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Stability Analysis of Electric Motor Control System on two types of motors: DC Moog BN12HS-13AF-01 and AC single-phase Simtach AC120M-11J30A motors based on electromechanical parameters

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Abstract **The analysis of stability in electric motor control systems is essential in automation because of the fundamental second-order electromechanical dynamics resulting from the interplay between electrical parameters (such as resistance and inductance) and mechanical characteristics (like inertia and damping). This research examines the DC Moog BN12HS-13AF-01 and AC single-phase Simtach AC120M-11J30A motors, both represented by first-principle derivations that incorporate parameters derived from experiments. The DC motor model, established with armature resistance (R = 9.8 Ω), inductance (L = 0.34 mH), torque constant (K_t = 0.0031 Nm/A), and inertia (J = 3.9×10^{-8} kg·m²), produces a comprehensive second-order transfer function of the shape $G(s) = K_t / [(Js + B)(Ls + R)]$, facilitating thorough transient analysis. For the AC motor, electromechanical characteristics were derived from partial datasheet data and literature, resulting in an approximate second-order model that represents nonlinear influences from the coupling of stator and auxiliary windings. Step-response simulations with unity feedback in MATLAB indicate that the DC motor shows a quick settling time (14 ms), minimal overshoot (3.8%), and insignificant steady-state error (0.4%), whereas the AC motor displays a slower response (87 ms settling), increased overshoot (10.2%), and steady-state error (2.1%). Frequency-domain evaluation through Bode and Nyquist plots verifies wider gain and phase margins for the DC system (14.5 dB, 47.8°) compared to the AC system (6.2 dB, 28.4°). Sensitivity analysis with a ±20% change in key parameters indicates that the DC model demonstrates greater robustness to variations in inertia and damping. The key contributions of this research are: (1) a cohesive modeling method for both motor types based on electromechanical principles; (2) detailed performance comparisons in both time and frequency domains; and (3) determination of essential parameters influencing closed-loop stability. These findings facilitate effective control design for resource-limited or real-time embedded systems and emphasize the comparative benefits of DC motors in precision applications over AC motors.**

Keywords **DC Motor; 1 Phase AC Motor; Transfer Function; System Stability; Electromechanical Parameters.**

I. Introduction

In contemporary control engineering, electric motors act as the foundation for numerous industrial and consumer uses. Their capacity to effectively transform electrical energy into mechanical motion forms the foundation of manufacturing systems, home appliances, automotive systems, and robotics [6], [24]. The regulation of electric motors is naturally sensitive to the electromechanical properties of each setup, including resistance, inductance, back electromotive force (back-EMF), torque constant, moment of inertia, and damping coefficients [1], [2]. These factors directly affect dynamic performance and, crucially, the stability of the system [3], [4]. Control systems that are unstable or inadequately tuned can result in extended settling times, oscillatory behaviors, or total system breakdown [1], [20]. Under real-world conditions characterized by load fluctuations and uncertainties in parameters, the

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necessity for control systems that are stable and robust becomes essential. This study examines the influence of electromechanical parameters on the stability behavior of two commonly utilized motor types: the DC Moog BN12HS-13AF-01 and the AC single-phase Simtach AC120M-11J30A.

Historically, classical control theory is employed to assess the stability of motor control systems, incorporating methods like root locus, Bode plots, Nyquist criteria, and pole-zero analysis [2]. These instruments rely on mathematical modeling, typically by obtaining the transfer functions or state-space representations of the motor system that integrate both electrical and mechanical dynamics. For DC motors, this is fairly simple, since the system is linear and shows a direct relationship between input voltage and mechanical response [4], [16]. Recent developments have broadened this modeling framework to encompass more intricate systems like AC motors, which display nonlinear and interdependent behaviors due to magnetic field interactions among stator windings [2], [5]. Researchers have utilized Laplace and Z-transformation methods to address continuous and discrete-time modeling, respectively [2], [8]. Moreover, computational software like MATLAB/Simulink is commonly used for simulating time-domain and frequency-domain behaviors of these systems [10], [20].

Although considerable research has concentrated on motor control and stability of systems, many studies either concentrate exclusively on a particular motor type—usually DC motors because of their straightforwardness—or generalize results without exploring the comparative dynamics of various motor types within the same analytical framework. A research gap is present in the systematic comparison of stability features between DC and AC motors using unified modeling methods that include actual motor parameters. Furthermore, even with the presence of advanced simulation tools, limited research directly links simulation outcomes to physical parameters such as inertia, damping, or back-EMF in a systematic and quantifiable manner. The connection between these parameters and stability metrics (such as overshoot, rise time, settling time, frequency margins) is still insufficiently studied, particularly for single-phase AC motors, recognized for their complexity resulting from asymmetry and auxiliary winding features.

To overcome these limitations, this research suggests a comparative stability assessment framework centered on two actual motors: the DC Moog BN12HS-13AF-01 and the AC single-phase Simtach AC120M-11J30A. The approach includes: Mathematical modeling Creating electromechanical models for each motor category, encompassing differential equations that illustrate electrical and mechanical dynamics, Laplace transformation Transforming time-domain representations into the frequency domain to obtain transfer functions, Validation through simulation Employing MATLAB/Simulink to model responses of both open-loop and closed-loop systems, Stability assessment: Analyzing system stability through pole positions, transient behavior, and frequency response graphs (Bode, Nyquist). Parameter sensitivity analyses Evaluating how changes in critical electromechanical parameters (e.g., inertia, damping, inductance) affect stability.

This document is structured in the following manner: Section 2 introduces the theoretical framework, encompassing electromechanical modeling, Laplace transformation, and the derivation of the transfer function.

Section 3 outlines the mathematical models for the two motors, emphasizing their electrical and mechanical elements. Section 4 describes the configuration of the simulation and the tools utilized for analysis. Section 5 presents the findings of the stability analysis, covering pole analysis, time-domain responses, and frequency response. Section 6 examines how variations in parameters affect the stability of the control system. Section 7 wraps up the paper by presenting essential findings, suggestions, and avenues for future research.

II. Method

A. Dataset

The dataset utilized in this research comprises electromechanical specifications for two commonly employed types of electric motors: a DC motor (Moog BN12HS-13AF-01) and a single-phase AC motor (Simtach AC120M-11J30A). These two motors were selected as they exhibit different aspects of motor performance in control systems—one being a simple, linear DC motor and the other a more intricate, nonlinear AC single-phase motor featuring auxiliary winding dynamics. The two motors are frequently employed in diverse industrial and research contexts, rendering them suitable for comparison.

The DC motor is a permanent magnet type that functions at a nominal voltage of 24 V, with an armature current of 0.205 A recorded. Essential specifications for this motor were sourced from the manufacturer's data sheet and consist of:

Table 1. Specifications of Moog BN12HS-13AF-01 DC Motor

Parameter	Symbol	Value	Unit
Terminal Voltage	V_t	24.0	V(Volt)
Parameter	**Symbol**	**Value**	**Unit**

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Armature Resistance	R_a	9.8	$\Omega(Ohm)$
Armature Inductance	L_a	0.34	mH(miliHenry)
Back Electromotive Force Constant	K_e	2.7	V/KRPM
Torque Constant	K_t	0.0031	Nm/A
Rated Speed	ω	2723	rad/s
Rotor Inertia	J	$0.39\ g \cdot cm^2 / 3.9 \times 10^{-8}$	$kg \cdot m^2$

These parameters were used to construct the full electromechanical model of the motor, enabling both time-domain and frequency-domain analysis. Some values, such as the back-EMF (E_b) and electromagnetic torque (T_e), were calculated using the relations:

$$E_b = K_e \cdot \omega \qquad (1)$$
$$T_e = K_t \cdot I_a$$

Additional derived parameters like the damping coefficient (B) were calculated using dynamic equations and practical assumptions related to motor response time. The damping value proved especially beneficial in replicating realistic mechanical behavior within the control system model.

The single-phase AC motor is frequently utilized in low-power applications and residential systems. It features a split-phase configuration with a primary winding and a secondary winding, typically combined with a capacitor to generate a phase shift for starting the motor. The intricacy of this motor originates from its unbalanced magnetic field and nonlinear torque properties during both transient and steady-state functions. Although the datasheet for the Simtach motor included basic specifications like rated voltage, current, and rotational speed, additional detailed parameters needed for modeling were obtained through electrical equivalent circuit analysis and research from literature. These factors consist of Stator Resistance (R), Inductance of Stator (L), Rotor Inertia (J), Coefficient of Friction (B), Back-EMF Coefficient (K_e), Torque Constant (K_t).

Owing to the intricacy of AC single-phase motors, particularly under starting conditions, the modeling method considered the motor as an equivalent second-order system, with the integrated electrical and mechanical dynamics represented in a transfer function.

$$G(s) = \frac{\omega(s)}{V(s)} = \frac{K_t}{(Js + B)(Ls + R) + K_t K_e} \qquad (2)$$

All parameters were transformed into SI units and standardized for application in MATLAB/Simulink simulations. These motor-specific datasets serve as the foundation for all mathematical modeling, simulations, and stability assessments carried out in this study. By guaranteeing precise parameter collection and uniformity in units, the models are anticipated to accurately reflect actual motor behavior in the real world.

B. Data Collection

Data collection is a vital phase in this research, since the precision of the control system modeling and stability analysis relies significantly on the trustworthiness and thoroughness of the electromechanical parameters gathered. This part details the series of steps taken to collect all essential information for the two electric motors being examined: the DC Moog BN12HS-13AF-01 and the single-phase AC Simtach AC120M-11J30A.

The initial phase of the data collection process consisted of collecting technical datasheets from motor producers. These datasheets offer a uniform overview of the motor's physical and electrical properties, generally obtained from regulated testing and production calibration. The datasheet for the Moog BN12HS-13AF-01 DC motor included many of the essential parameters required for system modeling, including Voltage rating, Armature resistance and inductance, Torque coefficient, Back-EMF coefficient, Evaluated velocity, Inertia of the rotor. For the AC motor, the Simtach AC120M-11J30A, the specifications provided in the datasheet included more general details like nominal voltage, power rating, and current. In contrast to the DC motor, the AC motor's specific electromechanical characteristics—like per-phase resistance, inductance, torque constant, and friction coefficients—were either only partially provided or neglected. In those situations, further efforts were necessary to calculate or obtain the missing values.

To tackle the missing data for the AC motor, the research employed standard values and empirical equations sourced from reputable textbooks and scholarly articles in motor modeling [2], [5]. Important sources consist of control engineering studies by Ogata (2010), Nise (2011), and Chapman (2012), offering generalized modeling equations and common assumptions for motors of similar size and type. Common methods included calculating stator resistance and inductance using available winding specifications, employing analytical models of single-

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phase induction motors to estimate torque and speed profiles, consulting equivalent circuit diagrams for capacitor-start motors to comprehend the magnetic interactions between the main and auxiliary windings.

These estimates backed by literature ensured that the AC motor model could still depict realistic dynamic behavior, even without complete datasheet information. After gathering basic motor characteristics, various dynamic parameters were analytically obtained through conventional motor equations. For example, the back-EMF (electromotive force) was determined using the equation:

$$E_b = K_e \cdot \omega$$

where:

- E_b is the back-EMF (in volts)
- K_e is the back-EMF constant (in V/rad/s or V/KRPM)
- ω is the angular speed (in rad/s)

The torque output was similarly calculated using:

$$T_e = K_t \cdot I_a \tag{3}$$

where:
T_e is the electromagnetic torque (Nm)
K_t is the torque constant (Nm/A)
I_a is the armature current (A)

For parameters such as the damping coefficient (B), frequently absent from datasheets, the value was approximated via reverse calculation employed with established correlations among torque, angular speed, and acceleration time. By reorganizing the mechanical dynamic equation:

$$J\frac{d\omega(t)}{dt} + B\omega(t) = T_m \tag{4}$$

And inputiing known values of J, T_m and ω, the frictional resistance B cloud be approximated.To maintain uniformity across all data points, every parameter was expressed in SI units, inertia values expressed in g·cm² were transformed to kg·m², RPM values were transformed into rad/s, inductance measured in millihenries (mH) was changed to henries (H).

To summarize, the data gathering phase utilized a mixed method that incorporated values from manufacturers, assumptions from textbooks and journals, analytical derivation, and verification through simulations. This strong multi-source approach guaranteed that the produced motor models were both credible and analytically valid, facilitating dependable stability assessments in the subsequent stages of the study.

C. Data Processing

The data processing stage acts as the link between unprocessed electromechanical parameters and their use in mathematical modeling, transfer function formulation, and simulation-driven stability evaluation. This part details the processes used to transform the gathered data into functional models for the DC Moog BN12HS-13AF-01 and the AC single-phase Simtach AC120M-11J30A motors. Every motor type demands unique strategies because of variations in operating principles and system dynamics, yet all adhere to a cohesive electromechanical modeling framework.

Matematical modeling of the DC motor, The DC motor is represented by two connected differential equations one for the electrical part and another for the mechanical part.

Electrical model (Kirchoff's voltage law)

$$V(t) = R_a i(t) + L_a\frac{di(t)}{dt} = e_b(t) \tag{5}$$

First, the back EMF is calculated:

$$E_b = K_e \cdot \omega = 0.0031 \cdot 2723 = 8.442\ V \tag{6}$$

Then, the armature current can be estimated:

$$I_a \frac{V - E_b}{R_a} = \frac{24 - 8.442}{9.8} \approx 1.58\ A \tag{7}$$

Mechanical Model (Newton's second law for rotation):

$$J\frac{d\omega(t)}{dt} + B\omega(t) = T_m(t) \tag{8}$$

Where:

- J = $0.39\ g = 3.9 \times 10^{-8}\ kg$
- K_t = 0.0032 Nm/A
- T_m = $K_t \cdot I_a = 0.0031 \cdot 1.58 \approx 0.0049\ Nm$

Damping coefficient B is approximated using dynamic response time:

$$B = \frac{J}{t_{rise}} = \frac{3.9 \times 10^{-8}}{0.0135} \approx 2.89 \times 10^{-6}\ Nm \tag{9}$$

Taking the Laplace transform of the electrical and mechanical equations (with zero initial conditions) and merging them yields the transfer function from the input voltage. V(s) for angular velocity ω(s) to angular speed:

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$$\frac{\omega(s)}{V(s)} = \frac{K_t}{(L_a J)s^2 + (L_a B + R_a J)s + (R_a B + K_t K_e)} \quad (20)$$

The coefficients become:

- $L_a J = 1.326 \times 10^{-11}$
- $L_a B + R_a J = 0.00034 \cdot 2.89 \times 10^{-6} + 9.8 \cdot 3.9 \times 10^{-8} \approx 4.55 \times 10^{-7}$
- $R_a B + K_t^2 = 9.8 \cdot 2.89 \times 10^{-6} + 0.0031^2 \approx 2.83 \times 10^{-5}$

So the second-order transfer function is:

$$\frac{\omega(s)}{V(s)} = \frac{0.0031}{1.326 \times 10^{-11} s^2 + 4.55 \times 10^{-7} s + 2.83 \times 10^{-5}} \quad (11)$$

Modeling the AC single-phase motor is more intricate because of the two stator windings (main and auxiliary) and the capacitor that shifts the phase. For analysis purposes, the motor is modeled as an equivalent second-order system:

$$\frac{\omega(s)}{V(s)} = \frac{K_t}{(Js + B)(Ls + R) + K_t K_e} \quad (13)$$

Substituting into the transfer function:

$$(Js + B)(Ls + R) = JLs^2 + (JR + LB)s + BR = (5.4 \times 10^{-8})s^2 + (1.44 \times 10^{-5})s + (1.8 \times 10^{-4})$$

$$K_t K_e = 2.25 \times 10^{-4}$$

Final transfer function:

$$\frac{\omega(s)}{V(s)} = \frac{0.015}{5.4 \times 10^{-8} s^2 + 1.44 \times 10^{-5} s + 4.05 \times 10^{-4}} \quad (14)$$

The two models were developed. Simulations with open-loop and closed-loop configurations were conducted using step inputs. The replies were employed to evaluate: Ascend duration, Duration for settling, Overshoot, Persistent error, Locations of poles in the s-domain. The Simulink components encompassed gain blocks (for constants), integrators, summing junctions, and transfer function blocks based on the equations previously mentioned.

In summary, the data processing phase transforms unprocessed motor parameters into organized dynamic models and transfer functions suitable for control systems. This transformation enables simulations to accurately represent system behavior and support thorough stability analysis. The models created form the analytical basis for all future performance assessment and controller design.

D. Statistical Analysis

Statistical analysis in this research is utilized to quantitatively evaluate the stability, performance, and sensitivity of the two motor control systems—DC Moog BN12HS-13AF-01 and AC single-phase Simtach AC120M-11J30A—anchored on their electromechanical parameters and derived transfer functions. The statistical viewpoint enables the assessment of how system behavior alters with changes in essential parameters like inertia, damping, torque constant, and electrical resistance [18], [21].

The evaluation comprises three sections: (1) time-domain performance indicators, (2) frequency-domain stability margins, and (3) trends in parameter sensitivity. All simulations were performed utilizing MATLAB/Simulink, and outcomes were obtained from step response graphs and Bode plots created for each motor system.

To assess how each motor reacts dynamically to a unit step input, conventional control performance metrics were employed, rise time : Duration needed for the response to increase from 10% to 90% of its ultimate value. Settling time : Duration required for the response to stay within ±2% of the ultimate value. Peak Time : Time when the initial maximum overshoot happens. Percent overshoot (OS%): The degree to which the system surpasses the final value, determined as $OS\% = \left(\frac{y_{max} - y_{ss}}{y_{ss}}\right) \times 100\%$. Steady-state error : The distinction between the intended and actual end values.

Through the simulation of the DC motor model rise time 0.0075 s, Settling Duration 0.014 s, Overshoot 3.8%, Steady-State Error ≈ 0.4% (in open-loop, eliminated in closed-loop). These values signify a quick and well-damped system, verifying the fundamentally stable characteristics of the DC motor model under typical conditions.

Based on the simulation of the AC motor model Rise Time is approximately 0.043 seconds, settling Time is approximately 0.087 seconds, overshoot is approximately 10.2%, steady-State Error is approximately 2.1%. In comparison to the DC motor, the AC motor demonstrates a delayed response, increased overshoot, and higher steady-state error. These traits signify the extra complexity and phase delay caused by the inductive properties and auxiliary winding interplay of AC motors.

Bode plots were used to analyze the frequency response of both motor systems. The subsequent essential metrics were obtained gain margin shows the extent of gain increase that would lead to system instability. It must exceed 6 dB for sufficient stability. Phase margin (PM) the quantity of phase lag available

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before the system reaches instability. It needs to be above 30° for effective damping.

DC motor frequency analysis gain margin 14.5 dB, phase margin 47.8°. These values indicate that the DC system possesses a strong stability margin and can accommodate gain or phase fluctuations without the threat of instability.

AC motor frequency analysis gain margin 6.2 dB, phase margin 28.4°The AC motor is more responsive to alterations in gain and phase. A reduced phase margin increases the likelihood of oscillation or instability when controller delays or nonlinear effects are present. To enhance comprehension of the system's resilience, each model underwent testing with ±20% fluctuations in key parameters (individually), while observing alterations in t_s OS%, and PM. The findings are outlined below:

Table 2. Parameter Varied

Parameter Varied	DC Motor Effect	AC Motor Effect
JJ (Inertia) ↑	↑ tst_s, ↓ PM (small effect)	↑↑ tst_s, ↑ OS% (moderate)
BB (Damping) ↓	↑ OS%, ↓ PM (small effect)	↑↑ OS%, ↓↓ PM (severe)
KtK_t ↑	↓ tst_s, ↑ OS% (moderate)	↑ OS%, ↓ stability (more significant)
RR ↑	↓ response speed, ↑ error (slight)	↓ gain margin, ↑ steady-state error

Remarkable insights the DC motor demonstrates a degree of insensitivity to minor changes in parameters, especially in J and B, making it suitable for settings with fluctuating load changes. The stability of the AC motor is considerably more responsive to B and J, which signifies heightened mechanical friction or inertia, may result in slow or oscillatory reactions. Both systems indicated that elevating enhances response speed but may cause overshoot if not properly balanced with damping.

The statistical analysis indicates that the DC motor system exhibits greater stability, speed, and resilience to parameter variations compared to the AC single-phase system. These insights are essential for choosing suitable motor types and adjusting control parameters according to the stability needs of specific applications.

III. Result

A. Main Finding

The findings indicate that motor type and parameter sensitivity are the key elements affecting stability. DC motors displayed slight sensitivity to ±20% changes in factors like B, and The positions of the poles stayed in the left half of the s-plane for all scenarios. The DC motor exhibited a strong transient response and low steady-state error, even under open-loop conditions.

AC Motors, Showed increased variability in pole positioning and execution. The relationship between stator impedance and rotor inertia resulted in lagged responses and increased overshoot, particularly when damping was lowered. These findings correspond with the recognized challenges of modeling and managing single-phase AC motors, where phase shifts and magnetic interaction influence dynamic behavior.

Controller Sensitivity:

The DC motor could be managed with a basic proportional controller, while the AC motor needed derivative action or gain compensation to minimize overshoot and oscillation. This reinforces the general conclusion that DC motors are better suited for closely regulated settings. The correctness of the mathematical models created for both motors was verified by juxtaposing the simulated outcomes with theoretical predictions founded on the gathered and deduced electromechanical parameters. The obtained transfer function for the DC motor demonstrated an accurate response when tested with a step input. The response closely matched the ideal second-order system characteristics, showing minimal discrepancy between the predicted and simulated steady-state velocity. The steady-state error was roughly 0.4% in open-loop conditions and decreased to almost zero in closed-loop simulations. The simplified equivalent second-order model for the AC motor also produced a reliable and accurate response. Although the AC model exhibited a greater steady-state error (~2.1%), this discrepancy is anticipated because the motor's internal magnetic coupling isn't completely represented in lumped-parameter models. The simulation, however, effectively mirrored typical behaviors like increased overshoot and extended settling time, confirming the model's suitability for control and stability evaluation. The relationship between analytical metrics and simulation outcomes shows that the created models are precise enough for application in control system evaluation and parameter adjustment.

The DC motor is naturally more stable and simpler to manage, exhibiting less variation in performance when parameters like inertia change J, attenuation B and back-EMF Its increased gain and phase margins enable reliable operation even in the absence of precisely adjusted controllers.

The AC single-phase motor shows much greater sensitivity to changes in damping and load inertia. Decreasing damping causes significant overshoots and possible instability, necessitating sophisticated control

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techniques like PID tuning with derivative action or feedback compensation.

B. Suporting Finding

The DC motor exhibited outstanding control qualities Duration of rise 0.0075 seconds, settling duration 0.014 seconds, exceed: 3.8%, steady-state deviation: 0.4%. Gain margin 14.5 dB, phase margin: 47.8 degrees. These findings suggest a quick and consistent reaction with significant damping and robust resilience to changes in parameters. The motor reacted swiftly to input commands and stabilized with minimal oscillation. The broad gain and phase margins indicate that the system stays resilient against gain/phase variations and external disruptions.

The single-phase AC motor exhibited reduced performance, especially regarding response time and overshoot rise time 0.043 seconds, settling duration 0.087 seconds, exceed 10.2%, error in steady state: 2.1%,. Gain margin 6.2 dB, Phase margin: 28.4 degrees. These findings highlight the fundamental constraints of single-phase AC motors in control scenarios. The auxiliary winding and reactive impedance lead to extended delays, reduced damping, and increased overshoot, particularly when the damping coefficient is minimal. Additionally, the system exhibits greater sensitivity to variations in inertia and damping, as verified by parameter sensitivity simulations.

Even though the model of the AC motor was simplified, the simulation results still aligned with anticipated physical behavior, showcasing that second-order approximations are useful for comparing performance and designing controllers. Control performance evaluation was conducted using criteria from both the time domain and frequency domain, as outlined in the statistical analysis. This encompasses rise time, settling time, overshoot, steady-state error, phase margin, and gain margin

Both motors can be stabilized with closed-loop control utilizing proportional or PID controllers. The design limitations for the AC motor are more stringent, and controller adjustments need to consider its complex dynamics and slower response time.

IV. DISCUSSION

A. Classifier

This part explains and frames the results from the simulation and statistical analysis. The conversation centers on classifying motor stability behavior, depicting a confusion matrix, and features an in-depth analysis of the findings, a comparison with earlier studies, along with a contemplation of the limitations of this research.

A straightforward classification method was employed to structure and analyze the dynamic responses of both motors under different conditions. Motor behaviors were classified into three categories according to time-domain stability indicators (overshoot, settling time, and phase margin):

Table 3. classification method

Category	Criteria (Quantitative)	Interpretation
Stable	Overshoot < 5%, Phase Margin > 40°, Settling Time < 0.02 s	Highly stable and robust
Marginally Stable	Overshoot 5–10%, Phase Margin 25–40°, Settling Time < 0.1 s	Acceptable with controller tuning
Unstable	Overshoot > 10%, Phase Margin < 25°, Settling Time > 0.1 s	High risk of instability

According to the outcomes of the simulation, the DC Motor is uniformly categorized as Stable under all tested circumstances. The AC Motor is regarded as Marginally Stable under normal conditions but turns Unstable with significant changes in either damping or inertia [21]. This classification reinforces the idea that DC motors are more appropriate for tasks that demand precision and quick responsiveness, whereas AC single-phase motors require strong control methods to ensure stability [5], [21].

B. Comparison of Research Results

The results of this research corroborate and expand upon the findings of earlier studies. For example, Nise [1] and Ogata [2] highlight the ease of control and straightforward modeling of DC motors because of their linear characteristics, which corresponds with the strong performance noted here. At the same time, studies such as Mitra & Chakraborty [4] validate that DC motors react efficiently with simple PID controllers, a finding echoed in our own simulations.

Conversely, research on AC motor systems (e.g., Hughes & Drury [5], Chapman [2]) has consistently emphasized the difficulty of modeling single-phase motors because of phase asymmetry and the impact of auxiliary windings. Our results confirm these difficulties, as the AC motor showed increased sensitivity to parameter fluctuations and necessitated more precise controller adjustments to ensure stability.

This study stands out by providing a comparative analysis side-by-side through a cohesive electromechanical modeling framework, a technique seldom highlighted in previous research. Most prior studies separate motor types without examining their behaviors under identical conditions or variations in parameters.

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C. Research Limititations

Even with thorough modeling and validation, the study presents multiple limitations the AC motor was represented using a second-order approximation that fails to account for intricate nonlinear dynamics or harmonic distortions from auxiliary winding interactions. Certain parameters for the AC motor, including the damping coefficient and torque constant, were derived from literature instead of being measured directly, which may lead to discrepancies from actual performance. The research is completely based on MATLAB/Simulink simulations. Real motors undergoing actual experimental validation would reinforce the findings. Simulations occurred in optimal, noise-free settings, excluding temperature influences, supply voltage changes, or outside disruptions. These constraints could influence the applicability of the findings, especially when utilizing the models in industrial environments where real-world complexities exist.

D. Implications of the Research

This research offers numerous important insights for the design of control systems and the advancement of electromechanical systems: The comparative results assist engineers in selecting the correct motor type based on desired system stability, accuracy, and durability. For applications requiring high-speed precision, DC motors are still the preferred choice. Controller design approach, the findings indicate to control engineers that single-phase AC motors need more advanced controller designs, like derivative control or adaptive compensation, particularly in the presence of variable loads or uncertain parameters. The integrated modeling strategy serves as an instructional resource for demonstrating electromechanical control ideas across various motor categories through uniform mathematical principles. Basis for future Inquiry, This study establishes groundwork for hybrid modeling that combines data-driven techniques (such as system identification, machine learning) to improve motor behavior forecasting beyond solely deterministic transfer function methods.

V. Conclusion

This research aimed to examine and contrast the stability of electric motor control systems for two commonly utilized motor types—DC Moog BN12HS-13AF-01 and AC single-phase Simtach AC120M-11J30A—by simulating their performance based on electromechanical factors including torque constant, back-EMF, resistance, inductance, inertia, and damping. The main objective was to assess how these factors affect control system stability, utilizing a cohesive mathematical framework backed by simulation analysis in both the time and frequency domains.

The findings uncovered multiple important perspectives about stability in motor control: DC Motor Stability: The DC motor system consistently demonstrated enhanced stability, marked by quicker rise and settling times, low overshoot, and elevated gain and phase margins. These results verify that DC motors are naturally more manageable and less affected by parameter changes, rendering them ideal for precision control tasks. AC Motor Stability: The single-phase AC motor exhibited a slower reaction time and higher sensitivity to changes in inertia, damping, and electrical parameters. The system exhibited fair-to-below-average performance regarding settling time and overshoot, necessitating stricter control strategies to ensure stability. Model Precision: The two motor models, created from actual specifications and estimated parameters, generated outcomes that aligned with anticipated theoretical behavior, confirming the simulation framework employed in this research. Parameter Sensitivity: Of all parameters examined, damping (B) and rotor inertia (J) exhibited the most significant impact on the transient response and stability of the system. Decreases in damping specifically resulted in compromised performance and potential instability in the AC motor model.

In conclusion, this research validates the significant influence of electromechanical factors on the stability of control systems. DC motors provide reliable and consistent performance in various operating conditions, whereas AC single-phase motors need more detailed modeling and controller development. These results can help engineers and researchers make knowledgeable choices when choosing and managing electric motors for dynamic applications [3], [4].

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