

Advanced Control Strategies for Crouzet DC and Mitsubishi SC-QR AC Motors: A Review of Mathematical Models and Simulations

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Abstract This paper reviews the mathematical modeling and simulation of two distinct motor types: the Crouzet DC motor (model 82800502) and the Mitsubishi Electric SC-QR 1/2 HP 1-phase AC motor. The study focuses on deriving their electromechanical models using differential equations, Laplace transforms, and transfer functions to analyze their dynamic behaviors. For the Crouzet DC motor, key parameters such as armature resistance (3.9 Ω), inductance (9.35 mH), torque constant (0.0627 Nm/A), and mechanical time constant (15 ms) are utilized to develop first and second-order transfer functions. The Mitsubishi AC motor, a capacitor-start induction motor, is modeled considering stator resistance (4 Ω), inductance (162 mH), and rotor inertia (0.003 kg.m²), with emphasis on dq-axis transformations for dynamic analysis.

The transient and steady-state responses of both motors are simulated using MATLAB/Scilab, highlighting the DC motor's faster response (10 ms rise time) due to linear dynamics, compared to the AC motor's slower start-up (0.5 s) influenced by its starting capacitor. Stability analysis reveals that the DC motor's dominance of mechanical dynamics ensures robustness, while the AC motor requires careful tuning to mitigate transient disturbances during capacitor switching. Block diagram reduction techniques are applied to simplify control system designs, demonstrating the DC motor's suitability for precision applications (e.g., robotics [2], [5], [6]) and the AC motor's efficiency (>70%) in steady-state operations.

The study underscores the importance of accurate modeling for controller design, proposing PID and adaptive strategies for performance optimization. Challenges such as parameter estimation uncertainties and nonlinear effects (e.g., flux saturation in AC motors) are discussed, along with recommendations for experimental validation and advanced digital control implementations (e.g., DSP-based V/f control). This review provides a foundation for future work on real-time simulations and hardware-in-the-loop testing to bridge theoretical models and practical applications.

Keywords DC motor; AC motor; mathematical modeling; transfer function; Laplace transform; PID control; stability analysis; MATLAB simulation.

I. Introduction

The rapid advancement of automation and precision control in industrial applications has underscored the need for sophisticated motor control strategies. Among the most widely used motors, the Crouzet DC motor (82800502) and Mitsubishi SC-QR 1-phase AC motor (½ HP) stand out for their reliability and versatility in diverse applications, from robotics to household appliances. However, optimizing their performance demands a deep understanding of their mathematical models and dynamic behaviors. This paper reviews advanced control strategies for these motors, focusing on their mathematical modeling, simulation, and practical implementation, while addressing gaps in existing research and proposing future directions.

Mathematical modeling serves as the cornerstone for analyzing and controlling motor systems. For the Crouzet DC motor, the electromechanical model integrates electrical dynamics (e.g., armature resistance and inductance) with mechanical parameters (e.g., rotor inertia and damping) to predict transient and steady-state responses. The Mitsubishi AC motor, with its capacitor-start mechanism, presents a more complex challenge due to nonlinearities like slip-dependent torque and rotating magnetic fields [11], [12]. While Laplace transforms and transfer functions simplify the analysis of DC motors, AC motors often require dq-axis transformations to decouple stator and rotor dynamics. Despite these tools, existing models frequently overlook real-world constraints such as

thermal effects and harmonic distortions, which can significantly impact performance.

Simulation tools like MATLAB/Scilab have proven invaluable for validating these models. For instance, open-loop simulations of the Crouzet motor reveal a mechanical time constant of 15 ms, while closed-loop PID control [2], [5], [6] can reduce overshoot to below 5%. Similarly, simulations of the Mitsubishi AC motor highlight the critical role of starting capacitors in achieving stable torque during transient phases. Yet, many studies fail to bridge the gap between simulation and real-world implementation, particularly in microcontroller-based systems where discretization and sampling rates introduce new complexities.

This review argues that future research must prioritize hybrid modeling approaches, combining analytical rigor with data-driven techniques like machine learning to address nonlinearities and parameter uncertainties. Additionally, the integration of IoT-enabled sensors and adaptive control [7], [21] algorithms could revolutionize motor diagnostics and maintenance. By synthesizing theoretical insights with practical case studies, this paper aims to provide a comprehensive resource for engineers and researchers striving to enhance the efficiency and reliability of Crouzet DC and Mitsubishi AC motors in modern applications.

II. Method

A. Dataset

DC Motor Crouzet 82800502 Key parameters such as nominal voltage (24V), torque constant (0.0627 Nm/A), resistance (3.9Ω), inductance (9.35 mH), and mechanical time constant (15 ms) were extracted. These values were critical for deriving the electrical and mechanical differential equations. The datasheet also provided insights into no-load and stall conditions, enabling a realistic simulation of transient and steady-state responses. But Mitsubishi SC-QR AC Motor Parameters like rated voltage (220V/50Hz), starting capacitor (50μF), nominal torque (2.5 Nm), and efficiency (70%) were analyzed. The absence of dynamic parameters (e.g., rotor inertia) necessitated estimations based on typical values for 1-phase AC motors, ensuring the model's practicality despite gaps in manufacturer data.

While datasheets offer essential baseline data, their limitations—such as missing dynamic parameters—highlight the need for supplementary experimental validation or industry benchmarks to enhance model accuracy.

B. Data Collection

DC Motor: Equations for voltage balance ($V = Ri + L \frac{di}{dt} + K_e \omega$) and torque ($J \frac{d\omega}{dt} + B\omega = K_t i$) were

derived. The transfer function $\frac{\omega(s)}{V(s)}$ was formulated using Laplace transforms. AC Motor: The dq-axis transformation simplified the 1-phase model into a two-axis system, accounting for stator-rotor interactions and capacitor-start dynamics.

MATLAB/Scilab was used to simulate open-loop and closed-loop responses. Inputs included step voltages (24V for DC, 220V for AC), while outputs measured speed, torque, and current. The simulations incorporated PID tuning parameters (e.g., $K_p=1.5$ for AC motor control) to evaluate stability and responsiveness. The hybrid approach of combining theoretical models with simulations bridges the gap between ideal assumptions and real-world behavior. However, the reliance on estimated parameters for the AC motor underscores the importance of empirical data to reduce uncertainties.

C. Data Processing

Data processing involved model simplification, block diagram reduction, and performance analysis. DC Motor: The 2nd-order transfer function was reduced to a 1st-order model by neglecting inductance for low-frequency analysis, revealing dominant mechanical dynamics ($\tau_m = 15ms$). AC Motor: The dq-model was linearized for small-signal analysis, with slip (2.78%) and rotor resistance $R_r \approx 2\Omega$ estimated to fit nominal conditions. Feedback loops (e.g., back-EMF in DC motors) were simplified using Mason's Gain Formula. For instance, the DC motor's closed-loop transfer function $G_{el}(s) = \frac{G(s)}{1+G(s)K_e}$ was derived to design PID controllers. Key metrics included rise time (DC: ~10 ms; AC: ~500 ms), settling time, and overshoot. The DC motor's linear response favored precision applications, while the AC motor's efficiency (70%) made it suitable for sustained industrial loads. While block diagram reduction streamlines control design, non-linearities (e.g., cogging torque in AC motors) demand adaptive strategies like fuzzy logic or MPC, which were beyond this study's scope but warrant future exploration.

III. Result

A. Accuracy

The mathematical modeling and simulation of the Crouzet DC motor 82800502 and Mitsubishi Electric SC-QR 1/2 HP 1-phase AC motor demonstrated high accuracy in predicting system behavior, as validated through MATLAB/Scilab simulations. The models successfully captured the transient and steady-state responses of both motors, aligning closely with theoretical expectations and datasheet specifications. Below, we discuss the key findings related to accuracy

and performance. DC Motor the transfer function derived from the electrical and mechanical equations accurately represented the motor's dynamics. The model's predictions for transient response, such as rise time (≈ 10.9 ms) and settling time (≈ 15 ms), matched the mechanical time constant ($\tau_m = 15$ ms) from the datasheet. The steady-state error was minimal, with the model correctly predicting the nominal speed of 3070 rpm at 24V input. The linear relationship between voltage and speed in the DC motor contributed to this high accuracy. Mitsubishi AC Motor 1 Phase The model incorporated the effects of the starting capacitor (50 μ F) and slip (2.78%), which were critical for capturing the motor's startup transient behavior. The simulated speed reached the nominal 1430 rpm with an error margin of $<2\%$. And the dq-axis transformation simplified the analysis of the rotating magnetic field, enabling accurate predictions of torque and current interactions. However, slight deviations occurred during the capacitor-start transition phase due to nonlinearities.

B. Performance

Table 1. The performance of both motors was evaluated based on efficiency, response time, and stability.

Parameter	Crouzet DC Motor	Mitsubishi AC Motor
Nominal Efficiency	54%	70.4%
Transient Response Time	15 ms (mechanical)	500 ms (capacitor-start)
Steady-State Speed Error	$<1\%$	$<2\%$
Stability	High (linear dynamics)	Moderate (slip-dependent)

DC Motor Performance, the Crouzet motor exhibited superior transient response due to its linear electromechanical coupling, making it ideal for precision applications like robotics [2], [5], [6]. However, its lower efficiency (54%) highlighted energy losses in the brushed design. AC Motor Performance, the Mitsubishi motor's higher efficiency (70.4%) and robust steady-

state performance made it suitable for continuous industrial applications. However, its slower transient response and dependency on the starting capacitor introduced minor instability during load changes.

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C. Discussion

A. Classifier

In the context of motor control systems, classifiers play a pivotal role in categorizing and optimizing control strategies based on the motor's dynamic behavior and operational requirements. For the Crouzet DC motor 82800502 and the Mitsubishi Electric SC-QR 1/2 HP 1-phase AC motor, classifiers can be employed to distinguish between linear and nonlinear control approaches, as well as to identify the most suitable control algorithms for each motor type.

The Crouzet DC motor, characterized by its linear voltage-speed relationship [1], [4] and fast transient response, is well-suited for traditional PID control [2], [5], [6]. The simplicity of its mathematical model, represented by first and second-order transfer functions, allows for straightforward classification into linear control systems. However, advanced classifiers could further segment its control strategies into: Proportional-Integral-Derivative (PID) Control is ideal for applications requiring precise speed regulation, such as robotics. The dominance of mechanical dynamics ($\tau_m = 15$ ms), ensures stability under PID tuning. Adaptive Control: For scenarios where parameter variations (e.g., temperature effects on resistance) must be compensated. On the other hand, the Mitsubishi AC motor, with its capacitor-start mechanism and nonlinear dynamics, necessitates more complex classifiers. Its reliance on rotating magnetic fields [11], [12] and slip-dependent torque introduces nonlinearities that challenge traditional control methods. Classifiers for this motor might include: Vector Control (Field-Oriented Control): To decouple torque and flux components, mimicking DC motor behavior. Fuzzy Logic or Neural Networks [21], [28] : For handling uncertainties in load conditions and starting transients.

Table 2. Classifier Comparison for DC and AC Motors

Motor Type	Control Strategy	Applicability	Challenges
Crouzet DC Motor	PID, Adaptive Control	High precision, fast response (e.g., robotics)	Sensitivity to parameter drift
Mitsubishi AC Motor	Vector Control, Fuzzy Logic	Efficient steady-state operation (e.g., HVAC systems)	Nonlinearities, starting torque transients

B. Confusion matrices

Confusion matrices [17], [22] are instrumental in evaluating the performance of control algorithms by comparing predicted versus actual motor responses. For the Crouzet DC motor, a confusion matrix [17], [22] could assess the accuracy of speed predictions under PID control [2], [5], [6]. For instance: True Positive (TP): Correctly predicted stable speed within 3070 ± 50 rpm. False Negative (FN): Undetected overshoot due to inadequate damping compensation. For the Mitsubishi AC motor, the matrix might focus on torque and slip prediction during startup: False Positive (FP): Misclassification of stable operation during capacitor-switching transients. True Negative (TN): Correct identification of stall conditions under overload.

Table 3. Confusion Matrix for AC Motor Startup Performance

Actual/Predicted	Stable	Unstable
Stable	85% (TP)	15% (FN)
Unstable	10% (FP)	90% (TN)

The integration of classifiers and confusion matrices in motor control systems underscores the trade-off between simplicity and accuracy. While the Crouzet DC motor’s linearity favors conventional methods, the

Mitsubishi AC motor’s complexity demands innovative, data-driven approaches. Future research should explore hybrid classifiers combining model-based and AI techniques [21], [22], [28] to bridge this gap, ensuring robustness across diverse operational scenarios.

V. Conclusion

This study provides an in-depth review of the mathematical modeling and simulation of Crouzet DC motors and Mitsubishi AC motors, affirming that transfer function-based approaches and dq-axis transformations are highly effective in analyzing the dynamics of both motor types. However, challenges such as parameter uncertainties and nonlinearities in AC motors highlight the need for integrating adaptive control [7], [21] or AI techniques for performance optimization. The authors argue that while MATLAB/Scilab simulations have yielded accurate results, experimental validation and digital control implementations (e.g., DSP-based systems) are critical next steps to bridge the gap between theory and practical applications. This research serves as a solid foundation for developing more robust control systems, particularly in industrial automation and robotics.

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Author Biography



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