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# Stability Control System for DC Motors Using Proportional-Integral-Derivative (PID) and Linear Quadratic Regulator (LQR) Methods

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## Abstract

A DC motor is widely applied due to its ease of use and extensive range of speed regulation, making it popular in various sectors such as industry, robotics, and households. The series DC motor, one of the motor types, is known for its high starting torque, which often results in overshooting at startup. It also exhibits less stability, where speed decreases at higher torque and increases when there's no load. However, without a load, the motor can reach excessively high speeds. In motor applications, it is essential to have the ability to adjust speed. Additionally, regulating smooth rotation is important to minimize vibrations and mechanical shocks during startup. To solve these problems, a control system is required, primarily addressing issues like overshoot, settling time, and system stability when the motor aims to reach a steady state. This is achieved through the use of a PID controller and a Linear Quadratic Regulator (LQR).

Keywords: PID, LQR, matlab, speed control, motor dc

## 1. Introduction

A DC motor is a widely used type of motor due to its ease of application and broad speed regulation range, making it common in industrial, robotic, and household settings (Lewis, 1996) (Fitzgerald, 1992). Among the different types of DC motors is the series DC motor, which is characterized by a high starting torque (Ogata, 1997). This often leads to overshoot when the motor is first turned on. Additionally, this motor can be unstable, where its speed decreases under high torque and increases under low torque (Bimbra, 1990). However, without any load, this motor may generate extremely high speeds (Linsley, 1998). In various motor applications, it is crucial to have adjustable speed. Additionally, smooth rotational control is needed to minimize vibrations and mechanical shocks during initial startup (Nugraha & Eviningsih, 2022a) (Dubey & Srivastava, 2013). To solve these issues, a control system is required, typically using a PID controller and a Linear Quadratic Regulator (LQR) to manage the motor's performance (Ogata, 2010) (Mehta & Chiasson, 1998).

The research focuses on understanding how to determine the parameters for PID and LQR controllers in controlling a DC motor, how to design and simulate both controllers to stabilize the motor at a desired speed, and how to compare the responses of both control systems (Nugraha et al., 2023a). The main objective of this research is to analyze the performance of both PID and LQR controllers in bringing the DC motor to a steady state with the desired speed, obtain optimal response results for each controller through simulations, and compare the system response curves produced by the PID and LQR controllers (Saputra et al., 2024) (Berahim, 1994).

## 2. Material and methods

### 2.1. Parameter Data

**Table 1.** Parameter Value

| Parameter | Symbol | Value Unit |
|---|---|---|
| Moment inertia | $J_n$ | **0.0007046 Kg.m2** |
| **Friction coefficient** | $B_n$ | **0.0004 N.m/(rad/s)** |
| **Torque constant** | $K_i$ | **0.1236 N.m/A** |
| **Reverse voltage constant** | $K_b$ | **0.1236 V/(rad/s)** |
| **Total coil resistance** | $R_t$ | **7.2 ohm** |
| **Total coil inductance** | $L_t$ | **0.0917 H** |

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### 2.2. Parameter PID

The values that need to be determined from the curve are the delay time (L) and the time constant (T) (Nugraha et al., 2020) (Mu'in et al., 2023). By using the straight line equation, the values of L and T will be determined (Anggono, 2011) (Prastyawan & Nugraha, 2022b). In Figure 1, there are two points with the coordinates: X1 = 0.03688, Y1 = 0.5884 and X2 = 0.3227, Y2 = 6.791.

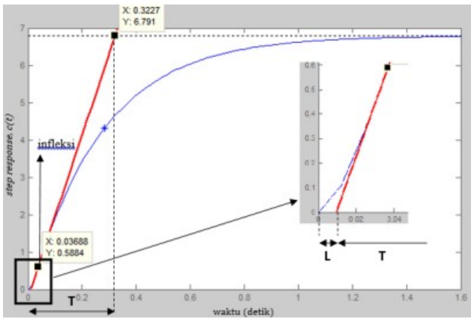


**Figure 1.** Parameter PID

General form of straight line equation (Fauzi et al., 2024)

$$Y_2 - Y_1 = m\left(X_2 - X_1\right)$$

Where M is gradient slope of the line.

$$6.791\text{-}0.588 = \text{m } (0.3227\text{-}0.03688)$$
$$\text{m} = 21.701$$

The tangent line touches the x axis at a point with coordinates (X,0), then

$$Y_2 - 0 = m\left(X_2 - X_1\right)$$
$$6.791\text{-}0 = 21.701(0.3227\text{-X})$$
$$\text{X} = 0.009765$$

T= $\left(X_2 - L\right)$

T= 0.3227-0.009765 = 0.3130

After value L and T already know, Next step is find a PID Parameter

- Propotional (Kp):
  Kp = 1.2 (T/L) = 1.2 (0.3130/0.009765) = 38.464
- Integral (Ki):
  Ti = 2L, Ki = Kp/Ti = 38.464/2(0.009765) = 1969.483
- Derivative (Kd):
  Td = 0.5L, Kd = Td Kp = 0.5(0.009765)(38.464) =0.1878

### 2.3. Parameter LQR

Obtaining LQR Parameters To obtain the Q and R matrices (Rahman et al., 2024), a Matlab program script was used using the trial and error method (Agna et al., 2023), where the terms for the Q matrix is a real positive semidefinite matrix (Q ≥ 0) and the R matrix is a real positive definite matrix (R > 0). We set the initial value (Apriani et al., 2022)

$$Q = \begin{bmatrix} 1 & 0 \\ 0 & 1 \end{bmatrix}$$

$$R = \left[1{,}011\right]$$

## 3. Results and discussion

### 3.1. PID Simulation

#### 3.1.1. PID Simulation circuit in 700 rpm speed reference

The simulation is carried out by entering a reference speed of 700 rpm as seen in Figure 2.

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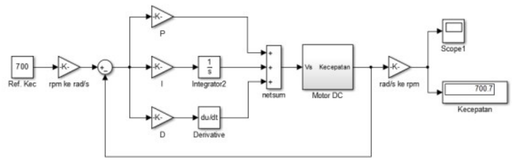


**Figure 2.** PID Simulation in 700 rpm

Obtained a steady speed of 700.7 rpm. The rotor speed response at a reference speed of 700 rpm is shown in Figure 3.

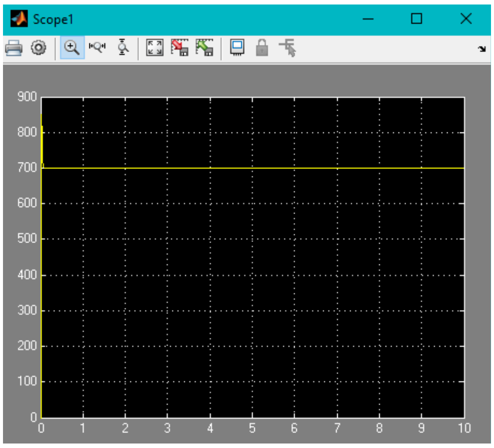


**Figure 3.** Respon of PID Simulation in 700 rpm

Result parameter respond for figure 3.
Rise time : 7.025 ms
Settling time : 53.7 ms
Max. Overshoot : 21.04 %
Error steady state : 0.001 %

### 3.1.2. PID Simulation circuit in 1000 rpm speed reference

The simulation is carried out by entering a reference speed of 1000 rpm as seen in Figure 4.

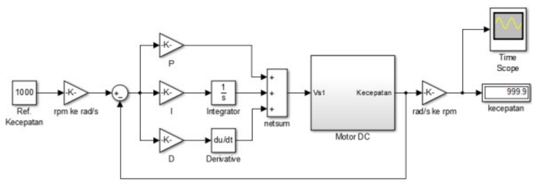


**Figure 4.** PID Simulation in 1000 rpm

Obtained a steady speed of 1000 rpm. The rotor speed response at a reference speed of 1000 rpm is shown in Figure 5.

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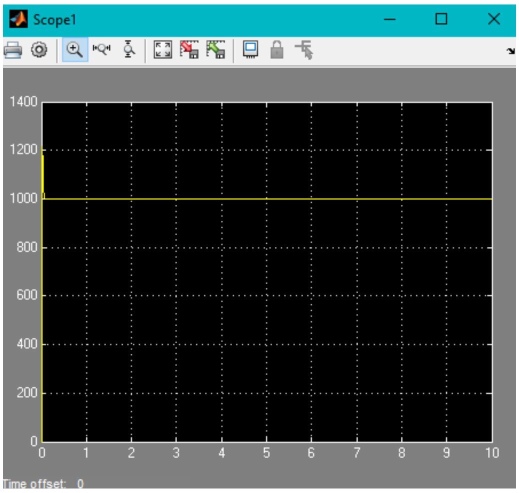


**Figure 5.** Respon of PID Simulation in 1000 rpm

Result parameter respond for figure 5.
Rise time : 6.910 ms
Settling time : 53.5 ms
Max. Overshoot : 21.08 %
Error steady state : 0. 0007 %

### 3.1.3. PID Simulation circuit in 1300 rpm speed reference

The simulation is carried out by entering a reference speed of 1300 rpm as seen in Figure 6.

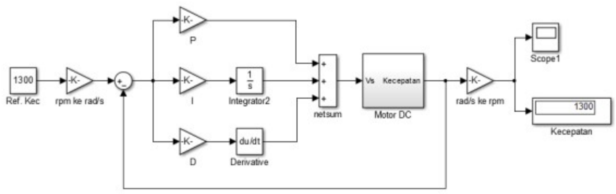


**Figure 6.** PID Simulation in 1300 rpm

Obtained a steady speed of 1300 rpm. The rotor speed response at a reference speed of 1300 rpm is shown in Figure 7.

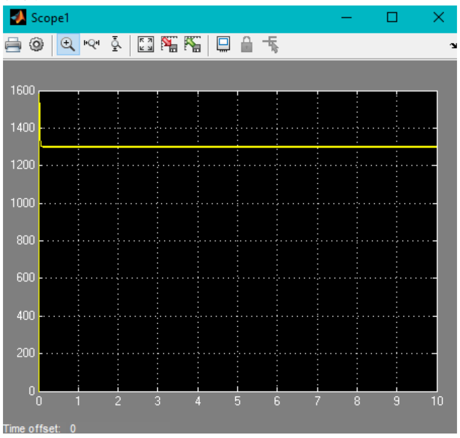


**Figure 7.** Respon of PID Simulation in 1300 rpm

Result parameter respond for figure 7.
Rise time : 6.995 ms
Settling time : 53.7 ms
Max. Overshoot : 21.09 %
Error steady state : 0 %

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### 3.2. LQR Simulation

#### 3.2.1. LQR Simulation circuit in 700 rpm speed reference

The simulation is carried out by entering a reference speed of 700 rpm as seen in Figure 8.

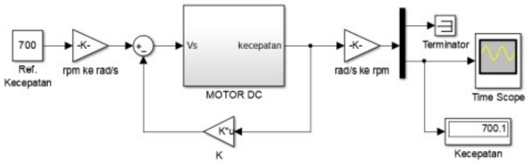


**Figure 8.** LQR Simulation in 700 rpm

Obtained a steady speed of 700 rpm. The rotor speed response at a reference speed of 700 rpm is shown in Figure 9.

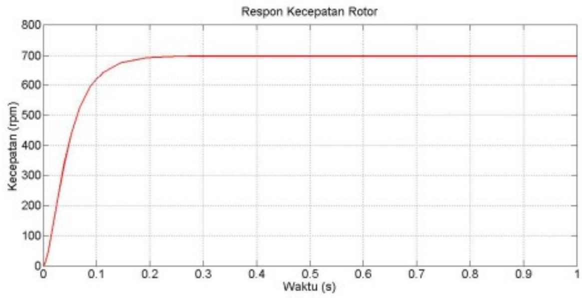


**Figure 9.** Result of LQR Simulation in 700 rpm

Result parameter respond for figure 9.
Rise time : 91.406 ms
Settling time : 171.2 ms
Max. Overshoot : 0 %
Error steady state : 0.00014 %

#### 3.2.2. LQR Simulation circuit in 1000 rpm speed reference

The simulation is carried out by entering a reference speed of 1000 rpm as seen in Figure 10.

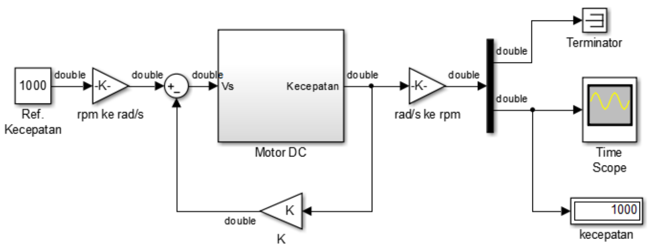


**Figure 10.** LQR Simulation in 1000 rpm

Obtained a steady speed of 1000 rpm. The rotor speed response at a reference speed of 1000 rpm is shown in Figure 11.

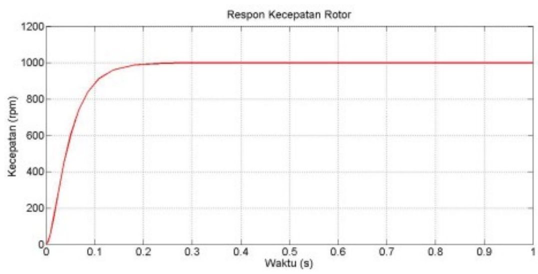


**Figure 11.** Result of LQR Simulation in 1000 rpm

Result parameter respond for figure 11.
Rise time : 90.877 ms
Settling time : 169.8 ms
Max. Overshoot : 0 %
Error steady state : 0 %

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#### 3.2.3. LQR Simulation circuit in 1300 rpm speed reference

The simulation is carried out by entering a reference speed of 1300 rpm as seen in Figure 12.

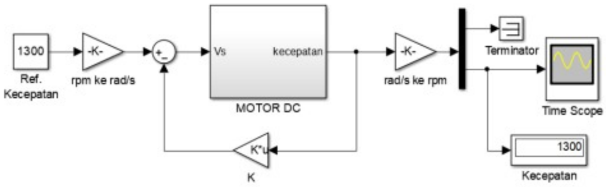


**Figure 10.** LQR Simulation in 1300 rpm

Obtained a steady speed of 1300 rpm. The rotor speed response at a reference speed of 1300 rpm is shown in Figure 13.

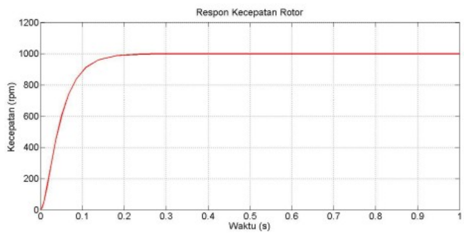


**Figure 13.** Result of LQR Simulation in 1300 rpm

Result parameter respond for figure 13.
Rise time : 89.743 ms
Settling time : 166.9 ms
Max. Overshoot : 0 %
Error steady state : 0 %

## 4. Conclusion

Based on the simulation results, the following conclusions can be made:

- To reach steady speed, the PID controller performs faster than the LQR controller. This is evident from the simulation results, where the rise time and settling time achieved using PID are shorter than those using LQR.
- The rotor speed response with LQR shows no overshoot, while with PID, the overshoot is quite significant, around 20%.

**Credit authorship contribution statement**

**Author Name**: Conceptualization, Writing – review & editing. **Author Name**: Supervision, Writing – review & editing. **Author Name**: Conceptualization, Supervision, Writing – review & editing.

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