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Position Control for Dynamic DC MOTOR with Robust PID Controller using MATLAB

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ABSTRACT

Dynamic DC motor one of the important parts used in different applications. Dynamic DC motor position control one of the important aspects for these applications. In this paper the position control of the dynamic DC motor was done by using robust PID controller, the tuning of PID parameters (K_d, K_p and K_i), was done using algorithms named robust PID controller applied many cases studies depended on the optimum coefficient for the Integral of Time Multiplied Absolute Error Criterion (ITAE) for step and ramp unit using MATLAB programs.

Key words: Position Control, Dynamic DC Motor, Robust PID Controller, ITAE, Step Unit, Ramp Unit, MATLAB.

1. INTRODUCTION

A dynamic DC motor is a device that converts electrical energy into mechanical energy. In this paper designed and implementation for a dynamic DC motor that can be controlled by using a robust PID controller. The in-position control holder for a destination position variation is automatically implemented Dynamic DC drives are more suitable for large position control and there are many adjustable speed motors.

The Proportional – Integrative – Derivative (PID) controls the majority of the control system in the world and PID is that it is a sufficiently flexible controller for many applications. The parameters robust of a classical PID controller is used to control the dynamic DC drive position, i.e. (K_d, K_p and K_i), are usually fixed during operation [1].

Applying a robust PID controller algorithm in a position controller are the effects of non-linearity in a dynamic DC motor [2]. The nonlinear characteristics of a DC motor such as saturation and fiction could degrade the performance of conventional controllers. PID controller provides robust and reliable performance for most systems if the PID parameters are set correctly [3].

The paper is arranged as in the following. In the section two displays theory of dynamic DC motor about the parameters i.e. $\mathbf{J_m, L_a, R_a, B_m, K_t}$ **and** $\mathbf{K_b}$. In section three, represents mathematical model (open and close loop) for dynamic DC motor without and with robust PID controller. In section four, represents the algorithm robust PID control. In section five, represents simulation and result for many cases studies using MTLAB program.

2. DYNAMIC DC MOTOR

The transfer function of the dynamic DC motor can be found from the schematic of the dynamic DC motor in figure 1. Also the dynamic DC motor depends on the base of the left palm where the thumb of the direction of the force (torque or thrust ($\tau(t)$). The finger between the thumb and center represents the direction of the magnetic field orientation (fixed (EMF)). The middle finger represents the direction of the current in the wire (current ($i(t)$)).

In the actual dynamic DC engine, many of these coils are wrapped on the rotor, all facing force, resulting in rotation. The higher the current in the wire, or the greater the magnetic field, the faster the wire moves because of the greater force generated. At the same time this torque is produced, and the conductors move in a magnetic field. In multiple positions, the associated flow changes, leading to EMF ($e = d\phi / dt$). This voltage is contrasted with the voltage that causes the current to flow through the connector and is referred to as an anti-voltage or EMF return.

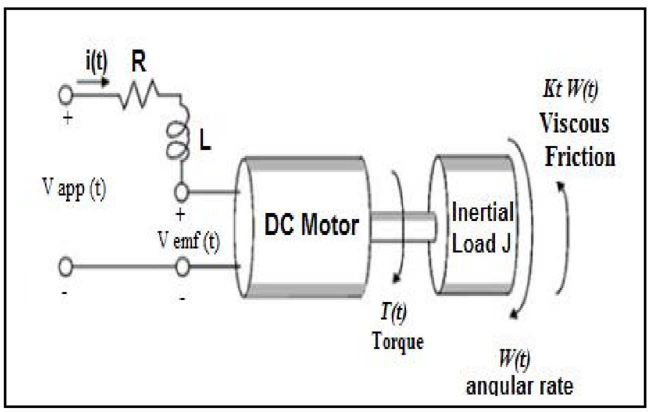

Figure 1: Scheme of the Dynamic DC Motor Circuit

Where: V= Armature Voltage (V).
I= Armature Current (I).
K_t= Motor Torque Constant (Nm/A).
L_a= Motor inductance (H).
J_m= Armature moment of inertia (Kg – m2).
R_a = Armature Resistance (Ω).
B_m =Viscous – Friction Coefficient (N-m/Rad/Sec).
K_b= Back EMF Constant (V/Rad/Sec).

3. MATHEMATICAL MODEL

3.1. Position Control of Dynamic DC Motor without PID Controller Model

❖ ***Open Loop***

Represent the block diagram for Dynamic DC Motor without PID Controller for open loop in figure 2, and the armature voltage equation is given by:

$$G_{DC}(S) = \frac{\emptyset(S)}{V(S)} = \left(\frac{1}{L_aS + R_a}\right)(K_t)\left(\frac{1}{J_mS + B_m}\right)\left(\frac{1}{S}\right) \qquad (1)$$

$$G_{DC}(S) = \left(\frac{K_t}{J_mL_aS^3 + R_aJ_mS^2 + B_mL_aS^2 + R_aB_mS}\right) \qquad (2)$$

After deriving and simplifying the equations of Dynamic DC model for open loop, the result of transfer function $G_{DC}(S)$ is as follows:

$$G_{DC}(S) = \left(\frac{K_t}{J_mL_aS^3+(R_aJ_m+B_mL_a)S^2+R_aB_mS}\right) \qquad (3)$$

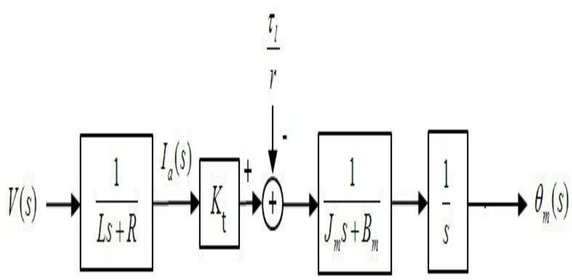

Figure 2: Block Diagram of the Dynamic DC Motor without PID Controller for Open Loop

❖ ***Close Loop***

Represent the block diagram for Dynamic DC Motor without PID Controller for close loop in figure 3, and the armature voltage equation is given by:

$$T.F\ (G_P(S)) = \frac{G_{DC}(S)}{1 + G_{DC}(S)H(S)}$$

$$G_{DC}(S) = \frac{K_t}{J_mL_aS^3 + R_aJ_mS^2 + B_mL_aS^2 + R_aB_mS},$$

$\&\ H(S) = K_b.$

$$\therefore T.F = \left(\frac{\frac{K_t}{J_mL_aS^3 + R_aJ_mS^2 + B_mL_aS^2 + R_aB_mS}}{1 + \frac{K_t}{J_mL_aS^3 + R_aJ_mS^2 + B_mL_aS^2 + R_aB_mS} * K_b}\right) \qquad (4)$$

After deriving and simplifying the plant equations of Dynamic DC model without PID Controller for close loop, the result of transfer function $G_P(S)$ is as follows:

$$G_P(S) = \left(\frac{K_t}{J_mL_aS^3 + (R_aJ_m + B_mL_a)S^2 + R_aB_mS + K_t K_b}\right) \qquad (5)$$

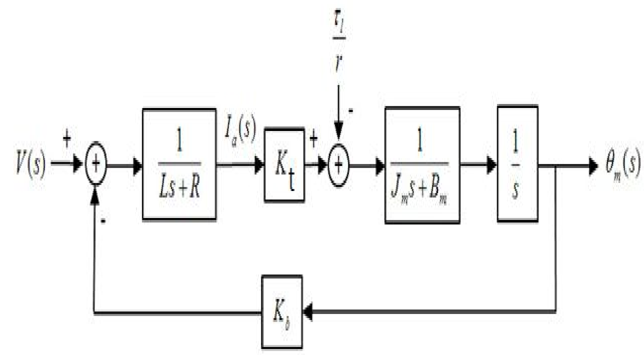

Figure 3: Block Diagram of the Dynamic DC Motor without PID Controller for Close Loop

3.2. Position Control of Dynamic DC Motor with PID Controller Model

❖ ***Open Loop***

Represent the block diagram for Dynamic DC Motor with PID Controller for open loop in figure 4, and the armature voltage equation is given by:

$$G_{sys}(S) = G_C(S) * G_p(S)$$

$$G_{sys}(S) = \left(K_P + \frac{K_i}{S} + K_dS\right) * \left(\frac{K_t}{J_mL_aS^3 + (R_aJ_m + B_mL_a)S^2 + R_aB_mS + K_t K_b}\right) \qquad (6)$$

$$G_{sys}(S) = \left(\frac{K_t * \left(K_P + \frac{K_i}{S} + K_dS\right)}{J_mL_aS^3 + (R_aJ_m + B_mL_a)S^2 + R_aB_mS + K_t K_b}\right) \qquad (7)$$

After deriving and simplifying the plant equations of Dynamic DC model with PID Controller for open loop, the result of transfer function $G_{sys}(S)$ is as follows:

$$G_{sys}(S) = \left(\frac{K_t K_d S^2 + K_t K_p S + K_t K_i}{J_m L_a S^4 + (R_a J_m + B_m L_a) S^3 + (R_a B_m) S^2 + (K_t K_b) S}\right) \quad (8)$$

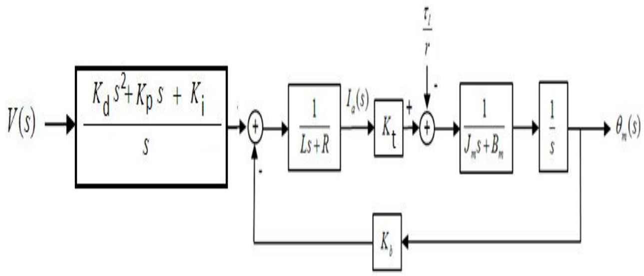

Figure 4: Block Diagram of the Dynamic DC Motor with PID Controller for Open Loop

❖ ***Close Loop***

Represent the block diagram for Dynamic DC Motor with PID Controller for close loop in figure 5, and the armature voltage equation is given by:

$$T.F = \frac{G_{sys}(S)}{1 + G_{sys}(S)H(S)}, \quad where \ H(S) = 1.$$

$$G(S) = \left(\frac{\dfrac{K_t K_d S^2 + K_t K_p S + K_t K_i}{J_m L_a S^4 + (R_a J_m + B_m L_a) S^3 + (R_a B_m) S^2 + (K_t K_b) S}}{1 + \dfrac{K_t K_d S^2 + K_t K_p S + K_t K_i}{J_m L_a S^4 + (R_a J_m + B_m L_a) S^3 + (R_a B_m) S^2 + (K_t K_b) S} * 1}\right) \quad (9)$$

$$G(S) = \left(\frac{K_t K_d S^2 + K_t K_p S + K_t K_i}{J_m L_a S^4 + (R_a J_m + B_m L_a) S^3 + (R_a B_m) S^2 + + K_t K_b S + K_t K_d S^2 + K_t K_p S + K_t K_i}\right) \quad (10)$$

After deriving and simplifying the plant equation of Dynamic DC model with PID Controller for close loop, the result of transfer function $G(S)$ is as follows:

$$G(S) = \left(\frac{K_t K_d S^2 + K_t K_p S + K_t K_i}{J_m L_a S^4 + (R_a J_m + B_m L_a) S^3 + (R_a B_m + K_t K_d) S^2 + (K_t K_b + K_t K_p) S + K_t K_i}\right) \quad (11)$$

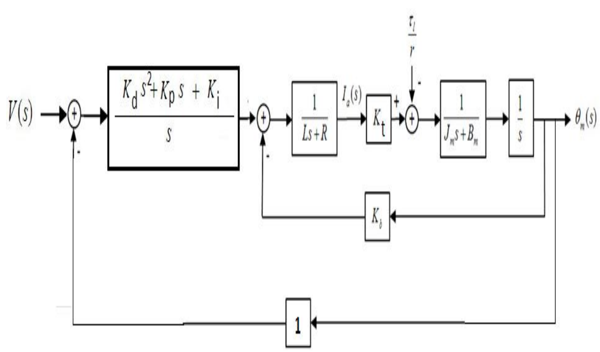

Figure 5: Block Diagram of the Dynamic DC Motor with PID Controller for Close Loop

4. ALGORITHM ROBUST PID CONTROL

1. Determined the input values of: L_a, B_m, R_a, J_m, K_t and K_b.
2. Calculated the transfer function plant for dynamic DC motor without PID control of the following :
   - Open Loop: from the equation (3).
   - Close Loop: from the equation (4).
3. Calculated the parameters of W_n, K_p, K_d and K_i for step unit depended on the Integral of Time Multiplied Absolute Error Criterion (ITAE) of the following:-

$$W_n = \frac{\left(\frac{L_a B_m + R_a J_m}{a_1}\right)}{2.1};$$

$$K_p = \frac{\left(\frac{2.7\, W_n^{\,3}}{a_1}\right) - K_t K_b}{K_t};$$

$$K_d = \frac{\left(\frac{3.4\, W_n^{\,2}}{a_1}\right) - R_a B_m}{K_t};$$

$$K_i = \frac{\left(\frac{W_n^{\,4}}{a_1}\right)}{K_t}$$

4. Calculated the transfer function for dynamic DC motor with PID control using step unit of the following :
   - Open Loop: from the equation (8).
   - Close Loop: from the equation (11).
5. Calculated the parameters of W_{nr}, K_{pr}, K_{dr} and K_{ir} for ramp unit depended on the ITAE criterion of the following:-

$$W_{nr} = \frac{\left(\frac{L_a B_m + R_a J_m}{a_1}\right)}{2.41};$$

$$K_{pr} = \frac{\left(\frac{4.93\, W_n^{\,3}}{a_1}\right) - K_t K_b}{K_t};$$

$$K_{dr} = \frac{\left(\frac{4.93\, W_n^{\,2}}{a_1}\right) - R_a B_m}{K_t};$$

$$K_{ir} = \frac{\left(\frac{W_n^{\,4}}{a_1}\right)}{K_t}$$

6. Calculated the transfer function for dynamic DC motor with PID control using ramp unit of the following :
   - Open Loop: from the equation (8).
   - Close Loop: from the equation (11).

5. SIMULATION AND RESULT

Case Study 1

In this case used the dynamic DC motor parameter values are, Motor-torque constant (K_t) =0.05 Nm/A, Load of Armature (L_a) =0.1 H, Armature resistance (R_a) =1.39 Ohm, Motor moment of inertia (J_m) =0.02 Kg.m2, Viscous damping coefficient (B_m) =0.02 N.m/rad/sec, Back EMF Constant (K_b) =0.05 V/Rad/Sec.

The results are:

Open loop dynamic DC motor in case study1

$$G_{DC}(S) = \left(\frac{0.05}{0.002\,S^3 + 0.0298\,S^2 + 0.0278\,S}\right)$$

In Figure 6 represented the structure of close loop dynamic DC motor response without PID controller, and the equations of close loop dynamic DC motor in case study1will be:

$$G_p(S) = \left(\frac{0.05}{0.002\,S^3 + 0.0298\,S^2 + 0.0278\,S + 0.0025}\right)$$

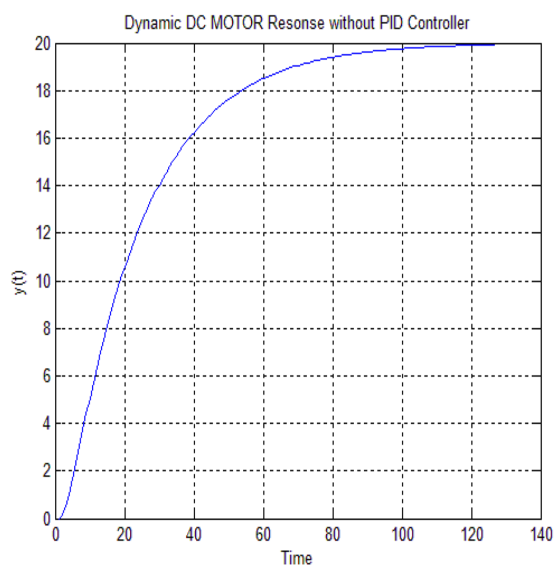

Figure 6: Structure of Close Loop Dynamic DC Motor Response without PID Controller in Case 1

The output parameters of robust PID controller(W_n, K_p, K_d and K_i) shows index in the table 1 in case study1. And open loop dynamic DC motor with PID using step unit in case study 1:

$$G_{sys}(S) = \left(\frac{8.558e004\,S^2 + 4.822e005\,S + 1.267e006}{0.002\,S^4 + 0.0298\,S^3 + 0.0278\,S^2 + 0.0025\,S}\right)$$

In Figure 7 represented the structure of close loop dynamic DC motor response with PID controller using step unit, and the equations of close loop dynamic DC motor with PID controller in case study1 will be:

$$G(S) = \left(\frac{8.558e004\,S^2 + 4.822e005\,S + 1.267e006}{0.002\,S^4 + 0.0298\,S^3 + 8.558e004\,S^2 + 4.822e005\,S + 1.267e006}\right)$$

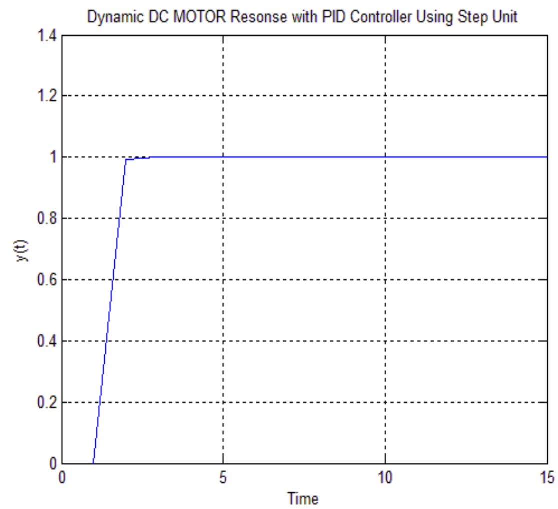

Figure 7: Structure of Close Loop Dynamic DC Motor Response with PID Controller using Step Unit in Case1

In Figure 8 represented the error integral time absolute error for structure of close loop dynamic DC motor response with PID controller using step unit in case study1.

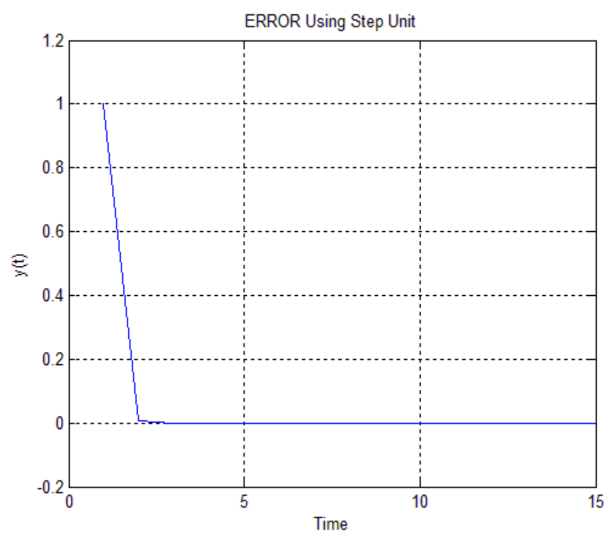

Figure 8 : Structure Errors (ITAE) of Close Loop Dynamic DC Motor Response with PID Controller using Step Unit in Case1

Open loop dynamic DC motor with PID using ramp unit in case study1:

$$G_{sys}(S) = \left(\frac{1.241e005\,S^2 + 9.18e005\,S + 1.267e006}{0.002\,S^4 + 0.0298\,S^3 + 0.0278\,S^2 + 0.0025\,S}\right)$$

In Figure 9 represented the structure of close loop dynamic DC motor response with PID controller using ramp unit, and the equations of close loop dynamic DC motor with PID controller using ramp unit in case study1 will be:

$$G(S) = \left(\frac{1.241e005\, S^2 + 9.18e005\, S + 1.267e006}{0.002\, S^4 + 0.0298\, S^3 + 1.241e005\, S^2 + 9.18e005\, S + 1.267e006}\right)$$

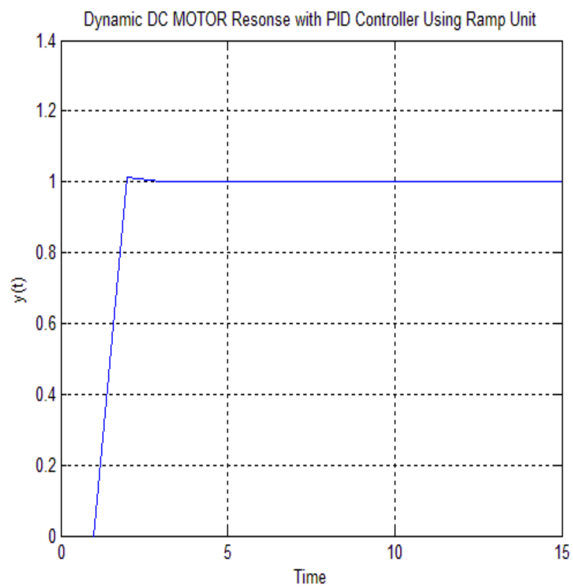

Figure 9: Structure of Close Loop Dynamic DC Motor Response with PID Controller using Ramp Unit in Case1

In Figure 10 represented the error integral time absolute error for structure of close loop dynamic DC motor response with PID controller using ramp unit in case study1.

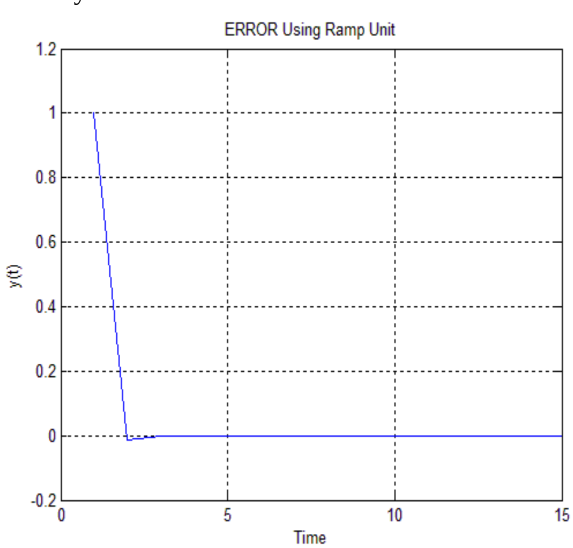

Figure 10: Structure Errors (ITAE) of Close Loop Dynamic DC Motor Response with PID Controller using Ramp Unit in Case1

Case Study 2

In this case used the dynamic DC motor parameter values are Motor-torque constant (K_t) =0.01 Nm/A, Load of Armature (L_a) =0.5 H, Armature resistance (R_a) = 1 Ohm, Motor moment of inertia (J_m) =0.01 Kg.m2, Viscous damping coefficient (B_m) =0.1 N.m/rad/sec, Back EMF Constant (K_b) =0.01 V/Rad/Sec.

The results are:

Open loop dynamic DC motor in case study2

$$G_{DC}(S) = \left(\frac{0.01}{0.005\, S^3 + 0.06\, S^2 + 0.1\, S}\right)$$

In Figure 11 represented the structure of close loop dynamic DC motor response without PID controller, and the equations of close loop dynamic DC motor in case study2 will be:

$$G_p(S) = \left(\frac{0.01}{0.005\, S^3 + 0.06\, S^2 + 0.1\, S + 0.0001}\right)$$

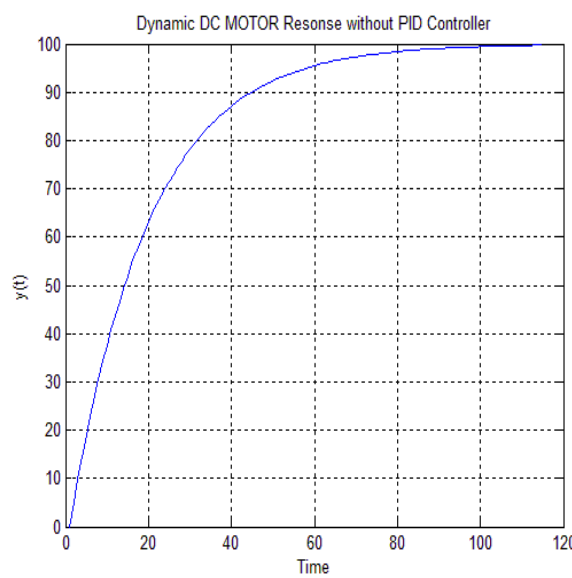

Figure 11: Structure of Close Loop Dynamic DC Motor Response without PID Controller in Case 2

The output parameters of robust PID controller W_n, K_p, K_d and K_i shows index in the table (2) in case study 2. And open loop dynamic DC motor with PID using step unit in case study 2:

$$G_{sys}(S) = \left(\frac{2.22e004\, S^2 + 1.008e005\, S + 2.132e005}{0.005\, S^4 + 0.06\, S^3 + 0.1\, S^2 + 0.0001\, S}\right)$$

In Figure 12 represented the structure of close loop dynamic DC motor response with PID controller using step unit, and the equations of close loop dynamic DC motor with PID controller in case study2 will be:

$$G(S) = \left(\frac{2.22e004\ S^2 + 1.008e005\ S + 2.132e005}{0.005\ S^4 + 0.06\ S^3 + 2.22e004\ S^2 + 1.008e005\ S + 2.132e005}\right)$$

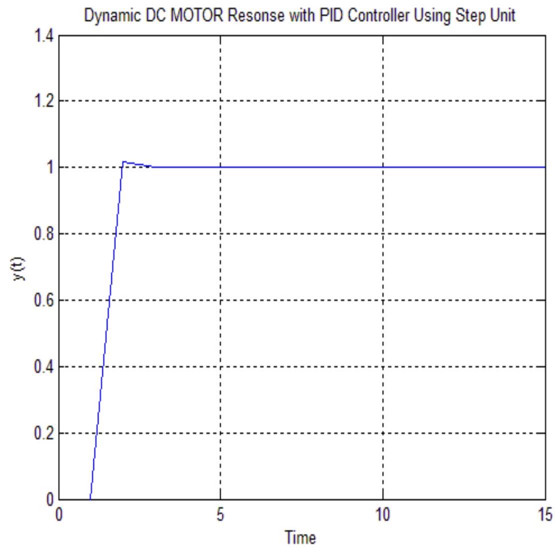

Figure 12: Structure of Close Loop Dynamic DC Motor Response with PID Controller using Step Unit in Case2

In Figure 13 represented the error integral time absolute error for structure of close loop dynamic DC motor response with PID controller using step unit in case study2.

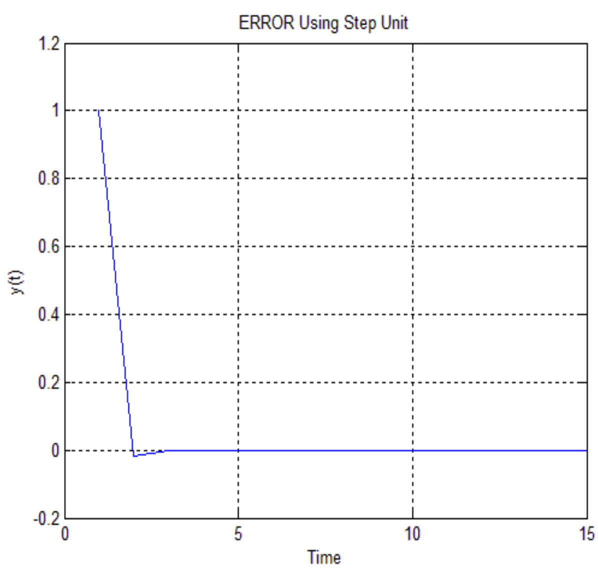

Figure 13: Structure Errors (ITAE) of Close Loop Dynamic DC Motor Response with PID Controller using Step Unit in Case2

Open loop dynamic DC motor with PID using ramp unit in case study2:

$$G_{sys}(S) = \left(\frac{3.22e004\ S^2 + 1.918e005\ S + 2.132e005}{0.005\ S^4 + 0.06\ S^3 + 0.1\ S^2 + 0.0001\ S}\right)$$

In Figure 14 represented the structure of close loop dynamic DC motor response with PID controller using ramp unit, and the equations of close loop dynamic DC motor with PID controller using ramp unit in case study 2 will be:

$$G(S) = \left(\frac{3.22e004\ S^2 + 1.918e005\ S + 2.132e005}{0.005\ S^4 + 0.06\ S^3 + 3.22e004\ S^2 + 1.918e005\ S + 2.132e005}\right)$$

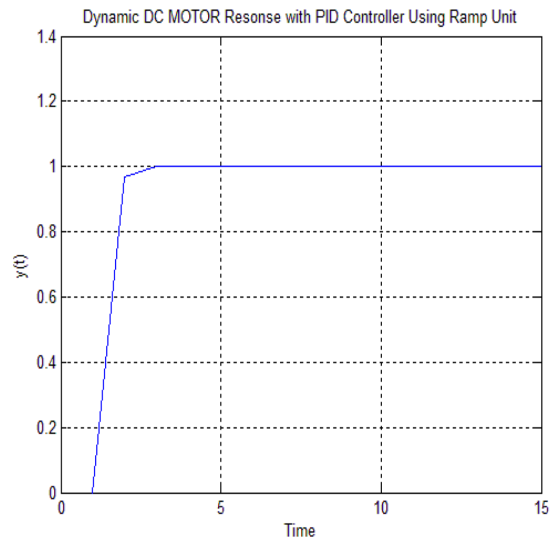

Figure 14: Structure of Close Loop Dynamic DC Motor Response with PID Controller using Ramp Unit in Case2

In Figure 15 represented the error integral time absolute error for structure of close loop dynamic DC motor response with PID controller using ramp unit in case study2.

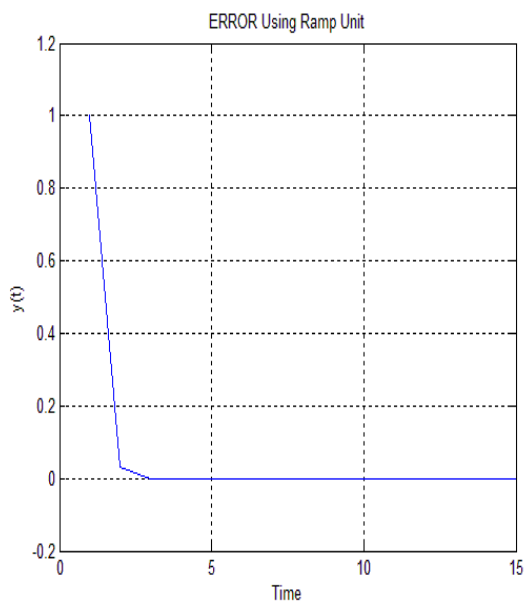

Figure 15: Structure Errors (ITAE) of Dynamic Dc motor Response with PID Controller using Ramp Unit in Case2

Index 1:

Table 1: shows the Parameters of Robust PID Controller using Step and Ramp Unit in Case Study1.

	Step Unit	Ramp Unit
W_n	7.0952	6.1826
K_p	9.6442e+006	1.8360e+007
K_d	1.7116e+006	2.4819e+006
K_i	2.5344e+007	2.5344e+007

Index 2:

Table 2: shows the Parameters of Robust PID Controller using Step and Ramp Unit in Case Study2.

	Step Unit	Ramp Unit
W_n	5.7143	4.9793
K_p	1.0076e+007	1.9181e+007
K_d	2.2204e+006	3.2196e+006
K_i	2.1324e+007	2.1324e+007

6. CONCLUSION

In this paper the position of a dynamic DC motor is controlled using robust PID controller. The dynamic DC motor was used (open, close) loop system without and with the robust PID controller. A robust PID controller based on the ITAE coefficients. Tuning the parameters of PID controller using robust method algorithm. The parameters of the robust PID controller were extracted: $(W_n, K_d, K_p \text{ and } K_i)$ and apply this method for the selection of the controller the ITAE performance index method, application of the equation and use of the step unit. Also applied this method using ramp unit. The results are obtained from step unit and ramp unit, stable to the system, error steady state equal to zero ($e_{ss} = 0$), increasing speed of response for position dynamic DC motor using MATLAB program.

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