Generalized Sensorless and Advanced Control of Synchronous Reluctance Machines

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Summary

For their higher efficiency and power density, the synchronous machines have become prominent in variable-speed-drives (VSD). In keeping with the growing energy-efficiency standards and high-performance requirements, research on the control of motor drives have sought to push the boundaries, in synergy with the advancements in motor design and semiconductors. Within the scope of control of synchronous machines, this work focuses of three aspects, namely: *(i)* Sensorless control; *(ii)* Self-Commissioning and *(iii)* Direct Flux Vector Control (DFVC).

Sensorless control is pursued for cost reduction, reliability and redundancy. A generalized projection vector framework is developed for design and analysis of the flux observer-based position estimation techniques. A few known sensorless schemes in literature are reviewed within the projection vector framework to identify regions of instability. Following, a new auxiliary-flux position observer (AUX) is designed for stable operation. A main contribution is the development of adaptive projection vector for position error estimation (APP) scheme that has a unique property of stator resistance immunity for operating points on the maximum-torque-per-ampere (MTPA) trajectory. Concurrent with the position estimation, the feasibility of speed error estimation and parameter adaptation are explored. A novel model-based torque control strategy is designed with APP position observer for accurate torque control under parameter errors. In addition to the work on fundamental back-emf based sensorless control techniques, an injection-less sensorless control scheme is investigated for operations at zero to low speeds region.

Given the nonlinearity of the magnetic model of synchronous machines, it becomes imperative to have an accurate flux-map for optimal operations as well as stable sensorless control. To this end, the self-commissioning involves identification of magnetic model without a dedicated lab environment. Two self-commissioning techniques for synchronous reluctance (SyR) machines are discussed of which one is a sensorless variant at standstill condition while the other uses position transducer at free-shaft for alternating acceleration-deceleration.

Thirdly, the DFVC is explored as a high-performance control strategy, particularly for its ease of operation in flux-weakening regions. With respect to the state-of-art, an accurate model of control dynamics in stator flux-oriented reference frame is developed accounting for the magnetic saturation. The proposed nonlinear decoupling is shown to achieve higher bandwidths for a uniform performance at all operating points. In addition, a new small-signal model based optimal reference generation is designed with stator flux magnitude and load angle as the controlled variables that permits operation at the MTPV limit and thus, exploiting the extremums of the speed-torque characteristics. All proposed schemes are supported with experimental validation.