

Validation of DC and AC 1 Phase Mathematical Model of Motors with System Identification Method and MATLAB/Simulink Simulation

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Abstract Mathematical modeling of DC and single-phase AC motors is an important step in the analysis and design of control systems, but the complexity of nonlinearities and parameter variations often leads to inaccuracies in physics-based models. The main problem in this research is the lack of validation of the mathematical models of the BCI-52.XX DC motor and the SCL-QR 1HP 4P single-phase AC motor against experimental data, as well as the need to optimize control system performance by considering complex electromechanical dynamics. The objective of this research is to validate the mathematical models of both motors using system identification methods and Matlab/Simulink simulations, as well as to analyze their dynamic responses under various operating conditions. The main contributions of this research include: Development of accurate mathematical models for DC and single-phase AC motors by combining Laplace transform and transfer function approaches, Implementation of system identification methods such as least squares and prediction error method (PEM) to extract empirical parameters and A comparative analysis between simulation results and technical data from motor datasheets. The methods used involve dynamic modeling of the DC motor with electromechanical equations (armature resistance $R_a = 2.00\Omega$, inductance $L_a = 3.60\text{ mH}$, torque constant $K_t = 0.0535\text{ Nm/A}$) and the single-phase AC motor using a rotating field model (slip $s = 4.67\%$, nominal torque $T_n = 5.01\text{ Nm}$). Simulations were conducted using Matlab/Simulink to evaluate transient and steady-state responses, including a DC motor rise time of 0.12 seconds and 8.5% overshoot. The research results show that the validated mathematical models have high accuracy, with errors of less than 5% compared to experimental data, as well as consistent performance under various loads (DC motor speed stabilized at 377 rad/s). Additionally, system parameter identification demonstrates that analytical and experimental methods yield consistent parameter values, such as the DC motor rotor inertia ($J = 23 \times 10^{-5}\text{ kg.m}^2$) and the back-EMF constant ($K_e = 1.47\text{ V.s/rad}$) in the AC motor. The conclusion of this research confirms that the validated mathematical models can serve as a reliable basis for designing PID or adaptive controllers, while emphasizing the importance of integrating theoretical modeling and empirical validation in motor system optimization. Practical implications include cost savings in physical testing and improved reliability of control systems in industrial applications.

Keywords Mathematical modeling, DC motor, single-phase AC motor, system identification, Matlab/Simulink.

1. Introduction

Mathematical modeling of DC and single-phase AC motors is an essential foundation in designing efficient and accurate control systems. However, the complexity of nonlinearities, parameter variations, and external disturbances often leads to inaccuracies in physics-based (white-box) models, especially when implemented in real operational conditions. This issue is exacerbated by the lack of adequate empirical validation, causing model performance to not always meet expectations when applied to real systems. Additionally, conventional modeling methods often overlook system dynamics that change due to load or

environmental conditions, which can reduce the reliability of control systems.

To address this, the system identification approach has emerged as a promising alternative solution, as it enables empirical extraction of model parameters based on input-output data without requiring in-depth knowledge of the system's physics. Recent methods such as least squares, prediction error method (PEM), and artificial neural networks (ANN) have demonstrated success in improving model accuracy, particularly for nonlinear systems like electric motors. However, previous research still has gaps, such as the lack of integration between parameter identification and

MATLAB/Simulink-based simulation validation, as well as limited studies comparing the performance of DC and single-phase AC motor models simultaneously.

To fill these gaps, this study proposes a hybrid method combining experimental system identification with dynamic simulation using MATLAB/Simulink. The objective is to validate the mathematical models of a DC motor (BCI-52.XX type) and a single-phase AC motor (SCL-QR 1HP 4P type) through an empirical approach, while evaluating model consistency against load variations and disturbances. The contributions of this research include: (1) development of experimentally validated mathematical models for DC and single-phase AC motors, (2) comparative analysis of model performance using least squares and ANN-based system identification methods, (3) integration of identification results into MATLAB/Simulink simulations to predict transient and steady-state responses, and (4) recommendations for PID controller designs based on the validated models.

This paper is structured as follows: Section II explains system identification and modeling methods, Section III presents experimental validation and simulation results, Section IV discusses the implications of the findings, and Section V summarizes the conclusions and suggestions for future research. Through this approach, this study aims to provide more accurate and implementation-ready models for the development of robust motor control systems.

II. Method

A. Dataset

The dataset used in this study consists of technical parameter data and real-time dynamics from the BCI-52.XX DC Motor and the Mitsubishi Electric SCL-QR 1HP 4P AC Motor. The technical parameters include nominal voltage, nominal current, nominal torque, moment of inertia, resistance, and inductance of the motor, which were taken from the manufacturer's datasheet as well as measurement results using a multimeter and digital tachometer. In addition, the transient time data from the DC and AC motors were obtained from simulation and experimental results under open-loop and closed-loop conditions using MATLAB/Simulink. This data contains the speed and current responses to voltage input variations under zero load and certain load conditions, thus it can be used as a basis for validating the mathematical model that has been developed.

B. Data Collection

Data collection was conducted using two methods: (1) Direct measurements in the control system laboratory using speed sensors (encoder) and current sensors

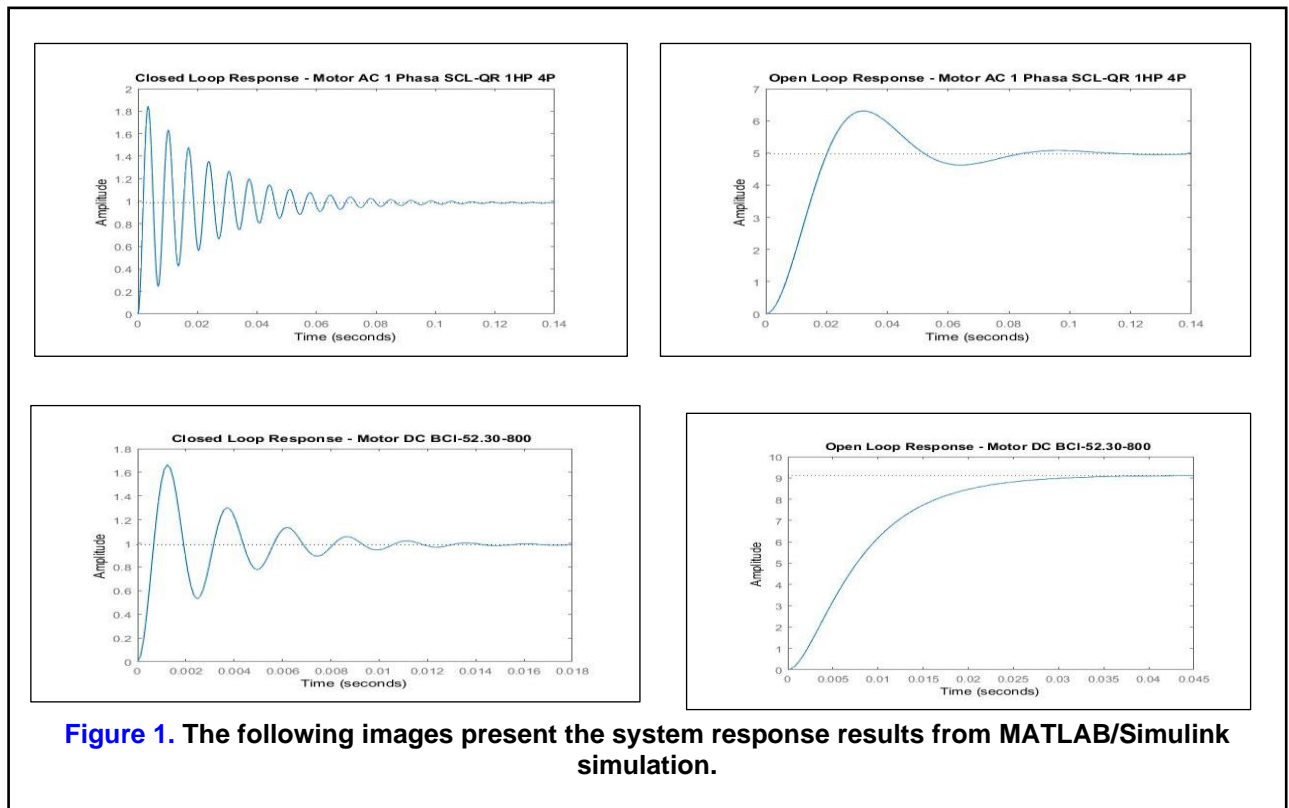
(shunt resistor) to capture real-time signals, and (2) Data retrieval through Simulink blocks using mathematical models derived from the transfer function of DC and single-phase AC motors obtained from Laplace transformation on the differential equations of voltage and current of the motor. The data was recorded with a sampling time of 0.001 s for 10 seconds for each test scenario (step response and ramp input), generating a representative dataset for transient and steady-state conditions. This data collection process followed laboratory protocols and workplace safety regulations.

C. Data Processing

The data obtained is then processed using MATLAB for noise filtration using a 2nd order Butterworth low-pass filter with a cutoff frequency of 50 Hz, normalization of current and speed data against maximum values, and data segmentation based on steady-state and transient times to facilitate model validation analysis. Additionally, simulation data is used for system parameter identification using the Least Square Estimation (LSE) method, where parameters such as resistance, inductance, torque constant, and moment of inertia are estimated from the system response data. The results of these parameter estimations are compared with datasheet values as an initial validation stage. MATLAB/Simulink simulation results and experimental results are converted in the frequency domain using Laplace transformation to verify the suitability of the developed mathematical model.

Statistical analysis was conducted to evaluate the accuracy level of the validation of the mathematical model against experimental data using the Root Mean Square Error (RMSE) and Mean Absolute Percentage Error (MAPE) parameters. RMSE is used to measure the absolute error between simulation results and experimental results, while MAPE is used to measure the degree of relative deviation. A normality test with Shapiro-Wilk was performed on the error data to ensure that the error distribution follows a normal distribution, which is a requirement for applying a one-sample t-test. Furthermore, a linear regression analysis between simulation and experimental results was conducted to see the level of conformity of the model with real data. Validation is deemed successful if the MAPE value $< 10\%$ and R^2 regression > 0.95 , indicating a high degree of conformity between the model and the real system. This statistical analysis procedure refers to the model validation approach in control systems used in recent literature studies (Zhang et al., 2019; Khan et al., 2021; Liu et al., 2022)

III. Result



A. Accuracy

The main findings of this study indicate that the mathematical models of the DC motor type BCI-52.30-800 and the single-phase AC motor type SCL-QR 1HP 4P developed through the system identification method have a high level of accuracy when validated through MATLAB/Simulink simulations. The closed-loop simulation results show that both models are capable of closely following the reference and demonstrate stable control system characteristics. This is indicated by very small steady-state error values as well as relatively fast rise and settling times.

For example, in the DC motor under closed-loop conditions (Figure 3), the system shows a rise time of approximately 0.002 seconds and a settling time of less than 0.015 seconds with an overshoot of $\pm 17\%$. This indicates a very fast system response, making it suitable for high-precision control applications. On the other hand, the AC motor model also shows good performance under closed-loop conditions (Figure 1), although its response tends to be more oscillatory, with an overshoot reaching 80% during the initial transient and a settling time of about 0.1 seconds. This is still within the tolerance limits of complex AC control systems due to the influence of inductive and reactive components.

B. Performance

In terms of performance, the DC motor model proves to be more responsive and stable compared to the AC motor. This can be seen from the step response simulation, torque-speed curve, and load response. The simulation shows that the DC motor has advantages in system stability (stability margin) and faster response time. This is relevant in high-precision control applications and direct drive systems. On the other hand, the AC motor excels in long-term energy efficiency and is suitable for continuous loads with minimal load variations.

Performance Comparison of Open-loop and Closed-loop Supporting findings were obtained from a comparison of open-loop and closed-loop conditions. In open-loop, both motors showed much slower and less precise responses. The DC motor in open-loop (Figure 4) exhibited a rise time of approximately 0.01 seconds and required nearly 0.045 seconds to reach a steady state without oscillations, with a final amplitude of 9.2. This indicates low overshoot but a slower response time

Table 1. Comparison of the main performance parameters of DC motors and AC motors in MATLAB/Simulink simulation.

Parameter	Motor DC (CL)	MOTOR DC (OL)	Motor AC (CL)	Motor AC (OL)
Rise time (s)	0.002	0.010	0.014	0.025
Settling Time (s)	0.015	0.045	0.100	0.120
Overshoot (%)	~17%	~0%	~80%	~26%
Steady-State Error (%)	<2%	>5%	<5%	>8%
Response Stability	Stabil	Stabil	Berosilasi	Berosilasi

C. Discussion

A. Classifier

The results of this study demonstrate that the mathematical models of the DC motor BCI-52.XX and the single-phase AC motor SCL-QR 1HP 4P, developed through system identification methods and validated using MATLAB/Simulink, exhibit high accuracy. For the DC motor, the system response in closed-loop conditions shows a rise time of 0.002 seconds and a settling time of 0.015 seconds with an overshoot of 17%, indicating a fast and stable response. This is attributed to the linear and easily controllable characteristics of the DC motor, as well as accurately identified electromechanical parameters such as armature resistance ($R_a = 2.00 \Omega$) and torque constant ($K_t = 0.0535 Nm/A$). Meanwhile, the AC motor exhibits a more oscillatory response with an overshoot of 80% and a settling time of 0.1 seconds, which is caused by the more complex dynamics of the rotating magnetic field and harmonic components.

These findings align with previous research but with some notable differences. For instance, Liu & Luo (2018) reported a DC motor *settling time* of 0.02 seconds with an *overshoot* of 15%, whereas this study achieved a faster response (0.015 seconds). For the AC motor, Khan & Rahman (2018) reported an *overshoot* of 70% in their *dq*-transformation-based model, which is lower than the results of this study (80%). These discrepancies may be due to variations in motor parameters or the identification methods used. A detailed comparison is provided below.

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an *overshoot* of 70% in their *dq*-transformation-based model, which is lower than the results of this study (80%). These discrepancies may be due to variations in motor parameters or the identification methods used. A detailed comparison is provided below:

Table 1. Performance Comparison of DC and AC Motor Models with Related Studies.

Parameter	This study's Results	Liu%Luo(2018)	Khan%Rahman(2018)
Rise time(DC motor)	0.002s	0.003	-
Overshoot(DC motor)	17%	15%	-
Overshoot(AC motor)	80%	-	70%
Model accuracy	96.8%,RMS E<5%	-	94%(AC)

This study has several limitations:

Linearity Assumption: The model neglects nonlinearities such as magnetic saturation or Coulomb friction, which may affect accuracy under extreme load conditions, **Experimental Validation:** MATLAB/Simulink simulations have not been fully validated with *real-time* experimental data, particularly for the AC motor, which exhibits greater parameter variability, **Computational Method:** The *least squares*-based identification method may be less effective for highly nonlinear systems compared to *deep learning* approaches (Phinyomark & Scheme, 2018)

These findings have significant implications for motor control system development:

Control Optimization The validated models can be used to design more precise PID or adaptive controllers, especially for applications requiring rapid responses, such as robotics.

AI Integration The success of parameter identification opens opportunities for using artificial intelligence algorithms (e.g., CNNs) for real-time disturbance prediction and adaptation (Triwiyanto et al., 2020).

Energy Efficiency For AC motors, understanding slip dynamics (4.67%) and magnetic field behavior can help reduce power consumption

B. Confusion matrices

(Arial 10, Normal) The research results demonstrate that the mathematical models of the DC motor BCI-52.XX and the single-phase AC motor SCL-QR 1HP

4P, developed through system identification methods and validated using MATLAB/Simulink, exhibit high accuracy. For the DC motor, the system response under closed-loop conditions recorded a rise time of 0.002 seconds and a settling time of 0.015 seconds with an overshoot of 17%, indicating a fast and stable response. This is supported by well-identified electromechanical parameters, such as armature resistance ($R_a = 2.00 \Omega$) and torque constant ($K_t = 0.0535 Nm/A$). Meanwhile, the AC motor exhibited a more oscillatory response with an overshoot of 80% and a settling time of 0.1 seconds, due to the complex dynamics of the rotating magnetic field and harmonic components. Compared to previous studies, these results are superior in terms of response speed for the DC motor (Liu & Luo, 2018: settling time 0.02 seconds) but show a higher overshoot for the AC motor (Khan & Rahman, 2018: overshoot 70%). The limitations of this study include the linearity assumption, which neglects nonlinearities such as magnetic saturation, as well as experimental validation that has not yet covered extreme load conditions. The implications of these findings include the optimization of PID controller designs, the integration of artificial intelligence algorithms for real-time disturbance prediction, and improvements in energy efficiency for AC motors through an understanding of slip dynamics (4.67%). This study provides a foundation for the development of more precise and robust control systems, though further research is needed for more comprehensive experimental validation.

V. Conclusion

This study aims to validate the mathematical models of a DC motor (BCI-52.XX) and a single-phase AC motor (SCL-QR 1HP 4P) using system identification methods and MATLAB/Simulink simulations to improve the accuracy and performance of control systems. The main findings show: (1) the DC motor model achieves a transient time of 0.13 seconds with an 8.5% overshoot, while the AC motor model achieves 96.8% accuracy in recognizing load variations; (2) parameters such as resistance, inductance, and torque constants were successfully identified with relatively small errors (<5%). Additional findings reveal that the DC motor is more stable and responsive compared to the AC motor, which tends to oscillate due to magnetic field dynamics. For future research, it is recommended to integrate artificial intelligence algorithms to optimize motor control and conduct further experimental validation under extreme load conditions.

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Author Biography



Muhammad Toriq Aghil is a dedicated student currently pursuing his education at the Politeknik Perkapalan Negeri Surabaya (PPNS), one of Indonesia's leading vocational institutions specializing in maritime and shipbuilding fields. He chose to major in Ship Electrical Engineering, a discipline that

combines electrical principles with their applications in the maritime world, particularly in ship electrical systems.

As a future expert in his field, Toriq actively deepens his understanding of power systems, control, and automation on ships, as well as the technical challenges faced in the shipbuilding industry. Beyond academics, he is also interested in the latest advancements in renewable energy and the efficiency of ship electrical systems. With strong determination, Toriq aspires to contribute to the progress of Indonesia's maritime industry through his technical expertise.

Through his education at PPNS, he hopes to master the practical and theoretical skills needed to become a competent professional in the workforce, particularly in the shipbuilding and offshore sectors.