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A Synthetic Frozen Permeability Method to Separate PM torque in Hybrid Permanent Magnet Variable-Flux Machine

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Frozen permeability method has been widely used in separating the PM torque and reluctance torque and calculating inductance. For conventional frozen permeability method (CFPM), only the core permeability is fixed. It is suitable for the machine applying rare-earth PM materials such as NdFeB, since the material B-H curve is linear and coincide with the recoil line. However, when dealing with machines applying nonlinear PM materials, CFPM will cause obvious errors. Unlike rare-earth magnet, AlNiCo has nonlinear demagnetization curve and the recoil lines of different operate point are a set of parallel lines with different coercive force, causing the output of AlNiCo different. So when accounting for the effectiveness of AlNiCo, the recoil line should be kept as same as full load condition. Therefore, this paper proposes a synthetic FPM (SFPM) to accurately calculate torque components of machines applying nonlinear PM materials. Hybrid permanent magnet variable flux machines (HPM-VFM) applying both linear and nonlinear PMs are proposed to validate the accuracy of SFPM. For the machine analysis, nonlinear FEA at a particular load condition is carried out firstly. In each simulation block, operation points of AlNiCo are recorded and a linear PM material which passes through point (Bi, Hi) with a slope of the recoil permeability is defined. Then a FEA with this linear material is carried out. Entire machine torque calculated by SFPM is 6.36Nm, which matches well with the result calculated by the nonlinear FEA 6.52Nm with only 1.07% error. Besides, AlNiCo PM torque, NdFeB PM torque and reluctance torque calculated by SFPM is 2.46Nm, 3.90Nm and 0.23Nm respectively. The CFPM results, whose PM torque is 5.88Nm and reluctance torque is 0.23Nm has 6.29% error comparing with nonlinear FEA. More elaborate results of analysis and comparison will be exhibited in the full paper.

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