Journal for Maritime in Community Service and Empowerment ISSN:
Vol. xx, No xx, Month-year

# Optimization of PG45RS775 DC Motor Using LQR and LQT Methods for Community Empowerment Applications

* Raffi Ardika Putra
Marine Electrical Engineering, Shipbuilding Institute of Polytechnic Surabaya, Indonesia
*Correspondence author: raffiardika@student.ppns.ac.id.

**Abstract:** *The role of control systems in improving the effectiveness and efficiency of manufacturing processes has become increasingly critical, particularly in the context of the Fourth Industrial Revolution. With a growing demand for high-performance systems, optimizing control strategies is of paramount importance, especially for community-driven initiatives that seek to address local economic and technological challenges. Among the various control methods available, Linear Quadratic Regulator (LQR) and Linear Quadratic Tracking (LQT) are two prominent techniques used to achieve optimal performance in dynamic systems. In this study, we applied the LQR and LQT methods to optimize the performance of a PG45RS775 DC motor, a key component that could be used in community-based applications, such as small-scale industrial production or educational workshops. The results indicated that the LQR method achieved the desired set point with a lower overshoot compared to LQT, demonstrating its potential for applications requiring precision and stability. Additionally, in real-world systems, noise or disturbances are often present, which can negatively affect the performance of control systems. In this research, noise was introduced into both LQR and LQT systems, and its impact on the output was analyzed. The addition of noise resulted in a noticeable increase in overshoot, especially within the LQT system. Understanding the effect of noise is crucial for community-based technological solutions, as it allows for the development of more robust systems that can withstand environmental challenges, ensuring the sustainability of community empowerment projects.*

**Keyword**: *LQR, LQT, Noise*

## Introduction

With the rapid advancements in science and technology, both manual and automated control systems have become crucial components across various industries and sectors. Automated control systems, in particular, play a central role in addressing the complex needs of modern societies, especially in the context of the Fourth Industrial Revolution. These systems are fundamental in enhancing the effectiveness and efficiency of production processes, contributing to greater productivity and resource optimization.

In the current era, control systems are indispensable in fields such as engineering, economics, law enforcement, politics, social services, and more. For example, in civil or mechanical engineering design, network maintenance, electrical machine operation, and power distribution systems, control systems are essential for decision-making processes. These systems enable efficient management by minimizing costs and maximizing the utilization of available resources, ensuring optimal outcomes for various applications.

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The issue of optimal control has garnered significant attention due to the growing demand for high-performance systems. The concept of control system optimization involves striking a balance between performance indices and engineering constraints, aiming to design a system that operates optimally within the boundaries of physical limitations. The goal of optimal control is to develop decision-making rules that minimize deviations from an ideal system behavior. This process often utilizes mathematical programming techniques, specifically research programming, to address the challenges faced by the system and identify the best possible solution.

In recent years, numerous methods have been developed to achieve optimal system performance. Among these methods, Linear Quadratic Regulator (LQR) and Linear Quadratic Tracking (LQT) have shown considerable promise, particularly when applied to DC motor systems. These methods are chosen for their ability to address significant disturbances that can affect system stability without compromising performance. Moreover, LQR and LQT can rapidly correct disturbances, ensuring that the system returns to optimal performance in a shorter time frame.

This research aims to apply the LQR and LQT methods to optimize the PG45RS775 DC motor, with a focus on maximizing its rotational speed. This work is particularly relevant for community empowerment applications, where efficient and cost-effective solutions are required. For example, small-scale industries, educational workshops, and local manufacturing projects can benefit from these optimized motor systems, leading to enhanced productivity and self-sufficiency in rural or underserved communities. By leveraging advanced control techniques, this study aims to provide innovative solutions that can be easily implemented in community development projects, contributing to local technological advancement and economic growth.

## Methodology

1. Data Sheet DC Motor

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Data & specification Motor

| Gearbox data | Data | Motor data | Data | Output after gearbox | Data |
|---|---|---|---|---|---|
| Number of stage | reduction | Motor name | Rs775 | Motor name | PG45RS775 |
| Reduction ratio | 19.2 | Rated torque | 780 gfcm | Torque | 15kgfcm |
| gearbok length | 44.9 | Voltage | 24Vdc | No load speed | 463Rpm |
| Max run in torque | 60kgf.cm | No load current | 1.5A | Rated load speed | 398 (10+- %) |
| max gear breaking torque | 120kg.fcm | Rated curent | 6.5A | Stall torque | 40kgfcm |
| Gearing efficincy | 81% | Output power | 70W | Rottation direction | CCW/CW |

*Figure 1. Specification*

| | |
|---|---|
| Motor | = Motor DC PG45RS775 |
| $\tau$ (Torque) | = 15 kgfcm |
| | = 1,47 N/m |
| No load current | = 1,5A |
| Rated Current | = 6,5A |
| Voltage | = 24V |
| Speed | = 500 rpm |
| | = 52,36 m/s |
| Diameter | = 34 mm |
| | = 0,034 m |
| Radius Motor | = 17 mm |
| | = 0,017 m |

2. Mathematic model

A mathematical model is a simple representation of a problem or phenomenon that occurs and is presented in mathematical concepts[12]. From a problem or phenomenon that occurs, a mathematical equation is formed that is simple and easy to solve [6].

The transfer function is a comparison of the output Laplace function with the input Laplace function with all initial conditions considered zero [10]. The transfer function serves to make it easier to see the characteristics of a system [1].

In general, the form of a 1st order system can be written as follows:

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

1st Order DC Motor Based on the PG45RS775 DC motor data sheet, the 1st order equation is obtained:
Where $\tau$= K.i so

$$K=\frac{\tau}{i}=\frac{1{,}47}{6{,}5}=0{,}226$$

With information:
K = DC motor coefficient
$\tau$ = DC motor torque
I = DC motor current

So we get the 1st order equation for a dc motor:

$$G(s)=\frac{0{,}226}{1{,}47\,s+1}$$

Meanwhile, the general form of the 2nd order system can be expressed in the following standard form:

$$G(s)=\frac{\omega n^2}{s^2+2\varsigma\omega n s+\omega n^2}$$

Based on the DC motor datasheet, the second order equation for the DC motor is obtained as follows:

$$G(s)=\frac{(2\,x\,3{,}14\,x\,50)^2}{s^2+2.19{,}2.314\,s+(2\,x\,3{,}14\,x\,50)^2}$$

$$G(s)=\frac{98596}{s^2+120575\,s+98596}$$

nformation :
$\omega n^2$ = natural frequency
$\varsigma$ = Damping Ratio

3. LQR (Linear Quadratic Regulator)

Linear Quadratic Regulator (LQR) is a modern control technique that uses an equation of state (state space) approach. The LQR controller has two parameters that must be determined to produce the desired control action, namely the weight matrices Q and R. The process of weighting the matrices Q and R is carried out to obtain a control response in accordance with the desired control specifications [11]. The control system to be reviewed is expressed by the following equation:

$$\dot{x}=Ax+Bu\,y=Cx$$

The optimization method with a linear quadratic regulator is to determine the input signal that will move a linear system state from condition $x(t0)$ to a final condition $x(t)$ which will minimize an index for quadratic performance work [13]. The performance index is a function of a price which can be considered to indicate how much the actual system performance corresponds to the desired performance. The cost function in question is the integral time of the curdratic form of the state vectors $x$ and $u$ as in the equation:

$$J = \int_0^\infty (x^T Q x + u^T u R)\, dt$$

Where Q is a positive definite real symmetric matrix (or positive semidefinite) and R is a positive definite real symmetric matrix. The Q matrix and the R matrix determine the relative importance of faults and energy requirements[14].

The principle of using the LQR method is to obtain optimal control signals from state feedback.

$$u = -Kx$$

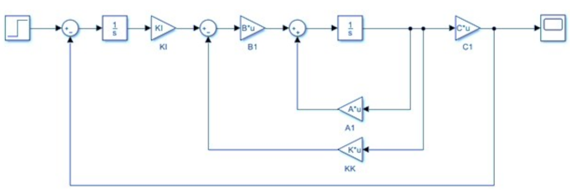


*Figure 2. LQR Circuit*

4. LQT (Linear Quadratic Tracking)

Linear Quadratic Tracking (LQT) is an optimal control method developed for linear plants to overcome tracking problems with a control system whose output is regulated so that it follows (tracking) a predetermined path through input [2][16].

The general form of the state equation of a linear system is shown by the following equation:

$$\dot{x} = Ax + Bu\, y = Cx$$

Apart from having a state equation, a system also has an error vector like the following equation:

$$e(t) = z(t) - y(t)$$

LQT aims to ensure that the system output follows the reference model output as closely as possible and minimizes the given performance index. Where the performance index is defined in the following equation:

$$J = \frac{1}{2} e'(t_f) F(t_f) e\text{¿}$$

Assuming that $F(t_f)$ and $Q(t)$ are symmetric positive semidefinite matrices with dimensions (m x m). R(t) is a positive definite matrix which is also symmetric (R×R)[15]. Matrix Q and R are weighting matrices that determine the performance of the system to be controlled.

After obtaining a mathematical model of the system in statespace form and matrices A(t) and B(t), the Riccati differential equation solution matrix can be obtained with the following equation for the finitetime case:

$$\dot{P}(t) = -P(t)A(t) - A'(t)P(t) + P(t)B(t)R^{-1}(t)B'(t)P(t)$$

and The following equation is for the infinite-time case

$$0 = -P(t)A(t) - A'(t)P(t) + P(t)B(t)R^{-1}(t)B'(t)P(t) + C$$

The Q and R matrices can be assumed to be in accordance with the desired performance of the system[17]. After obtaining the Riccati equation, the non-homogeneous vector differential equation can be searched using Eq:

$$\dot{g}(t) = -[A(t) - B(t)R^{-1}(t)B'(t)P(t)]' + C'(t)Q(t)$$

After getting the matrix P(t) which is a symmetric positive definite matrix and g(t), the feedback gain values K(t) and u*(t) can be found using the Riccati equation:

$$K(t) = R^{-1}(t)B'(t)P(t)$$
$$u*(t) = -K(t)x*(t) + R^{-1}(t)B'(t)g(t)$$

From the equation above, we get a constant K matrix value that does not change as a function of time.

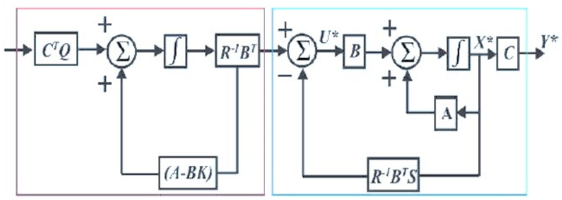


*Figure 3. Block Diagram LQT*

Where the red block is the following model of LQT and the blue block is the control block.

5. Noise

Noise or disturbance is a signal that tends to influence the output value of a system. Disturbance produced by the system is called internal disturbance, while disturbance that arises from outside the system is called external disturbance[18][19]. This noise will of course make the output value not match what we want. Noise is also used as a term for electrical interference that causes audible noise in a system [4][20].

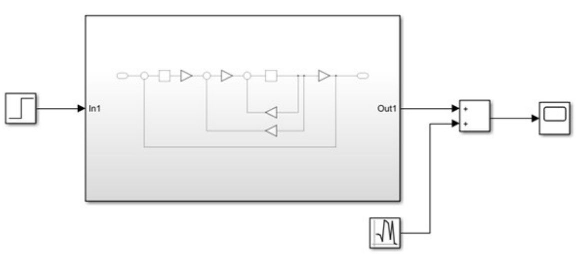


*Figure 4. LQR with noise*

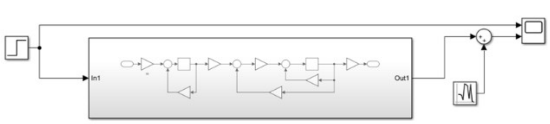


*Figure 5. LQT with noise*

## Results and Discussions

1. Result LQR without noise

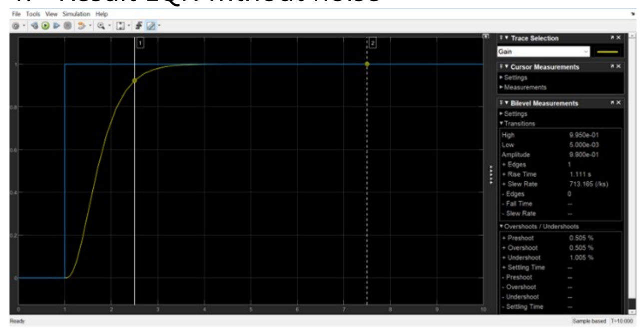

*Figure 6. LQR without noise*

Based on the results shown in Figure 6, the amplitude value obtained from LQR without noise is 0.99 with a maximum rise time of 1.111s. Meanwhile, for the overshoot and undershoot values, the values obtained were quite small, namely 0.505% for overshoot and undershoot of 1.005%.

2. Result LQR with noise

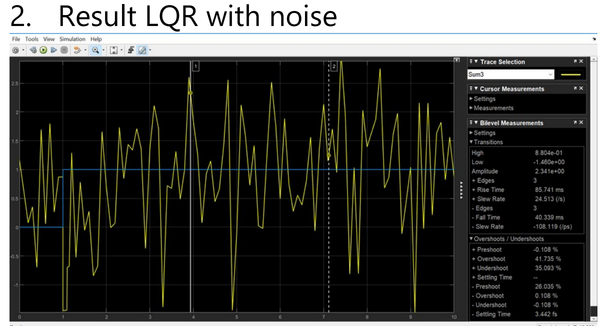

*Figure 7. LQR with noise*

Based on the results shown in Figure 7, noise disrupts the output value produced by a system. The amplitude value obtained from LQR with noise is 2.34 with a rise time of 85.741s. Meanwhile, for the overshoot and undershoot values, the values obtained were quite high, namely 41.735% for overshoot and undershoot of 35.093%.

3. Result LQT without noise

*Figure 8. LQT without noise*

Based on the results shown in Figure 8, the amplitude value obtained from LQT without noise is 0.99 with a rise time of 54.964μs. Meanwhile, the overshoot value was 5.851% and the undershoot was 0.452%.

4. Result LQT with noise

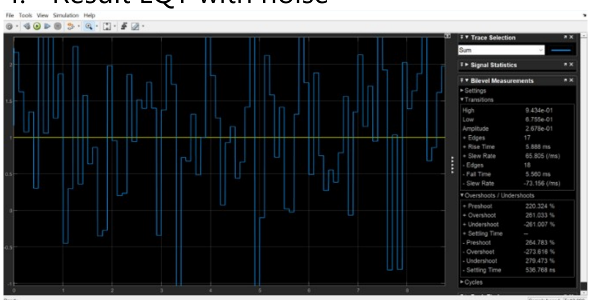

*Figure 9. LQT with noise*

Based on the results shown in Figure 3.4, noise disrupts the output value produced by a system. The amplitude value obtained from LQT with noise is 0.2678 with a rise time of 5.888ms. Meanwhile, the overshoot and undershoot values obtained were high, namely 261.033%, for overshoot and undershoot -261.007%.

5. Comparation

*Table 1. Result of LQR and LQT without noise*

| No | LQR | LQT |
|---|---|---|
| Amplitudo | 0,99 | 0,99 |
| Overshut | 0,505% | 5,851% |
| Undershut | 1,005% | 0,452% |
| Rise Time | 1,111s | 54,964μs. |

Based on the results from table 1, obtained from a comparison of experiments using LQR and LQT. The results obtained are that the amplitude of the LQR and LQT results is the same. However, the overshoot of LQT is higher than LQR. Meanwhile, the undershoot of LQR is higher than LQT.

*Table 2. Result of LQR and LQT with noise*

| No | LQR | LQT |
|---|---|---|
| Amplitudo | 2,34 | 0,2678 |
| Overshut | 41,735% | 261,033% |
| Undershut | 35,093% | -261,007% |
| Rise Time | 85,741s | 5,888ms |

Based on the results from table 2, obtained from a comparison of LQR and LQT experiments where noise makes the resulting output value not match the desired one. The change in output value is quite significant in the circuit where noise is added. The circuit to which this noise is added has quite high overshoot and undershoot values and the resulting graph also becomes irregular. From the two methods used and the added noise, it can be seen that the overshoot value from LQT is very high and very different from the overshoot produced by LQR.

## Conclusion

Based on the simulations conducted, the LQR method applied to the DC motor showed promising results. The output produced by the LQR method aligned well with the desired set point, exhibiting a smaller overshoot compared to the LQT method. This indicates that the LQR method performs more efficiently in maintaining the system's stability and minimizing deviations from the ideal behavior.

However, the presence of noise in the system significantly impacted the output. The introduction of disturbances led to noticeable fluctuations, causing all circuits to experience higher overshoot levels. This underscores the importance of addressing noise when optimizing control systems, particularly in community-based applications where environmental factors may introduce unexpected variables that affect system performance.

To mitigate the negative effects of noise and enhance the overall system performance, an additional filtering method or noise reduction technique is essential. Implementing such a solution would ensure that the system operates more optimally, producing more stable and predictable results. This aspect is particularly crucial for community empowerment applications, where reliable and consistent performance is key to the success of small-scale projects and local industries.

By incorporating noise filters and refining the control strategies, this study demonstrates how advanced control methods like LQR and LQT can be effectively applied to real-world community development scenarios, where technological solutions must adapt to external disturbances while still providing reliable outcomes.

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