Design and analysis of a less-rare-earth PM-assisted synchronous reluctance machine considering tradeoffs of PM flux linkage and magnetic saliency

Wenyu Wu, Xiaoyong Zhu, Li Quan, Yi Du and Zixuan Xiang, Xuhui Zhu
School of Electrical and Information Engineering, Jiangsu University, Zhenjiang 212013, Jiangsu

Abstract
In this paper, a new PM-assisted synchronous reluctance machine is proposed, where two types of PM materials of rare earth PM and ferrite PM are felicitously arranged in its rotor. Considering the complexity of the rotor structure and multiple flux barrier properties, a hierarchical design method is employed in its rotor design, in which the design is divided into two levels: magnetic saliency design level and PM usage design level. In saliency design level, a reasonable flux barrier shape with high average torque is achieved. And in PM usage design level, the low torque ripple, high efficiency and high power factor is obtained, and meanwhile a low rare earth usage is retained. Finally, based on the hierarchical design, the electromagnetic performance are investigated to verify the feasibility and validity of the proposed motor and design method.

Hierarchical design method
Since complex flux barriers and multi design variables is owned in this motor, a multi-dimensional optimization is very complicated and time-consuming, sometimes even non-convergent when all design objectives are considered simultaneously. Therefore, a hierarchical design method is adopted in this proposed motor to solve the problem of multi objective and multi variables, in which the design process is divided into two levels, it is magnetic saliency design level and PM flux linkage design level, respectively.

PM usage-design level

Design Method

PM flux linkage design

Response surface analysis

Flux linkage design

Magnetic field distribution

Topology and Design specifications

Topological and Magnetic Field

Conclusion

By theoretical analysis, it can be observed that only when the saliency ratio is higher than 2.73, can it achieve a PM-assisted reluctance motor.

By incorporating both rare-earth PM and non-rare-earth ferrite PM materials into rotor flux barriers, the proposed motor can not only offer the comparable electromagnetic performance, but also achieve a low rare-earth PM usage, which offers a competitive price advantage compared with the pure rare-earth motors.

The proposed hierarchical design method is verified to be effective in the motor design, especially for the motor with complex flux barriers and multi-excitation sources.

Here, the ratio of magnet torque $T_m$ and reluctance torque $T_r$ is defined as a value of $k$, that is

$$k = \frac{T_m}{T_r} = \frac{k_1}{(L_q-L_r)}$$

Where the maximum torque is obtained, the above equation can be expressed as following condition

$$\frac{\partial}{\partial \theta} \psi_m = \rho \psi_m - k \psi_r$$

If $L_q$ is chosen as its optimum value, $L_{opt}$, namely, the maximum current is enough to offset permanent magnet flux linkage completely. Hence, a relationship between $k$ and $p$ can be given below

$$\rho = \frac{k}{k+rac{1}{2}}$$

Finally, the optimal point is proposed, $W_{m(OP)}$, the PM flux linkage and magnetic saliency is achieved.