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Robustness Investigation of State Estimation Methods for PMSM

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Abstract

This paper presents a robustness analysis of three state estimation methods for sensorless control of permanent magnet synchronous motors (PMSM): a conventional back electromotive force (BEMF) observer, a gradient-based adaptive flux observer, and a nonlinear observer based on Dynamic Regressor Extension and Mixing (DREM). Their theoretical foundations and convergence properties are analyzed. Simulation and experimental tests under measurement noise, parameter perturbations, and load disturbances evaluate steady-state error, dynamic response, and robustness. Results show that the conventional observer is parameter-sensitive, the adaptive observer achieves asymptotic convergence, while the DREM-based observer provides faster convergence.

Keywords

Permanent magnet synchronous motor, position sensorless control, back electromotive force observer, adaptive observer, DREM observer, robustness analysis, parameter uncertainty

Исследование робастности наблюдательных методов оценки состояния в системах управления синхронными двигателями с постоянными магнитами

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Аннотация

В статье представлен анализ робастности трёх методов оценки состояния для систем бездатчикового управления синхронными двигателями с постоянными магнитами (СДПМ): традиционного наблюдателя на основе противо-ЭДС, адаптивного наблюдателя потокосцепления на основе градиентного метода и нелинейного наблюдателя, основанного на методе динамического расширения и смешивания регрессора (DREM). Проанализированы их теоретические основы и свойства сходимости. По результатам моделирования и экспериментов с учётом шумов измерения, параметрических возмущений и изменений нагрузки оценены установившаяся ошибка, динамический отклик и робастность. Показано, что традиционный наблюдатель чувствителен к параметрам, адаптивный обеспечивает асимптотическую сходимость, тогда как наблюдатель на основе DREM демонстрирует более быструю сходимость.

Ключевые слова

Синхронный двигатель с постоянными магнитами, бездатчиковое управление положением, наблюдатель на основе противо-ЭДС, адаптивный наблюдатель, наблюдатель на основе DREM, анализ робастности, параметрическая неопределённость

In the sensorless control system of permanent magnet synchronous motors (PMSM), the performance of the flux and rotor position observers directly determines the dynamic response and steady-state accuracy of the system. This study conducts a comparative analysis of three representative observers: the traditional observer based on the back electromotive force (BEMF) model[1], the flux observer based on gradient descent/adaptive structure[2], and the nonlinear robust observer based on the dynamic regulator extension and mixture (DREM) with finite-time convergence[3].

Firstly, this study analyzes the theoretical framework and convergence characteristics of these observers. The traditional observer-based observer is highly dependent on machine parameters and is prone to be affected by noise in low-speed and weak BEMF conditions. The adaptive observer partially alleviates the parameter sensitivity issue, but its convergence speed highly depends on the excitation conditions. In contrast, the observer based on DREM decouples the flux and parameter estimates by constructing an extended regulator model, thereby achieving finite-time convergence under interval excitation (IE) conditions. Through simulation and experimental platforms (including current measurement noise, stator resistance/inductance perturbations, and load torque disturbances), these observers are systematically evaluated in terms of steady-state error, dynamic response time, anti-noise ability, and parameter robustness. The results show that although the traditional observer has significant steady-state deviations when the parameters are mismatched, the adaptive observer can only achieve asymptotic convergence. However, the observer based on DREM outperforms in terms of convergence speed to parameter uncertainties and external disturbances. Simulation and experimental studies, including current measurement noise, stator resistance and inductance perturbations, and load torque disturbances, are conducted to evaluate steady-state error, dynamic response speed, noise immunity, and robustness to parameter uncertainties [4]. The results demonstrate that DREM-based observers exhibit superior convergence performance compared to conventional and adaptive methods. This study provides a basis for the selection of observers in high-performance sensorless permanent magnet synchronous motor control systems.

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