

# System Optimization Using LQR and LQT Methods on 42D29Y401 DC Motor

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## Abstract

Control systems are critical for managing, commanding, and regulating the behavior of dynamic systems. A DC motor converts direct current electrical energy into kinetic energy, requiring positive and negative voltage terminals for operation. Due to their ease of control across wide speed ranges, DC motors are widely applied in various industrial sectors. Speed regulation is typically achieved using control devices tailored to specific system requirements. To optimize DC motor performance, this study employs mathematical modeling and control strategies using MATLAB software. The 42D29Y401 DC motor is modeled and simulated using the Linear Quadratic Regulator (LQR) and Linear Quadratic Tracking (LQT) methods. Simulation results show that the first-order DC motor achieved a stable step response with an amplitude of 3.40, a rise time of 3.11 seconds, and minor overshoot and undershoot values of 0.501% and 1.98%, respectively. The LQR-optimized system improved performance with an amplitude close to 1, a faster rise time of 1.1 seconds, and reduced overshoot and undershoot at 0.505%. Comparatively, the LQR-based system demonstrated better overall performance than the unoptimized model, while the LQT-based system yielded the highest level of performance among all configurations.

**Keyword:** Matlab, Performance, DC Motor, LRT, LQT

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## 1. Introduction

The rapid development of technology and automation in modern industries has increased the demand for reliable and efficient control systems [1] [2] [3]. A control system plays a fundamental role in managing, commanding, and regulating dynamic system behavior to achieve desired operational objectives [4] [5] [6]. Among various actuators employed in industrial processes, the DC (Direct Current) motor remains a preferred choice due to its straightforward control characteristics,

wide speed range, and high efficiency in converting electrical energy into mechanical motion [7] [8]. The 42D29Y401 DC motor, with its specific performance attributes, is widely utilized in industrial applications that require precise speed and position control. However, achieving optimal performance from DC motors demands effective control strategies that can handle dynamic variations and minimize system deviations such as overshoot, undershoot, and response time [9][10].

To address this need, mathematical modeling and control system optimization are necessary. In this study, the DC motor model is developed and optimized using two well-known control techniques: the Linear Quadratic Regulator (LQR) and the Linear Quadratic Tracking (LQT) methods [11] [12]. MATLAB software is employed as a simulation tool to design, analyze, and evaluate system performance. By comparing the system response under different control approaches, this research aims to demonstrate the advantages of LQR and LQT in enhancing the stability, speed, and accuracy of DC motor operation. Ultimately, the findings provide valuable insights into the practical implementation of optimal control methods for industrial motor systems.

## 2. Research Method

In this study, a closed-loop control system was implemented to analyze the dynamic response of the 42D29Y401 DC motor when modeled as a first-order plant using mathematical modeling. The simulations were carried out using both the Linear Quadratic Regulator (LQR) and Linear Quadratic Tracking (LQT) methods [13]. LQR is a state-space control technique that requires full state feedback of the system. To obtain optimal gain values, appropriate weighting matrices Q and R must be selected to balance system performance and control effort [14].

LQT, on the other hand, is a primary method for solving tracking problems in linear systems. It is designed to generate optimal control such that the linear system is capable of accurately following a predefined reference trajectory [15]. The optimization objective is achieved by minimizing a quadratic cost function. The LQT controller comprises both feedback and feedforward components, which are computed using the Algebraic Riccati Equation (ARE) [16].

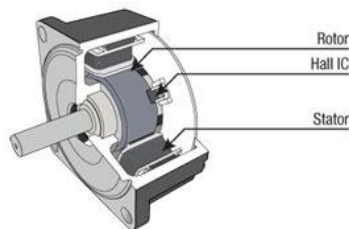
MATLAB Simulink was employed as the simulation environment to implement and evaluate both LQR and LQT-based control strategies. Simulink, a graphical extension of MATLAB, allows the modeling and simulation of dynamic systems using block diagrams. These diagrams incorporate elements such as transfer functions, summing junctions, as well as virtual input and output devices including function generators and oscilloscopes [17].

The mathematical model used in this study is derived based on the specifications found in the datasheet of the 42D29Y401 DC motor. A first-order transfer function model was formulated to represent the plant, describing the mathematical relationship between the input and output of the motor system. The main objective of this research is to analyze the step response behavior of the 42D29Y401 DC motor system, both in noise-free conditions and under the influence of system output noise.

### 2.1. DC Motor

DC (Direct Current) motors are widely recognized for their simplicity in application, making them a popular choice across a broad range of uses from industrial machinery and household appliances to children's toys and electronic instrumentation systems [18]. A DC motor operates using a direct current power supply and features two terminals, positive and negative, through which voltage is applied to generate motion. Its fundamental function is to convert electrical energy into mechanical energy. The basic working principle of a DC motor involves the interaction between a

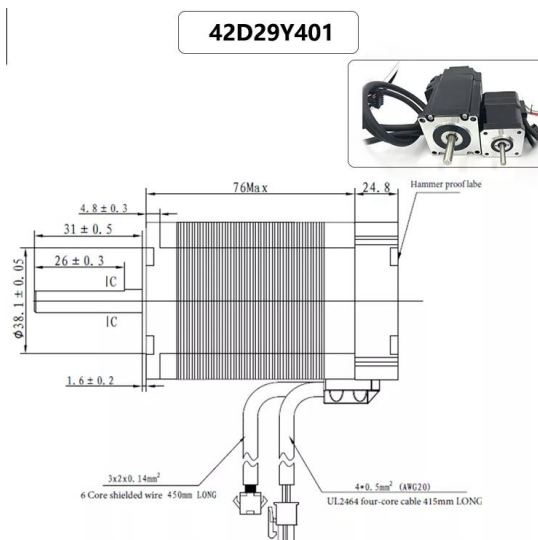
magnetic field and a current-carrying conductor, resulting in rotational motion. The core components of a DC motor typically include the rotor (rotating part) and the stator (stationary part), which together facilitate the conversion process.



**Figure 1.** Components of a DC Motor

Due to the growing industrial reliance on DC motors, it is essential to apply optimization strategies within control systems [19]. Control system optimization involves analytical and computational techniques to derive the most efficient solutions for a given system’s operation. A control system, in this context, refers to the structured approach of regulating one or more variables to maintain them at desired levels or within specific ranges. In practical terms, a control system consists of an arrangement of physical components designed to guide the flow of energy to machines or processes, ensuring the desired output is achieved efficiently and reliably [20].

- Datasheet of 42D29Y401 DC motor



Electrical Characteristics		6.Phase inductance	1. 4mH ± 20% (1kHz 1V rms)
1.Phase number	2 Phase	7. Holding torque	2. 2N.m Min (两相通电)
2. Step angle	1. 8°	8. Rotor inertia	300g.cm <sup>2</sup>
3.Rated voltage	2. 31V	9. Motor weight	680g Ref.
4. Rated current	4. 2A	10. Insulation resistance	100MΩ Min. (DC 500V)
5. Phase resistance	0. 54Ω ± 10% (20° C)	11. Insulation class	B (130° C)

**Figure 2.** Datasheet of 42D29Y401 DC motor

Specification:

- $\tau$  = 2,2 N/m
- Rated Current = 4.2 A
- Voltage = 31 V
- Speed = 6000 rpm atau 628,32 m/s

From the specifications that have been obtained the general form of the function is instead of order 1:

$$G(s) = \frac{K}{\tau s + 1} \quad (1)$$

Order 1 DC Motor

Based on the DC motor datasheet, the 1st order equation is obtained:

Where  $\tau = K \cdot i$  so that

$$K = \frac{\tau}{i} = \frac{2.2}{4.2} = 0.523 \quad (2)$$

First order equation of DC motor:

$$G(s) = \frac{0,523}{2.2s + 1} \quad (3)$$

## 2.2. Matlab Program

In the practicum of optimizing the DC motor system 42D29Y401 with the LQR and LQT methods, a MATLAB script program is needed to simulate the system on Simulink. Below is the MATLAB script program used.

- **LQR**

```
clear; clc;
% Model Motor DC
J = 30 ; % J = Moment of Inertia
b = 0.14 ; % b = Damping Ratio
K = 0.0298 ; % K = Constant
R = 0.54 ; % R = Resistance
L = 0.0014 ; % L = Inductance

A = [-b/J K/J; -K/L -R/L];
B = [0; 1/L];
C = [1 0];

AA = [ A zeros(2,1); -C 0];
BB = [B;0];

% Pole Placement
J = [-3 -4 -5];
K = acker(AA, BB, J)
KI = -K(3);
KK = [K(1) K(2)];
```

```

% Matrix LQR
Q = [1 0 0;
     0 1 0;
     0 0 1000];
R = [1] ;

K_lqr = lqr(AA,BB,Q,R)
KI2=-K_lqr(3);
KK2=[K_lqr(1) K_lqr(2)];

```

- **LQT**

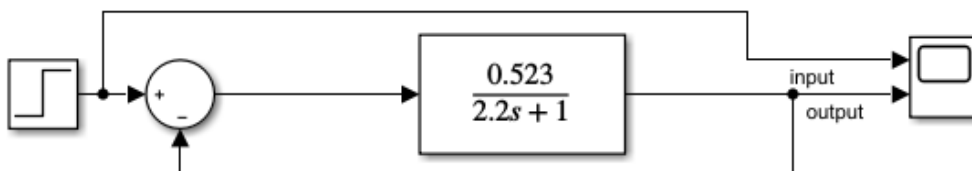
```

clear;
clc;
% Model DC Motor
J = 30 ; b= 0.14 ; K= 0.0298 ; R= 0.54 ; L = 0.0014 ;
% J = Moment of inertia, b = Damping ratio, K = constant, R =
resistance, L = Inductance
A = [-b/J K/J; -K/L -R/L];
B = [0; 1/L];
C = [1 0]
Q=10; R=0.0000000001; %0.00000000000001
W=C'*Q; %
[S,o,m,n]=care(A,B,C'*Q*C,R) %m=v(t) %S=P
K=inv(R)*B'*S %feedback Gain
ACL=(A-B*K) '
L=inv(R)*B' %model following gain

```

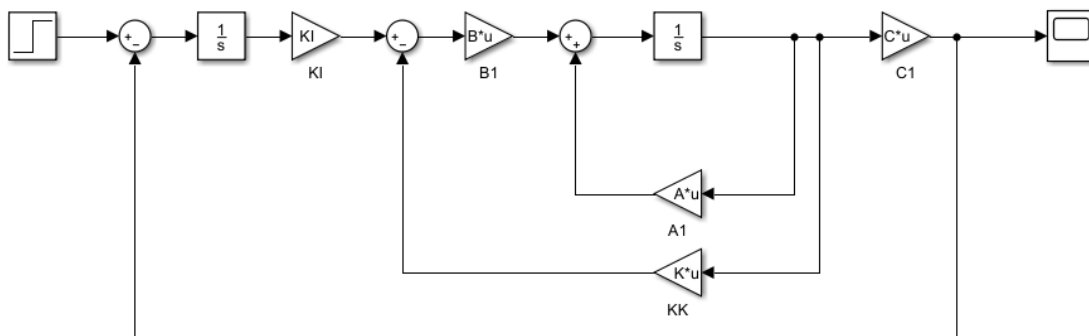
The following is a display of the simulation circuit in Matlab Simulink:

- 42D29Y401 DC motor circuit 1st order



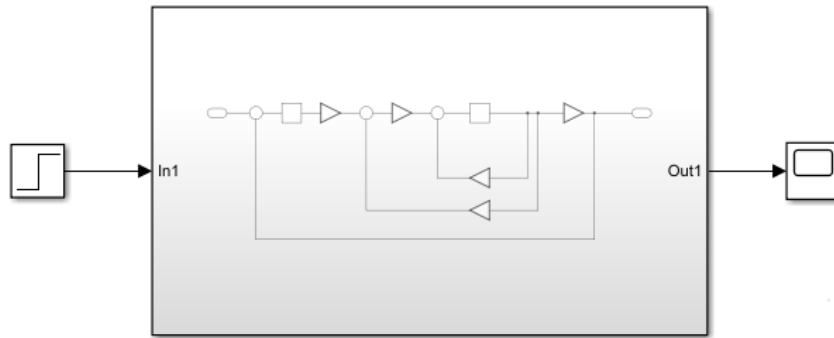
**Figure 3.** DC motor circuit 1st order

- LQR Circuit



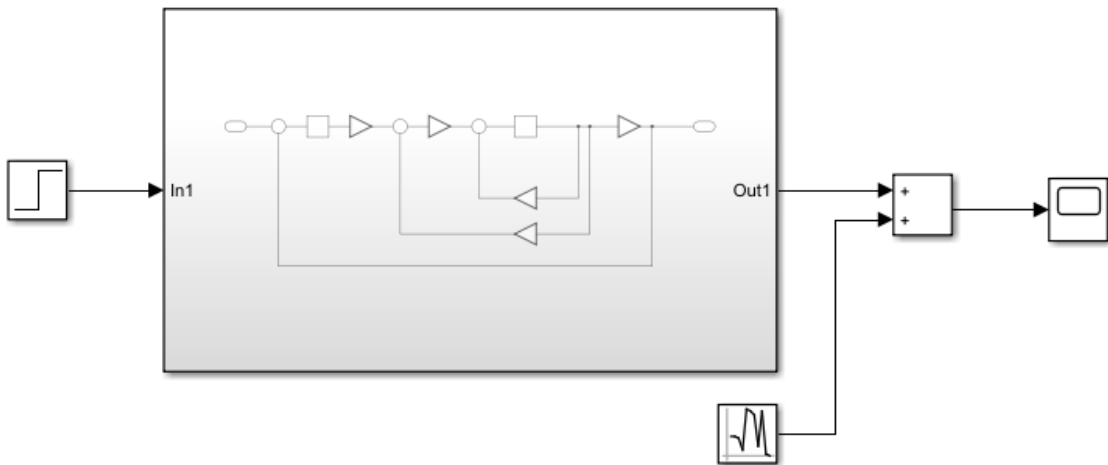
**Figure 4. LQR Circuit**

- Noise-free LQR Subsystem



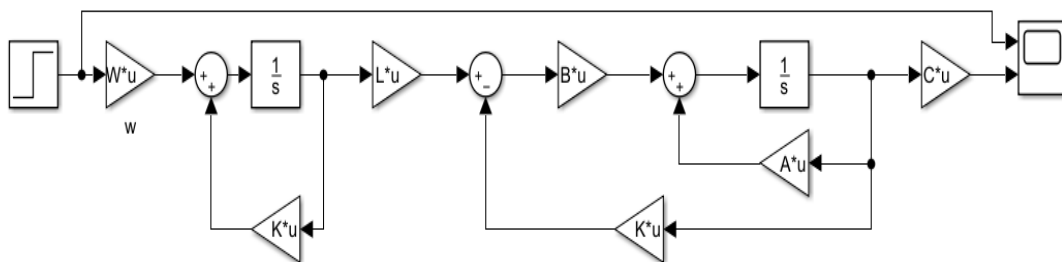
**Figure 5. Noise-free LQR Subsystem**

- Noise LQR Subsystem



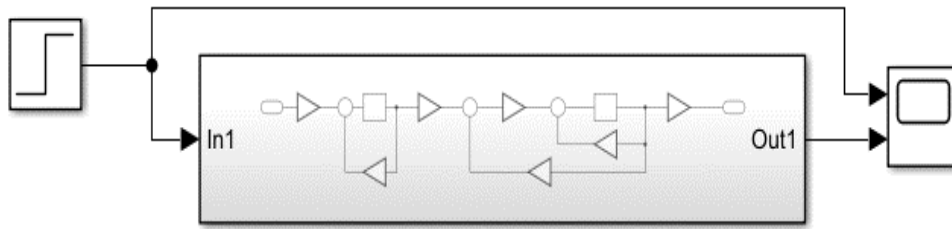
**Figure 6. Noise LQR Subsystem**

- LQT Circuit



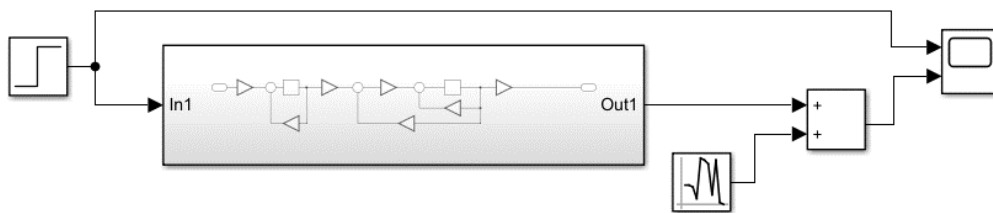
**Figure 7. LQT Circuit**

- Noise-free LQT Subsystem



**Figure 8.** Noise-free LQT Subsystem

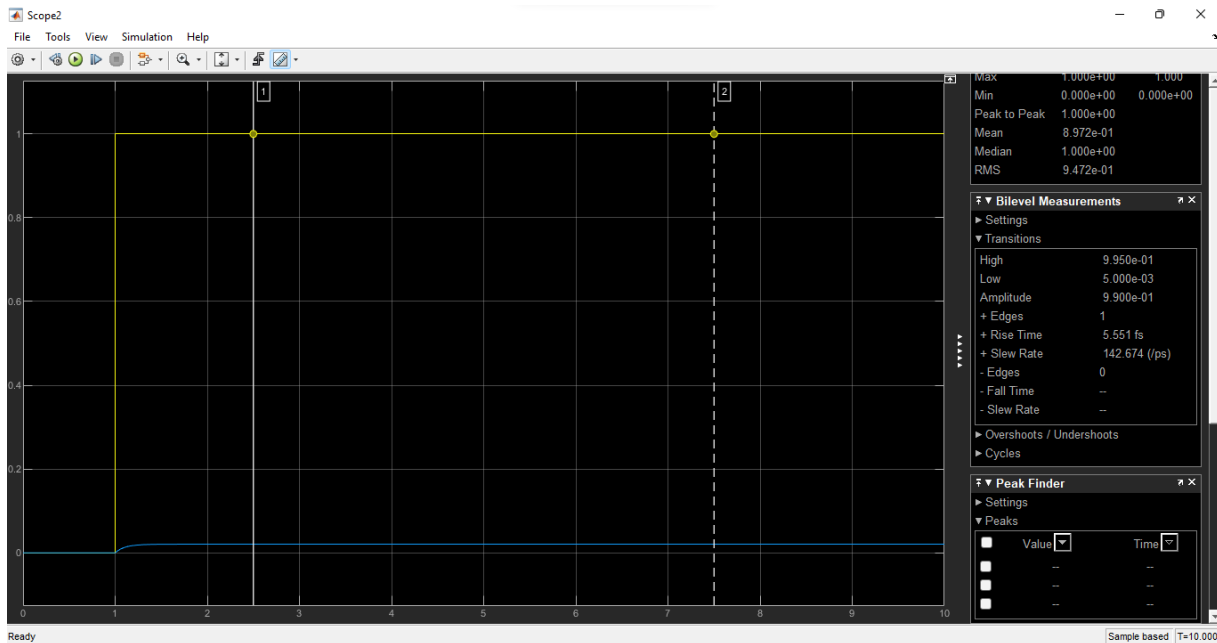
- Noise LQT Subsystem



**Figure 9.** Noise LQT Subsystem

### 3. Results And Discussion

#### 3.1. Analysis of Simulation Results of 42D29Y401 DC Motor Order 1



**Figure 10.** Results of 42D29Y401 DC Motor Order 1

Figure 10 illustrates the step response of the 42D29Y401 DC motor modeled as a first-order SISO (Single Input Single Output) system. The graph displays two distinct curves: the yellow line represents the input signal or reference setpoint applied to the system, while the blue line shows the

motor's actual step response output. Based on the figure, it can be observed that the output response of the first-order SISO system does not fully reach the desired setpoint. However, the output maintains a stable behavior, with an amplitude of approximately 0.0204 and a rise time of 231.789 milliseconds. Additionally, the system exhibits a slight overshoot of 0.505% and an undershoot of 0.499%, indicating a modest deviation from the ideal response.

### 3.2. Analysis of Simulation Results of Optimization of LQR DC Motor System 42D29Y401 without Noise

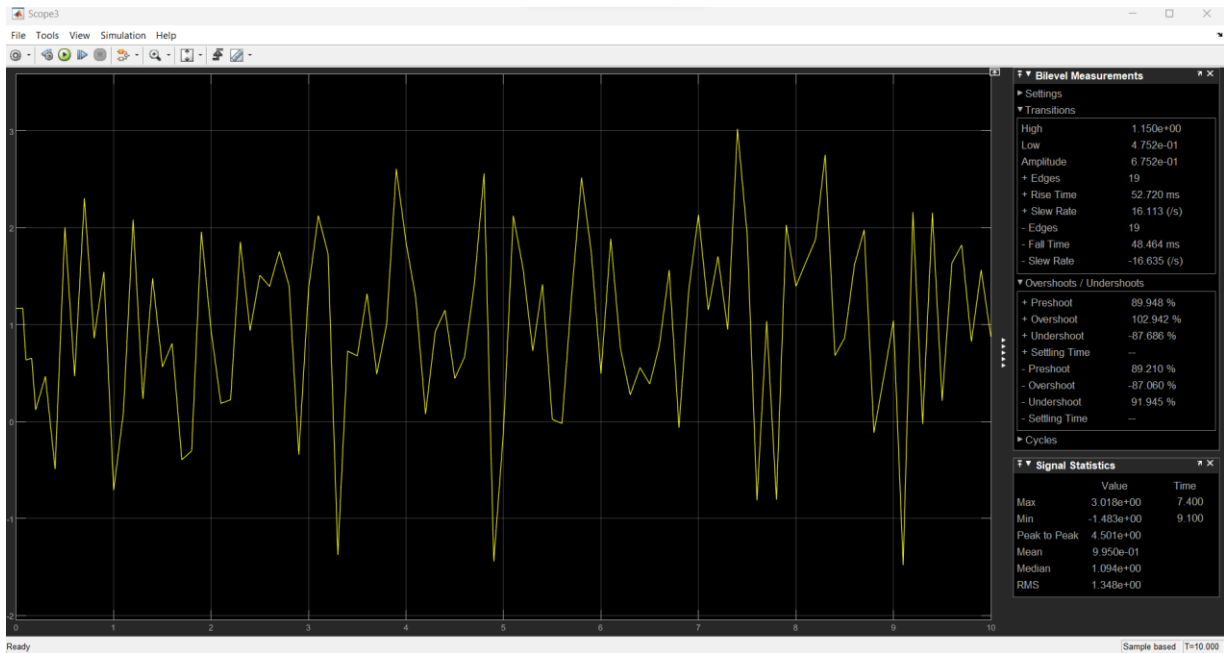
Figure 11 presents the step response of the 42D29Y401 DC motor under LQR optimization in a noise-free environment. The graph shows that the system's output reaches an amplitude of approximately 0.99, which can be rounded to 1, indicating that the system successfully achieves the designated setpoint. The LQR-optimized response demonstrates a relatively efficient rise time of 3.11 seconds. Additionally, the system exhibits an overshoot of 0.501% and an undershoot of 1.98%, reflecting a moderate deviation from the ideal response trajectory.



Figure 11. Results of Optimization of LQR DC Motor System 42D29Y401 without Noise

### 3.3. Analysis of Simulation Results of Optimization of LQR DC Motor System 42D29Y401 with Noise

Figure 12 shows the step response of the 42D29Y401 DC motor under LQR optimization with noise interference. It can be observed that the system's output exhibits significant fluctuations due to the noise introduced into the system. The response has an amplitude of 0.67 and a rise time of 52.72 milliseconds. Additionally, the system experiences considerable deviations, with an overshoot of -87.06% and an undershoot of 91.94%, indicating a severe response deviation caused by the noise.



**Figure 12.** Results of Optimization of LQR DC Motor System 42D29Y401 with Noise

### 3.4. Analysis of Simulation Results of Optimization of LQT DC Motor System 42D29Y401 without Noise



**Figure 13.** Results of Optimization of LQT DC Motor System 42D29Y401 without Noise

Figure 13 illustrates the step response of the 42D29Y401 DC motor under LQT optimization in a noise-free environment. The graph demonstrates that the system's output reaches an amplitude of 0.99, with a rise time of 7.43 milliseconds. The system exhibits an overshoot of 1.53% and an undershoot of 0.45%, indicating a relatively stable response with minimal deviations from the desired setpoint.

### 3.5. Analysis of Simulation Results of Optimization of LQT DC Motor System 42D29Y401 with Noise

Figure 14 presents the step response of the 42D29Y401 DC motor under LQT optimization with noise interference. It is evident that the system's output exhibits significant fluctuations due to the noise introduced into the system. The response has an amplitude of 0.18 and a rise time of 92.71 milliseconds. Additionally, the system shows considerable deviations, with an overshoot of 12.41% and an undershoot of -6.55%, indicating a significant impact of noise on the system's performance.

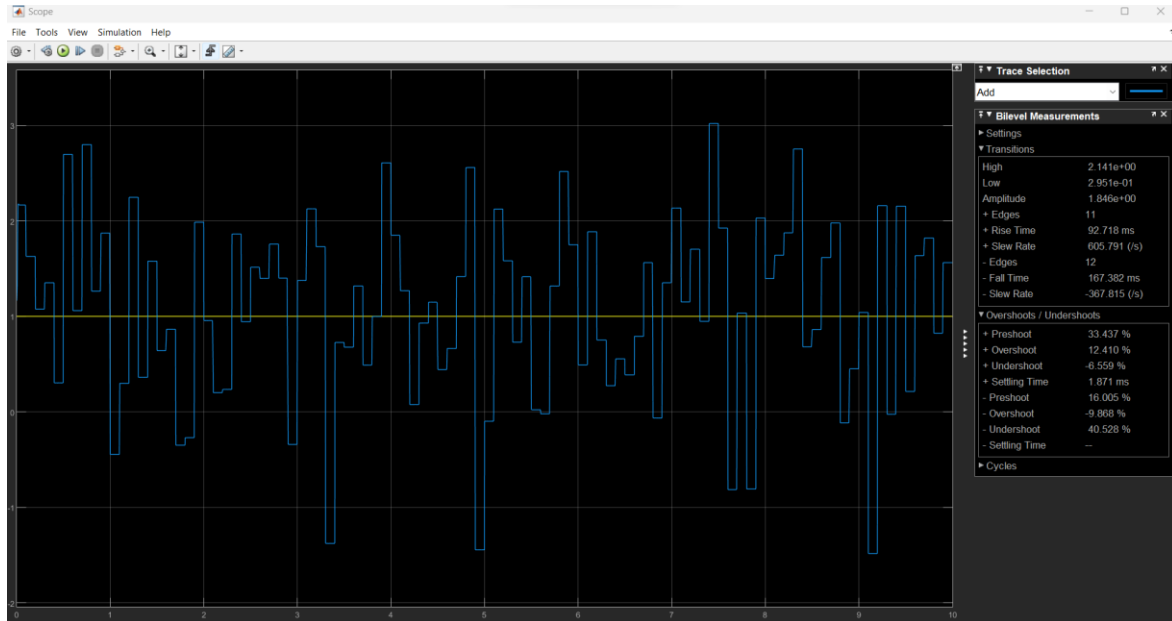


Figure 14. Results of Optimization of LQT DC Motor System 42D29Y401 without Noise

### 3.6. Comparison Data

Below is the data from the experimental simulation results in MATLAB Simulink.

Table 1. Comparison data result

Model Sisystem	Amplitudo	Rise Time (s)	Overshoot (%)	Undershoot (%)
SISO Orde 1	3.40	3.11	0.501	1.98
LQR tanpa Noise	0.99	1.1	0.505	1.518
LQR dengan Noise	0.67	52.72	-87.06	91.94
LQT tanpa Noise	0.99	7.43	1.53	0.45
LQT dengan Noise	0.18	92.71	12.41	-6.55

Based on the comparative analysis, it can be concluded that the LQT (Linear Quadratic Tracking) method without noise delivers the best overall performance among the evaluated systems. It achieves a near-ideal amplitude, the fastest rise time, and minimal overshoot and undershoot, indicating superior stability and tracking accuracy compared to the standard first-order SISO model and the LQR method. Although both LQR and LQT methods are affected by the presence of noise,

LQT still maintains relatively better performance under noisy conditions, highlighting its robustness and effectiveness in optimizing the DC motor 42D29Y401 system.

## 4. Conclusion

Based on the step response analysis, the first-order model of the 42D29Y401 DC motor exhibited a stable output with an amplitude of 3.40, a rise time of 3.11 seconds, an overshoot of 0.501%, and an undershoot of 1.98%. The implementation of the LQR method significantly improved the system's performance, achieving an amplitude of 0.99 (effectively reaching the setpoint), a faster rise time of 1.1 seconds, and smaller overshoot and undershoot values. It can be compared and concluded that the 42D29Y401 DC motor system with LQR optimization performs better than the first-order model, as LQR allows the motor to reach the setpoint accurately, produce a stable output curve, achieve a faster rise time, and maintain low overshoot and undershoot. Nevertheless, the step response obtained through LQT optimization demonstrates an even superior performance compared to both the first-order model and LQR-based control. Therefore, it can be concluded that the LQT method provides the most optimal system performance for the 42D29Y401 DC motor.

## References

- [1] Nugraha, Anggara Trisna, and Rachma Prilian Eviningsih. *Konsep Dasar Elektronika Daya*. Deepublish, 2022.
- [2] Jamil, M. H., et al. "The existence of rice fields in Makassar City." *IOP Conference Series: Earth and Environmental Science*. Vol. 681. No. 1. IOP Publishing, 2021.
- [3] Yuniza, Salsabila Ika, Diego Ilham Yoga Agna, and Anggara Trisna Nugraha. "The Design of Effective Single-Phase Bridge Full Control Resistive Load Rectifying Circuit Based on MATLAB and PSIM." *International Journal of Advanced Electrical and Computer Engineering* 3.3 (2022).
- [4] Nugraha, Anggara Trisna, and Chusnia Febrianti. "Implementasi Sensor Flowmeter pada Auxiliary Engine Kapal Berbasis Outseal PLC."
- [5] As'ad, Reza Fardiyan, Salsabila Ika Yuniza, and Anggara Trisna Nugraha. "The Effect of 3 Phase Full Wave Uncontrolled Rectifier on 3 Phase AC Motor." *International Journal of Advanced Electrical and Computer Engineering* 3.2 (2022).
- [6] Arifuddin, Rahman, et al. "Baby Room Temperature and Humidity Control System Using Fuzzy Logic." *Emitor: Jurnal Teknik Elektro* (2024): 275-280.
- [7] Nugraha, Anggara Trisna. "MPPT Algorithm Based on Zebra Optimization Algorithm for Solar Panels System with Partial Shading Conditions." *Indonesian Journal of Electronics, Electromedical Engineering, and Medical Informatics* 6.4 (2024).
- [8] Sheila, Sindy Yurisma, et al. "Coffee Drying Tool with LQR-PID Control." *MEIN: Journal of Mechanical, Electrical & Industrial Technology* 1.2 (2024): 18-23.
- [9] Dermawan, Deny, et al. "Pengontrol Kecepatan Respon Motor dengan Pid dan Lqr." *Seminar MASTER PPNS*. Vol. 8. No. 1. 2023.
- [10] Dermawan, Deny, et al. "Kendali Kecepatan Motor Dengan Kontrol Pid Menggunakan Metode Metaheuristik." *Seminar MASTER PPNS*. Vol. 8. No. 1. 2023.
- [11] Wibowo, Muhammad Ferdiansyah, and Anggara Trisna Nugraha. "PERENCANAAN SISTEM PROPULSI ELEKTRIK PADA FAST PATROL BOAT 28 METER." *Proceedings Conference on Marine Engineering and its Application*. Vol. 6. No. 1. 2023.
- [12] Nugraha, Anggara Trisna, and Alwy Muhammad Ravi. "Experimental Study of the Effect of Excitation Current on the Output Voltage of a Self-excited Synchronous Generator." (2023).

- [13] Agna, Diego Ilham Yoga, Rama Arya Sobhita, and Anggara Trisna Nugraha. "Penyearah Gelombang Penuh 3 Fasa Tak Terkendali dari Generator Kapal AC 3 Fasa." Seminar MASTER PPNS. Vol. 8. No. 1. 2023.
- [14] Sobhita, R. A. (2024, November). Differential Optimization Control for MG-16B DC Motor with LQR and LQT Circuits. In Conference of Electrical, Marine and Its Application (Vol. 3, No. 1, pp. 1-11).
- [15] Nugrahaa, Anggara Trisna, and Rahman Arifuddin. "O2 Gas Generating Prototype In Public Transportation."
- [16] Sobhita, R. A. (2024, November). Linear Quadratic Regulator (LQR) and Linear Quadratic Tracking (LQT) control systems on M66 Series DC motors. In Conference of Electrical, Marine and Its Application (Vol. 3, No. 1, pp. 1-10).
- [17] Fauzi, A. R., Sobhita, R. A., Nugraha, A. T., & Santosa, A. F. (2024). Performance of Permanent Magnet Synchronous Generator (pmsg) 3 Phase Radial Flux Results Modification of Induction Motor. MEIN: Journal of Mechanical, Electrical & Industrial Technology, 1(2), 5-11.
- [18] Saputra, F. Y., Sobhita, R. A., Nugraha, A. T., & Firdaus, A. A. (2024). Efficiency Of Generator Set On Changes In Electrical Load On Fishery Vessels. MEIN: Journal of Mechanical, Electrical & Industrial Technology, 1(2), 1-4.
- [19] Nugraha, Anggara Trisna, et al. "Penyearah Setengah Gelombang Tiga Fasa Tak Terkontrol Menggunakan Motor Induksi Tiga Fasa." *Elektriase: Jurnal Sains dan Teknologi Elektro* 11.02 (2021): 78-88.
- [20] Ainudin, Fortunaviaza Habib, Muhammad Bilhaq Ashlah, and Anggara Trisna Nugraha. "Pengontrol Kecepatan Respon Motor dengan Pid dan Lqr." Seminar MASTER PPNS. Vol. 7. No. 1. 2022.