同步磁阻馬達之建模與向量控制器設計

Modeling and Vector Control Design of a Synchronous-Reluctance Motor

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・模型建構	Modeling
・能源效率	Energy Efficiency
・向量控制	Vector Control

摘要(Abstract)

同步磁阻馬達是一種同步機，但其轉子不像一般同步機那樣，需要在轉子繞線以激磁或裝置永久磁鐵，它的轉子材料是如矽鋼片的導磁材料，藉由轉子凸極現象造成磁阻的不均勻，來產生力矩而轉動，它也不會像永磁同步馬達那樣，其轉子磁鐵經年累月運轉後會產生磁性減弱的問題。故其構造簡單，具有堅固的特性，近年來吸引著工業界的注目。故精確的馬達模型，以分析其特性與效率，以及其控制器設計，使其性能優化是非常重要的。

本文描述一個同步磁阻馬達之相變數模型之建構，以電磁、機電與機械三部份來推導感應馬達的數學方程式，並利用 PSIM 模擬軟體工具建立該同步磁阻馬達的相變數模型，仿如一實際的馬達操作，在其三相輸入端以電阻、電感與相依電壓源電路元件來建構其模型。所建模型的特色有二：一是三相定子輸入端是採用電路元件建立的，可以和馬達變頻驅動電路連接，以便做馬達驅動控制的整合模擬；二是負載轉矩輸入端是以數學函數元件建立的，可用數學函數的形式加入負載轉矩。給予三相輸入電壓的頻率並加入負載

轉矩來模擬分析，驗證了該模型轉速穩態響應的正確性。

本文並提出以鎖相迴路為基礎的功率因數角量測電路，藉由機械功率與輸入電功率的比值，得出該同步磁阻馬達在不同負載轉矩情況下運轉時的能效曲線，並得出定子電阻大小是影響該馬達的能效的主因。

除此，本文並推導在同步旋轉座標之 d-q 模型，依此模型設計以轉子轉軸為導向的向量控制器，包含 PI 解耦電流控制器與包含一前饋補償器的二自由度 PI 轉速控制器，模擬結果顯示所設計的控制器對轉速命令與負載轉矩的瞬間加入皆有理想的轉速響應。

The synchronous reluctance motor (SynRM) is one kind of synchronous machine. But, unlike the general synchronous machine, where the rotor is wound with wires for magnetic excitation or is equipped with a permanent magnet, the rotor material of the SynRM is high-permeability material such as silicon steel. The torque generation for rotation of the SynRM is by means of the reluctance unbalance due to the salient pole effect. In addition, the SynRM is unlike the permanent magnet synchronous motor (PMSM), in which the rotor magnetism will decrease after long-time rotation. Recently, with its features of simple and rugged construction, the SynRM has received a lot of attention in industry. Therefore, both the modeling of the SynRM for analysis of the motor characteristics and energy efficiency, and the control design for optimization of the motor performance are important.

This paper presents the phase-variable modeling of a SynRM in the PSIM simulation tool. It can be divided into an electromagnetic part, an electro-mechanic part, and a mechanical part in deriving the mathematical model of the synchronous reluctance motor. Just like a real motor, the three-phase inputs are modeled by means of the resistor, inductor, and the dependent voltage source circuit elements. There are two features of the constructed model block. One is that the three-phase inputs are circuit-based, so it can be directly connected to the inverter for integrated system simulation. The other one is that the load torque input is equation-based, so the load torque can be given by a mathematical function. Given a three-phase input voltage and a constant load torque, the stead-state speed response can be proven to be correct.

For evaluation of the motor's energy efficiency, the power factor angle is calculated by means of a phase-locked loop scheme. The energy efficiency curve under different load-torque cases was obtained by calculating the ratio of the mechanical power to the electric power of the motor. The stator resistance value dominates the motor efficiency.

In addition, the model of the motor in the d-q synchronously rotating frame is derived, based on which the rotor-axis oriented vector controller is then designed. This controller contains two PI-decoupling current controllers and a

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