A Comparision of IMC and PID controller using Matlab/Simulink program

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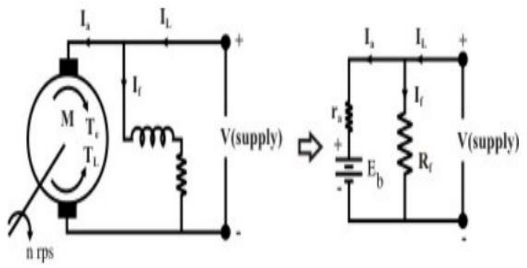
Abstract—This paper brings out the parameter comparisons between two most used conventional controllers- PID and IMC. One of the important applications where controllers are used is in controlling the speed of DC motor. Shunt connected DC motor will be used as the process plant. With the system response obtained by adding the both controllers, will be compared based on settling time, rise time and maximum overshoot.

Keywords—*DC shunt motor, PID controller, IMC, Simulink*

1. INTRODUCTION

The electric machines can be broadly classified into DC(Direct Current) and AC(Alternating Current) machines, further DC machines can be classified into generators and motors. The motor is a machine which converts electrical energy into mechanical energy. DC motor generally have field and armature windings. Based on the field windings position DC motors are classified into DC series and DC shunt motor. In shunt motor connection, field windings are connected in parallel with armature winding as shown in



the Fig. 1. This paper will focus only on DC shunt motor.

Fig. 1. DC shunt motor connection and circuit representation

The speed of shunt motor is given by,

$$n = \frac{Va - Ia * ra}{k\emptyset} \quad (1)$$

In this paper [1], tuning methods of a PID speed controller for separately excited Direct current motor is presented, based on Empirical Ziegler-Nichols tuning formula and modified Ziegler-Nichol PID tuning formula. Both these methods are compared with respect to output response, minimum settling time, and minimum overshoot for speed demand application of DC motor.

In [2] author has reviewed classical control techniques used for tuning of PID(Proportional Integral Derivative) controllers and other optimization techniques involving neural networks, fuzzy logic as well and this paper served as a comprehensive source for selecting the perfect PID tuning method.

In this paper [3], implementation of IMC based controller for flow control application to achieve the set point tracking in presence of load disturbance is discussed. To show the disturbance rejection ability of IMC (Internal Model Controller) based controller, results of the flow control system using IMC based controller are compared with the results using a PID controller for the same system.

2. MODELLING SHUNT CONNECTED DC MOTOR

DC motor is modelled using Kirchhoff laws and Newton laws of motion and the model is checked by performing simulations in Simulink/MATLAB.

The connection diagram of Dc shunt motor is shown in the Fig. 2.

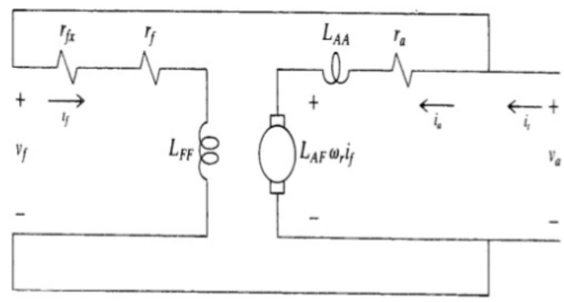


Fig. 2. Equivalent circuit of DC shunt motor

Lf is the field winding inductance, rf is the field resistance, rfx is an external variable resistance, if is the field current, and vf is the field voltage. La is the armature winding, Ra is the armature resistance, ia is the armature current, and va is the armature voltage. Laf is the mutual winding inductance

and w is the rotor speed. The Transfer function of DC shunt motor is shown in the equation (2).

$$G_p = \frac{Kt}{(J_m L_a s^2) + (J_m R_a + B_m L_a)s + (KtKb + BmRa)} \quad (2)$$

Substituting the values of motor constants,

$$Gp = \frac{2}{s^2 + 2s + 20.02} \quad (3)$$

3. PID AND IMC CONTROLLER DESIGN

A. Proportional Intergal Derivative (PID) Controller

The most used controllers in industries are PID controllers because most PID controllers adjusted on-site, many tuning rules have been proposed to tune the constants of the controller, using these tuning rules fine tuning of PID controllers can be made. The process of determining the controller parameters to meet the given specifications is known as controller tuning. Ziegler and Nichols proposed the rules for tuning controller parameters Kp, Ki, Td based on experimental step response or based on the values of Kp that results in marginal stability when proportional controller is acting and other two (integrator, derivative) controllers are disabled.

Ziegler and Nichols proposed rules to determine the values of PID gains based on the transient response characteristics of given plant, which helps engineers to tune on-site by experiments on the plant. There are two methods in Ziegler-Nichols tuning namely First and Second methods of Ziegler-Nichols. In this paper Second method of Ziegler-Nichols is used for tuning the PID constants.

In this method, first Ti is set to infinity and Td = 0. Using the proportional control action only increase the Kp from 0 to a critical value Kcr at which the output exhibits sustained oscillations, if the output does not exhibit sustained oscillations for any values of Kp then this method does not apply. Table I shows the calculations of the constants Kp, Ti and Td for different types of controller used

TABLE I. ZIEGLER-NICHOLS TUNING RULE, SECOND METHOD

Type of Controller	K_p	T_i	T_d
P	$0.5K_{cr}$	∞	0
PI	$0.45K_{cr}$	$\frac{1}{1.2}P_{cr}$	0
PID	$0.6K_{cr}$	$0.5P_{cr}$	$0.125P_{cr}$

B. Internal model Controller (IMC)

IMC is the model-based design method which was developed by Morari. The IMC method is based on the process model and leads to the analytical expression for controller settings. The block diagrams for conventional feedback control and

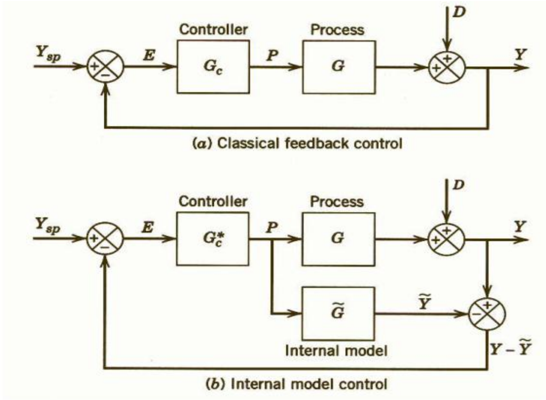


Fig. 3. Internal module control scheme

IMC are compared and shown in the Fig. 3.

The theory of IMC states that control can be achieved only if the control system encapsulates, either implicitly or explicitly, some representation of the process to be controlled. The Internal Model Controller is based on the inverse of the process model which is to be controlled. If cascaded with the process transfer function with a controller which is the exact inverse of the process, then effectively the gain becomes unity and we have perfect set-point tracking. The main feature of internal model controller is that the process model is in parallel with the actual process.

Equations related to IMC are as follows

$$Gc = \frac{Gimc}{1 - Gp^{\sim}.Gimc} \quad (4)$$

$$G_{IMC} = [\tilde{G}]^{-1} G_f \quad (5)$$

$$G_f = \frac{1}{(1 + \lambda s)^n} \quad (6)$$

Where, Gf is low pass function, λ is the closed loop time constant and n tells the order of the filter. A good rule of thumb is to choose λ to be twice fast as open loop response and λ = 0.9 is selected.

$$Gimc = \frac{s^2 + 12s + 20.02}{1.62s^2 + 3.6\, s + 2} \quad (7)$$

$$Gc = \frac{s^2 + 12\ s + 20.02}{1.62\ s^2 + 3.6s + 0} \qquad (8)$$

4. Simulink Model Details

This section will discuss about the Simulink model created for IMC and the PID controller, tuned by Ziegler-Nichols method.

C. PID with motor

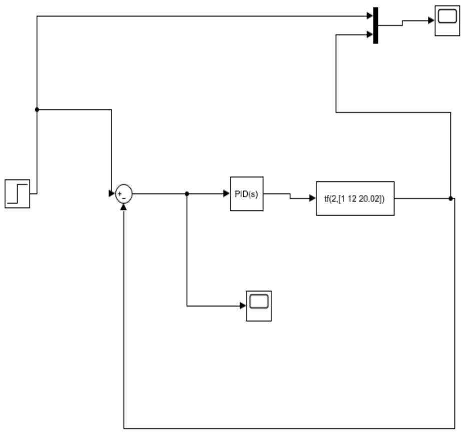


Fig. 4. Simulink model of PID controller

In Figure (4) PID controller is used along with the transfer function of the motor shown in the equation (3) in a unity feedback loop with the set-point as 1.

D. IMC with the motor

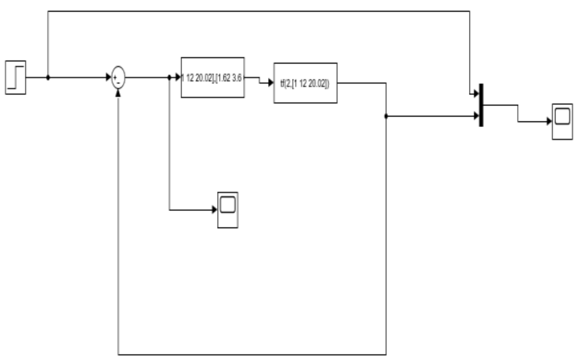


Fig 5. Simulink model of IMC Controller

In Figure (5) IMC controller is used along the with transfer function of the motor shown in equation (3) in a unity feedback loop with the setpoint as 1. The transfer function of IMC controller is shown in the equation (8).

5. Results & Discussions

E. PID with motor

From the closed loop oscillation method of Ziegler - Nichols, Kcr (critical gain) obtained is 13 and T period of oscillation is 2 sec, which implies Kp = 7.5, Ki = 1 and Kd = 0.5. The initial design values of PID controller obtained by this method needs to be adjusted repeatedly through simulations until the closed loop system performs as desired. These adjustments are done in MATLAB simulation and after continuous simulations the achieved system response is shown in the Figure (6) the final values of the controller constants Kp, Ki, Kd are 330, 343.25 and 19.172 respectively. The peak amplitude value reached by the system is 1.12 i.e., 12 % overshoot.

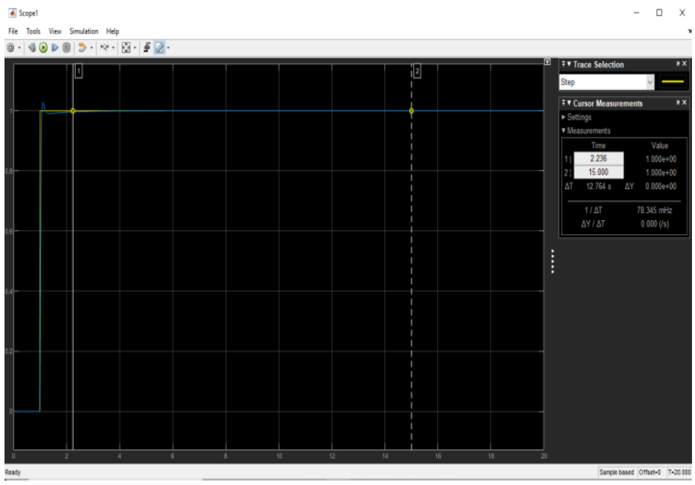


Fig 6. Step response of PID controller

F. IMC with the motor

The system step response using IMC controller is as shown the Figure (7) which has the settling time of 8.211 secs with zero percent overshoot. Settling time can be observed by cursor 1 measurements shown in the Figure (7).

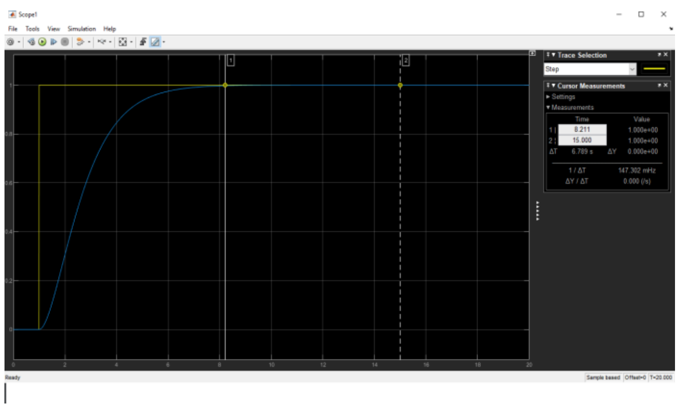


Fig. 7. Step response of PID controller

G. *Performance Comparision*

Comparison between two controllers IMC and PID with the same plant (DC shunt motor) in terms of overshoot, settling time and rise time is as shown in the Table II

TABLE II. PARAMETERS COMPARISON OF BOTH CONTROLLERS

Controller	Parameters		
	Overshoot in %	*Settling time (secs)*	*Rise time (secs)*
PID	12	2.236	1.2
IMC	0	8.211	5

The PID controller gives 12 % peak overshoot with settling time of 2.236 sec. The peak overshoot is in a higher side. The IMC controller reduces the peak overshoot to 0% and increases the settling time to 8.3 sec. Even though there is no overshoot in IMC controller-based system the time taken by DC shunt motor to reach its steady state value is longer i.e., settling time is more compared to system with PID controller.

PID controller had the upper hand over the IMC controller as the system with PID controller reaches steady state value 26.98 % faster than the system with IMC controller with a trade of 12 % overshoot in PID controller-based system.

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