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Simulation of DC Motor Control Systems Using SISO, SIMO, MISO, and MIMO Configurations with LQR and LQT Control for Sustainable Community

*Muhamad Rifqi Anugrah Syafa'at[1], Rama Arya Sobhita[2]
[1,2] Marine Electrical Engineering, Shipbuilding Institute of Polytechnic Surabaya, Indonesia
*Correspondence author: mrifqi09@student.ppns.ac.id

Abstract: *Electric motors are devices that convert electrical energy into mechanical energy. In a DC motor, this energy conversion occurs as a current flows through a coil in the stator, causing the rotor to rotate due to magnetic field repulsion. This research focuses on the application of DC motors in community service projects, particularly in systems that support sustainable development efforts in rural and underdeveloped areas. In such settings, DC motors are often used in various community development projects, including water pumping systems, small-scale energy generation, and agricultural machinery. The ease of controlling DC motors, particularly through advanced control systems, makes them ideal for these applications. This study investigates the impact of different control strategies on the performance of DC motors, specifically comparing SISO (Single Input, Single Output), SIMO (Single Input, Multiple Output), MISO (Multiple Input, Single Output), and MIMO (Multiple Input, Multiple Output) systems. Each of these systems offers unique advantages for controlling the motor's performance, such as optimizing speed, torque, and energy efficiency, which are critical in real-world community applications. The simulation results will provide insights into the advantages of each control system and highlight how these can improve the overall efficiency and reliability of systems that directly impact community welfare. The findings from this study are expected to be highly relevant for community service applications, offering practical solutions for enhancing the quality of life through better-designed technologies and optimized systems.*

Keyword: *Dc Motor, Simulation, Control*

Introduction

System optimization is a crucial subject, particularly in the field of electrical engineering, as it equips students with theoretical and practical knowledge for analyzing and designing systems. This course enables students to understand how a system is designed, operates, and achieves the desired outcomes effectively and efficiently. In community service contexts, systems are created to optimize processes that directly benefit society, particularly in rural and underserved communities. By comprehensively designing and simulating these systems, we can improve the quality of life in these areas through technology that supports sustainable development.

In this study, the primary system of interest is the DC motor, which is widely used in various community projects such as water pumping, small-scale energy generation, and agricultural machinery [2]. A DC motor converts electrical energy into mechanical energy, and its speed and direction can be controlled using various techniques[3]. When voltage is applied to the motor terminals, the rotor turns in one direction. If the polarity of the voltage is reversed, the rotor spins in the opposite direction[8]. The speed of the motor is determined by the voltage applied to the motor's coil [9]. This control of motor speed is essential in many community service applications that require reliable and sustainable technology.

To regulate the performance of DC motors, a DC-DC converter, such as the Buck-Boost Converter, is often employed. This converter allows for the control of voltage levels, transforming a constant DC voltage into a variable one, which is crucial for applications where precise voltage control is needed to optimize energy use [7].

The transfer function of a system, which is the operational method of differential equations connecting input and output variables, is a fundamental concept in system analysis[10]. The transfer function describes the inherent properties of the system and is independent of the input's size or characteristics. It provides a mathematical model for understanding how the system responds to different inputs, offering insights into its dynamic behavior[12]. This is especially important in community projects, where understanding the dynamics of a motor system can significantly improve its performance in the field.

By utilizing linear differential equations, the mathematical modeling of a DC motor system allows for a more detailed understanding of the factors that influence motor performance. This model provides clarity on how various elements, such as voltage input and load conditions, affect the motor's transition behavior. In complex systems that integrate motors with other equipment, dynamic system analysis is often necessary to ensure effective operation, a task that is made much easier with computational tools like MATLAB.

Antennas, similarly, are devices that convert electrical signals into electromagnetic waves, enabling communication across distances[14]. The evolution of smart antennas has led to significant advancements in communication systems, moving from SISO (Single Input, Single Output) to more complex configurations like SIMO (Single Input, Multiple Output), MISO (Multiple Input, Single Output), and the widely popular MIMO (Multiple Input, Multiple Output) systems [5]. These systems are now critical in ensuring reliable communication in remote and rural areas, where traditional infrastructure may be lacking.

In this course on system optimization, we will explore these configurations—SISO, SIMO, MISO, and MIMO—and how they can be applied to improve the performance of community-based systems, including DC motor-driven applications. The simulations will include the impact of external noise and disturbances, allowing for a deeper understanding of how these systems respond to real-world challenges. Using MATLAB and Simulink, we will model these systems and evaluate their behavior in a DC motor setup, which is a key component of many community-driven technologies.

The DC motor used in this study is the PS150-24-25 model, and the simulations will compare the performance of SISO, SIMO, MISO, and MIMO systems under various conditions. This comparison will help identify the most suitable control strategies for different community applications. The system will be controlled using Linear Quadratic Regulator (LQR) and Linear Quadratic Tracking (LQT) methods, which will provide insights into the system's response to disturbances and its ability to track desired performance goals.

In the context of community service, this research aims to provide actionable insights into how optimization techniques can be applied to improve the efficiency and sustainability of motor-driven systems in rural development projects. By using advanced control methods like LQR and LQT, we can enhance the performance of systems that are crucial for improving the quality of life in underserved communities.

Methodology

1. Control

A control system is a process of controlling one or more quantities (parameters), so that they are in certain conditions which serve as a reference. The parameters that serve as a reference influence the performance of the control system, including measurement, comparison, calculation and improvement [8][15]. In general, control systems are classified into several systems, including manual and automatic control systems, open control systems and closed control systems

- Openloop

An open control system has a system where the system output has no influence on the control action so that the output cannot provide feedback on the input[16]. The open control system diagram display looks simple and straight like the following image.

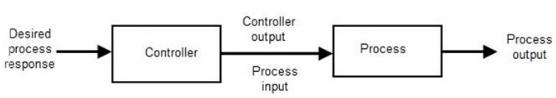

Figure 1. Open loop diagram block

- Closeloop

A closed control system is a control system where the output signal provides influence or feedback, so the system output can have an influence on the input[17]. It is fed to the controller to minimize errors so that it can produce the desired output better. In other terms, a closed control system uses feedback effects to reduce system errors

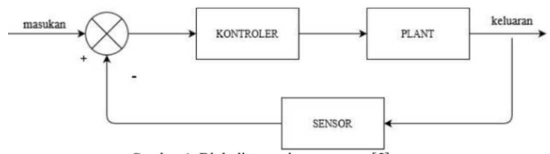

Figure 2. Close loop diagram block

2. Noise

Noise is an unwanted disturbance to an image [1]. This disturbance is a disturbance that occurs from outside the system or from the surrounding environment. Therefore, we need a system with filtering so that interference can be filtered out and the results of the system can produce output that remains stable.

3. Mathematic model

This mathematical model is obtained from an Order 1 and Order 2 calculation from a DC motor datasheet. The following is the datasheet that I have for a DC motor type PS150-24-25

Specifications

Attribute	Value
Supply Voltage	24 V
DC Motor Type	Brushed Geared
Primary Keyword	DC Geared Motor
Power Rating	9.6 W
Output Speed	180 rpm
Shaft Diameter	5.5mm
Maximum Output Torque	20 Ncm
Gearhead Type	Planetary
Gear Ratio	25:1
Dimensions	30 (Dia.) x 71.2 mm
Current Rating	400 mA
Length	71.2mm
Series	PS150

Figure 3. Parameter motor

- Model ordo 1

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

Orde 1 Motor DC Base on datasheet DC motor get ordo 1

$$\frac{K}{Torsi\ S + K}$$

$$K = \frac{Torsi}{Arus}$$

$$K = \frac{0,02}{0,4} = 0,05$$

$$F_{1(s)} = \frac{K}{Torsi\ S + K} = \frac{0,05}{0,02S + 0,05}$$

Keterangan :

K = Koefisien motor DC
τ = Torsi motor DC

I = Arus motor DC

Sehingga diperoleh Persamaan orde 1 motor dc :

$$G_{(S)} = \frac{K_s}{T_s s + K_s}$$

$$G_{(s)} = \frac{0,05}{0,02S + 0,05}$$

- Model ordo 2

$$G(s) = \frac{Wn^2}{s^2 + 2RWns + Wn^2}$$

Base on datasheet DC motor

$$\omega n_{(s)} = 2.\pi.f$$

$$\omega n_{(s)} = 2\,.\,3{,}14\,.\,50$$

$$\omega n_{(s)} = 314$$

$$G_{(S)} = \frac{\omega n_{(s)}{}^2}{s^2 + 2.\varsigma.\omega n_{(s)} s + \omega n_{(s)}{}^2}$$

$$G_{(S)} = \frac{98.596}{s^2 + 2.(25)3{,}14s + 98.596^2}$$

$$G_{(S)} = \frac{98.596}{s^2 + 15.700s + 98.596^2}$$

When : $\omega n^2 = frekuensi\ natural$

$\varsigma = Rasio\ redaman$

4. SISO
SISO is a simple control system that has one input and one output[18]. This system is the first generation and there are still many weaknesses. One of the weaknesses of SISO is that it is easily affected by external interference, for example bad weather. The following is an image of the block diagram of the SISO system.

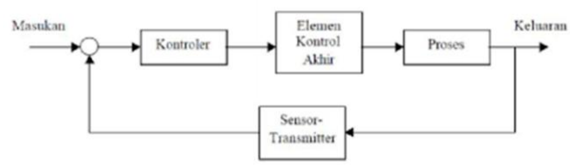

Figure 4. SISO Block

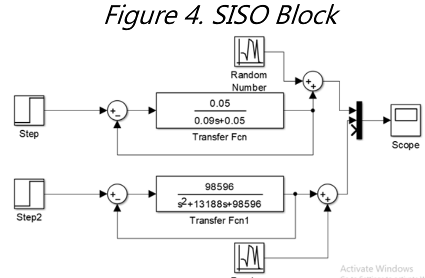

Figure 5. SISO with noise

5. SIMO
SIMO is a control system that has one input and two or more outputs. The following is a picture of an example of a SIMO system control.

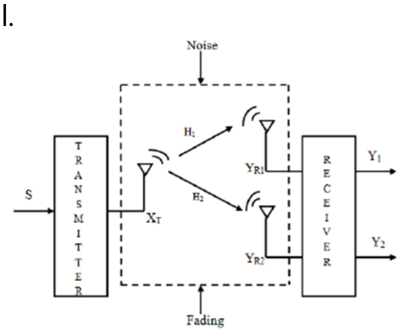

Figure 6. Bolck diagram simo

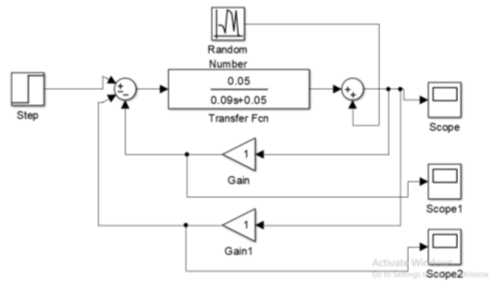

Figure 7. Blok Diagram SIMO in Simulink

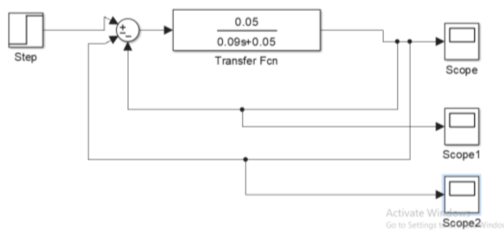

Figure 8. Blok Diagram SIMO with Noise

6. MISO

MISO is the third generation of smart antenna after SISO and SIMO [5]. MISO is a communication antenna technology where several antennas are used as transmitters. These antennas are combined to minimize errors and optimize data speeds

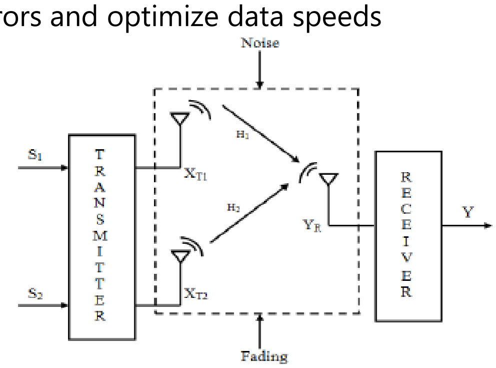

Figure 9. Block diagram MISO

Based on the picture above, the MISO system works by sending 2 different variables and then the receiver will only receive one variable. This system only accepts one variable from several variables that the transmitter sends to minimize errors. Below is a series of block diagrams for simulation in Simulink.

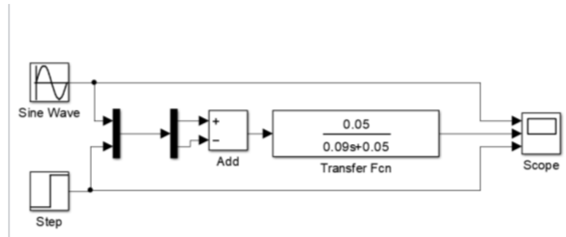

Figure 10. Blok Diagram MISO in Simulink

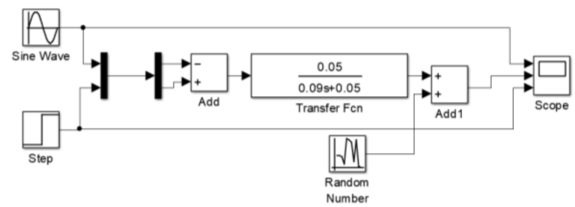

Figure 11. Blok Diagram MISO with noise

7. MIMO

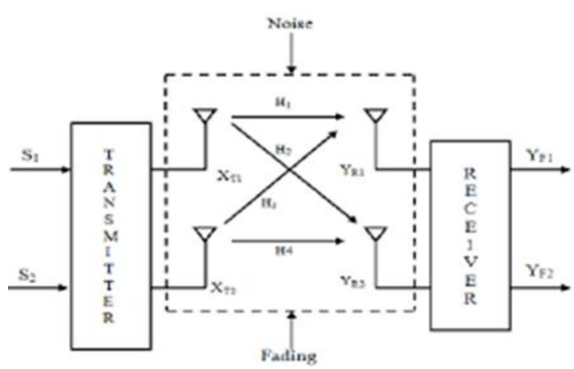

Figure 12. Blok diagram MIMO

The picture above explains that the MIMO system works with more than one transmitter and more than one receiver. This smart antenna system is better than the previous type. This system is very strong in bad weather and also very fast in sending a signal. Now all communication systems use this MIMO system because it is superior and also has few disadvantages.

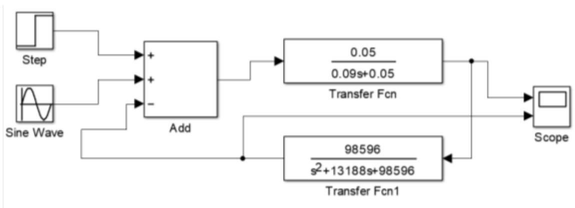

Figure 13. Blok Diagram MIMO in Simulink

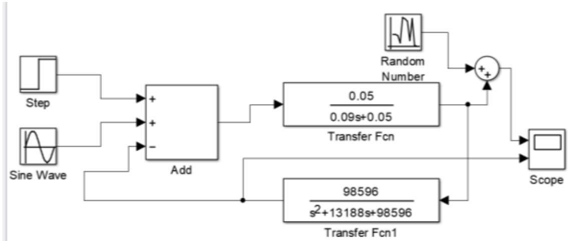

Figure 14 Blok Diagram MIMO with noise

8. LQR

LQR is one of the optimal controls which means the best results obtained and achieved by paying attention to the conditions and constraints of a system[19]. Linear Quadratic Regulator (LQR) is an optimal control aimed at bringing the final state to zero by minimizing the cost function. LQR is a special form of optimal control system. LQR control is simple and easy to obtain control because only by entering the Q and R values it produces the K parameter (gain feedback). LQR is called linear because the model and shape of the controller are linear [20]. Meanwhile, it is called quadratic because the cost function is quadratic and because the reference is not a function of time, it is called a regulator

LQR in the program is used with the aim of being able to control the position control of a DC motor by providing changes in position input and seeing the effect on the desired output. LQR will also produce better and better graphic output like using a filter.

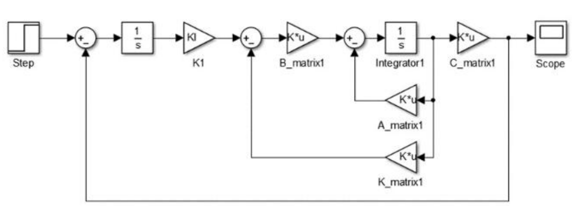

Figure 15. Simulation in SIMULINK

```
clear; close all; clc
J = 0.01; b = 0.1; K = 0.0077; R = 0.32; L = 0.0416;
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 = [-10 -10 -10];
K = acker(AA,BB,J)
KI = -K(3);
KK = [K(1) K(2)];
%LQR
Q = [1 0 0;
    0 1 0;
    0 0 10000];
R = [1];
K_lqr = lqr(AA,BB,Q,R)
kI2 = -K_lqr(3);
KK2 = [K_lqr(1) K_lqr(2)]:
```

Figure 16. Program Simulation in SIMULINK

Results and Discussions

These results and discussion will explain that the results of the simulation that has been carried out will produce a sinusoidal wave which has the meaning of each color and size of the wave. The yellow wave is the value of an input and the blue wave is sensor one of feedback, then the red wave is sensor two of feedback.

1. SISO LQR

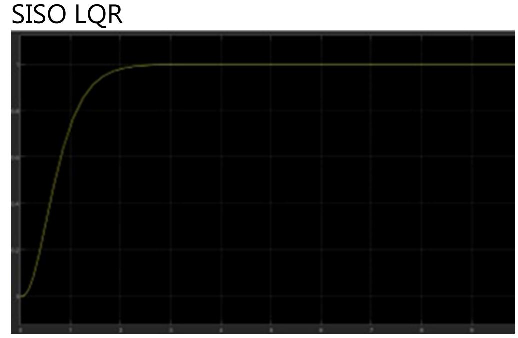

Figure 17. SISO LQR Result without noise

The graph shows the simulation results using one input and one output and using the LQR program. The graph explains that LQR works well, it can be seen that the waves originate from the bottom and then climb steadily and straighten. LQR works almost like a filter in that it works by clarifying the output graph.

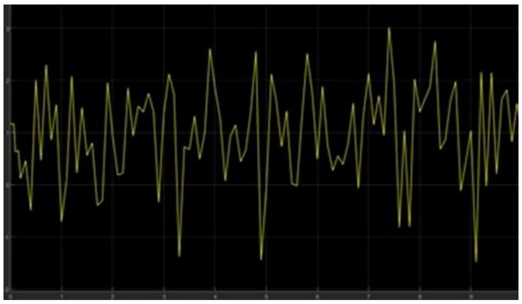

Figure 18. SISO LQR Result with noise

If there is noise in the simulation block diagram, the resulting graph will change irregularly. Noise will interfere with work results and produce poor output.

2. SIMO LQR

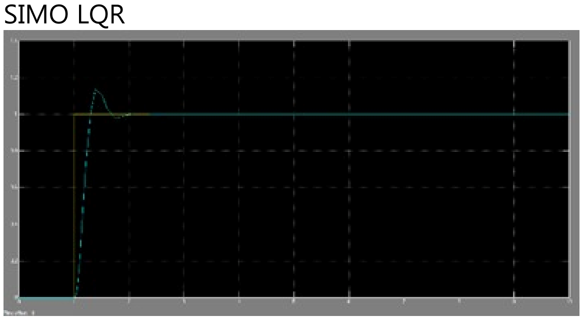

Figure 19. SIMO LQR Result without noise

LQR SIMO produces almost the same graphic form as SISO. The difference is that the wave rises and then decreases a little before the graph will work straight and well. LQR SIMO output produces good and regular output as desired.

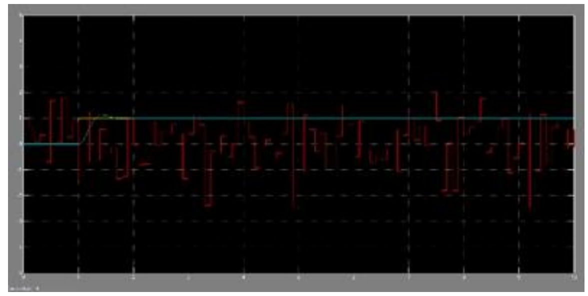

Figure 20. SIMO LQR Result with noise

The results of the SIMO LQR output graphic are if there is noise in the block diagram, the noise will change the output and will damage the graphic results of the program. It can be seen that the red graph will be irregular when read. Meanwhile, on the green line, the graph or wave is similar to the results from SISO where the wave continues to run well even though there is noise.

3. MISO LQR

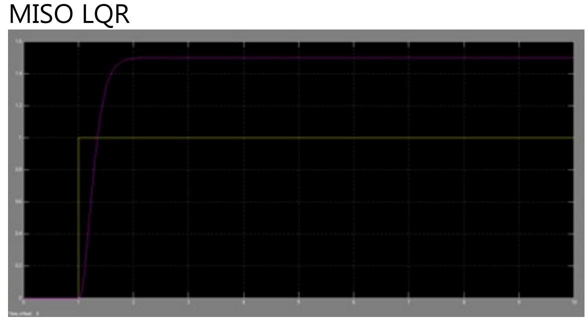

Figure 21. MISO LQR Result without noise

The graph shows the simulation results using one input and one output and using the LQR program. The graph explains that LQR works well, you can see the waves coming from the bottom and then climbing steadily and straight. LQR works almost like a filter in that it works by clarifying the graph

Figure 22. MISO LQR Result with noise

If there is noise in the simulation block diagram, the resulting graph will change irregularly. Noise will interfere with work results and produce poor output

4. MIMO LQR

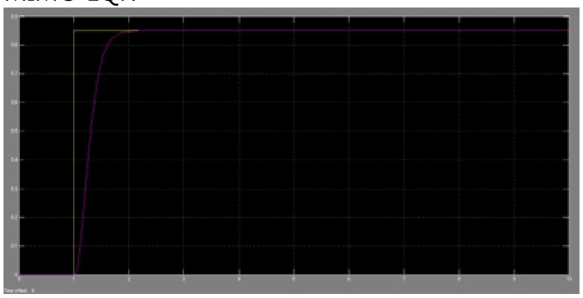

Figure 22. MIMO LQR Result without noise

The graph shows the simulation results using one input and one output and using the LQR program. The graph explains that LQR works well, it can be seen that the waves originate from the bottom and then climb steadily and straighten. LQR works almost like a filter in that it works by clarifying the graph

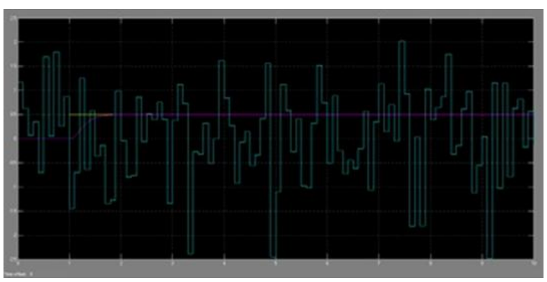

Figure 23. MIMO LQR Result with noise

If there is noise in the simulation block diagram, the resulting graph will change irregularly. Noise will interfere with work results and produce poor output.

Conclusion

After conducting simulations on the DC motor using SISO, SIMO, MISO, and MIMO control systems, each with varying levels of noise interference, several conclusions can be drawn based on the results:

1. Evolution and Technological Advancements: As time progresses, technological advancements continuously emerge, addressing the shortcomings of existing systems. For example, the SISO (Single Input, Single Output) system, which is foundational in motor control, has evolved into more complex systems like MIMO (Multiple Input, Multiple Output). The MIMO system offers improvements over SISO by addressing its limitations, such as better handling of multiple inputs and outputs, leading to more efficient and reliable performance. This evolution in control systems highlights the ongoing progress that will likely introduce even more innovative solutions in the future, especially for community-driven applications in areas such as renewable energy, water supply, and agricultural machinery.
2. Diversity of Control Systems: SISO, SIMO (Single Input, Multiple Output), MISO (Multiple Input, Single Output), and MIMO are all distinct systems with their own strengths and weaknesses. Each of these systems can be utilized effectively depending on the specific needs of the application. For example, in rural community projects where resources are limited, a simpler SISO system might suffice. However, for more complex applications, such as integrated systems for energy generation or irrigation, a MIMO configuration could be more appropriate due to its ability to manage multiple inputs and outputs.
3. DC Motor Control and Adaptability: The DC motor can be effectively controlled using converters, and the simulations

conducted with various systems reveal that each system's response differs. These variations highlight the adaptability of DC motors when integrated into different control frameworks, making them suitable for a variety of community service applications. For instance, a well-controlled DC motor could power a small-scale community water pumping system or an off-grid electricity generator for rural areas.

4. Impact of Sinusoidal Waves: The sinusoidal waves produced by each system vary significantly due to the differences in input and output configurations. These variations in waveforms can affect the system's overall performance. In practical applications, such as energy generation or irrigation systems in remote areas, ensuring that the system operates with stable waveforms is crucial for maintaining efficiency and reliability.
5. Noise and Its Effect on System Performance: Noise interference has a significant impact on the sinusoidal waveforms, causing disruptions in the system. When a signal is affected by noise, the receiver may struggle to interpret the data accurately, leading to potential system failures. This is particularly important in community service applications where reliability is critical, such as in medical equipment powered by motors or in agricultural machinery. Noise reduction strategies must therefore be incorporated to ensure uninterrupted performance in real-world environments.
6. Optimal Control with LQR: The Linear Quadratic Regulator (LQR) is an optimal control method used to bring the final state of the system to zero by minimizing the cost function. In the context of community service, this control method ensures that resources are used efficiently, and the motor's operation is as energy-efficient as possible. LQR's ability to minimize disturbances and maintain system stability is particularly useful for applications where consistent and reliable performance is essential, such as in off-grid water systems or rural electrification projects.
7. Tracking Control with LQT: The Linear Quadratic Tracking (LQT) method is used to minimize the objective function and guide the system to follow a desired reference trajectory. This method is especially valuable for community projects that require precise and continuous tracking, such as in automated agricultural systems that track water levels or solar energy systems that adjust based on sunlight. LQT ensures that the system adapts to varying conditions while maintaining optimal performance.

Performance of LQR Control: The results from the LQR control system were particularly impressive, with the system displaying steady output in a manner similar to a well-functioning filter. The consistency and predictability of LQR's performance make it an excellent choice for applications that require high precision and stability, ensuring that community-driven projects operate efficiently over time.

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