Design and Comparative Study of Modified IMC from IMC for The DC Motor Speed Control Application

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Abstract— The internal model control (IMC) philosophy relies on the internal model principle, which states that control can be achieved only if the control system encapsulates, either implicitly or explicitly. If the control scheme is developed based on an exact model of the process, then perfect control is theoretically possible. The research browses the DC motor system and gets its transfer function to be the base of the design, which examines IMC and our proposed controller. Matlab/simulink is used to simulate the procedures and validate the performance. The results approved that Modified approach gives better results than IMC in terms of error reduction.

Key words: IMC, DC motor

I. INTRODUCTION

Every feedback controller is designed by employing some form of a model for the process that is to be controlled and/or the dynamics of the exogenous signal affecting the process. Consequently, the term "model-based" is often used here. 30-years ago, a new model-based controller design algorithm named "Internal Model Control" (IMC) has been presented by Garcia and Morari, which is developed upon the internal model principle to combine the process model and external signal dynamics.

In the control theorem, the control systems design is fundamentally determined by the steady state and dynamic behavior of the process to be controlled. It is an important issue to know the way in which the process characteristics influence the controller structure. The internal model control (IMC) viewpoint appeared as alternative to traditional feedback control algorithm, which link the process model with the controller structure.

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 main objective is to design an IMC Controller for the proposed pendulum system to reduce the effect of disturbance due to mismatching in modeling.

II. INTERNAL MODEL CONTROL

Schematic representation of the IMC structure is presented in Figure 1, in which G(s) represents the process itself. Gd(s) the process transfer function of the disturbance, G’(s) the mathematical model (transfer function) of the process, and the transfer function of the IMC controller.

As may be observed from the block diagram of the IMC structure, there are two parallel paths starting from the manipulated variables u(s): one passing through the real process G(s) and the other passing through the model process G’(s). The role of the parallel containing the model G’(s) is to make possible the generation of the difference between the actual process output y(t) and an estimation predication of the manipulated variable effect on the process output.Assuming that the process model is a perfect representation of the real process that is G’ (s) = G(s).

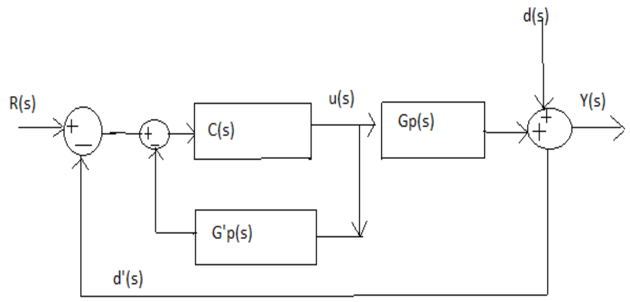

Fig. 1: Schematic diagram of IMC

A. *IMC Tuning Rules:*

IMC scheme is one of the strongest techniques that raise these motivations:

1) IMC technique has been used in many linear systems to control its states and it is considered as a robust controller while the process model is near from the real plant. In this thesis, we will apply the IMC technique on the non-linear pendulum system, which is not tested before.
2) Because of the non-linearity of the pendulum system and the IMC demands a model of the plant, so we will be directed to get the linearized form as our base model. Then the distance between the real process and the plant model is increased and it will be a good challenge to IMC to be approved.
3) As the gap between the process model and the plant was increased, the uncertainty of the system also increased and the IMC here will be tested for robustness as the parameters values will be varied.
4) A new proposed approach of IMC technique was suggested to be put under the same mentioned circumstances, tested and compared with the traditional one. The new approach modifies some block in the structure of IMC to get better results.

B. *Internal Model Controller Design:*

1) Factor the model G’p(s) into two parts:
$$G'p(s) = G'p\text{-}(s)\,.G'p\text{+}(s)$$
2) To improve robustness, the effects of mismatch between the process, and process model should be minimized. Since the differences between process and the process model usually occur at the systems high frequency response end, a low-pass filter f(s) is usually added to attenuate this effect.

Thus, IMC is designed using the inverse of the process model in series with a low-pass filter. A common filter choice that conforms to this requirement is

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$$f(s) = \frac{1}{(\lambda s+1)^n}$$

The filter order n is selected large enough to make Gp(s) proper

3) In addition to this criterion, the filter time constant λ must satisfy

$$\lambda \geq (\lim_{s\to\infty} \frac{D(s)N(0)}{20s^n N(s)D(0)})^{\frac{1}{n}}$$

4) Augment with a filter f(s) such that the final IMC controller is now,

Gc(s)=G'p-1(s).f(s)

III. Model Identification of DC Motor System for Controller Design

DC motors convert the electrical power to the mechanical power. Here, V is the voltage source of DC Motor, J is the moment of inertia, Ra is the resistance of the armature, La is the inductance of the armature and ω is the speed of DC motor.

Electrical characteristics of the circuit shown in Figure 5 can be expressed by Kirchhoff's law. When Kirchhoff's law is applied to the electrical loop, differential equation for the circuit can be derived.

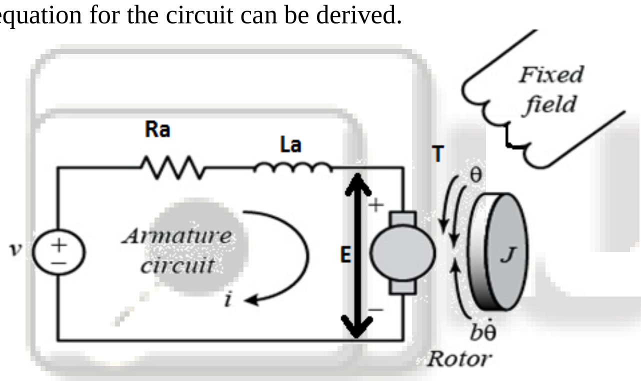

Fig. 2: Block diagram of DC motor

$$V = Ra * i(t) + L\frac{di(t)}{dt} + E \text{ ……………………….. (1)}$$

Also,

$$E = Ke\ \omega(t) \text{ ………………………………. (2)}$$

The relationship between torque and angular velocity or speed of the motor is:

$$\tau = J * \frac{d\omega(t)}{dt} \text{ ……………………………….. (3)}$$

Also,

$$\tau = Kt * i(t) \text{ …………………………… (4)}$$

From eq. (3) and (4)

$$Kt * i(t) = J * \frac{d\omega(t)}{dt} \text{ ……………………..… (5)}$$

From eq. (1) and (2)

$$V = Ra * i(t) + L\frac{di(t)}{dt} + Ke\ \omega(t) \text{ ………….. (6)}$$

From eq. (5)

$$\frac{d\omega(t)}{dt} = \frac{Kt * i(t)}{J} \text{ …………………….. (7)}$$

From eq. (6)

$$\frac{di(t)}{dt} = \frac{1}{L}(V - Ra * i(t) - Ke\ \omega(t)) \text{ ………. (8)}$$

Taking Integration

$$\omega(t) = \frac{Kt * i(t)}{J} \text{ ………………………….. (9)}$$

$$i(t) = \frac{1}{L}(V - Ra * i(t) - Ke\ \omega(t)) \text{ .... (10)}$$

IV. Modified IMC

- It can be seen from literature that IMC technique can be used in many linear systems to control its states and it is considered as a robust controller when the process model is near to the real plant.
- As the gap between the process model and the plant increased, the uncertainty of the system also increased and the IMC will be tested for robustness.
- Then if the distance between the real process and the plant model is increased then it will be a good challenge for IMC to be approved.
- A new proposed approach of IMC technique is suggested to be put under the same mentioned circumstances, tested and compared with the traditional one. The new approach modifies some block in the structure of IMC to get better results.

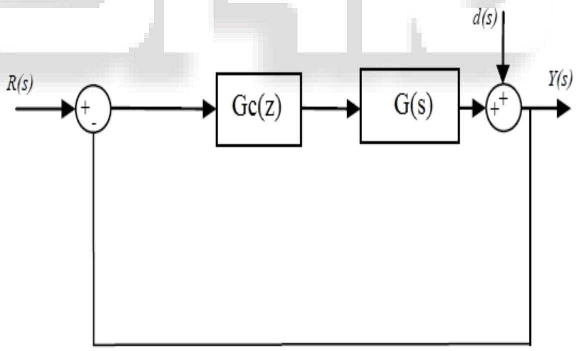

Fig. 3: Block Diagram of Modified IMC

- The figure above illustrates the structure of this approach and we can see the disappearance of the reference model. The new proposed IMC structure cancels the repeated model appeared in the general IMC structure.
- We can use following equation

$$G_c(z) = G(z)^{-1} G_f \text{ ……………………… (32)}$$

- Where, Gf is the filter having value Bf /Af.
- Hence,
- The IMC equivalent conventional feedback controller is given by

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$$G_c = \frac{\frac{B_f}{A_f}\frac{A}{B^g B_r^{nm+} B_s^-}}{1 - \frac{B_f}{A_f}\frac{A}{B^g B_r^{nm+} B_s^-}\frac{B_g B^{nm+} B^-}{A} z^{-k}} \quad .... \quad (33)$$

– Where Bg is the factor of B with roots inside the unit circle and with positive real part, B- is the factor of B with roots that have negative real parts, Bnm+ is the part of B containing non-minimum zeros of B with positive real parts, Bs- is the steady state equivalent of B-, Brnm+ is Bnm+ with reversed coefficient, filter have the value of

$$\frac{B_f}{A_f} = \frac{1-\alpha}{1-\alpha z^{-1}} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \ (34)$$

– Simplifying the eq. (33) we get,

–

$$G_c(z) = \frac{B_f A}{B^g (A_f B_r^{nm+} B_s^- - B_f B^{nm+} B^- z^{-k})} \cong \frac{S_c(z)}{R_c(z)} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \ (35)$$

– The controller is in the form

$$R_c(z)u = T_c(z)r - S_c(z)y \quad \ldots\ldots\ldots\ldots\ldots \ (36)$$

– Where

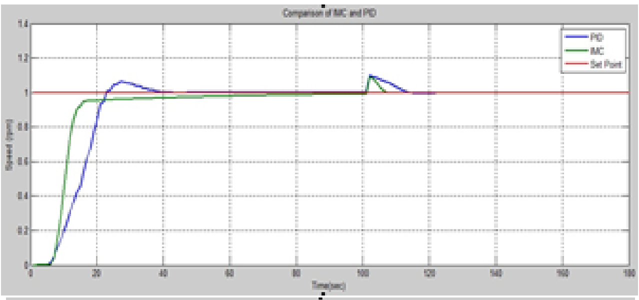
$$T_c(z) = S_c(z) \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots \ (37)$$

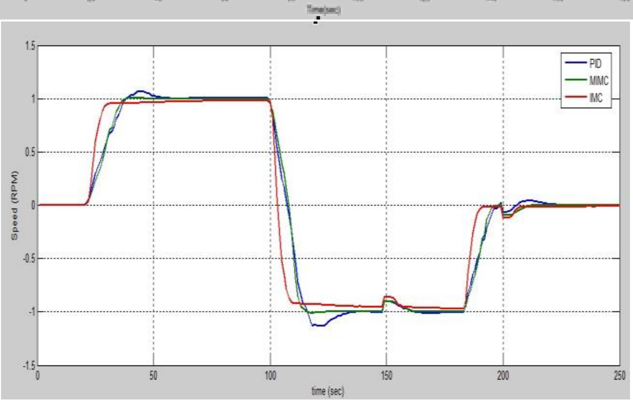
– If filter is chosen as in eq. (34) then using eq. (33) we see that,

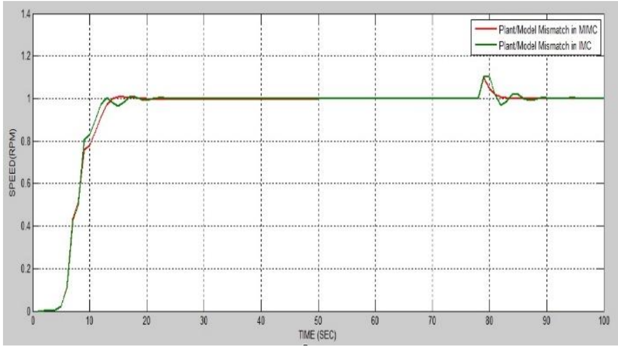
$$R_c(1) = 0 \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \ (38)$$

V. Simulation and Result

Figure 11 shows the comparison between PID and IMC. From the response we can see that PID has high overshoot, high rise time and it takes more time to reject disturbance and more time to settle.







VI. Conclusion

A new approach of control design of internal model controller was proposed in this thesis. The proposed design method focused on modifying the old general structure of IMC and got a new one with saving the same general concept of using the invertible version of the system in the controller design. The new approach combines the IMC structure and the traditional structure of a control problem and this demonstrate an excellent performance and behavior against different disturbance inputs and model uncertainty presented in model mismatch.

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