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A Review on Adaptive tuning and Auto tuning of PI &PID Controllers for Effective speed control of DC Motor

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ABSTRACT
This Paper presents the effective speed control of DC motor by different tuning techniques of PI and PID controllers. The usage of DC motors are vast in industries even though the maintenance cost is lofty than AC motors because of its easy speed control techniques in DC motors. The tuning of PI and PID controllers is complicated than conventional controllers to control the speed of DC motor but tuning of parameters of controllers plays a vital role in performance and stability of the control system.
Key Words: Fuzzy logic Controller, Genetic algorithm sliding mode control (SAM), Linear Quadratic Regulator, Neural Networks Controller, PI, PID controllers, Ziegler – Nicholas.

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I. INTRODUCTION

Direct current (DC) motors are used widely due to its variable-speed characteristics and easy speed control. DC motor has a high starting torque than AC motor. The DC motors form the backbone of electric drive machines. Disk drives, cooling fans, cranes, elevators, drills, robotic manipulators, guided vehicles, electric traction are some of applications where DC motors are employed. With such a wide variety of applications, the speed control of motor is of very crucial importance. This paper gives a review study on the performance evaluation of different types of tuning techniques for conventional controller implemented with a clear objective to control the speed of separately excited DC motor. There are various types of applications which have vital role in modern industry where the load on the DC motor varies over a speed range. These applications may insist high-speed control accuracy and good dynamic responses.

The speed torque characteristics of DC motors are much loftier to that of AC motors and also DC motors provide excellent control of speed for deceleration and acceleration. DC motors are meant for wide speed adjustable machines and a wide range of options have evolved. In these applications, the motor should be exactly controlled to give the required performance.

There are several controller types of conventional controllers like Proportional Controller (P Controller), Proportional Integral Controller (PI Controller), Proportional Integral Derivative Controller (PID Controller),which are widely used in industry due to its simplicity and effectiveness of control. To implement PI, PID controller, the gains of controller must be determined. Up to now, tuning of PID controllers has always been an area of active interest in the process control industry. Great effort has been devoted to develop methods to reduce the time spent on optimizing the choice of PID controller parameters.

There are several techniques to tune the PID Controller like Ziegler-Nichols, Neural Network Controller, Fuzzy Logic Controller and Linear quadratic regulator controller. Among these methods, the ZN method is one of the most familiar and in demand method. For a wide range of industrial processes, ZN tuning method works quite well. However, one of disadvantage of this method is the necessary of the prior knowledge regarding plant model. Once tuned the controller by ZN method a good but not optimum system response will be reached. The transient response can be even worse if the plant dynamics change. It must be noticed that a great amount of plants has time-varying dynamics due to external/environmental causes, to assure an environmentally independent good performance, the controller must be able to adapt the changes of plant dynamic characteristics. Recent years, artificial intelligent techniques-fuzzy logic, neural networks and genetic algorithms (GA), Sliding mode control (SAM) are well established.

II. CONVENTIONAL CONTROLLERS

In the modern control industries, the main issue is to develop methodologies, concepts, algorithms, technologies for the design of process control systems which must be able to evolve, self develop, self organize, and self evaluate and to self improve. Since many years, in industrial control of system is achieved by conventional Proportional Integral Derivative (PID) controllers because of its low cost design, simplicity and robust performance in wide operating conditions. Conventional control systems have main drawback of steady state problems like rise time, settling time and overshoot and transient. Various alterations and techniques have been employed to overcome these difficulties, which includes adaptive techniques, compensation techniques and auto tuning of proportional integral derivative (PID) controllers. Automatic tuning procedures are required for satisfactory control of controller parameters.

1.1 Proportional Controller:

In a proportional controller the output (also called the actuating signal) is directly proportional to the error signal.Writing mathematically we have,

$$A(t) \propto e(t)$$

(1)

Removing the sign of proportionality we have,

$$A(t) = K_p \times e(t)$$

(2)

where, Kp is proportional constant also known as controller gain. It is recommended that Kp should be kept greater than unity. If the value of Kp is greater than unity (>1), then it will amplify the error signal and thus the amplified error signal can be detected easily. The advantages using Proportional controller are i) It helps in reducing the steady state error, thus makes the system more stable.

ii) In case of over damped system, slow response can be made faster with the help of these P Controllers.

The disadvantages of Proportional Controller are:

Now there are some serious disadvantages of these controllers and these are written as follows:

i) Due to presence of these controllers we get some offsets in the system.
ii) Proportional controllers also increases the maximum overshoot of the system.

2.2. Proportional Integral Controller:

As the name suggests, it is a combination of both Proportional and Integral controller. The output (also called the actuating signal) is equal to the summation of proportional and integral of the error signal.

Writing this mathematically we have,

$$A(t) \propto \int_0^t e(t)dt + A(t) \propto e(t)$$

(3)

Removing the sign of proportionality we have,

$$A(t) = K_i \int_0^t e(t)dt + K_p e(t)$$

(4)

where, K_i and k_p proportional constant and integral constant respectively.

Though PI controller have many advantages like simple structure, easy to design and low cost, it fails when the controlled object is highly nonlinear and uncertain. Steady state error and forced oscillations will be eliminated by PI controller resulting in operation of on-off controller and P controller respectively. Thus,the speed response of DC motor cannot be increased by PI controller. By introducing integral mode to P controller, it shows anti effect on over all stability and speed of the response of the system and PI controller cannot forecast in upcoming what is going to happen with the error. This issue can be rectified by introducing derivative mode which has ability to forecast what is going to happen with the error in upcoming thus to decrease a reaction time of the controller.

Under PI Controller the controller keeps changing its output as long as the error exists and once the error become zero or it die the controller does not change its output.

- Integration is the mode that it may make transient response worse some time but eliminate the offset or the error.
- In PI Controller, the output is changed proportional to the integral of the error.
- PI Controller has the following disadvantages:
- The response is sluggish at the high value of the integral time Tn.
- The control loop may oscillate at the small value of integral time Tn.

1.2 Proportional Integral Derivative Controller:

The PID controller is more popular and broadlyused to enhancethe dynamic response of the system as well as the steady state error is minimized or removed.These controllers are more well known of its good closed-loop response characteristics, where itcan be tuned using relatively simple design rules, and are easy to construct so that plant's speed must be accurately regulated.

The PID controller is placed in the forward path, so that its output becomes the voltage applied to the motor's armature the feedback signal is a velocity, measured by a tachometer, the output velocity signal C (t) is summed with a reference or command signal R(t) to form the error signal e(t). Finally, the error signal is the input to the PID controller.

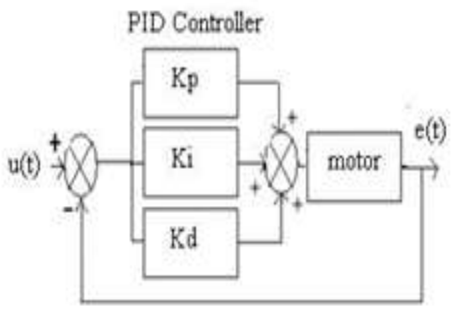
The corresponding three adjustable PID parameters are most commonly selected to be

- Controller gain- (increased value gives more proportional action and faster control)
- Integral time- (decreased value gives more integral action and faster control)
- Derivative time- (increased value gives more derivative action and faster control)

Although the PID controller has only three parameters, it is not easy, without a systematic procedure, to find good values for them.PID Controller includes all the three control actions i.e. proportional, integral and derivative.

- A PID controller calculates and outputs a corrective action, which corrects the error between the process output and the desired set point that adjusts the process accordingly and rapidly.
- The output of the controller or the manipulated variable is obtained by adding P, I and D components and their associated coefficient.

PID controllers are commonly used to regulate the time-domain behavior of many different types of dynamic plants. These controllers are extremely popular because they can usually provide good closed-loop response characteristics. Consider the feedback system architecture that is shown in Fig. 1 where it can be assumed that the plant is a DC motor whose speed must be accurately regulated.



III. TUNING TECHNIQUES FOR CONVENTIONAL CONTROLLERS

For desired output, this controller must be properly tuned. The process of getting ideal response from the PID controller by PID setting is called tuning of controller. PID setting means set the optimal value of gain of proportional (kp), derivative (kd) and integral (ki) response. PID controller is tuned for disturbance rejectionmeans staying at a given setpoint and command tracking, means if setpoint is change, output of controller will follow new setpoint. If controller is properly tuned, output of controller will follow variable setpoint, with less oscillation and less damping.

There are several methods for tuning PID controller and getting desired response. Methods for tuning controller is as below:

1. Trial and error method
2. Ziegler-Nichols method
3. Astrom Relay Method
4. Schei Relay Method
5. Neural network controller
6. Fuzzy logic controller

3.1 Trial and error method:

Trial and error method is also known as manual tuning method and this method is simplest method. In this method, first the value of $k_p$is increased until system reaches to oscillating response but system should not make unstable and the values of k_d and k_i are kept at zero. Then, the value of $k_i$is set such that, oscillation of system is stops. Then value of k_d is set for fast response.

3.2 Ziegler-Nicholas method:

In 1942, Ziegler-Nichols presented a tuning formula [13], based on time response and experiences. Although it lacks selection of parameters and has an excessive overshoot in time response, still opens the way of tuning parameters. Modified Ziegler-Nichols tuning based on Chien-Hrones-Reswick (CRR) PID tuning formula for set-point regulation accommodate the response speed and d overshoot. In this paper, an optimal PID controller for DC motor speed control is developed using Ziegler-Nichols (ZN) and Modified Ziegler-Nichols .The performance measure to be minimized contains the following objectives of the PID controller that will be studied separately.

- ✓ Minimize the rise time, time required for system response to rise from 10% to 90% (over damped); 5% to 95%; 0% to 100% (Under damped) of the fmal steady state value of the desired response,
- ✓ Minimize the maximum overshoot, Maximum overshoot is the maximum peak value of the

response curve measured from the desired response of the system, and

- ✓ Minimize the settling time, Time required for response to reach and stay within 2% of final value.

The PID controller tuning methods can be classified into two main categories
(1)Closed loop methods
(2)Open loop methods.

The Zeigler Nichols Open-Loop Tuning Method is a means of relating the process parameters - delay time, process gain and time constant - to the controller parameters - controller gain and reset time. It has been developed for use on delay-followed-by-first-order-lag processes but can also be adapted to real processes.

The Zeigler Nichols Closed loop Tuning method is based on experiments executed on an established control loop (a real system or a simulated system), see Fig. below.

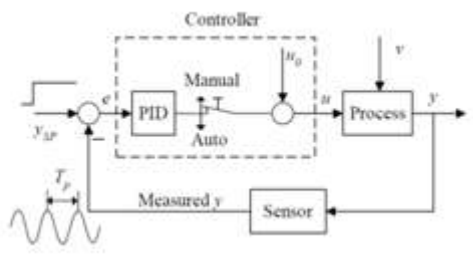


Fig. The Ziegler-Nichols' closed loop method is executed on an established control system.

The tuning procedure is as follows:
1. Bring the process to (or as close to as possible) the specifiedoperating point of the control system to ensure that the controllerduring the tuning is “feeling” representative process dynamic and tominimize the chance that variables during the tuning reach limits.You can bring the process to the operating point by manuallyadjusting the control variable, with the controller in manual mode,until the process variable is approximately equal to the setpoint.
2. Turn the PID controller into a P controller with gain Kp = 0 (setTi = ∞ and Td = 0). Close the control loop by setting the controller in automatic mode.
3. Increase Kp until there are sustained oscillations in the signals in thecontrol system, e.g. in the process measurement, after an excitationof the system. (The sustained oscillations corresponds to the systembeing on the stability limit.) This Kp value is denoted the ultimate(or critical) gain, Kpu.
4. Measure the ultimate (or critical) period Tu of the sustainedoscillations.
5. Calculate the controller parameter values according to Table below, anduse these parameter values in the controller.The lowpass filter time constant Tf can be set toTf = 0.1Td.

If the stability of the control loop is poor, it is tried to improve the stabilityby decreasing Kp.

Controller	K_p	T_i	T_d
P Controller	0.5 K_{pu}	∞	0
PI Controller	0.45 K_{pu}	$T_u/1.2$	0
PID Controller	0.6 K_{pu}	$T_u/2$	$T_u/8$ $=T_u/4$

Table: Formulas for the controller parameters in the Ziegler-Nichols' closed loop method.

These controller settings were developed to give a 1/4 decay ratio. However, other settings have been recommended that are closer to critically damped control (so that oscillations do not propagate downstream). These PID controller settings are shown in the following table
.

Controller	K_p	T_i	T_d
Original	0.6 K_u	$P_u/2$	$P_u/8$
Some Overshoot	0.33 K_u	$P_u/2$	$P_u/3$
No Overshoot	0.22 K_u	$P_u/2$	$P_u/3$

Table: Formulas for the controller parameters in the Ziegler-Nichols' closed loop method.

3.3 Åstrom Relay Method:

Åstrom modified the transient response experimentation with a relay in a feedback loop with the process. The major aim of this method is to be able to automate the Z-N method in other to capture the ultimate gain and period of the process. Åstrom uses a simple relay in a feedback loop to achieve the same aim as Nichols and Ziegler tuning rules. The critical point of a process determined by Z-N by increasing the proportional gain indefinitely was achieved by Åstrom with the use of relay experimentation with just a fractional perturbation signal of the process range. The amplitude of the relay is a small amount of the control effort usually between 2% to 10% of the control effort [11]. This method ensure that the system oscillation is achieved without the risk of making the system goes into definite instability. As shown in Figure below, the control input into the system is the relay output. This varies between positive and negative values of the relay amplitude, h, as given in equation 5 and 6. Some process like the Air heater process does not accept a negative control value and as such the Åstrom relay tuner cannot be implemented on such a system.

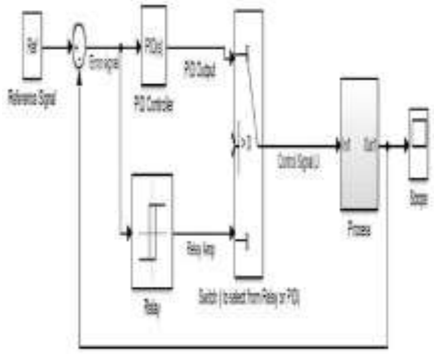


Figure Shows 'Åstrom Relay Auto Tuner showing the Relay and PID controllers' connection to the Process in a feedback loop. The operator can perform auto tuning by switching from the controller to the relay in which case the input into the process will oscillate between the set point +/- the relay amplitude.

If processes gain is positive,

$$u = \begin{cases} h & \text{if } e \geq 0 \\ -h & \text{if } e < 0 \end{cases} \qquad (5)$$

If processes gain is negative,

$$u = \begin{cases} -h & \text{if } e \geq 0 \\ h & \text{if } e < 0 \end{cases} \qquad (6)$$

3.4 Schei Relay Method

Schei method is like Åstrom with the same principle of relay feedback experimentation during the tuning process. The method assume that a stable controller is in operation before the experiment and this need to be improved. The reference signal to the PID controller is varies between positive and negative values of the relay. Therefore, the control signal to the process is a function of the relay switching and thus a limit cycle will be established . It's also employed a filter in the derivative loop to help in noise situation . Figure below shows the block diagram of the implementation of Schei scheme

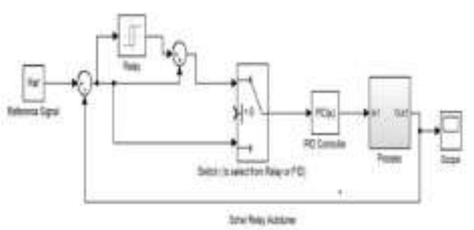
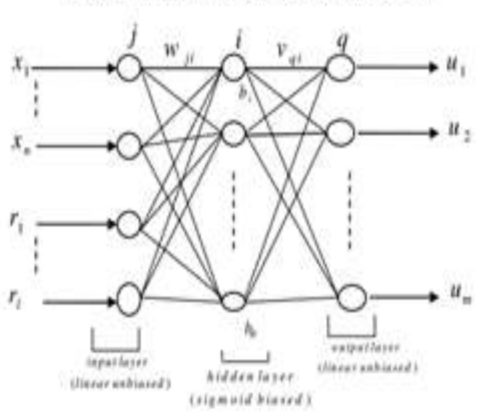


Figure Shows Schei Relay Auto Tuner showing the Relay and PID controllers' connection to the Process in a feedback loop. During relay experiment the reference signal varies in step by the relay output. The relay is made to switch by the error signal by the application of a linear zing element as shown in equation 5.

3.5 Neural network Controller:

A neural network comprises simple elements operating in parallel. In fact, it is a massively parallel distributed processor that stores experiential knowledge and makes it available for use when needed. In using neural networks for system identification, training data can be obtained by observing the input-output

Figure : Structure of the Neural Network (MIMO model)



behavior of a plant. This process is called as "one step ahead prediction" and the structure is called Time Delayed Neural network.

In designing and training an ANN to emulate a function, the only fixed parameters are the number of inputs and outputs of the ANN, which are based on the input/output variables of the function. It is also widely accepted that maximum of two hidden layers are sufficient to learn any arbitrary non-linearity. The back-propagation training technique adjusts the weights and bias in all connecting links in the nodes so that the difference between the actual output and target output are minimized for all given training patterns [16] the time delayed neural network is a multilayer neural network and has four inputs. The output layer of the NN has only one neuron with pure linear activation function. Neural networks are wonderful tools, which permit the development of quantitative expressions without compromising the known complexity of the problem.
Neural networks resemble the human brain in the following two ways:

- A neural network acquires knowledge through learning.

- A neural network's knowledge is stored within inter-neuron connection strengths known as synaptic weights
- An Artificial Neural Network (ANN) is an information processing paradigm that is inspired by the way biological nervous systems, such as the brain, process information.

3.6 Fuzzy logic controller:

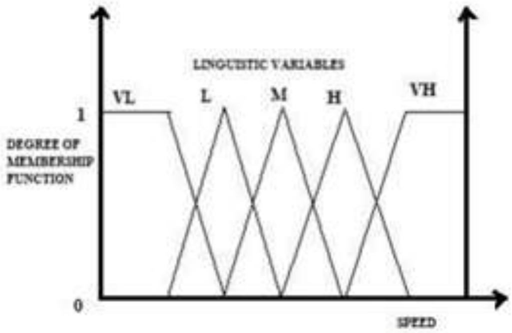
Fuzzy logic concept is similar to the human mind. Unlike classical control strategy, which is a point-to-point control, fuzzy logic control is a range-to-point or range-to-range control strategy. The associated membership functions are used to produce the output in a fuzzy logic controller by fuzzification of inputs and defuzzification of outputs. The different members of the associated membership functions are defined based on the values of crisp inputs. From this point of view, the memberships of different membership function are considered as range of inputs. These membership functions decide the output of a fuzzy logic controller. The implementation of fuzzy logic technique to an application involves the following three steps:

1. Fuzzification – converts crisp sets or crisp data into fuzzy sets or Membership Functions
2. Fuzzy Inference Process – combines membership functions with the control rules to obtain the fuzzy output
3. Defuzzification – different methods are available to calculate each associated output and prepare the lookup table. It selects the output from the lookup table based on the current input during an application.

Fuzzification is the first step in fuzzy control system. Most of the variables are crisp variables. In a fuzzy system, these variables are needed to be converted into fuzzy variables and this data is processed in fuzzy inference process to obtain the desired output. This can be achieved in two steps, firstly derive the membership functions and represent them using linguistic variables. For DC motor, we may partition the input variable as VL (very low speed), L (low speed), M (medium speed), H (high speed), VH (very high speed). The membership functions of input variable are shown in Fig. below.

The fuzzy inference process determines the control rules known as fuzzy rules. In the field of artificial intelligence (machine intelligence) there are

Fig. Membership functions.



various ways to represent knowledge. Perhaps the most common way to represent human knowledge is to form it into natural language expressions of the type; IF premise (antecedent), THEN conclusion (consequent). The form in Expression is commonly referred to as the IF–THEN rule based form. It typically expresses an inference such that if we know
a fact (premise, hypothesis, antecedent), then we can infer, or derive, another fact called a conclusion (consequent).

Defuzzification is when all the actions that have been activated are combined and converted into a single non-fuzzy output signal which is the control signal of the system. The output levels are depending on the rules that the systems have and the positions depending on the non-linearity's existing to the systems. To achieve the result, develop the control curve of the system representing the I/O relation of the systems and based on the information; define the output degree of the membership function with the aim to minimize the effect of the non-linearity.

Advantages:

Field Programmable Gate Array (FPGA) offers the most preferred way of designing PWM Generator for Power Converter Applications. They are basically interconnection between different logic blocks.

When design is implemented on FPGA they are designed in such a way that they can be easily modified if any need arise in future. We have to just change the interconnection between these logic blocks. This feature of Reprogramming capability of FPGA makes it suitable to make your design using FPGA.

Also using FPGA we can implement design within a short time. Thus FPGA is the best way of designing digital PWM Generators. Also, implementations of FPGA-based digital control schemes prove less costly, high speed, complex functionality, and low power consumption and hence they are economically suitable for small designs.

IV. CONCLUSIONS

In this paper, an attempt has been made to review various literatures for the classical controller techniques introduced by the different researchers for tuning of PID controller for speed control of DC motor to optimize the best result. This review article is also presenting the current status of tuning of PID controller for speed control of DC motor using classical controller techniques.

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