Evaluating the Impact of Noise on Optimal LQR Control Methods in Enhancing the Performance of DC Motor Systems for Community

*Rama Arya Sobhita
Marine Electrical Engineering, Shipbuilding Institute of Polytechnic Surabaya, Indonesia
*Correspondence author: ramasobhita@student.ppns.ac.id

Abstract: *In today's fast-paced and ever-evolving world, technological advancements are rapidly transforming various sectors, and their impact is profoundly felt across multiple domains. The usefulness of technology and information is vast, with applications that touch almost every aspect of human life. As we witness these developments, the continuous progress in science becomes a key factor that drives innovation. By utilizing and refining existing knowledge, we can ensure that it functions optimally in addressing future challenges. In particular, the demand for electricity in industries is growing exponentially, necessitating well-distributed and efficient energy systems. One area where this need is crucial is in the optimization of electrical systems, specifically in propulsion engines, which play a significant role in community-based energy solutions. This research focuses on exploring the impact of noise on the optimization of control methods such as Linear Quadratic Regulator (LQR) and Linear Quadratic Tracking (LQT) when applied to DC motor systems. The goal is to investigate how these advanced control methods can be adapted for community-scale energy applications, ensuring efficiency and sustainability in energy distribution, especially in rural or underserved areas. By evaluating the effects of external noise on system performance, this study seeks to provide insights that can improve the reliability and effectiveness of DC motors used in renewable energy systems for local communities. The findings will contribute to the ongoing efforts to innovate and optimize technology for community empowerment and sustainable energy solutions.*

Keyword: *Optimization, DC Motor, Noise, Control, LQR*

Introduction

As time progresses, rapid changes occur across various sectors, with technology being one of the most significant areas of development. Technology has become an integral part of human life, as it greatly simplifies daily activities and operations in numerous fields. Technological advancements, continuously evolving in tandem with society, also lead to the enhancement of various electrical equipment. Understanding the fundamental concepts of electrical devices is essential for shaping the future, as electrical machinery plays a crucial role in various industries.

Among the wide variety of electrical machines, the DC motor stands out due to its widespread use in industrial machinery. Learning about DC motors is not only valuable for advancing industrial applications but also for contributing to the optimization of electrical systems in community-based projects. With the growing demand for electricity and the need for efficient energy systems in industries and rural areas, focusing on optimizing DC motors is crucial. When properly optimized, these systems will significantly improve the effectiveness and ergonomics of the electrical circuits involved.

The need for reliable electrical systems in modern industries is more pressing than ever, and the continual updating of knowledge regarding electrical machinery, particularly DC motors, is essential for progress. These motors are used in numerous types of machinery, each with specific operational needs that require regular maintenance to ensure peak performance. By focusing on the optimization of DC motors, this research aims to enhance the efficiency of their operation, thereby contributing to the broader goal of improving industrial performance.
This study aims to provide new insights into the operation and use of DC motors in industrial applications, which are pivotal to many sectors. The findings will not only contribute to the advancement of electrical systems in industrial settings but will also provide innovative approaches to optimizing the use of DC motors for more effective and sustainable industrial machinery, which has significant implications for community-based energy solutions and local development.

Methodology

1. DC motor

A DC motor is a device that converts electrical energy into kinetic energy or motion[15]. Direct current motor is a type of electric machine [8]. The movement in the form of rotation is obtained from the reaction of the creation of a magnetic or electromagnetic field reaction that occurs inside the motor body. DC motors are very commonly used, there are various reasons why DC motors are widely used. One of them is that the DC power system is still commonly used in industry and even though there is no DC power system, a rectifier circuit can be used to produce the desired DC power source [3]. Good motor rotation quality can be seen from how constant the rotation speed of the motor is from the start until the end of use. The number of rotations produced by the motor during each minute is usually called RPM (Revolutions per minute). Motor rotation that is always constant from the beginning to the end of use can be obtained if a system optimization is carried out on the motor.
The transfer function used in this study is:

A. Order 1

$K=\frac{T}{I}=$……………………………….[1]

$G(s)=\frac{K}{T.s+K}=¿$……………..………..[2]

Information:
[1] Formula for finding the value of a constant
[2] Formula for finding a first-order mathematical model
K = Constant
$T=Torsi(Nm)$
I = Current

2. SISO

SISO (Single Input- Single Output) is a control system that uses one variable or a simple single variable which uses one input/sender and one output/receiver. The system has an approach that emphasizes a network procedure that is interconnected, grouped and works together to achieve the desired goals[5]. Input is something that is desired in a control system, while output is something that happens, the actual state, or is the system's response [9]. This control system is the simplest form of other systems. In its use, this system uses orders, starting from order one to other higher orders. The control object is a SISO (single-input single-output) system, either first order, second order or higher order [13].

3. SIMO

SIMO (Single Input-Multiple Output) is a wireless communication system that uses one input/sender and many outputs/Receivers. This control system is an advanced form of SISO, because SIMO has advantages in terms of speed at the receiver and also overcomes problems due to multipath. In its use, this system is often used in radio transmitters

4. MISO

MISO (Multiple Input-Single Output) is a wireless communication system similar to SISO and SIMO but the difference is that it uses multiple inputs/senders and one or single output/Receiver. It is the third generation of smart antennas after SISO and SIMO[7]. The results of this study indicate that the accuracy of the MISO system is better than the accuracy of the SISO system[12]. This control system is the inverse form of SIMO.

5. MIMO

MIMO (Multiple Input- Multiple Output) is a wireless communication system that is the same as other systems, but the difference is that it uses multiple inputs/senders and multiple outputs/receivers. MIMO technology uses at least two antennas [10]. MIMO technology is present as a development of ordinary wireless technology that uses Single Input Single Output (SISO) [11].The main character in MIMO system control is the existence of an interaction process [18].This control system is a form of demand for better system performance in this era. This is done so that the data transmission process can be carried out simultaneously and increase delivery according to channel capacity [6]. This MIMO system can be said to be a Smart Antenna because its performance can meet existing needs and is also capable of carrying a lot of information in it without requiring bandwidth, Current wireless communications demand maximum data levels that can be achieved without intervention [16]. Behind the advantages of MIMO, of course, there are disadvantages behind it, including the occurrence of delays in receiving data and also requiring time in sending because of the division of signals in each antenna. The working concept of MIMO itself is to send a sequence of different data groups but at the same frequency, so that the performance of this system is quite adequate. For a MIMO system, the representation of the transfer function can be expressed by the transfer function matrix [17].

6. Noise

Noise which means Noise or commonly called noise is a disturbance in acoustic, electrical, or electronic signals in a system which will result in signal changes due to interference that does not come from the signal itself, resulting in the inability to achieve the desired signal [14]. In the field of communication, the original sound signal without noise is said to be important because it provides clear information, if the original sound signal has been mixed with noise, the sound signal becomes weak and eventually disappears/is useless [2]. In general, any type of signal recorded during the data acquisition process and disturbing the main signal we want can be categorized as noise [4]. Noise has various forms, but the most commonly used is White Noise, which is a collection of various disturbing noises that are then conveyed through the air.

7. Linear Quadratic Regulator (LQR)

Linear Quadratic Regulator (LQR) is one of the optimal control methods in state space-based systems [1]. Its use as a control method has been widely used in industrial activities. As a controller, LQR has two parameter values that must be determined to produce a desired control action. The LQR control method works based on the weighting of the Q and R matrices to obtain the best K value, which affects the system response according to the desired specifications [19]. The parameters referred to are in the form of a matrix with a weight of Q and a matrix with a weight of R.

8. Research plan

Starting with determining the DC motor datasheet that will be used as the object of research. continued by finding the 1st and 2nd order transfer functions of the DC motor [20]. then preparing the simulation circuit in Matlab Simulink software correctly according to the type of communication (SISO, SIMO, MISO, and MIMO) installed optimal method LQR and LQT. if it is felt wrong, then you must return to the simulation circuit preparation stage, continue again to simulate the circuit that has a transfer function installed in it, and do it again with a circuit that has added noise in it. then the stage is continued by comparing the simulation results whether there is a significant difference. if these things have been completed, then the research stage this time is complete.

9. Simulation

In the simulation circuit used in this experimental experiment, several component parts are installed to support the simulation. The following are the components installed in the simulation circuit.

Table 1. Requirements

No	Component Name	Location	Ways of working
1	Step	Located at the beginning of the circuit as input or input	Providing input into the simulation
2	Sum	Located after the step or after the transfer function block	Adding more than one input and feedback into the simulation leads to a transfer function.
3	Integrator	Located after Sum or as the core of the simulation	Internal gain work control of DC motor system in simulation
6	Gains	Located after the noise and before the scope, heading back towards the sum	Provides the function of the sensor system in the simulation work
5	Noise	Located at the end of the transfer function before the scope	Introducing noise into the transfer function output signal
6	Scope	Being at the end of the simulation process	Capture the signal or waveform of the simulation results for analysis.

a. Circuit of LQR without noise

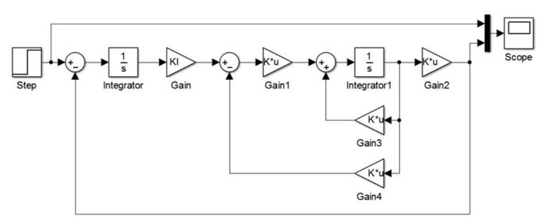


Figure 1. LQR without noise

b. Circuit of LQR with noise

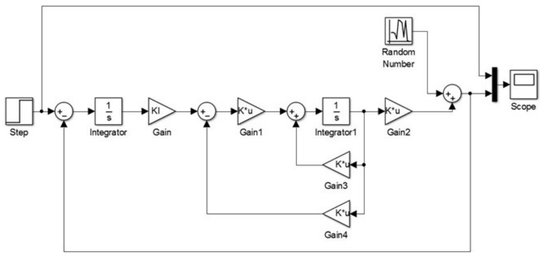


Figure 2. LQR with noise

Results and Discussions

1. Mathematical modeling

Table 2. Datasheet motor

Nominal Voltage	**12Vdc**
Body Diameter	**32**
RS Stock No.	**224-3530**
Nominal Speed [RPM]	**3700**
Torque [mNm]	**7.7**
Output Power [W]	**3**
Input Power, No Load [W]	**1.2**
Input Current, No Load [A]	**0.1**
Protection rating	**IP40**
Max usable power [W]	**3.9**
Starting torque [mNm]	**30**
Starting current [A]	**1.5**
Resistance [Ω]	**8**
Inductance [mH]	**10**
Weight [g]	**96**
Life [h]	**2000**
Ratio	**125:1**

From the datasheet owned by the DC motor above, we can take some information to find the matrix model which will later be used as the main data in the simulation.

The transfer function used in this study is:

A. Order 1

$$K=\frac{T}{I}=\frac{0,0077}{0,1}=0,077$$

Information:

K = Constant

$T=Torsi(Nm)$

I = Current

The DC motor specifications are known:

T (Torque) = 7.7 mNm = 0.0077 Nm

K (Constant) = 0.077

R (Resistance) = 8 Ω

L (Inductance)= 10 mH

From the results of the calculations that have been carried out, the value of the matrix model is obtained which is used as a simulation system in Simulink Matlab

2. Simulation without noise

a. SISO

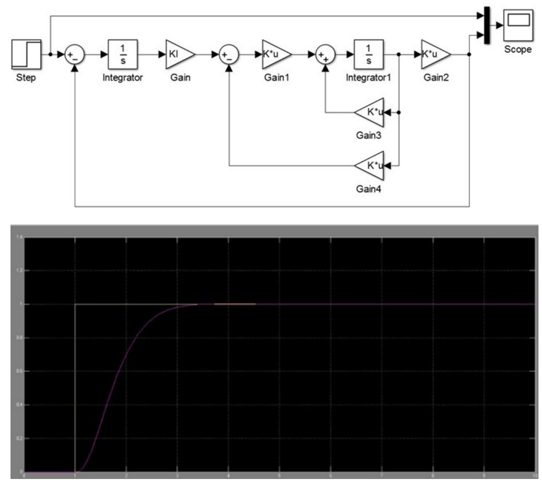


Figure 3. LQR SISO without noise circuit and waveform

The image above shows the results of the waves received by the scope on the SISO circuit with the LQR control method. The waves formed have 2 colors, each representing the voltage flowing in the circuit. The yellow wave depicts the original voltage results coming from the supply and nothing has been done. The purple wave depicts the signal results after going through the LQR method. The yellow wave appears to have a high and sharp spike shape, this happens because the voltage formed comes from the original voltage and has not been optimized. The purple wave has a gentler shape than the purple wave and approaches the set point, this happens because the voltage has been optimized using the LQR method

b. SIMO

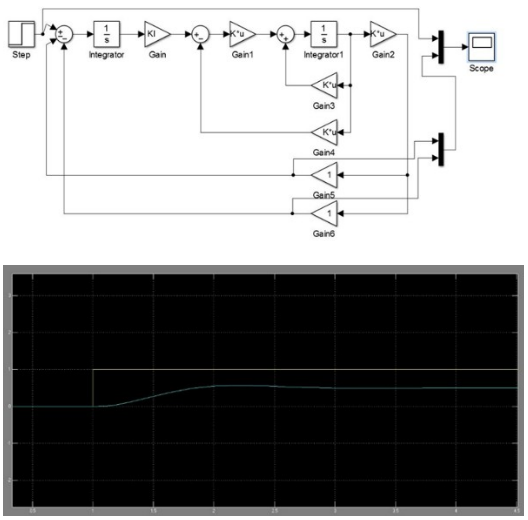


Figure 4. LQR SIMO without noise circuit and waveform

The image above shows the results of the waves received by the scope on the SIMO circuit. The waves formed are divided into 2 waves with different colors, yellow and cyan. The yellow wave represents the original signal from the supply before the optimization of the LQR method. The cyan wave is the result of the wave from the signal that has gone through the LQR method process. It can be seen that the cyan wave does not reach the setpoint on the yellow wave, so it can be concluded that the performance is not good in this communication system

c. MISO

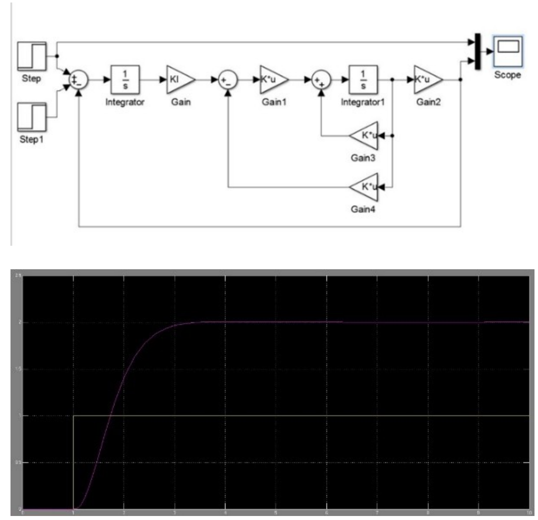


Figure 5. LQR MISO without noise circuit and waveform

The image above shows the results of the waves received by the scope on the MISO circuit with the LQR control method. The waves formed have 2 colors, each representing the voltage flowing in the circuit. The yellow wave depicts the original voltage results coming from the supply and nothing has been done. The purple wave depicts the signal results after going through the LQR method. The yellow wave appears to have a high and sharp spike shape, this happens because the voltage formed comes from the original voltage and has not been optimized. The purple wave has a shape that exceeds the setpoint of the yellow wave, this happens because the voltage is 2 times higher at the input even though optimization has been carried out using the LQR method

d. MIMO

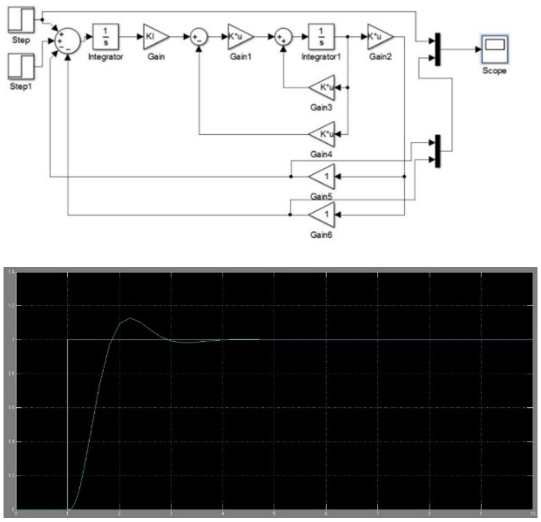
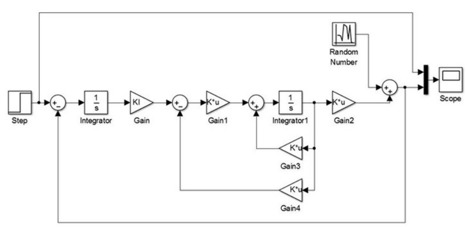


Figure 6. LQR MIMO without noise circuit and waveform

The image above shows the results of the waves received by the scope on the MIMO circuit. The waves formed are divided into 2 waves with different colors, yellow and cyan. The yellow wave represents the original signal from the supply before the optimization of the LQR method. The cyan wave is the result of the wave from the signal that has gone through the LQR method process. It can be seen that the cyan wave rises above the set point at the beginning but continues with the suitability of the set point, so it can be concluded that the performance is not good in this communication system.

3. Simulation With noise
   a. SISO



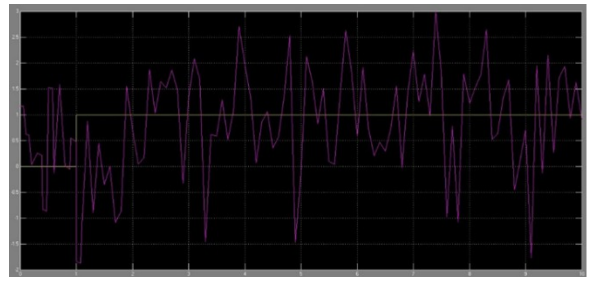
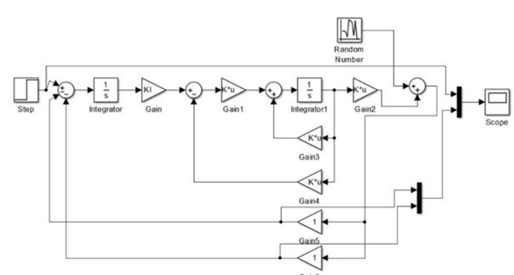


Figure 7. LQR SISO with noise circuit and waveform

The image above shows the results of the waves received by the scope on the SISO circuit with the LQR control method. The waves formed have 2 colors, each representing the voltage flowing in the circuit. The yellow wave depicts the original voltage results coming from the supply and nothing has been done. The purple wave depicts the signal results after going through the LQR method and adding noise. The yellow wave appears to have a high and sharp spike shape, this happens because the voltage formed comes from the original voltage and has not been optimized. The purple wave has a shape that is increasingly inconsistent with the initial setpoint, this happens because the voltage has been added with noise even though optimization has been carried out using the LQR method.

b. SIMO



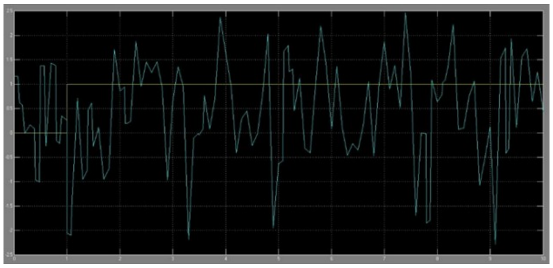
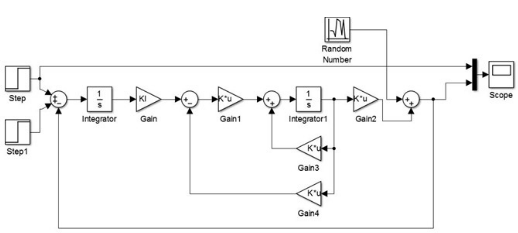


Figure 8. LQR SIMO with noise circuit and waveform

The image above shows the results of the waves received by the scope on the SIMO circuit with the LQR control method. The waves formed have 2 colors, each representing the voltage flowing in the circuit. The yellow wave depicts the original voltage results coming from the supply and nothing has been done. The cyan wave depicts the signal results after going through the LQR method. The yellow wave appears to have a high and sharp spike shape, this happens because the voltage formed comes from the original voltage and has not been optimized. The cyan wave has an irregular shape due to the addition of noise in the signal. Irregular waves that do not even match the setpoint mean that the circuit in this communication system is bad to use or not optimal.

c. MISO



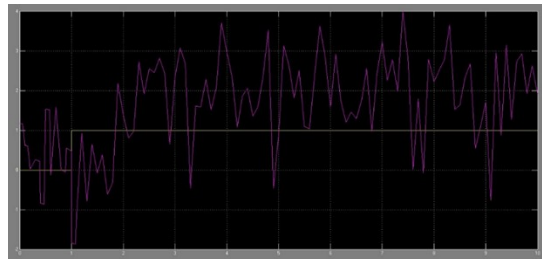


Figure 9. LQR MISO with noise circuit and waveform

The image above shows the results of the waves received by the scope on the SISO circuit with the LQR control method. The waves formed have 2 colors, each representing the voltage flowing in the circuit. The yellow wave depicts the original voltage results coming from the supply and nothing has been done. The purple wave depicts the signal results after going through the LQR method and adding noise. The yellow wave appears to have a high and sharp spike shape, this happens because the voltage formed comes from the original voltage and has not been optimized. The purple wave has a shape that is increasingly inconsistent with the initial setpoint, this happens because the voltage has been added with noise even though optimization has been carried out using the LQR method.

d. MIMO

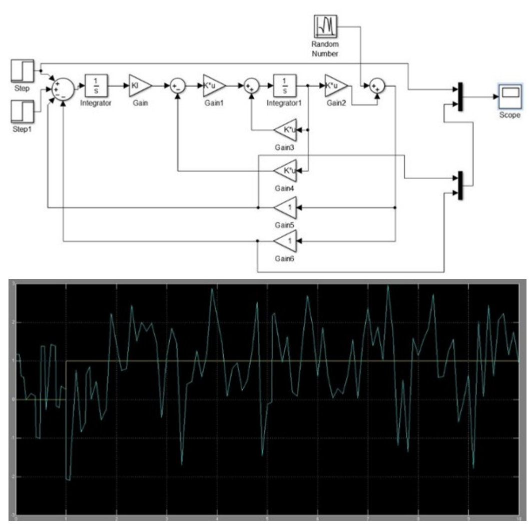


Figure 10. LQR MIMO with noise circuit and waveform

The image above shows the results of the waves received by the scope on the MIMO circuit with the LQR control method. The waves formed have 2 colors, each representing the voltage flowing in the circuit. The yellow wave depicts the original voltage results coming from the supply and nothing has been done. The cyan wave depicts the signal results after going through the LQR method. The yellow wave appears to have a high and sharp spike shape, this happens because the voltage formed comes from the original voltage and has not been optimized. The cyan wave has an irregular shape due to the addition of noise in the signal. Irregular waves that do not even match the setpoint mean that the circuit in this communication system is bad to use or not optimal.

Conclusion

The research conducted obtained comparative results that were quite clearly visible through the waveform created by Matlab Simulink software. The effect of Noise on the waveform created by the work of the DC motor with the optimal LQR method is very influential, because with the presence of noise in the signal wave, it will make the machine performance move away from the optimal line or setpoint. Therefore, the use of the optimal LQR method system is used to minimize or reduce noise interference itself. A good communication system used with the optimal LQR method is the MIMO system. Results that are close to the initial setpoint are a sign of optimal performance, but not yet perfect.

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