Reducing torque ripple and power consumption in

Switched Reluctance Motors: a systematic approach to commutation function design

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Abstract

Switched Reluctance Motors (SRMs) are attracting increased attention since they enable energy-efficient actuation while being mechanically simple and cheap in maintenance and construction. Examples of applications that particularly benefit from these aspects include optical satellite communication [1] and electric vehicles [2]. The SRM is depicted schematically in Figure 1.

At the same time, SRMs exhibit highly nonlinear dynamics due to their three-phase actuation principle, which complicates control design, see Figure 2. The nonlinear dependency of the torque-current relationship on rotor position is typically linearized by designing a commutation function to divide currents over coils. The design of commutation functions is not unique: at any rotor position, multiple combinations of currents produce the same torque.

Although some existing design methods of torque sharing functions found in literature make use of the design freedom in the commutation problem (see, e.g., [3]), these methods do not feature intuitive tuning knobs based on physical insights, or do not address torque ripple arising from sampled-data aspects.

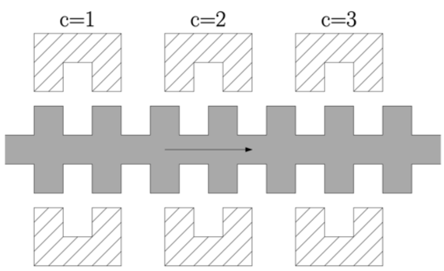

Figure 1. Working principle of a switched reluctance motor. By magnetizing the three shaded coils sequentially, the grey rotor teeth are attracted by different coils, and a torque is applied to the rotor.

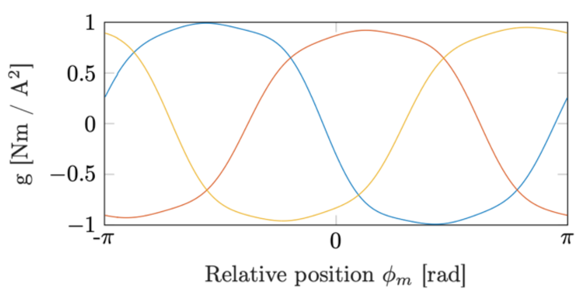

Figure 2. The torque-current relationship of the coils of an SRM is periodic in the rotor position. Hence, at every position, the current can non-uniquely be divided over coils using a commutation function to achieve a desired torque.

The aim of this work is to develop a design strategy for commutation functions that leverages this design freedom in an intuitive manner. The key idea is to pose the commutation design as an optimization problem, where the design variables are commutation function values F at discrete rotor angles, and the cost function can be chosen freely. For example, consider the following problem,

$$\begin{aligned} \min_{F} \quad & J(F) = \alpha\|F\|_1 + \beta\|F\|_{\mathcal{S}} + \gamma\|T_{\text{ripple}}(F)\|_2 \\ \text{s.t.} \quad & GF = 1, \\ & F \geq 0, \end{aligned} \tag{1}$$

where the cost function consists of a term that penalizes the power consumption of the commutation function, as well as the rate of change of currents, and sampling-induced torque ripple, respectively. The equality constraints ensure that the commutation function correctly linearizes the nonlinear angle-torque-current relationship *G* at all rotor positions, see Figure 2, and that all commutation values are positive. The values α, β, and γ are intuitive tuning knobs that shape the resulting commutation functions towards a different solution, depending on the user's priority.

The optimization problem (1) is convex and can be solved efficiently to find a global minimizer, i.e., commutation function values that satisfy the user-defined cost function. To obtain a continuous commutation function that can be used online, Gaussian Process regression is used to interpolate between the discrete solution points, see Figure 3. Figure 4 illustrates how different values of α, β, and γ lead to different commutation functions.

In conclusion, the developed method for commutation design allows the user to linearize SRM dynamics intuitively and systematically, by leveraging the design freedom inherent in commutation.

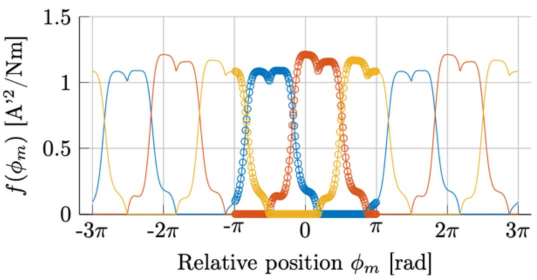

Figure 3. The optimization problem (1) yields commutation function values at discrete locations, and GP regression is used to obtain a continuous function.

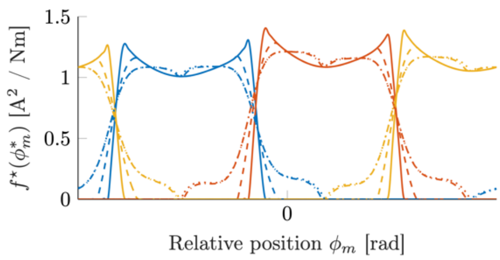

Figure 4. Commutation functions that follow from solving (1) for different values of α, β, and γ. By tuning these parameters, the user can influence properties of the commutation function such as power consumption and torque ripple.

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