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RESEARCH ARTICLE

Performance Analysis of DC Motor in SISO Circuit Using LQR Control Method: A Comparative Evaluation of Stability and Optimization

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Abstract

The rapid advancement of telecommunications has significantly influenced various engineering applications, including control systems for electrical and mechanical systems. One crucial aspect of control system design is ensuring signal integrity and stability, particularly in Single-Input Single-Output (SISO) circuits. In this study, we analyze the performance of a DC motor within a SISO circuit using Linear Quadratic Regulator (LQR) and Linear Quadratic Tracking (LQT) control methods. The research employs a simulation-based approach, evaluating first-order and second-order system responses under different conditions, including scenarios with and without external noise interference. Experimental results indicate that each control approach exhibits distinct dynamic characteristics, influencing system stability, response time, and noise suppression capability. The presence of noise significantly affects system behavior, leading to deviations from the desired set point. An optimal control circuit is defined by minimal ripple, rapid convergence to the set point, and robustness against disturbances. Comparative analysis highlights that LQR and LQT methods offer significant improvements in trajectory tracking and system optimization, with LQT providing enhanced adaptability in the presence of external perturbations. This study contributes to the field of control engineering and automation by offering insights into the optimization of DC motor control in SISO circuits, with potential applications in robotics, industrial automation, and power electronics.

Keywords: control circuit, DC Motor, matlab, SISO.

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1 Introduction

Over the past decade, the telecommunications industry has experienced exponential growth, significantly impacting various engineering applications, including control systems, industrial automation, and real-time data processing. This rapid technological advancement has driven the transition from 2G to 5G networks, resulting in significant improvements in connectivity, data transmission speed, and system efficiency [3, 4]. The evolution of wireless technology has enabled a broader range of applications, from smart grid infrastructure to

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autonomous systems, where reliable and high-speed communication is critical. However, one of the critical factors affecting signal transmission quality is the communication channel, where various forms of unwanted interference, such as multipath fading, thermal noise, and electromagnetic disturbances, may distort the original signal as it propagates from the transmitter (XT) to the receiver (YR). Addressing these interferences is crucial in ensuring optimal system performance and signal integrity.

Wireless communication has become the backbone of modern engineering solutions due to its ability to provide efficient and reliable data transmission over the air, ensuring high signal-to-noise ratio (SNR) values with minimal data loss. The efficiency of a wireless system largely depends on the antenna configuration, where each type presents distinct advantages and limitations based on the transmission environment. For instance, advanced configurations such as Multiple-Input Multiple-Output (MIMO) enhance communication capacity and reliability. However, for many applications, Single-Input Single-Output (SISO) systems remain the preferred choice due to their simplicity, ease of deployment, and reduced computational overhead.

In SISO systems, a single transmitter and a single receiver are employed, making it the simplest and most straightforward configuration among multiple antenna models. This simplicity facilitates ease of implementation and minimizes computational complexity, making SISO systems particularly advantageous for control applications, such as DC motor control in automated systems, robotics, and industrial processes. The effectiveness of a SISO system is often evaluated based on its ability to maintain a stable and reliable signal, even in environments where external disturbances, such as noise and interference, are present. Given the increasing complexity of modern control systems, ensuring a robust communication channel within a SISO framework is essential for maintaining system efficiency and reliability.

A standard SISO communication model follows Shannon's channel capacity theorem, which defines the maximum theoretical data rate that can be transmitted error-free over a bandwidth-limited channel in the presence of noise [5–7]. According to this theorem, the presence of noise significantly influences the system's stability, leading to signal fading, degradation in transmission quality, and reduced overall system efficiency. As a result, implementing advanced control methods, such as Linear Quadratic Regulator (LQR) and Linear Quadratic Tracking (LQT), becomes crucial in optimizing signal integrity, minimizing fluctuations, and improving system resilience against external disturbances [8]. These control strategies allow for dynamic adjustments in system parameters, ensuring that the output remains stable and accurately follows desired reference values despite noise interference.

This study evaluates the impact of Single-Input, Single-Output (SISO) circuits on DC motor performance under various operating conditions, with a focus on stability, noise mitigation, and response optimization. The SISO system, as shown in Figure 1, serves as the foundation for implementing LQR-LQT control techniques, which aim to enhance system efficiency, robustness, and adaptability in dynamic environments. The findings contribute to the field of control engineering and industrial automation by providing valuable insights into improving communication-based control systems. Furthermore, the study provides a framework for implementing SISO-based control strategies in future intelligent systems, ensuring seamless integration with evolving telecommunications technologies [9, 10].

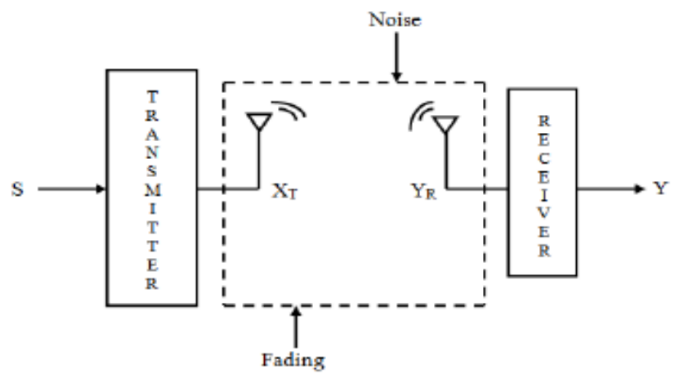

Figure 1. SISO system.

2 Related Work

This section examines prior research relevant to this study, summarizing key findings and developments in the field. These studies serve as a basis for understanding the current research landscape, highlighting gaps in knowledge, and situating this study within a broader context. Through the analysis of related literature, this research leverages existing knowledge while striving to offer fresh perspectives on the topic.

2.1 SISO

The study conducted by Dharmawan et al. [1] focuses on the implementation of stability control for a quad tiltrotor during translational movement using two advanced control strategies: the Linear Quadratic Regulator (LQR) and the Linear Quadratic Gaussian (LQG) controllers. One of the key elements of this research is the adoption of a Single-Input Single-Output (SISO) control approach, where individual control loops are specifically designed to regulate distinct motion parameters of the tiltrotor system.

The study systematically evaluates the performance of both LQR and LQG controllers in maintaining the quad tiltrotor's stability, particularly when subjected to external disturbances and system uncertainties. By analyzing how each controller responds to variations in system dynamics, the researchers provide valuable insights into the effectiveness of these methods in improving flight stability.

The results demonstrate that both LQR and LQG significantly enhance the overall stability of the quad tiltrotor. The LQR controller effectively minimizes deviations by optimizing state feedback gains, while the LQG controller further refines performance by incorporating a state estimator to address uncertainties and external disturbances. This research offers a meaningful contribution to the field of UAV control, paving the way for the development of more precise and reliable stabilization systems for tiltrotor unmanned aerial vehicles (UAVs).

2.2 Linear Quadratic Regulator (LQR) Control

The study conducted by Arrofiq et al. [2] explores the implementation of a Linear Quadratic Regulator (LQR)-based control system for an eddy current brake (ECB) dynamometer. The research aims to optimize braking performance by developing a control strategy that ensures precise and stable regulation of braking force.

To achieve this, the study formulates a state-space model of the ECB system, allowing for the application of LQR to balance control effort with system performance. The optimization process focuses on minimizing control input while maintaining a rapid response time and reducing steady-state error. Through simulation and analysis, the results indicate that the LQR controller significantly enhances braking stability and efficiency when compared to conventional control methods. By demonstrating the advantages of LQR in improving precision and robustness, this research contributes to the development of more advanced braking systems. The findings underscore the potential of LQR in optimizing ECB-based dynamometers, making them more reliable and effective for industrial and automotive applications.

3 Methodology

This section provides a detailed description of the materials and software used in the research. The materials refer to the physical components or resources essential for the study. Additionally, the software includes the programs and tools employed for data processing and analysis.

3.1 Calculation analysis

In this section, manual calculations are carried out using mathematical models of both first and second order and the results are then entered into a plant for each series.

3.1.1 Order 1

General form of first order equation

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

Known parameter is

Rated Torque : 0,89

Current : 2,4 A

K :0,371

So the order 1 is

$$G(s) = \frac{0.371}{0.89s + 0.371} \tag{2}$$

3.1.2 Order 2

The equation form of the second order transfer function is:

$$G(s) = \frac{\omega_n^2}{s^2 + 2\varsigma\omega_n S + \omega_n^2} \tag{3}$$

Known parameter is

Rated Torque : 0,89

Current : 2,4 A

K : 0,371

Damping ratio : 0,037

ω_n : $314\ rad/s$

So the order 2 is

$$G(s) = \frac{98.596}{s^2 + 23.24S + 98.596} \tag{4}$$

3.2 Matlab Simulation

To comprehensively evaluate the performance and stability of the system, a simulation is conducted using MATLAB software. This simulation plays a critical role in validating whether the results obtained from theoretical models align with both the mathematical plant model and the corresponding circuit configurations employed in the experiment [11]. By integrating computed parameters for first-order and second-order systems, the study ensures that the simulation accurately represents real-world system dynamics within the MATLAB environment [12, 13]. These parameters are derived from a combination of theoretical calculations and empirical data extracted from the DC motor datasheet, ensuring a precise model representation.

This simulation approach enables a thorough analysis of system behavior, allowing for an in-depth assessment of transient and steady-state responses. Additionally, it provides insights into the optimization of control performance using the Linear Quadratic Regulator (LQR) and Linear Quadratic Tracking (LQT) methods [14]. The results obtained from these simulations serve as a crucial benchmark in evaluating the effectiveness of the control strategy. By minimizing errors, enhancing system stability, and improving overall motor response characteristics, the study contributes to the development of more efficient and reliable control systems for DC motors and related applications.

3.2.1 *Circuit without noise*

Here is a series of various types of signals with different shapes and models but without noise. Figure 2 depicts the SISO system in MATLAB, which plays a crucial role in validating the system's performance and stability. This simulation ensures an accurate representation of real-world dynamics, allowing for the optimization of control performance.

As depicted in Figure 3, the system consists of a Single Input Single Output (SISO) circuit, where each input is connected to a distinct plant, resulting in unique outputs displayed on the scope. This setup allows for precise monitoring and evaluation of how different inputs influence the system's response. By analyzing

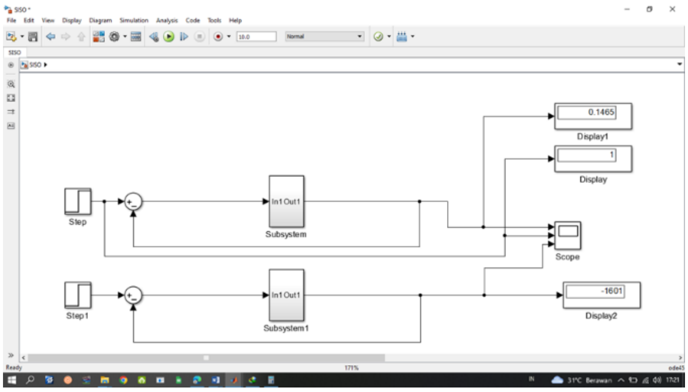

Figure 2. SISO system in matlab.

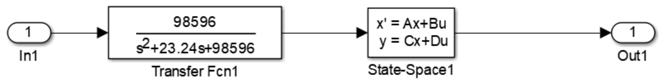

Figure 3. SISO system.

these outputs, the performance and characteristics of each plant can be assessed, providing valuable insights into the system's behavior under varying conditions.

3.2.2 *Circuit With noise*

Figure 4 illustrates the SISO system in MATLAB with noise, showcasing the impact of unwanted interference on the system's output. This noise can cause fluctuations and signal distortion, highlighting the importance of mitigating such disturbances to maintain the reliability and stability of the control system.

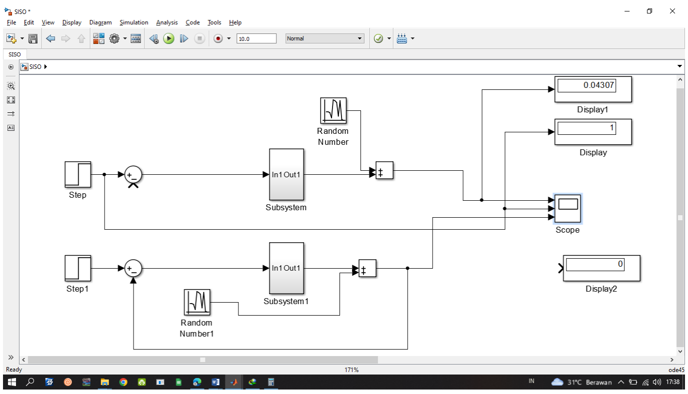

Figure 4. SISO system in matlab with noise.

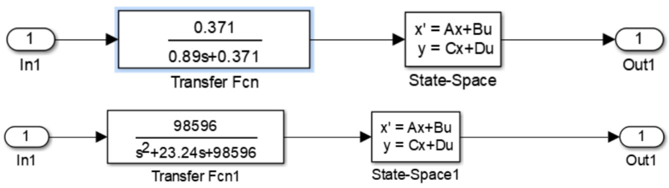

Figure 5. SISO system with noise.

As illustrated in Figure 5, the system features a Single

Input Single Output (SISO) circuit, where each input corresponds to a unique plant, resulting in distinct outputs displayed on the scope. This configuration enables precise monitoring of the system's response under different input conditions.

However, the circuit also incorporates noise—an inevitable signal present in any transmission system. This unwanted interference affects the quality of the received signal, potentially degrading data transmission accuracy. The presence of noise introduces fluctuations in the system's output, which can lead to performance variations and signal distortion. Understanding and mitigating the impact of noise is crucial for ensuring the reliability and stability of the control system, particularly in applications that require high precision and minimal signal disruption.

3.3 Linear Quadratic Regulator

The Linear Quadratic Regulator (LQR) is an optimal control strategy designed for systems represented in state-space form. LQR shares a structural similarity with pole placement control, as both methods utilize full-state feedback [15, 16]. However, the fundamental difference between LQR and pole placement lies in the way the feedback gain matrix (K) is determined.

In pole placement control, a significant drawback arises in the process of computing the gain matrix (K), which is responsible for shifting system poles to desired locations [17]. This limitation is particularly associated with the lack of consideration for control effort, which can lead to high actuator energy consumption when attempting to stabilize the system response.

To address this issue, the LQR control method provides an optimized solution by computing the gain matrix (K) through the selection of weighting matrices Q and R [18]. The Q matrix emphasizes system performance, while the R matrix accounts for control effort, ensuring a balanced trade-off between response accuracy and energy efficiency.

The advantage of this method is that it can provide optimal solutions to system control problems defined in state space [19, 20]. Because it is based on state space, the LQR method can well solve control problems in Single Input Single Output (SISO) systems. Below is the code program:

```
close all;
clc;
clear;

%LQR
J = 0.00063554;
b = 0.01;
K = 0.0272;
R = 5.7;
L = 0.0135;

%state space
A = [-R/L -K/L; K/J -b/J];
B = [1/L; 0];
C = [1 0];
D = 0;
Q = [0.00000001 0; 0 0.000000001];
R = 1;
[K,S,e] = lqr(A,B,Q,R);
Ac = A - B*K;
step (Ac,B,C,D,1)
```

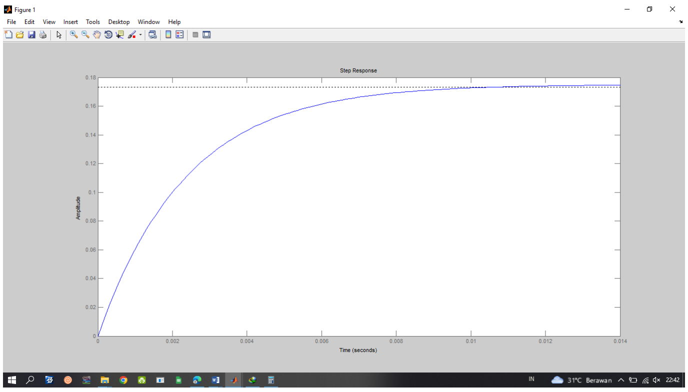

Figure 6. Graphic of LQR simulation.

Figure 6 illustrates the graphical output of the LQR simulation, showcasing the system's response under the Linear Quadratic Regulator control method. This simulation provides valuable insights into the system's behavior when optimized with LQR.

4 Experiments

After conducting an experiment with a simulation on the circuit, this sub-chapter discusses the results and a discussion related to the experiment with the method used.

4.1 Simulation without noise

Figure 7 presents the simulation results without noise, where the system exhibits distinct behaviors, including steady-state responses, stability, and oscillations. These observations provide crucial information about the system's dynamic characteristics and its performance under ideal conditions.

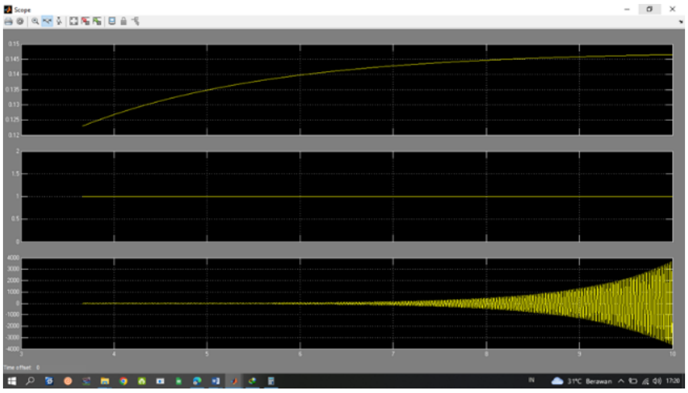

Figure 7. Result simulation without noise.

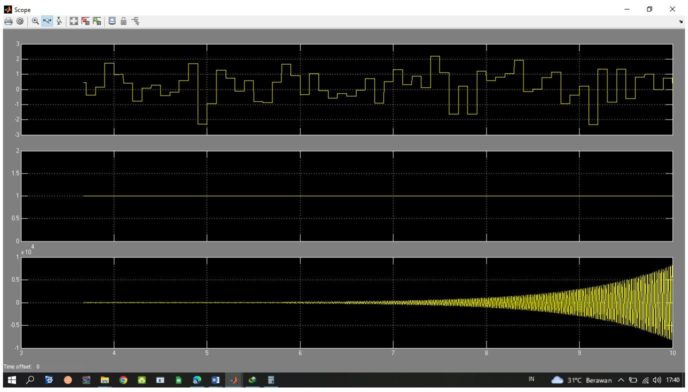

Figure 8. Result simulation with noise.

From the simulation results displayed in the scope window, the system exhibits distinct behaviors across different plots. The first plot demonstrates a gradual increase in signal value, starting from approximately 0 and rising to around 0.15 over time. This trend suggests a steady-state response, potentially indicating a system reaching equilibrium.

In contrast, the second plot remains nearly constant at a low value, with minimal variation. This stability suggests that the parameter being measured experiences little to no fluctuation, possibly indicating a well-regulated or non-responsive state in that aspect of the system.

The third plot, however, presents an oscillatory response with increasing amplitude, ranging from approximately -3000 to 4000. This pattern suggests a system experiencing growing oscillations, which may indicate resonance effects, inadequate damping, or instability in the control mechanism. The combination of these behaviors provides crucial insights into the system's dynamic characteristics, highlighting aspects such as progressive changes, stability, and oscillatory tendencies that must be analyzed for optimization and control improvements.

4.2 Simulation with noise

Figure 8 shows the simulation results with noise, highlighting the system's behavior under fluctuating signals. The presence of noise introduces oscillations and quantized responses, offering insight into the system's response to real-world disturbances and the need for noise mitigation strategies. From the simulation results displayed in the scope window, the system exhibits different dynamic behaviors across the three plots. The first plot shows a fluctuating signal with discrete variations, oscillating approximately between -0.1 and 0.1. This behavior suggests a non-continuous or quantized response, potentially caused by system noise, signal discretization, or control limitations affecting smooth signal transitions.

The second plot remains nearly constant at a low value, displaying minimal variation. This stability indicates that the corresponding parameter is either well-regulated or largely unaffected by external influences, contributing to a steady system response in that aspect.

The third plot reveals an oscillatory response with an increasing amplitude, beginning with small oscillations and progressively growing to around 0.5 in magnitude. This pattern suggests that the system undergoes an increasing oscillation effect, which may be attributed to resonance, feedback loop instability, or inadequate damping. Such behavior highlights the need for further analysis to determine whether the system requires additional stabilization measures to prevent excessive oscillations and ensure optimal performance.

5 Conclusion

From the comparative analysis of the two simulation results, it is evident that the application of the LQR control method significantly influences the stability and optimization of the DC motor in the SISO circuit. In the first simulation (without noise), the system demonstrates a smooth and stable response, with a gradual increase in the first parameter, minimal variation in the second parameter, and controlled oscillations in the third. This indicates that the LQR controller effectively optimizes performance, ensuring stability and reducing excessive fluctuations in the system response.

However, in the presence of noise (second simulation), the system performance is significantly affected. The first parameter exhibits irregular fluctuations, which indicate disturbances impacting signal consistency.

Despite this, the LQR control still manages to maintain overall system stability, as shown in the second and third plots, where the oscillatory response continues to increase in amplitude but remains structured.

Data Availability Statement

Data will be made available on request.

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Conflicts of Interest

The authors declare no conflicts of interest.

Ethical Approval and Consent to Participate

Not applicable.

References

[1] Dharmawan, A., Ashari, A., & Putra, A. E. (2018). Translation movement stability control of quad tiltrotor using LQR and LQG. *Int. J. Intell. Syst. Appl*, *10*(3), 10-21. [Crossref]

[2] ARROFIQ, M., NUGROHO, L. S., FAHMIZAL, F., & APRIASKAR, E. (2021). Sistem Kendali Eddy Current Brakes Dinamometer menggunakan Linear Quadratic Regulator (LQR). *ELKOMIKA: Jurnal Teknik Energi Elektrik, Teknik Telekomunikasi, & Teknik Elektronika*, *9*(4), 923. [Crossref]

[3] Nuriev, M., Kalyashina, A., Smirnov, Y., Gumerova, G., & Gadzhieva, G. (2024). The 5G revolution transforming connectivity and powering innovations. In E3S Web of Conferences (Vol. 515, p. 04008). EDP Sciences. [Crossref]

[4] Syahdana, O. P. (2022). *RANCANG BANGUN AUTOFEEDER DENGAN SISTEM NAVIGASI WAYPOINT DAN KENDALI KESTABILAN POSISI MENGGUNAKAN METODE FUZZY LOGIC* (Doctoral dissertation, Politeknik Perkapalan Negeri Surabaya).

[5] Agna, D. I. Y., Yuniza, S. I., & Nugraha, A. T. (2022). The Single-Phase Controlled Half Wave Rectifier with Single-Phase Generator Circuit Model to Establish Stable DC Voltage Converter Result. *International Journal of Advanced Electrical and Computer Engineering*, *3*(3).

[6] Yuniza, S. I., Agna, D. I. Y., & Nugraha, A. T. (2022). 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).

[7] Aziz, M. B. (2024). *High-speed Optical Interconnects in harsh environments* (Master's thesis, Chalmers Tekniska Hogskola (Sweden)).

[8] Aicardi, M., Bozzi, A., Graffione, S., Sacile, R., & Zero, E. (2024). Alternating direction method of multipliers in distributed control of a system of systems: Application to a quadruple tank plant. *Control Engineering Practice*, *149*, 105972. [Crossref]

[9] Shoukat, H., Khurshid, A. A., Daha, M. Y., Shahid, K., & Hadi, M. U. (2024, June). A Comparative Analysis of DNN and Conventional Signal Detection Techniques in SISO and MIMO Communication Systems. In *Telecom* (Vol. 5, No. 2, pp. 487-507). MDPI.[Crossref]

[10] Kaur, R., Bansal, B., Majhi, S., Jain, S., Huang, C., & Yuen, C. (2024). A survey on reconfigurable intelligent surface for physical layer security of next-generation wireless communications. *IEEE open journal of vehicular technology*, *5*, 172-199. [Crossref]

[11] Ma, T., Li, M. J., Fan, C. H., & Dong, H. S. (2024). A novel real-time dynamic performance evaluation and capacity configuration optimization method of generation-storage-load for integrated energy system. *Applied Energy*, *374*, 123896. [Crossref]

[12] Tarkhani, R., Krim, S., Mansouri, M., & Mimouni, M. F. (2025). Robust Current Sensor Fault-Tolerant Controller Using Third Order Super-Twisting Sliding Mode Observer and Controller for Induction Motors. *IEEE Access*. [Crossref]

[13] Saeed Kandezy, R., Jiang, J., & Wu, D. (2024). On SINDy Approach to Measure-Based Detection of Nonlinear Energy Flows in Power Grids with High Penetration Inverter-Based Renewables. *Energies*, *17*(3), 711. [Crossref]

[14] Nugraha, A. T., & Eviningsih, R. P. (2022). *Konsep Dasar Elektronika Daya*. Deepublish.

[15] Saleem, O., Rizwan, M., & Iqbal, J. (2023). Adaptive optimal control of under-actuated robotic systems using a self-regulating nonlinear weight-adjustment scheme: Formulation and experimental verification. *Plos one*, *18*(12), e0295153. [Crossref]

[16] Sengupta, I., Gupta, S., Deb, D., & Ozana, S. (2021). Dynamic stability of an electric monowheel system using LQG-based adaptive control. *Applied Sciences*, *11*(20), 9766. [Crossref]

[17] Kaushik, G., & Veerachary, M. (2024, December). Pole-placement Based Controller Design for High Gain Quadratic Boost Converter. In *2024 IEEE 11th Power India International Conference (PIICON)* (pp. 1-6). IEEE. [Crossref]

[18] Muhssin, M. T., Ajaweed, M. N., & Khalaf, S. K. (2023). Optimal control of underwater vehicle using LQR controller driven by new matrix decision control algorithm. *International Journal of Dynamics and Control*, *11*(6), 2911-2923. [Crossref]

[19] Zamfirache, I. A., Precup, R. E., Roman, R. C., & Petriu, E. M. (2022). Policy iteration reinforcement

learning-based control using a grey wolf optimizer algorithm. *Information Sciences, 585*, 162-175. [Crossref]

[20] Schwenzer, M., Ay, M., Bergs, T., & Abel, D. (2021). Review on model predictive control: An engineering perspective. *The International Journal of Advanced Manufacturing Technology, 117*(5), 1327-1349. [Crossref]

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