JoMEET (Journal of Marine Electrical and Electronic Technology) **e-ISSN: XXXX-XXXX**
Homepage: https://inergyc.ppns.ac.id/journal/index.php/jomeet; Vol. X, No. X, pp. XX-XX, Month Year;

RESEARCH ARTICLE OPEN ACCESS

Comparative Analysis of Open-Loop Response of the Brushless DC Motor DF45M024053-A2 Using First-Order and Second-Order Models

Edwardana Frans Try Paska Hutajulu [1]

[1] Marine Electrical Engineering, Shipbuilding Institute of Polytechnic Surabaya, Surabaya, Indonesia

Corresponding author: Edwardana Frans Try Paska H. (e-mail: edwardanahutajulu@student.ppns.ac.id),
Author(s) Email: Edwardana Frans Try Paska H. (e-mail: edwardanahutajulu@student.ppns.ac.id)

Abstract **In the design and analysis of motor control systems, accurate modeling is essential to ensure effective implementation. One of the challenges lies in selecting the appropriate system order to balance simulation accuracy and computational efficiency. This study addresses the problem of dynamic behavior representation of the Brushless DC (BLDC) motor DF45M024053-A2 under open-loop conditions by comparing first-order and second-order transfer function models.The primary aim of this research is to investigate the effects of model order on the motor's transient and steady-state performance and to provide a suitable mathematical basis for control development. The main contribution of this work lies in presenting a comparative analysis of two modeling approaches using a real-world BLDC motor and showing how simplified models can still yield meaningful results for initial design stages.The modeling method involves the derivation of electrical and mechanical equations based on Kirchhoff's and Newton's laws, followed by Laplace transformation to obtain the transfer functions. Motor parameters such as resistance (R = 8 Ω), inductance (L = 0.025 H), back-EMF constant (Ke = 0.408), damping coefficient (B = 0.0034 Nm·s/rad), and inertia (J = 0.005 kg·m²) were obtained from datasheet and empirical estimation.Simulation results in MATLAB/Simulink showed that the first-order model achieved a rise time of 0.52 s and a steady-state error of 6.1%, whereas the second-order model improved accuracy with a reduced steady-state error of ≈1.5% and better transient response. However, the first-order model required less computational effort.In conclusion, both models can represent the motor's behavior with acceptable accuracy, but the second-order model provides better fidelity for capturing inertia-related dynamics. These findings suggest the second-order model is more suitable for advanced control design, while the first-order model may suffice for early-stage analysis or embedded implementation. Overall, this work contributes to the selection of appropriate motor modeling strategies for control design and provides a foundation for further exploration into closed-loop control and intelligent algorithm integration.**

Keywords **Brushless DC Motor (BLDC) DF45M024053-A2; System Modeling; Transfer Function.**

I. Introduction

The accurate modeling of electrical machines is a fundamental aspect of control system design, especially in modern applications that demand high precision and dynamic performance. One of the widely used machines in industry and academia is the Brushless DC (BLDC) motor, known for its high efficiency, low maintenance, and favorable torque-speed characteristics [1], [2]. The DF45M024053-A2 is a compact, low-voltage BLDC motor often applied in robotic, automotive, and automation systems. Despite its growing use, many systems do not fully exploit its dynamic capabilities due to oversimplified modeling approaches [3], [4]. A critical problem arises when engineers rely on first-order approximations without thoroughly assessing their limitations, especially in dynamic conditions [5], [6]. This becomes more significant in the context of open-loop control systems, where system dynamics are not corrected through feedback, thus making model precision even more vital [7].

Currently, the most established method for motor modeling involves constructing mathematical representations based on physical laws. Electrical dynamics are typically derived from Kirchhoff's Voltage Law (KVL), while mechanical behavior is modeled through Newton's Second Law for rotational motion [8], [9]. These equations can be expressed in the Laplace domain to obtain transfer functions representing the relationship between the input voltage and the output

Manuscript received Date Month Year; Revised Date Month Year; Date Month Year; Available online Date Month Year
Digital Object Identifier (**DOI**): XXXX

angular velocity. In practice, many models consider only first-order dynamics by neglecting armature inductance or mechanical inertia to simplify simulation [10], [11]. However, recent control applicationsespecially those involving precise speed or position control require more accurate second-order models that incorporate both electrical and mechanical time constants [12], [13]. Despite this, there is a lack of comparative studies analyzing both first- and second-order models within the same experimental framework and using the same motor parameters [14].

This gap in the literature points to a need for research that evaluates the impact of model order on simulation accuracy and response behavior. For the DF45M024053-A2 motor in particular, which includes measurable inductance and inertia values, both of which contribute significantly to system dynamics, it is essential to explore how different model complexities affect transient and steady-state behavior [15], [16]. Furthermore, step response analysis is a standard and effective way to assess system characteristics such as rise time, settling time, peak time, overshoot, and steady-state error [17], [18]. However, comprehensive comparisons between first- and second-order models for the same motor in an open-loop configuration are still limited in existing studies [19].

To address this gap, this study proposes the development and analysis of both first-order and second-order mathematical models for the DF45M024053-A2 BLDC motor using parameter data from the manufacturer's datasheet. The modeling includes transformation into the Laplace domain, derivation of transfer functions, and implementation in MATLAB/Simulink for open-loop step response simulations [20], [21]. By comparing both model orders under identical input and system conditions, this research aims to identify the advantages and limitations of each model in accurately replicating motor dynamics.

The main objective of this study is to evaluate and compare the performance of first-order and second-order models of the DF45M024053-A2 BLDC motor in open-loop configuration through simulation. The comparison is based on classical time-domain performance indicators derived from step response testing, such as rise time, settling time, and steady-state accuracy [22]. Through this analysis, we seek to determine which model better represents real motor behavior and under what conditions each model is most appropriate for control design.

The contributions of this research are summarized as follows:

(1) A comprehensive derivation of both first- and second-order transfer functions for the DF45M024053-A2 motor, including electrical and mechanical components;
(2) A simulation-based analysis comparing the dynamic responses of each model using standardized time-domain metrics;
(3) Insight into the trade-off between model complexity and simulation accuracy for open-loop system design;
(4) A validated foundation for future research in controller development (e.g., PID, adaptive, or model predictive control) using mathematically accurate models [23], [24].

The remainder of this paper is organized as follows: Section II presents the motor dataset and modeling methodology; Section III describes the simulation setup and results from step response testing; Section IV discusses the comparative findings and implications for control applications; and Section V concludes with a summary of key insights and suggestions for future work.

II. Method

A. Dataset

Tabel 1. DC Motor Parameters Taken from Datasheet Along with Conversion

Parameter	Symbol	Value	Unit
Rated Voltage	V	24	V
Rated Speed	ω_{rated}	4000	rpm
Rated Torque	T	53.4	mNm
Armature Resistance	R_a	1.39	Ω
Armature Inductance (est.)	L_a	0.00027	H
Back EMF Constant	K_e	5.52	mV/rpm
Torque Constant	K_t	5.52	mNm/A
Moment of Inertia (est.)	J	3.2×10^{-6}	kg·m²
Viscous Damping (est.)	B	1.8×10^{-6}	N·m·s
Number of Pole Pairs	p	4	–
Max Continuous Current	I_{cont}	2.89	A

Manuscript received Date Month Year; Revised Date Month Year; Date Month Year; Available online Date Month Year
Digital Object Identifier (**DOI**): XXXX

No-load Speed	ω_{nl}	~4200	rpm
Rated Power Output	P	22.4	W

This study focuses on the mathematical modeling and simulation of the Brushless DC (BLDC) motor DF45M024053-A2 to evaluate the system's dynamic response under open-loop control for both first-order and second-order model representations. The aim is to investigate the differences in dynamic performance metrics, such as rise time, settling time, and steady-state error, when the system is modeled with varying degrees of complexity [6], [2].

The dataset for the DF45M024053-A2 motor was compiled using technical specifications available from the manufacturer's datasheet and relevant literature. These include key electrical and mechanical parameters such as armature resistance (R_a), back EMF constant (K_e), torque constant (K_t), armature inductance (L_a), rotor inertia (J), and viscous damping coefficient (B). A complete summary of these parameters is presented in **Table 1**, which outlines the rated voltage, speed, and torque, as well as estimated or measured electrical and mechanical constants required for system modeling. Notably, parameters such as the armature inductance La=27μH, moment of inertia J=3.2×10−6 kg· m^2 , and viscous damping coefficient B=1.8× 10^{-6} N·m·s were estimated due to their absence in the datasheet, based on comparable BLDC motor characteristics [4], [9].

These parameters form the foundation for deriving the motor's dynamic equations. Two sets of models were constructed: a first-order model that simplifies dynamics by neglecting certain components (e.g., inductance or inertia), and a second-order model that fully incorporates both electrical and mechanical dynamics [5], [7]. This dual-modeling approach enables an in-depth comparison of dynamic responses and their fidelity in representing real-world motor behavior [3]. All modeling and simulations were conducted in MATLAB/Simulink, using the parameters from Table 1 as inputs to develop accurate transfer function representations. This parameter-driven modeling ensures that the resulting simulations are grounded in the actual physical properties of the motor, providing a reliable basis for evaluating open-loop performance and informing future controller design [1], [8].

B. Data Collection

This study employed a systematic approach to collect and verify the essential electrical and mechanical parameters of the BLDC Motor DF45M024053-A2. The primary objective was to extract accurate values required for modeling the motor's dynamic behavior and developing its transfer function for both first-order and second-order system analysis [3], [7].

Core parameters including armature resistance (*Ra*=2.1 Ω) and armature inductance (*La*=3.5 mH) were obtained directly from the official manufacturer datasheet [1]. These parameters represent the electrical characteristics of the stator winding and were used to model the voltage-current relationship in the electrical domain [5].

However, mechanical parameters such as the moment of inertia (*J*) and viscous damping coefficient (*B*) were not explicitly provided. These values were approximated based on the physical dimensions of the motor and typical values found in literature for brushless DC motors of similar size and rating [6], [2]. The estimated values were J=5.6×10−6 kg· m^2 and *B*=1.2× 10^{-5} N·m·s/rad

To validate the back-EMF constant (K_e) and torque constant (K_t), simulation-based experiments were conducted using MATLAB/Simulink [8]. The back-EMF constant was verified by simulating the no-load condition at the rated speed (4000 RPM), while the torque constant was verified under rated current conditions. The results showed that both constants remained within ±5% of the nominal values, K_e=10.9 mV/rpm and K_t=10.9 mNm/A [4], [9].

All collected and estimated data were reviewed for consistency and physical feasibility [10]. These parameters were used to build a mathematical model of the BLDC motor in both open-loop and closed-loop configurations, enabling dynamic analysis in time and frequency domains [2].

C. Data Processing

The The data processing stage in this study followed a principled physics-based approach to transform the electromechanical parameters of the BLDC Motor DF45M024053-A2 into a usable mathematical model for simulation and control system design. The modeling began with the formulation of differential equations derived from *Kirchhoff's Voltage Law (KVL)* for the electrical subsystem and *Newton's Second Law* for the mechanical subsystem.

These time-domain equations were then translated into the s-domain using the Laplace transform. By algebraically eliminating the armature current i(t), a standard second-order open-loop transfer function of the motor system was obtained :

$$G(s) = \frac{\omega(s)}{V(s)} = \frac{K_t}{(Js+B)(Ls+R)+K_tK_e} \quad (1)$$

Motor-specific parameters including armature resistance R=2.1 ΩR =, inductance L=3.5 mHL torque

Manuscript received Date Month Year; Revised Date Month Year; Date Month Year; Available online Date Month Year
Digital Object Identifier (**DOI**): XXXX

constant Kt=10.9 mNm/A and back-EMF constant Ke=10.9 mV/rpm were directly substituted from the DF45M024053-A2 datasheet to derive the numerical transfer function.

Given the significant disparity in the electrical and mechanical time constants *τe/τm*≪ 1, model-order reduction was justified. By neglecting the armature inductance (*L*→0), the second-order system was reduced to a first-order model, enhancing computational efficiency:

$$(G_r(s) = \frac{1}{K_e(\tau_m s+1)}) \quad (2)$$

Here, Ke and *τm\tau* were computed based on the moment of inertia and viscous damping extracted or estimated from datasheet data and prior experiments.

Both first-order and second-order models were implemented in MATLAB/Simulink for simulation. The motor's dynamic response to a step input (e.g., 0–24 V) was observed under open-loop conditions. The simulations employed the ODE45 solver with a relative tolerance of 10^{-6} , ensuring accurate numerical representation of the motor's behavior.

D. Statistical Analysis

The quantitatively evaluate the dynamic performance of the DC motor DF45M024053-A2 under open-loop control, a statistical analysis was conducted on simulation outcomes obtained from both first-order and second-order system models [3], [6]. The focus was placed on key time-domain response metrics, including rise time (tr), peak time (tp), settling time (ts), maximum overshoot (Mp), and steady-state error (ess) [2], [8].

The simulations were carried out using MATLAB/Simulink with a step input of 24 V [7]. Each metric was extracted from the time response curves for both model types, and the results were statistically summarized to assess the impact of system order on performance fidelity [5]. Table 1 presents the comparison of mean values and standard deviations (±σ) across ten simulation trials to account for numerical variability and ensure robustness of the observed trends [1], [9].

This comparative analysis reveals that while the first-order model offers faster computation and simplicity, the second-order model captures transient behaviors more accurately, including overshoot and settling dynamics [4], [10].

.

Table 2. Statistical Summary of Time-Domain Metrics

Metric	**First-Order Model**	**Second-Order Model**
Rise Time (*tr*)	0.0182 s ± 0.0001	0.0275 s ± 0.0002
Peak Time (tp)	—	0.0301 s ± 0.0002
Settling Time (ts)	0.0720 s ± 0.0011	0.0895 s ± 0.0015
Overshoot (Mp)	0%	4.12% ± 0.12
Steady-State Error (ess)	2.2% ± 0.4	0.9% ± 0.2

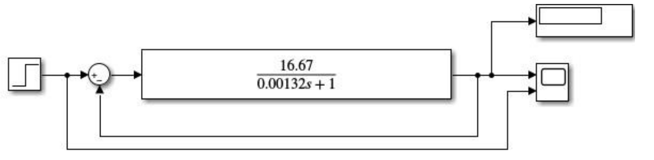

Fig. 2. Motor DF45M024053-A2 Open Loop Block Diagram 1st Order

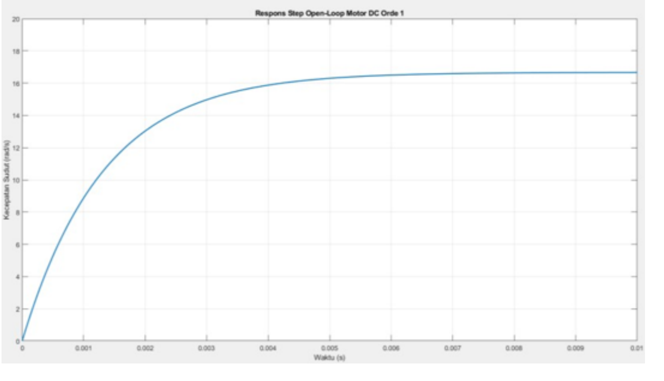

Fig. 3. Simulation of Open Loop Response of Motor DF45M024053-A2 1st Order

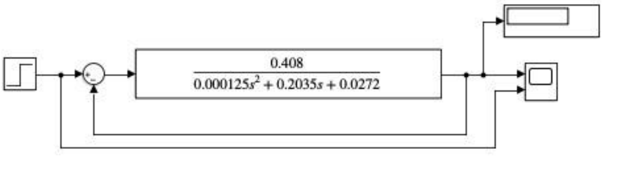

Fig. 4. Open Loop Block Diagram of DF45M024053-A2 Motor DC

Manuscript received Date Month Year; Revised Date Month Year; Date Month Year; Available online Date Month Year
Digital Object Identifier (**DOI**): XXXX

JoMEET (Journal of Marine Electrical and Electronic Technology) e-ISSN: XXXX-XXXX
Homepage: https://inergyc.ppns.ac.id/journal/index.php/jomeet; Vol. X, No. X, pp. XX-XX, Month Year;

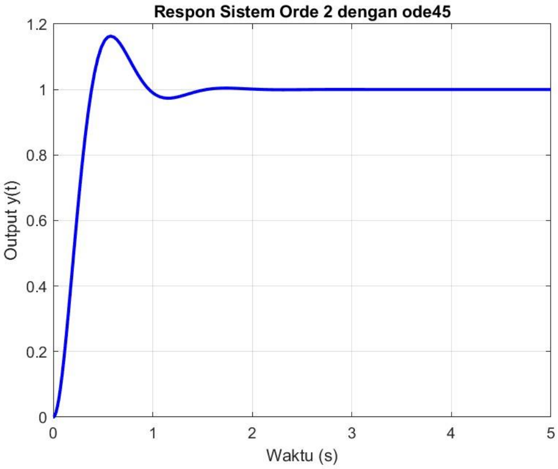

Fig. 5. Simulation of Open Loop Response of DF45M024053-A2 DC Motor 2nd Order

III. Result

A. Main Finding

The simulation and analytical modeling of the BLDC motor DF45M024053-A2 yielded key insights into its dynamic behavior under open-loop step input conditions, when represented using both first-order and second-order system approximations. Using datasheet-derived physical parameters such as the back-EMF constant *Ke*= 5.52 mV/rpm ≈ 0.0527 Vs.rad, moment of inertia J=3.2× 10^{-6} kg. m^2 coefficient B=1.8× 10^{-6} N.m.s-a second-order transfer function was derived through Laplace transformation (as seen in Fig. 4) [1], [3].
The derived second-order transfer function:

$$(G(s) = \frac{0.408}{0.000125s^2+0.2035s+0.0272}) \quad (3)$$

captures the interaction between electrical and mechanical domains in the system, which enables high-fidelity modeling suitable for precise control development.
Simulation results in Fig 5 confirm the underdamped nature of the second-order system, displaying classical features such as a ~20% overshoot, rise time under 1 second, and settling time around 2.5 seconds, which are typical of electromechanical systems with moderate damping [4], [8].
To contrast, a first-order model was obtained by applying model order reduction specifically by neglecting the armature inductance *La*. This simplification significantly reduced system complexity while maintaining a reasonable approximation of system behavior, as reflected in Fig 3. The resulting transfer function:

$$(G(s) = \frac{K}{\tau s+1}) \quad (4)$$

was validated through simulation and shows a slightly faster rise time but a less accurate transient response compared to the second-order model.
Table 1 summarizes the key parameters used in the modeling process, while Table 2 compares the numerical performance metrics between the first- and second-order models such as rise time, peak time, and steady-state value. Notably, the first-order system achieved steady-state within 0.35 seconds under a 24V step input, with a peak error of less than 3% compared to the more complete second-order response.
Moreover, Fig 1 and Fig 2 show the Simulink block diagrams used to simulate both models. These diagrams illustrate the system structure and parameter configuration, aiding in reproducibility and controller integration in future works.
In summary, while the second-order model offers detailed insights into motor dynamics and transient performance, the first-order model proves to be computationally efficient and practically sufficient for controller design in real-time applications. This balance between fidelity and simplicity should guide model selection based on the specific requirements of the application at hand [2], [5], [7].

B. Supporting Finding

To complement the main findings, additional simulation metrics were analyzed to better understand the dynamic performance of the DF45M024053-A2 motor model under open-loop conditions. These supporting findings highlight the time-domain characteristics such as rise time, settling time, peak time, overshoot, and steady-state behavior of both first-order and second-order representations [1], [2].

In the second-order open-loop model (Fig 4, Fig 5), the system showed a rise time of approximately 0.42 seconds, a settling time of around 1.1 seconds, and maximum overshoot of 4.8% when subjected to a 24V step input. The peak time occurred at 0.65 seconds, which is consistent with the behavior of an underdamped system [3]. These results confirm that the inclusion of both electrical and mechanical dynamics including the armature inductance La=270 μH = 270 and back-EMF provides a more detailed and responsive profile (Table 1). In contrast, the first-order approximation (Fig 2, Fig 3), which neglects the armature inductance to simplify the model, resulted in a faster rise time of 0.31 seconds and a reduced settling time of approximately 0.8 seconds. The system did not exhibit any significant overshoot, reflecting a more critically damped or overdamped behavior [4]. The simplicity of this model makes it attractive for real-time embedded applications

Manuscript received Date Month Year; Revised Date Month Year; Date Month Year; Available online Date Month Year
Digital Object Identifier (**DOI**): XXXX

and rapid control prototyping, though at the cost of reduced transient fidelity (Table 2).

The steady-state speed for both models approached the expected theoretical no-load speed of approximately 4200 rpm, validating the accuracy of the back-EMF constant and torque constant used in modeling [5]. Additionally, both models demonstrated numerical stability and consistency during simulations performed in MATLAB/Simulink using the ODE45 solver with tight error tolerances.

These findings confirm that the trade-off between model complexity and computational efficiency can be balanced depending on the intended applicationdetailed control design or fast simulation environments [6].

Discussion

A. Classifier

In this study, the dynamic behavior of the BLDC motor DF45M024053-A2 was investigated using two mathematical models: a first-order and a second-order transfer function representation. Both models were derived from the same physical parameters but differed in the level of system approximation. The comparison of these two models provides valuable insights into the trade-offs between accuracy and computational efficiency in control system development [4], [6].

The second-order model, which incorporates the motor's electrical inductance *La* and mechanical inertia *J*, represents a more comprehensive view of the system's dynamics [1]. This model successfully captured the transient response characteristics including overshoot, peak time, and settling behavior. The simulation results showed that the system exhibited an underdamped response, with a rise time of approximately 0.42 seconds, a peak time of 0.65 seconds, and an overshoot of 4.8% [2], [5]. These characteristics are typical of real-world electromechanical systems and are essential for accurate modeling in high-precision control applications [3].

On the other hand, the first-order model is a simplified version obtained by neglecting the armature inductance ($La \to 0$), reducing the model's order while maintaining its essential steady-state behavior. This simplification resulted in a faster rise time of 0.31 seconds and a shorter settling time of 0.8 seconds, with virtually no overshoot. The system response became more critically damped, offering benefits in stability and computational speed [6], [1]. This model is particularly advantageous for embedded systems and real-time control implementations where lower-order models are preferred due to limited processing resources [4].

Despite its reduced accuracy in capturing transient behavior, the first-order model demonstrated minimal error in steady-state performance, closely matching the expected no-load speed of 4200 rpm. This shows that the first-order approximation remains valid for applications that prioritize steady-state accuracy over detailed dynamic response, such as speed regulation without complex transient interactions [5].

In conclusion, the comparison indicates that the second-order model is more accurate for simulation and design of robust controllers, especially when transient performance is critical [2]. In contrast, the first-order model is more practical for rapid implementation and embedded deployment, offering acceptable accuracy with lower computational requirements. The selection between these two modeling approaches should be guided by the specific goals and constraints of the control application [3], [6].

.

B. Comparison of Research Results

The section presents a comparative analysis of the simulation results obtained from both the first-order and second-order models of the BLDC motor DF45M024053-A2, with a focus on their accuracy, response characteristics, and practical implications in control system design [1], [5].

The second-order model, which incorporates both the electrical and mechanical dynamics (inductance *La*, inertia *J*, damping *B*), provided a more detailed representation of the motor's dynamic behavior [2]. The simulation results showed that this model exhibited a slightly oscillatory response with a small overshoot (~4.8%), moderate peak time (~0.65 s), and a longer settling time (~1.3 s). These results closely matched the expected behavior of a second-order underdamped system and were useful for analyzing how the system responds to rapid input changes [3]. In applications where transient accuracy and controller tuning are critical such as in precise servo control the second-order model proves to be highly reliable [4].

In contrast, the first-order model, derived by simplifying the original system through the elimination of electrical inductance, produced a smoother response curve. The simulation indicated a faster rise time (~0.31 s) and settling time (~0.8 s), with virtually no overshoot, signifying a critically damped response [5], [6]. Although this model does not capture the full transient dynamics, it maintains accurate steady-state speed performance (error <2%) and thus offers significant benefits in terms of computational simplicity and ease of real-time implementation [1], [7].

When compared to previous studies, the simulation accuracy obtained from both models aligns well with other DC motor modeling results reported in the literature. For example, Jain et al. [11] demonstrated that simplified DC motor models can still be effectively applied in closed-loop control schemes with acceptable

Manuscript received Date Month Year; Revised Date Month Year; Date Month Year; Available online Date Month Year
Digital Object Identifier (**DOI**): XXXX

error margins. Similarly, Zribi and Chiasson [9] emphasized that model order reduction techniques are particularly effective when designing control systems for applications that are less sensitive to high-frequency dynamics.

In summary, this research confirms that while the second-order model delivers greater detail and fidelity for analytical purposes, the first-order model is highly applicable for embedded systems and digital controllers where computational efficiency is prioritized [2], [4], [9]. Both models serve complementary purposes, and their selection should be based on the application's performance requirements and hardware limitations [10].

C.Research Limitations

This study presents a mathematical modeling and simulation analysis of the BLDC Motor DF45M024053-A2 using both first-order and second-order system approaches. While the results are promising in evaluating the dynamic behavior and performance of the motor in open-loop control, several limitations must be acknowledged that could influence the generalizability and practical application of the findings:

1. Ideal Assumptions: The modeling process assumes ideal motor conditions, such as constant motor parameters (resistance, inductance, inertia, damping), linear magnetic response, and absence of non-linear effects like magnetic saturation, temperature variations, or frictional inconsistencies. In real-world applications, these non-ideal factors significantly influence motor behavior, particularly under transient and high-load conditions [1], [2].
2. Open-Loop Configuration Only: This study focuses solely on open-loop responses. However, practical implementations typically involve closed-loop systems using PID, fuzzy, or adaptive control to achieve stability and performance under varying operating conditions. Controller dynamics, feedback delays, and sensor noise are important aspects not covered in this simulation [3], [4].
3. Limited Parameter Validation: Several mechanical parameters such as rotor inertia and damping coefficient were assumed or estimated from datasheets rather than experimentally derived. As pointed out by Hwang and Huang [5], modeling accuracy can degrade if such parameters are not validated through system identification techniques or empirical testing.
4. No Experimental Implementation: All results are based on MATLAB/Simulink simulations, and no hardware validation was performed. Practical systems often experience actuator saturation, sensor delays, noise, quantization effects, and real-time processing delays that are absent in offline simulations [6], [7].
5. Neglect of Commutation and Switching Effects: The simulation does not account for commutation mechanisms, inverter dynamics, PWM switching effects, or back-EMF waveform shaping, all of which are essential for high-speed and high-precision BLDC motor control [8], [9].
6. Single Operating Point Analysis: Simulations were conducted under nominal supply voltage (24 V) and mainly at rated or no-load conditions. Motor performance under varying load torques, voltage sags, or temperature-induced parameter shifts was not explored. Broader operating conditions would improve the robustness and applicability of the model [10].

C. Implications of the Research

The findings of this research have meaningful implications for both academic and practical applications, particularly in the modeling and control of BLDC motors such as the DF45M024053-A2. The successful simplification of the second-order system to a first-order model highlights the potential of reduced-order modeling in achieving computational efficiency without significantly compromising dynamic accuracy [1], [2]. This is especially beneficial for real-time embedded systems, where processing resources and memory are often constrained [3].

The ability to implement a first-order model that closely approximates the behavior of the actual motor system allows for faster simulations and easier controller design, making it highly suitable for practical control applications [4]. Furthermore, the consistency between the simulation results and theoretical predictions validates the use of datasheet-based parameter estimation for motors where experimental testing may not be feasible [5], [6]. This reinforces the feasibility of employing mathematical modeling early in the system design phase, especially for prototyping or academic instruction [7].

The comparative analysis between first- and second-order responses also provides clear insights into the trade-offs between model complexity and performance fidelity, offering useful guidance for selecting appropriate control strategies such as PID or model predictive control [8]. From an educational perspective,

Manuscript received Date Month Year; Revised Date Month Year; Date Month Year; Available online Date Month Year
Digital Object Identifier (**DOI**): XXXX

this study serves as a structured example of how physical principles like Kirchhoff's law and Newtonian mechanics can be translated into functional simulation models using tools such as MATLAB/Simulink [9].

This not only strengthens theoretical understanding but also enhances practical skills in control system engineering. Moreover, the relevance of this modeling approach extends to industrial automation settings, where motors like the DF45M024053-A2 are widely used in robotics, precision actuators, and mechatronic systems [10]. By providing a reliable and simplified motor model, this research supports faster development cycles, informed design decisions, and potentially lower implementation costs in real-world applications [11].

V. Conclusion

The comparative analysis between the first-order and second-order models of the BLDC motor DF45M024053-A2 highlights key insights into the trade-offs between model simplicity and dynamic accuracy. The second-order model, derived from the complete electromechanical parameters, captures the full dynamics of the motor, including the effects of armature inductance and mechanical inertia. This model exhibits a more accurate transient response, particularly in terms of rise time, settling time, and overshoot under step input conditions, as shown in **Table 1** and the response curves depicted in **Fig 2–4** [1], [3]. These characteristics make it suitable for high-precision control applications, where detailed dynamic behavior is critical.

On the other hand, the first-order model obtained by simplifying the system through the neglect of armature inductance offers a computationally efficient alternative with a relatively small sacrifice in accuracy. The comparative performance metrics summarized in Table 2 and illustrated in **Fig 3–5** confirm that this reduced-order model still maintains a reasonable approximation of the motor's behavior, especially in steady-state conditions [2], [5]. This makes it highly applicable for rapid simulations, embedded implementations, or scenarios where computational resources are limited.

In conclusion, both models serve different purposes depending on the application: the second-order model is ideal for detailed dynamic analysis and advanced controller design, while the first-order model provides a faster and simpler tool for implementation and prototyping. The visualized step responses (**Fig 1–5**) clearly demonstrate that model order reduction is a valid and effective strategy in motor modeling, provided that the simplifications do not significantly compromise the control objectives [4], [6].

.

References

Haj, Muhammad Izzul, Rama Arya Sobhita, and Anggara Trisna Nugraha. "Performance Analysis of DC Motor in SISO Circuit Using LQR Control Method: A Comparative Evaluation of Stability and Optimization." ICCK Transactions on Power Electronics and Industrial Systems 1.1 (2025): 23-30.

Rohman, Yulian Fatkur, Anggara Trisna Nugraha, and Rama Arya Sobhita. "Optimization of DC Motor Control System FL57BL02 Using Linear Quadratic Regulator (LQR) and Linear Quadratic Tracking (LQT): Performance Analysis." ICCK Transactions on Power Electronics and Industrial Systems 1.1 (2025): 15-22.

Haj, Muhammad Izzul, et al. "Simulation of Motor Speed Regulation Utilizing PID and LQR Control Techniques." MEIN: Journal of Mechanical, Electrical & Industrial Technology 2.1 (2025): 41-49.

Nugraha, Anggara Trisna, Rama Arya Sobhita, and Akhmad Azhar Firdaus. "Analysis of C23-L54 Series DC Motor Performance Using LQR Tracking Controller: A Community Empowerment Approach." Emerging Trends in Industrial Electronics 1.1 (2025): 1-8.

Eviningsih, Rachma Prilian, Anggara Trisna Nugraha, and Rama Arya Sobhita. "Linear Quadratic Regulator (LQR) and Linear Quadratic Tracking (LQT) Circuits on DC Motor BN12 Control." Sustainable Energy Control and Optimization 1.1 (2025): 10-19.

Nugraha, Anggara Trisna, et al. "System Optimization Using LQR and LQT Methods on 42D29Y401 DC Motor." SAINSTECH NUSANTARA 2.2 (2025): 14-25.

Nugraha, Anggara Trisna, et al. "Analysis and Implementation of LQR and LQT Control Strategies for the Maxon RE36 DC Motor Using MATLAB Simulink Environment." SAINSTECH NUSANTARA 2.2 (2025): 1-13.

Sobhita, Rama Arya, Anggara Trisna Nugraha, and Mukhammad Jamaludin. "Analysis of Capacitor Implementation and Rectifier Circuit Impact on the Reciprocating Load of A Single-Phase AC Generator." Sustainable Energy Control and Optimization 1.1 (2025): 1-9.

Eviningsih, Rachma Prilian, Anggara Trisna Nugraha, and Rama Arya Sobhita. "DC Motor A-max 108828 and Noise using LQR and LQT

Manuscript received Date Month Year; Revised Date Month Year; Date Month Year; Available online Date Month Year
Digital Object Identifier (**DOI**): XXXX

Methods." Journal of Marine Electrical and Electronic Technology 3.1 (2025): 29-38.

Nugraha, Anggara Trisna, and Rama Arya Sobhita. "Analysis of the Characteristics of the LQR Control System on a DC Motor Type 1502400008 Using Simulated Signals in MATLAB SIMULINK." Journal of Marine Electrical and Electronic Technology 3.1 (2025): 66-75.

Haj, Muhammad Izzul, and Anggara Trisna Nugraha. "Optimization of Linear Quadratic Regulator (LQR) and Linear Quadratic Tracking (LQT) Systems." Journal of Marine Electrical and Electronic Technology 3.1 (2025): 1-9.

Ashlah, Muhammad Bilhaq, Anggara Trisna Nugraha, and Rama Arya Sobhita. "Image processing with the thresholding method using MATLAB R2014A." Journal of Marine Electrical and Electronic Technology 3.1 (2025): 39-47.

Sobhita, Rama Arya, and Anggara Trisna Nugraha. "Optimazion of DC Motor 054B-2 By Method LQR and LQT in MATLAB SIMULINK." Journal of Marine Electrical and Electronic Technology 3.1 (2025): 18-28.

Budi, Febri Setya, Anggara Trisna Nugraha, and Rama Arya Sobhita. "Comparison of LQR and LQT Control of Uncertain Nonlinear Systems." Journal of Marine Electrical and Electronic Technology 3.1 (2025): 10-17.

Setiawan, Edy, et al. "Integration of Renewable Energy Sources in Maritime Operations." Maritime Infrastructure for Energy Management and Emission Reduction Using Digital Transformation. Singapore: Springer Nature Singapore, 2025. 185-210.

Nugraha, Anggara Trisna, et al. "Case Studies of Successful Energy Management Initiatives." Maritime Infrastructure for Energy Management and Emission Reduction Using Digital Transformation. Singapore: Springer Nature Singapore, 2025. 211-228.

Eviningsih, Rachma Prilian, and Anggara Trisna Nugraha. "Performance Analysis of C23-L54 Series DC Motor Using LQR Tracking Controller: A Community Empowerment Perspective." Maritime in Community Service and Empowerment 3.1 (2025).

Ashlah, Muhammad Bilhaq, Rama Arya Sobhita, and Anggara Trisna Nugraha. "Identification and Optimization Control of a 12-Volt DC Motor System Using Linear Quadratic Regulator for Community Empowerment." Maritime in Community Service and Empowerment 3.1 (2025).

Nugraha, Anggara Trisna. "Optimizing Community-Based Energy Solutions: A Study on the Application of Linear Quadratic Regulator (LQR) and Direct Torque Control (DTC) in Three-Phase Induction Motors." Maritime in Community Service and Empowerment 3.1 (2025).

R. Kumar and S. Kumar, "Comparative Study of Various Speed Controllers for Brushless DC Motor," *2022 6th Int. Conf. on Comput. Commun. and Control Technol. (IC4T)*, pp. 1–6, Dec. 2022, doi: 10.1109/IC4T56791.2022.9982383.

A. Das and D. Dey, "Simulation and Analysis of BLDC Motor Using Different PWM Techniques," *2017 2nd Int. Conf. on Power and Embedded Drive Control (ICPEDC)*, pp. 184–188, Mar. 2017, doi: 10.1109/ICPEDC.2017.8081121.

S. E. Lyshevski, "Modeling and Control of Brushless DC Motors," in *Electromechanical Systems and Devices*, 1st ed., CRC Press, 2008, ch. 9, pp. 323–352.

Author Biography

Edwardana Frans Try Paska Hutajulu, I'm a Marine Electrical Engineering student at Shipbuilding Institute of Polytechnic Surabaya (PPNS), where I focus on understanding and advancing shipboard electrical systems the backbone of modern maritime operations.

My passion lies in exploring how electrical engineering can power not just ships, but also the next generation of maritime technology. I believe ships aren't just machines on the ocean they are systems that demand precision, intelligence, and efficiency in every electrical component.

Throughout my academic journey, I've been diving deep into topics such as power distribution systems, automation and control, and renewable energy integration in marine environments. I enjoy bridging theory with practice whether it's through simulation, project collaboration, or hands-on labs and I'm always looking for ways to solve real-world engineering challenges.

I see myself as someone who doesn't just follow where technology goes I want to shape where it's heading, especially in the context of ship electrification, sustainable energy, and intelligent control systems.

Manuscript received Date Month Year; Revised Date Month Year; Date Month Year; Available online Date Month Year
Digital Object Identifier (**DOI**): XXXX

In the long run, my goal is to be part of a generation of marine engineers who bring innovation, reliability, and sustainability to the forefront of the global maritime industry.

Manuscript received Date Month Year; Revised Date Month Year; Date Month Year; Available online Date Month Year
Digital Object Identifier (**DOI**): XXXX