Theoretical Analysis of Synchronous Machines with Displaced Reluctance Axis

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Conventional IPMSM

PMSM with Displaced Reluctance Axis (Magnetically Asymmetric)

Conventional EESM

Unified Theory

Assumptions
- no losses (no stator resistance)
- iron is linear (no saturation)
- no harmonics
- current feeding

Description
- normalized PM flux linkage: \( \psi_{PM} \)
- saliency (ratio of inductances): \( \zeta = \frac{i_d}{i_q} \)
- displacement angle (d→r): \( \beta \)

Special Cases
- conventional IPMSM: \( \beta = 90^\circ \)
- conventional EESM: \( \beta = 0^\circ \)

Transformation
\[
\begin{align*}
    i_d &= i_d \cdot \cos \beta + i_q \cdot \sin \beta \\
    i_q &= -i_d \cdot \sin \beta + i_q \cdot \cos \beta
\end{align*}
\]

Control Strategies
example machine with \( \psi_{PM} = 0.4, \zeta = 3, \beta = 30^\circ \)

Machine Design I: \( \zeta \)-Curves
advantages through variation of the displacement angle \( \beta \)

Machine Design II: Parameter Planes

Conclusion
- unified theory of synchronous machines with displaced reluctance axis, dependent on only three parameters
- derivation of optimal torque control strategies
- further degree of freedom for machine design:
  - optimization of cost (e.g. case B1: 11.4% less PM material for equal torque)
  - optimization of performance (e.g. case B2: 4.3% more torque using the same amount of PM)