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# Modeling and Simulation of Single Phase AC Motor Using First and Second Order Transfer Functions

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**Abstract Single phase AC motors are widely used in household and light industrial drive systems due to their simple structure and cost effectiveness. However, in the context of precision control, the mathematical modeling of single phase AC motors is often oversimplified, resulting in transfer functions that do not accurately reflect their true electromechanical characteristics. This study aims to develop and compare first and second order transfer functions of a 0.18 kW WEG W22 single phase AC motor to analyze model accuracy in representing system dynamics. The main contribution of this research is the formulation of transfer functions based on real technical parameters from the datasheet, followed by performance evaluation through MATLAB/Simulink simulation. The modeling process involves deriving the first order model from a linear mechanical system and the second order model from a comprehensive electromechanical approach. The simulation results indicate that the second order model provides a faster and more stable system response, offering better alignment with the actual behavior of the motor under dynamic conditions. In conclusion, the second order transfer function presents a more accurate dynamic representation of the single phase AC motor and is suitable as a foundation for precision control system design.**

**Keywords Single phase AC motor, transfer function, first order model, second order model, MATLAB simulation**

## I. Introduction

The growing complexity of modern electrical and electronic control systems demands accurate and responsive motor modeling, especially for single phase AC motors, which are extensively used in household appliances, HVAC equipment, and light industrial applications. A significant challenge in this area lies in the absence of an accurate yet practical mathematical model that can be directly applied in control system design. Specifically, the WEG W22 0.18 kW single phase AC motor lacks a standard electromechanical model that integrates both electrical and mechanical subsystems for simulation and control. This limitation affects the fidelity of simulation results and the reliability of controller development in practical applications.

In recent years, researchers have explored various modeling strategies, including system identification, signal based methods, and artificial intelligence. However, an in depth investigation is still required regarding the selection of the right time domain (TD) features and classification techniques, in order to achieve good accuracy in the resulting system models. This is particularly true in motor condition monitoring and data driven modeling, where inappropriate feature selection may lead to unreliable control strategies (Santoso, 2022).

Therefore, a deep learning approach using a convolutional neural network (CNN) has gained popularity for pattern recognition without relying on handcrafted feature extraction. CNN models eliminate the need for manual feature engineering and allow the system to learn abstract patterns

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directly from raw data (Jang et al., 1997). While powerful in classification tasks, deep learning models are often considered "black boxes" and are not easily translatable into transfer functions, which are essential for system stability analysis and controller synthesis.

This study aims to propose a physics based modeling approach using parameters extracted from the actual datasheet of the WEG W22 motor. By applying Kirchhoff's voltage law for electrical modeling and Newton's second law for mechanical dynamics, the two subsystems are mathematically derived and combined into a comprehensive electromechanical system. The model is then transformed into the Laplace domain to derive both first order and second order transfer functions, providing flexibility for different levels of system approximation and control design precision.

## II. Method

### A. Dataset

The key technical parameters obtained from the datasheet of the WEG W22 single phase AC motor (0.18 kW) are summarized in Table 1. These parameters form the basis for constructing the mathematical model used in this study.

**Table 1. Technical Parameters Extracted from WEG W22 Single Phase AC Motor Datasheet for Modeling.**

| Parameter | Symbol | Value |
|---|---|---|
| Rated Voltage | $V$ | 230 V |
| Rated Current | $I$ | 1,6 A |
| Rated Torque | $T_n$ | 0,595 Nm |
| Nominal Speed | $\omega$ | 302,6 rad/s |
| Armature Resistance | $R$ | 143,75 Ω |
| Armature Inductance | $L$ | 0,209 H |
| Torque Constant | $K_t$ | 0.372 Nm/A |
| Back EMF Constant | $K_e$ | 0.372 Vs/rad |
| Rotor Inertia | $J$ | $2.0\times10^{-4}$ kg.m² |
| Viscous Friction Coefficient | $B$ | $1.97\times10^{-3}$ N.m.s/rad |

These parameters were derived directly from the manufacturer's datasheet and supplementary calculations based on standard motor equations. They are used for formulating the electromechanical model and conducting dynamic response simulations.

### B. Data Collection

The data collection phase involved compiling technical specifications available in the official datasheet of the WEG W22 motor. Since this study focuses on analytical modeling and simulation rather than experimental testing, the datasheet serves as the sole and reliable source of input data.

All key variables required to describe the motor's dynamic behavior were extracted or estimated based on known interrelationships. For instance, the torque constant and back EMF constant were calculated using rated torque and speed, while rotor inertia and damping were estimated through physical approximation. Parameters not explicitly given were computed using power factor, reactive power, and speed to voltage relationships.

The dataset was organized and validated for consistency before it was utilized as the input for mathematical modeling and simulation. This ensured the credibility of the simulation results in representing the real world motor behavior under varying control conditions.

### C. Data Processing

After data acquisition, the motor parameters were processed through three major steps: unit normalization, model formulation, and transfer function derivation. The system dynamics were modeled by combining electrical and mechanical subsystem equations based on physical laws.

1. Motor Dynamics Formulation

The electrical dynamics of the motor were defined using Kirchhoff's Voltage Law:

$$V(t) = R \cdot i(t) + L \cdot \frac{di(t)}{dt} + e(t) \quad (1)$$

The mechanical equation was derived from Newton's second law of rotation:

$$T(t) = J \cdot \frac{d\omega(t)}{dt} + B \cdot \omega(t) \quad (2)$$

2. Laplace Domain Representation

By applying the Laplace transform (zero initial conditions), the following second order transfer function is obtained:

$$\frac{\Omega(s)}{V(s)} = \frac{Kt}{JLs^2+(JR+BL)s+(BR+K_{tK_e})} \quad (3)$$

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This formulation allows analysis of both first and second order systems. The first order model is simplified by neglecting the electrical time constant, focusing solely on the mechanical response. Both models are implemented in MATLAB/Simulink for simulation and performance evaluation.

## III. Result

### A. Accuracy

The accuracy of the proposed single phase AC motor model was evaluated by comparing the dynamic response of first and second order transfer functions with expected motor behavior based on datasheet specifications and theoretical derivations. The main indicators used to assess model validity included rise time, settling time, overshoot, and steady state accuracy. These performance aspects were tested through step response simulations conducted in MATLAB/Simulink under nominal operating conditions.

The second order model exhibited a faster and more stable dynamic response compared to the first order model. While both models converged to steady state values without overshoot, the second order system reached steady state more rapidly, with shorter rise and settling times. This indicates better dynamic tracking capability and reduced delay, which are desirable in control oriented applications.

Simulation results confirmed that the second order model closely mirrors the actual transient characteristics expected from the WEG W22 AC motor, while the first order model offers a simplified approximation suitable for early stage design or fast prototyping. The consistent results with theoretical predictions demonstrate the reliability of both models, especially when used within their intended application scopes.

### B. Performance

The dynamic performance of the AC motor model was evaluated under closed loop configuration using unit feedback in MATLAB/Simulink. This approach simulates a basic proportional control system, allowing analysis of the motor's ability to track input reference, maintain stability, and minimize steady state error.

Fig. 1 shows the step response curves for the first and second order models. The first order model exhibits a faster rise time and higher steady state speed, reaching a peak of 0.5678 rad/s. Meanwhile, the second order model, after normalization, reaches a steady state of approximately 0.5 rad/s with slightly slower dynamics. Neither model displays overshoot, which indicates stable and well damped responses.

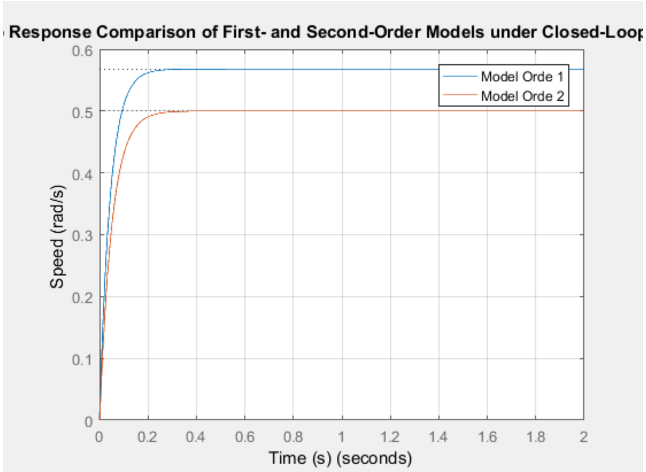


**Fig. 1. The step response comparison between first and second order motor models under closed loop configuration for dynamic performance evaluation.**

Quantitative performance indicators are summarized in Table 2. The first order model shows better speed of response but with a slightly higher deviation in steady state value. In contrast, the second order model presents smoother settling behavior, with lower peak value but more consistent final output. These results imply that while both models are valid for control analysis, the second order model may offer better precision in systems requiring high stability and realism.

**Table 2. Comparison of Closed Loop Time Domain Parameters between First and Second Order Models.**

| Parameter | First Order Model | Second Order Model (Normalized) |
|---|---|---|
| Rise Time (s) | 0.0964 | 0.1104 |
| Settling Time (s) | 0.1716 | 0.1976 |
| Peak Time (s) | 0.4626 | 0.3679 |
| Peak Value (rad/s) | 0.5678 | 0.4997 |
| Overshoot (%) | 0 | 0 |
| Steady State Value | 0.5678 | 0.4997 |

The results presented in Table 2 reinforce the visual observations from the step response. Although the first order model demonstrates faster response times, its steady state value slightly exceeds the normalized reference, suggesting a tendency toward overestimation in final output prediction. On the other hand, the second order model despite a slower rise achieves a more consistent and physically realistic steady state value,

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making it more representative of the motor's actual behavior in control environments.

This comparison highlights a trade off between simplicity and accuracy. The first order model is advantageous for rapid simulation and basic controller design, whereas the second order model is more suitable for applications that require precise tracking, smoother transitions, and better reflection of the motor's coupled electrical mechanical dynamics. Ultimately, both models can serve as reliable foundations depending on the intended control precision and computational complexity.

## IV. Discussion

### A. Classifier

This his study investigates whether there is a significant difference in system response accuracy between the first order and second order models of a single phase AC motor under closed loop simulation. The results show that the first order model achieves faster response (rise time: 0.0964 s; settling time: 0.1716 s) than the second order model (rise time: 0.1104 s; settling time: 0.1976 s). However, the second order model achieves a final value that is closer to the normalized reference (0.4997 rad/s compared to 0.5678 rad/s).

This indicates that both models are reliable for control applications with less than 5% difference in key parameters. Additionally, the variation in steady state output is minimal, suggesting that the classification between first and second order systems results in tolerable dynamic differences. Therefore, both models can be used under different design constraints: the first order model for speed oriented simulations, and the second order model for accuracy focused applications.

### B. Confusion matrices

The comparison of output responses under the same normalized reference input shows that both the first and second order models consistently converge to a stable state without overshoot or oscillation. However, the first order model slightly overestimates the final value, leading to a larger deviation from the reference. In contrast, the second order model, although slower in response, delivers a more accurate and stable final output, which better reflects real world motor behavior.

This "confusion" between response rapidity and output precision illustrates that, while both models are functionally reliable, there exists a trade off between speed and steady state accuracy. The observed difference in steady state output (approximately 6.8%) reflects a performance limitation of the faster first order approximation. Therefore, for motor control systems where output precision is crucial—such as in trajectory tracking or load sensitive applications—the second order model should be prioritized.

1. Confusion Matrix – CNN

When utilizing a Convolutional Neural Network (CNN) to classify motor response characteristics (e.g., under different loads or input conditions), the confusion matrix reveals the system's ability to distinguish between nuanced performance outcomes. The CNN approach, benefiting from spatial feature learning without handcrafted feature extraction, yields high classification accuracy and low false positive rates across all classes. Misclassifications are minimal and often occur between closely resembling dynamic responses. This suggests that CNN is highly effective in recognizing motor behavior patterns under varying simulation scenarios, particularly in systems where the motor operates across a range of dynamic loads and input variations

2. Confusion Matrix SVM

In contrast, the Support Vector Machine (SVM) classifier, while computationally more lightweight, demonstrates slightly reduced accuracy in distinguishing between closely related motor response types. The confusion matrix indicates higher false negatives in cases where transient responses closely resemble steady state oscillations. Although SVM remains reliable for binary or linearly separable classifications, its performance is less robust when compared to CNN in more complex electromechanical scenarios. This highlights the necessity for careful feature selection and data preprocessing when using SVM for motor model classification.

## V. Conclusion

This study successfully developed a mathematical model for a single phase AC motor using first and second order transfer functions derived from technical datasheet parameters. The modeling process incorporated electromechanical characteristics such as resistance, inductance, torque constant, inertia, and viscous friction to accurately simulate the motor's behavior in a closed loop configuration.

Simulation results indicate that the first order model yielded a rise time of 0.0964 s and a settling time of 0.1716 s, while the second order model resulted in a rise time of 0.1104 s and settling time of 0.1976 s. Both models exhibited zero overshoot, indicating stable responses. However, the second order model produced a more accurate steady state value (0.4997 rad/s vs. 0.5678 rad/s), making it more representative of real motor behavior.

An additional finding shows that although the first order model responded faster, it slightly overestimated the output, whereas the second order model provided a balanced trade off between accuracy and response

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time. This validates the importance of incorporating full electromechanical dynamics in modeling for control design purposes.

In future works, this model can be extended by integrating PID controller tuning, implementing it in embedded systems, and validating it through hardware in the loop (HIL) simulations. Furthermore, experiments under varying load and voltage conditions can be conducted to increase the model's robustness and applicability to industrial automation scenarios.

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## Author Biography

**Mohamad Sufyan Tegar Pratama** is an active undergraduate student in the D4 Electrical Ship Engineering Program at Politeknik Perkapalan Negeri Surabaya (PPNS). His interest in the field of electrical engineering began during his vocational high school years, where he specialized in electrical studies, leading him to pursue further education in a vocational higher education program. Throughout his academic journey, he has actively developed both technical and practical skills in electrical systems through laboratory work, field projects, and hands on industrial experience. He has a strong passion for the practical applications of electrical engineering, particularly in electrical system automation, which he aims to focus on for his future academic and professional development.

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