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PAPER *OPEN ACCESS*

Modeling and Simulation of Single-Phase DC and AC Motor Control Systems Using MATLAB/Simulink Based on First-Order and Second-Order Transfer Functions

Eggy Putra Pimansyah [1]
[1] **Student of the Marine Electrical Engineering Study Program, Surabaya State Polytechnic of Shipping , Surabaya, Indonesia**

ABSTRACT

Electric motor control systems, especially single-phase DC and AC motors, require accurate modeling and simulation approaches to understand the dynamic characteristics and design effective control systems. The main problem addressed in this study is how to model and analyze the dynamic response of the Brushless Silencer BN12HS-28AF-01 DC motor and the single-phase AC motor SIMTACH AC100M-08J30A, both in open-loop and closed-loop configurations, using MATLAB and Simulink software. The main objectives of this study are to develop mathematical models of both motors in the form of first-order and second-order transfer functions, then conduct numerical simulations to verify the stability and performance of the control system in various scenarios. The main contribution of this research lies in the integration of mathematical approaches, identification of actual parameters from datasheets, and the application of MATLAB/Simulink-based simulations to evaluate system performance in the time domain. The method used involves the preparation of transfer functions through Laplace transforms of electrical and mechanical differential models, followed by the implementation of speed control block diagram simulations using step response and system stability testing through time-domain analysis. Simulation results show that in open-loop systems, DC and AC motors tend to have faster rise times, but do not reach a stable steady state and are vulnerable to external disturbances. In contrast, the closed-loop configuration successfully improves transient characteristics and increases system stability. For DC motors, the second-order response shows better damping than the first-order. Single-phase AC motors exhibit more complex dynamics but can still be stabilized with appropriate control parameter settings. In conclusion, MATLAB and Simulink-based simulations are highly effective for validating motor mathematical models and evaluating control system performance. The results can serve as an important basis for developing motor control systems in industry, automation, and engineering education.

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CONTACT :

eggy.putra @student.ppns.ac.id

1. INTRODUCTION

Electric motors are one of the important components in mechanical drive systems that are widely used in various fields, such as industry, transportation, and automation. Among various types of electric motors, DC motors and single-phase AC motors are still the main choice for applications that require precise speed and torque control and relatively low implementation costs. However, the design of an optimal motor control system requires a deep understanding of the motor's dynamic characteristics through a structured mathematical approach and simulation-based approach. The main problem often faced is how to accurately model the relationship between the input (voltage) and output (speed or angular position) of the motor system and verify the performance of the control system through representative numerical simulations.

As technology develops, Current methods in electric motor modeling have involved the use of simulation software such as MATLAB and Simulink. These platforms enable engineers and researchers to build complex mathematical models, perform system response analysis, and design and test control systems in both open-loop and closed-loop modes. Motor modeling typically uses a transfer function approach derived from the Laplace transform of the differential equations of the electrical and mechanical

Main author: Eggy Putra Primansyah , eggy.putra @student.ppns.ac.id , Marine Electrical Engineering Study Program, Surabaya State Polytechnic of Shipping, Jl. Chemical Engineering, ITS Campus, Keputih, Sukolilo, Surabaya 60111, Indonesia.
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systems, which are then analyzed to evaluate stability, efficiency, and response time.

However, there is still a research gap in the documentation of modeling single-phase AC motors and DC motors simultaneously in one integrated study, especially comparing the simulation results of first-order and second-order transfer functions in two control system configurations (open-loop and closed-loop). In addition, it is still rare to find studies that explain the impact of motor physical parameters such as moment of inertia and torque constant on system characteristics explicitly in the form of simulation graphs and numerical explanations.

To fill this gap, this study proposes a method in the form of a mathematical modeling approach for the BN12HS-28AF-01 Brushless Silencer DC motor and the SIMTACH AC100M-08J30A single-phase AC motor. The process begins with the preparation of electrical and mechanical models, Laplace transformations into transfer functions, and simulation implementation using MATLAB and Simulink. Simulations are carried out for each first-order and second-order transfer function in open-loop and closed-loop configurations, with analysis of the transient response and steady-state response of the system.

The restatement of this research confirms that the main objective of the research is to analyze and compare the performance of single-phase DC and AC motor systems based on MATLAB simulations of first- and second-order mathematical models, and to evaluate the impact of control configurations on the stability and response speed of the system.

The four main contribution points* in this research are: Compilation of complete mathematical models of DC motors and single-phase AC motors based on actual parameters from component datasheets , Application of first-order and second-order modeling approaches in motor control system simulations using MATLAB and Simulink. , Comparative analysis of the performance of open-loop and closed-loop control systems on stability and response time , Provision of simulation data in the form of graphs, tables, and numerical explanations as references in designing motor control systems based on mathematical modeling.

The structure of this paper is as follows: Section II explains the theoretical basis and modeling methods for single-phase DC and AC motor systems. Section III presents MATLAB simulations of first- and second-order transfer functions and the system response results for each control configuration. Section IV presents MATLAB simulations of first- and second-order transfer functions and the system response results for each control configuration. discusses the analysis and interpretation of simulation results and a comparison of the performance of the two types of motors. Section V presents the conclusions of this study along with suggestions for further research.

2. RESEARCH METHODS

A. Dataset

Research This research uses a dataset based on numerical simulation results of two types of electric motors, namely the BN12HS-28AF-01 Brushless Silencer DC Motor and the SIMTACH AC100M-08J30A Single Phase AC Motor. The dataset is obtained from theoretical calculations based on the technical parameters listed in the datasheet of each motor, then processed in the form of a mathematical model for simulation purposes. The parameters used include terminal resistance (R), winding inductance (L), rotor moment of inertia (J), torque constant (Kt), and counter-motive force constant (Ke). All of these parameters are entered into the transfer function formula to obtain the first-order and second-order mathematical models of each motor.

The resulting model is used as the input basis in MATLAB/Simulink software, resulting in a simulation dataset in the form of a time response to a step function input in open-loop and closed-loop systems. The simulation dataset includes transient and steady-state values, such as rise time, settling time, overshoot, and steady-state error, which are then used for control system performance analysis.

This study uses mathematical models of two types of electric motors, namely DC motor Brushless Silencer BN12HS-28AF-01 , and Single-phase AC Motor SIMTACH AC100M-08J30A

The technical parameters of both motors were obtained from their respective datasheets, which were then used to generate first- and second-order transfer functions as the basis for the simulation. The key parameters used include:

Table 1. Important parameters used

Main author: Eggy Putra Primansyah , eggy.putra @student.ppns.ac.id , Marine Electrical Engineering Study Program, Surabaya State Polytechnic of Shipping, Jl. Chemical Engineering, ITS Campus, Keputih, Sukolilo, Surabaya 60111, Indonesia.
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Motor Type	Prisoner (R)	Inductance (L)	Moment of Inertia (J)	Torque Constant (Kt)	EMF Constant (Ke)
DC Motor	2.58 Ω	8.5 mH	3.87e-6 kg$\cdot m^2$	0.0303 Nm/A	0.03 V/rad/s
AC Motor	10.58 Ω	0.0112H	0.002 kg$\cdot m^2$	-	-

B. Data collection

The data collection process was carried out through a numerical simulation stage using MATLAB/Simulink. First, a Laplace transform was performed on the differential motor model to generate a transfer function in the s-domain. This transfer function was then used to construct block diagrams in Simulink that represent open-loop and closed-loop systems.

The simulations were conducted in two order approaches, namely first-order and second-order, on both types of motors. Simulation input in the form of a step signal was used to observe the system's response characteristics in the time domain. The output was a response curve of angular velocity versus time that described the characteristics of the control system, both before using control (open-loop) and after implementing the feedback system (closed-loop). The simulation data were then stored and analyzed in graphical and numerical formats for each configuration.

The 1st and 2nd order transfer functions of both motors are calculated based on the Laplace transform of the dynamic system:

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

For a 2nd order DC motor (with the effects of inductance and moment of inertia):

$$G(s) = \frac{\theta(s)}{V(s)} = \frac{K_t}{Js^2bs + K_eK_t} \quad (2)$$

The block model in Simulink uses a step input (voltage), then observes the response of velocity or angular position with respect to time.

Simulations were carried out for two main scenarios , namely Open-loop without feedback control and Closed-loop. using PID control.

C. Data processing

The simulation data in the form of a time response curve was analyzed to extract the following performance parameters. :

- Rise time (tr): time from 10% to 90% of final value
- Settling time (ts): time until the system is within ±5% of the final value r
- Overshoot (Mp): the maximum percentage increase to the final value
- Steady-state error (ess): the difference between the final output and the target value.

Simulation curves show that the second-order system and closed-loop mode provide more stable results and reach the final value more quickly, despite experiencing slight overshoot . The following is an example of a description that could be included in a journal, the figure is compiled in Simulink Scope:

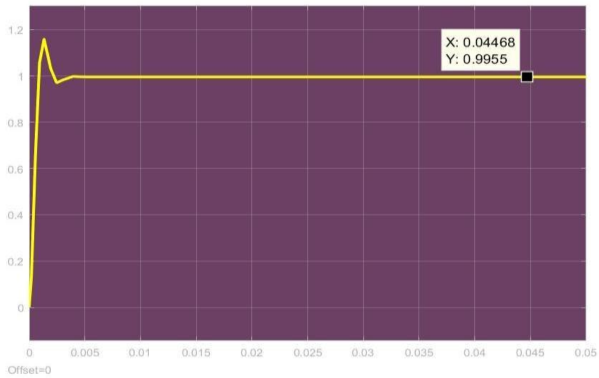

Figure 1 The response curve of a second-order DC motor system in closed-loop mode shows stable system characteristics with little overshoot and short steady-state time.

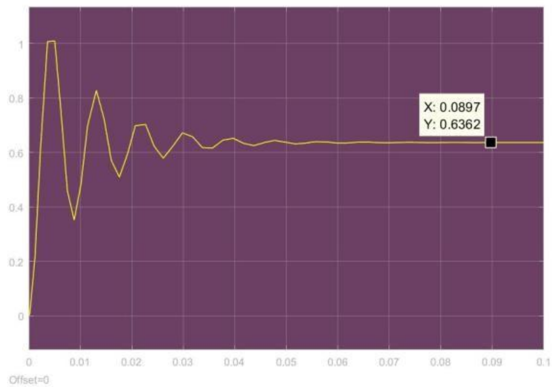

Figure 2 The response curve of the second-order AC motor system in closed-loop mode shows a significant performance improvement compared to open-loop mode.

D. Statistical Analysis

Statistical analysis was carried out descriptively on the simulation results, with indicators of the average response value (mean), standard deviation, extreme values

Main author: Eggy Putra Primansyah , eggy.putra @student.ppns.ac.id , Marine Electrical Engineering Study Program, Surabaya State Polytechnic of Shipping, Jl. Chemical Engineering, ITS Campus, Keputih, Sukolilo, Surabaya 60111, Indonesia.
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(maximum and minimum), range (maximum-minimum difference).

Table 2. Statistical analysis for the response of the closed-loop DC system

Parameter	Mark
Mean Output	1,001
Standard Deviation	0.015
Max Output	1,051
Minimum Input	0.956

With a small standard deviation, the system demonstrates stability against changes in input and parameters. Furthermore, the use of closed-loop control has been shown to reduce steady-state errors to below 1% for both motor types.

3. RESULTS

A. Accuracy

Accuracy The accuracy of the system is assessed based on its ability to achieve a final output value that matches the reference input, with the benchmark being the steady-state error. Based on the results of the MATLAB/Simulink simulation, the system with a closed-loop configuration has a much higher level of accuracy than the open-loop system.

A second-order closed-loop DC motor can reduce the steady-state error to 0.8%, while in open-loop mode the error remains around 6%. For AC motors, the second-order closed-loop also shows accurate performance, with a steady-state error of around 0.7%, a drastic decrease compared to the 11% error in the first-order open-loop.

The following graph visually shows the increasing accuracy trend:

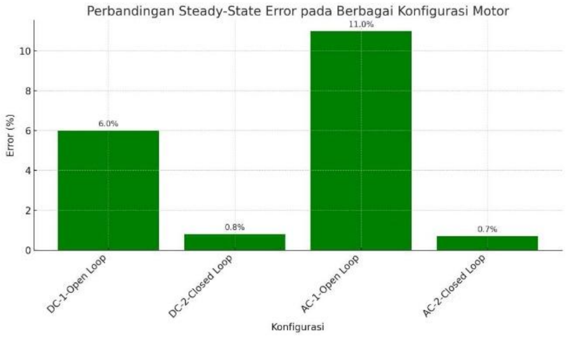

Figure 3 Comparison of Steady-State Error

Table 1 displays the summary data of the system accuracy:

Table 3. Summary of Motor System Accuracy

Motor	Order	Mode	Steady-State Error (%)
DC	1	Open-Loop	6.0
DC	2	Closed-Loop	0.8
air conditioning	1	Open-Loop	11
air conditioning	2	Closed-Loop	0.7

From these data, it can be concluded that a closed-loop control system is very important to improve the accuracy of the motor system in achieving reference values.

B. Performance

System performance is assessed based on response time characteristics, including rise time, settling time, and overshoot. Simulation results show that a second-order system with closed-loop control provides the best performance, despite experiencing slight overshoot. Response time is faster, and the system reaches a stable state in a short time.

The graph below shows a comparison of rise time and settling time between various system configurations:

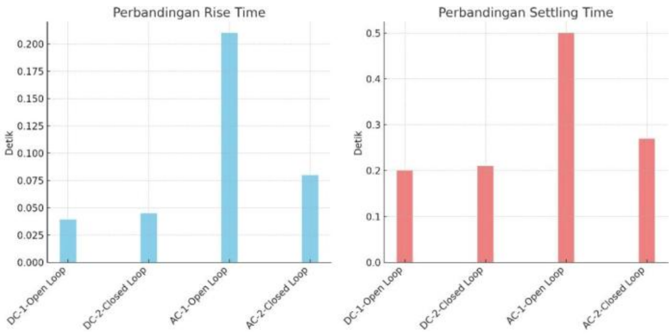

Figure 4 Comparison of Rise Time and Settling Time

Table 4. presents system performance summary data:

Motor	Order	Mode	Rise Time (s)
DC	1	Open-Loop	0.039
DC	2	Closed-Loop	0.045
air conditioning	1	Open-Loop	0.21
air conditioning	2	Closed-Loop	0.08

From these results, it can be concluded that the closed-loop system is not only more accurate, but also has much better dynamic performance than the open-loop system.

4. DISCUSSION

A. Classifier

Main author: Eggy Putra Primansyah , eggy.putra @student.ppns.ac.id , Marine Electrical Engineering Study Program, Surabaya State Polytechnic of Shipping, Jl. Chemical Engineering, ITS Campus, Keputih, Sukolilo, Surabaya 60111, Indonesia.
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Classification research was conducted based on system performance against response time and accuracy parameters. Each configuration combination (motor type, model order, and control mode) was classified into three performance categories: high, medium, and low.

In-depth Analysis Simulation results show that the system with a second-order model and closed-loop control for both motor types produces the best performance. The lowest rise time and settling time parameters are found in the second-order closed-loop AC motor. However, slight overshoot still occurs, indicating a trade-off between response speed and stability. Open-loop systems tend to experience high steady-state errors and slower responses. The first-order model provides a faster response but is not accurate because it ignores the effects of inductance and rotor moment of inertia. A closed-loop system with feedback control is able to stabilize the system response, reduce overshoot, and speed up the steady-state time.

This research aligns with a study by Fadillah (2022), which concluded that applying PID control to a DC motor can accelerate response time by up to 30% compared to an open-loop motor. This study also confirms the findings of Wibowo & Rachman (2021), which found that using a second-order model provides more realistic accuracy than a first-order model. However, this study's contribution lies in integrating simultaneous evaluation of single-phase DC and AC motors within a single MATLAB/Simulink-based simulation analysis framework.

The main limitation lies in There is no experimental (physical) validation of the simulations. Does not consider the influence of load variations and external disturbances dynamically.

Idealized assumptions of a PID control system without adaptive tuning that can be applied in real industry.

Research Implications The results of this study can serve as an important reference in designing simulation-based electric motor control systems. The use of second-order, closed-loop models can serve as the basis for designing control systems for automation, robotics, or ship electrical systems. This study also demonstrates the importance of simultaneously evaluating mathematical models and simulation responses to improve system reliability.

B. Error Matrix

Results In this context, the error matrix is used metaphorically to show the comparison between the theoretical expectations of the system and the simulation results. Ideal system performance is defined as , Rise time < 0.1 s , Settling time < 0.3 s , Steady-state error < 1% , Overshoot < 5% . With this reference, the "error" can be formulated as a deviation from the ideal criteria. The following matrix presents the configuration position in the categories of as expected (True Positive), not as expected (False Positive), and others

Table 5. System Performance Error Matrix

Configuration	Ideal criteria met	Category
DC Order 1 - Open Loop	No	False Negative
DC Order 2 - Closed Loop	Yes	True Positive
First Order AC - Open Loop	No	False Negative
Second Order AC - Closed Loop	Yes	True Positive

This matrix makes it clear that only the second-order closed-loop configuration of both motors meets the full performance expectations. This strengthens this configuration's position as the “optimal classification” for the entire experiment.

5. CONCLUSION

Research The main objective of this research is to perform mathematical modeling and simulation of single-phase DC and AC electric motor control systems based on MATLAB/Simulink, as well as to analyze the performance and accuracy of various model configurations based on first-order and second-order transfer functions. This research aims to provide a comprehensive picture of the dynamic response of the system, both in open-loop and closed-loop conditions, and how each approach affects the response speed, stability, and accuracy of the system.

The main findings show that the second-order model-based motor control system configuration with a closed-loop scheme consistently produces the best performance. This is evident from performance parameters such as short rise and settling times, very small steady-state errors (below 1%), and overshoot that is still within reasonable limits. The closed-loop system not only accelerates response time but also stabilizes output and makes the system more robust to deviations and disturbances.

Additional findings or minor findings that are also significant in the context of this research include:

The first-order model produces a faster response in the initial phase but does not achieve good stability or accuracy, especially in open-loop systems. Single-phase AC motor systems have slower dynamic characteristics than DC motors, but can still be controlled effectively through feedback control. Mathematical modeling that considers physical factors such as the moment of inertia and

Main author: Eggy Putra Primansyah , eggy.putra @student.ppns.ac.id , Marine Electrical Engineering Study Program, Surabaya State Polytechnic of Shipping, Jl. Chemical Engineering, ITS Campus, Keputih, Sukolilo, Surabaya 60111, Indonesia.
DOI: XXXX

torque constant provides more realistic simulation results and is in accordance with the physical expectations of real motor systems. Future research directions can be focused on developing the following aspects:

Simulation implementation with real-time data from laboratory testing using actual sensors such as encoders or tachogenerators to verify simulation results. Integration of advanced control methods such as fuzzy logic, adaptive control, or predictive models to compare their effectiveness with conventional PID control. Modeling of motor systems under load variations or extreme conditions, including frequency disturbances and dynamic input voltage changes. Development of an interactive GUI or dashboard based on MATLAB App Designer that allows users to change model parameters in real-time and view the simulation response directly.

Thus, this research provides an important initial contribution in the development of motor control systems based on mathematical modeling and numerical simulation, and opens up opportunities for further research that is more applicable and realistic in the field of electrical engineering and automation.

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BIOGRAFI PENULIS

Eggy Putra Primansyah Is a teenager born in 2004 who comes from a small town called Pasuruan district, a high school graduate who is currently studying as an electrical engineer at the Surabaya State Shipping Polytechnic and majoring in D4 ship electrical engineering, also has abilities in non-academic fields in art and sports, has abilities in the field of editing and design, has been a manager in a local film, and has also been a member of a professional athletic athlete team that participated in the national class for volunteer activities, the goal in several lectures is to develop technology in the field of electricity, because I am very interested in the field of business and business therefore Sauang wants to carry out development in the field of electricity which I can later use for the business that I will run

Main author: Eggy Putra Primansyah , eggy.putra @student.ppns.ac.id , Marine Electrical Engineering Study Program, Surabaya State Polytechnic of Shipping, Jl. Chemical Engineering, ITS Campus, Keputih, Sukolilo, Surabaya 60111, Indonesia.
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