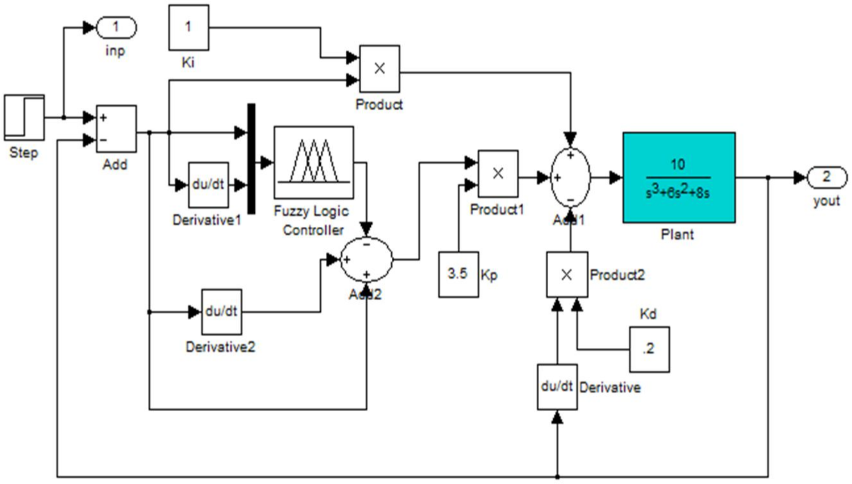


Figure 13. Proposed Approach for Fuzzy PID controller

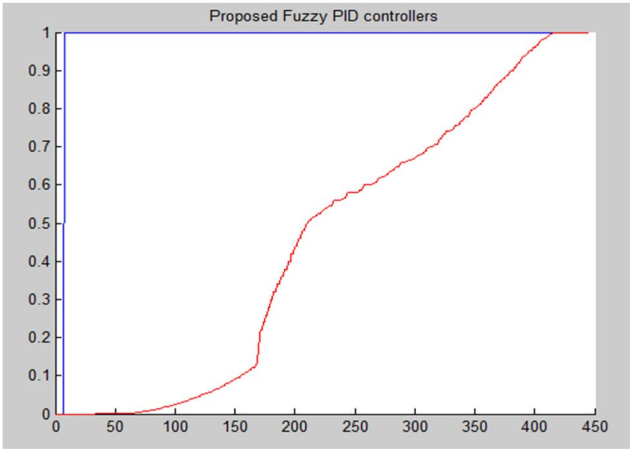


Figure 14. Results obtained by proposed fuzzy logic PID controller

Conclusion and Future Scope

Proposed system discussed in this paper concludes that the PID controller parameters may vary and shows impact on the performance of the system. There are various methods that can be used to provide efficiency and optimal solution to the problem. As compared to other controllers PID gives good response. PID controllers are designed for various purposes including mechanical or industrial areas. Results show that the proposed system is better than the conventional system in terms of robustness as well as stability issues. In Conventional Fuzzy Logic Controller advancements have been done to make it possible for other parameters in terms of performance and stability.

As results above shows that traditional system value overshoots at 50 to 1 with high variations whereas in the proposed system it shoots at 100 to 1but with fewer variations in the graph which resultant into enhanced system. In comparison with ideal state which is at 1 proposed system works competently rather than traditional system.

It is concluded that the proposed modal having the derivative output with the fuzzy system which is providing the better results than the traditional approach.

Various techniques have been applied to check the performance of the individual approach. More features can be added as there is always a space for advancements. Thus, in future, more techniques or methods can be applied to obtain optimal result. Stability of the system can also be improved in future.

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