Comparison of Synchronous Reluctance Machines with High-Anisotropy Rotors

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Abstract – **In terms of torque capability, power factor and efficiency, synchronous reluctance machines with high-anisotropy rotors represent an alternative to conventional induction machines. In particular, they have very robust rotors and can therefore operate at constant power in a wider field-weakening range. The paper discusses a comparison of the various machine concepts using an identical machine geometry by using finite element analyses.**

I. Machine Designs

In the dq rotor fixed reference frame, the stator current and stator flux space vectors are given by

$$\underline{i}_{S,dq} = i_{Sd} + j\, i_{Sq} \quad = i_S\ \mathrm{e}^{j\beta} \quad , \tag{1}$$

$$\underline{\psi}_{S,dq} = \psi_{Sd} + j\, \psi_{Sq} = \psi_S\ \mathrm{e}^{j\vartheta} \quad , \tag{2}$$

where β,ϑ denote stator current angle and stator flux angle, respectively. By using direct and quadrature axis stator inductances l_d,l_q, the components of the stator linkage flux are defined as

$$\psi_{Sd} = l_d\, i_{Sd} + \psi_{Md} \ \ , \tag{3a}$$

$$\psi_{Sq} = l_q\, i_{Sq} + \psi_{Mq} \ \ . \tag{3b}$$

The conventional reluctance machine can be described with a vanishing linkage flux $\psi_M = 0$. With the permanent magnet assisted reluctance machine, $\psi_{Mq} < 0$ represents the permanent magnet linkage flux which counteracts to any quadrature axis stator current $i_{Sq} > 0$. On the other hand, the permanent magnet excited reluctance machine with $\psi_{Md} > 0$ can be designed as either a normal-saliency machine $l_d > l_q$ or an inverse-saliency machine with $l_d < l_q$.

Fig. 1 depicts the cross section of the high-saliency rotors of the different machine designs concerned. With all these four designs, the stator is identical and consists of 24 slots with a conventional three-phase full-pitch winding.

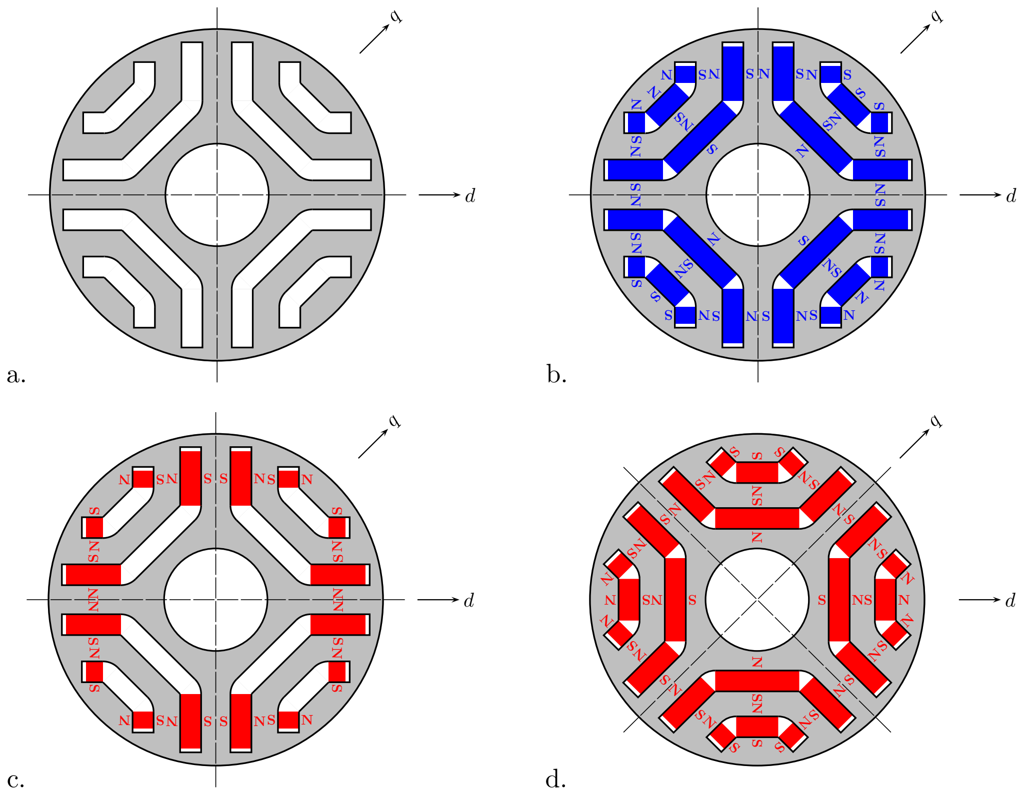

Fig. 1: Comparison of the machine designs: a. conventional reluctance machine,
b. permanent magnet assisted reluctance machine with $\psi_{Mq} < 0$, $l_d > l_q$,
c. normal-saliency permanent magnet excited reluctance machine with $\psi_{Md} > 0$, $l_d > l_q$,
d. inverse-saliency permanent magnet excited reluctance machine with $\psi_{Md} > 0$, $l_d < l_q$

II. Sample Analysis Results

Fig. 2 shows the ratio l_d/l_q of the apparent inductances in dependence of the stator current magnitude i_S with a current angle of $\beta = \pi/4$ for both the conventional reluctance machine and the permanent magnet assisted reluctance machine with $\psi_{Mq} = -0.3$. Therefore, the permanent magnets significantly increase the saliency-ratio resulting in a wider speed range with constant power.

Fig. 3 and Fig. 4 show the ratio l_d/l_q or l_q/l_d of the apparent inductances in dependence of the stator current magnitude i_S with current angles of $\beta = \pi/4, \pi/2, 3\pi/4$ for the normal-saliency and the inverse-saliency permanent magnet excited reluctance machine with $\psi_{Md} = 0.6$, respectively.

In comparison of the four machine designs, the latter concept yields the highest saliency-ratio resulting in the widest speed range with constant power.

III. Concluding Remarks

Synchronous reluctance machines with internal rotor flux barriers are well suited for an application in position-sensorless drives with a wide field-weakening range due to their high effective saliency. By using an identical machine geometry, the conventional reluctance machine and the permanent magnet assisted reluctance machine as well as the normal-saliency permanent magnet machine and the inverse-saliency permanent magnet machine are compared against their operational behaviour in particular in the field-weakening range.

The full paper will additionally discuss the current trajectories for maximum torque with respect to the dq reference frame. These diagrams obviously depict the advantages of a high saliency ratio l_d/l_q in case of normal-saliency machines or l_q/l_d in case of inverse-saliency machines in particular in the field-weakening region. Additionally, a comparison with measurement data will be given.

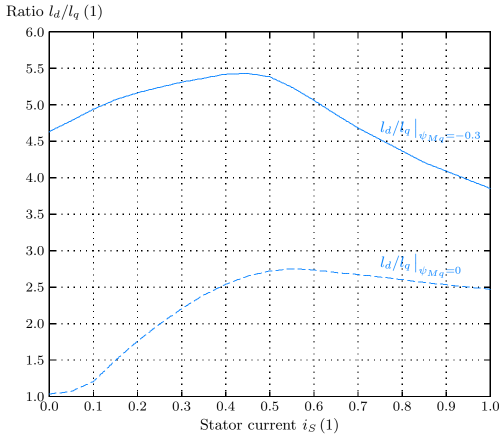

Fig. 2: Ratio l_d/l_q versus stator current magnitude i_S, current angle $\beta = \pi/4$, conventional reluctance machine (dashed line), permanent magnet assisted reluctance machine (straight line)

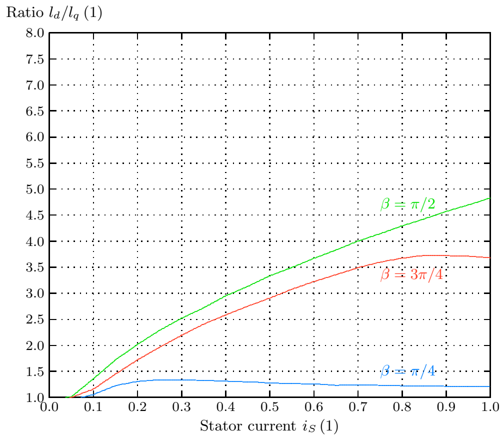

Fig. 3: Ratio l_d/l_q versus stator current magnitude i_S, current angles $\beta = \pi/4, \pi/2, 3\pi/4$, normal-saliency permanent magnet excited reluctance machine

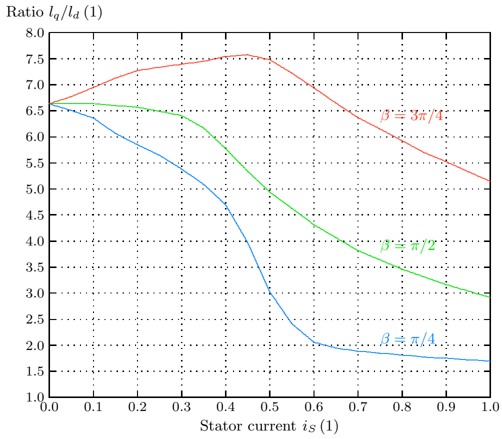

Fig. 4: Ratio l_q/l_d versus stator current magnitude i_S, current angles $\beta = \pi/4, \pi/2, 3\pi/4$, inverse-saliency permanent magnet excited reluctance machine

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