T2-16 MEP-(Maximum efficiency point) control of PMSM, based on an improved typical equivalent circuit representation of electric machine instead of an ordinary MTPA/MTPA (Maximum torque per ampere/voltage)

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Summary

Today, for controlling a Permanent Magnet Synchronous Machine (PMSM) either a constant control angle for the current is used or it is obtained from a circuit based modelling of PMSM in order to get the Maximum Torque Per Ampere (MTPA) trajectory. This, however, does not necessarily produce the maximum torque per ampere for the entire operating region of the machine since the circuit based model is simple and may not accurately present the torque production in the machine.

The aim of the project is to create knowledge about the applicability of the equivalent circuit of electric machines for efficiency calculations. The main goal is to obtain a PMSM control strategy that maximizes the efficiency considering the equivalent inductances and magnet factors with dependency on the operating point and temperature.

The developed algorithm has shown to improve the torque capacity of the machine at very low speeds to up to 6% compared to an ordinary control strategy, however the energy benefit is shown to be less significant and is limited to 0.2% depending on the drive cycle.

Start of the project **1/10 2014** end of the project **30/6 2015**

Budget and resource requirement: 865 kkr

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Reference group:

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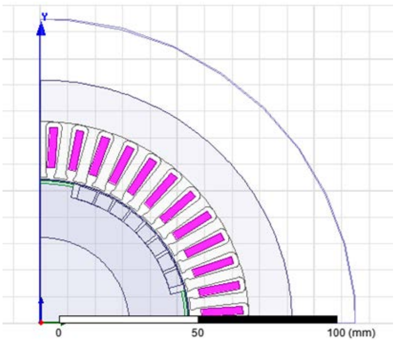
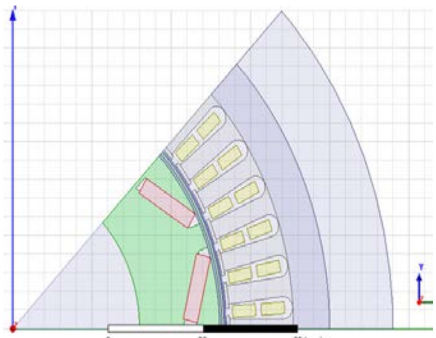
Background

In order to get a certain output torque in a PMSM, the input current of the machine needs to be controlled. However, the three phase alternating currents (ac) in the machine can, with the help of the rotor position and mathematic equations be transformed to another system called direct-quadrature (dq) system where only two direct current (dc) variables need to be controlled. However, many different combinations of dq currents can lead to a specific output torque. Which combination gives the highest torque for a given current magnitude? How good are already available methods in relation to the proposed method? Does the temperature influence the choice of dq current?

General project description

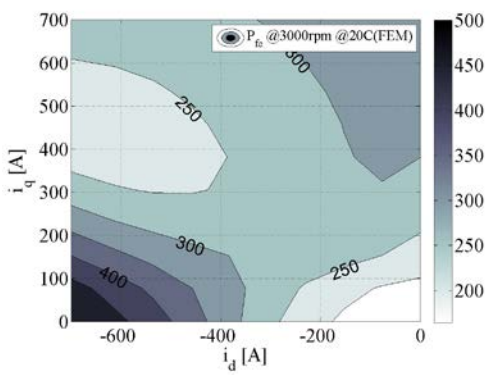
Two representative vehicle-PMSMs (i.e. an electric machine with a reduced size so it can be fitted in a vehicle and therefore has significant iron losses) is implemented in Maxwell and is depicted in the figure below.

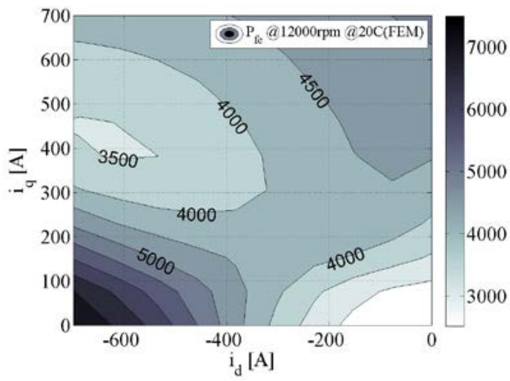




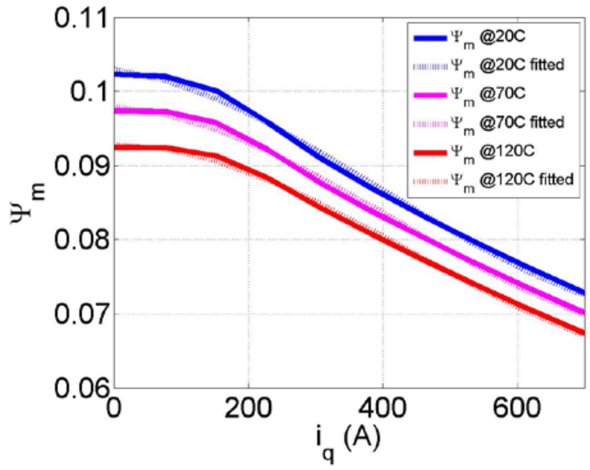
Machine and iron losses of the machine in particular are obtained from FEA for key current, speed and temperature combinations.

In the following figure the iron loss is depicted for two different speeds for all possible dq current combinations for the machine shown in the left hand figure.

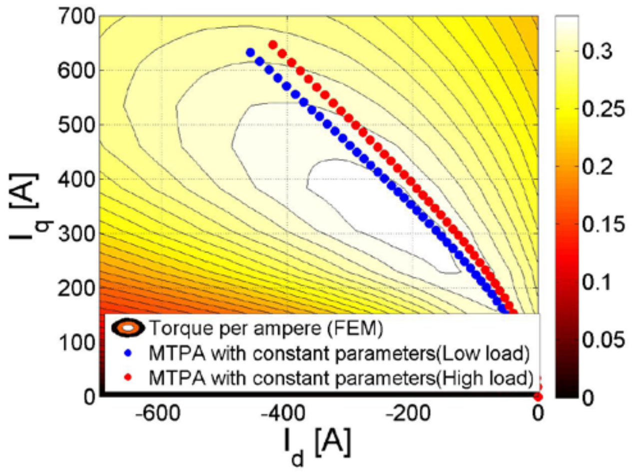




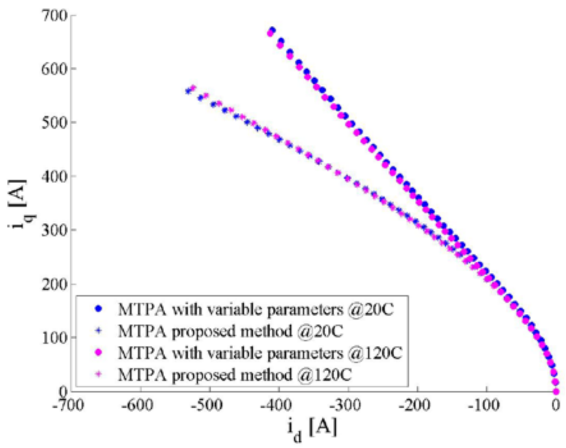
Electrical equivalent parameters of the machine such as $L_d/L_q/\Psi_m$ are obtained from FEM simulations and are approximated by analytical expressions. The saturation effect, the cross coupling and the temperature influence are also considered. In the following figure the actual Ψ_m obtained from FEM simulations and the approximated one is illustrated in three different temperatures.



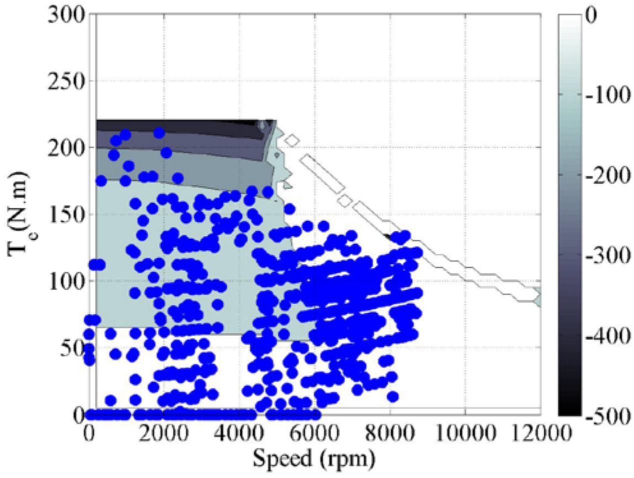
After the machine is developed and the parameters are extracted, an ordinary MTPA control of machine based on constant parameters is developed. Using the machine parameters obtained in either high load or low load condition still shows a deviation from the absolute maximum torque per ampere contours shown in the figure below.



An improved MTPA control strategy which is obtained based on the Lagrange method including the cross coupling, saturation and the temperature is developed. The current trajectory (dq currents) obtained from this method are compared with the MTPA using variable parameters which are updated outside the optimization problem. It can be seen that the dq current trajectory from the proposed method deviates from the ordinary MTPA. However the temperature does not affect the current trajectory significantly.



Finally the total power loss difference between the ordinary control strategy and the developed one in the entire torque-speed map of the machine is obtained for drive cycle investigation. As it can be seen in the figure below, the power loss decrease can be up to 500W at high torque area. This can be utilized to improve the maximum output torque of the machine at very speeds.



Achieved results

The development of the algorithm, modelling of the machine and iron losses and the quantification of benefit gained by the use of the algorithm is gathered in an article that is underway and will be submitted for review by the end of this project.

The developed algorithm has shown to improve the torque capacity of the machine at very low speeds to up to 6%, however the energy benefit is shown to be less significant and is limited to 0.2%.

Contribution to hybrid vehicle technology

The work gives the possibility to reduce the losses in the electrical machine without adding any extra hardware, just slight software modifications are needed. The reduced losses lead to longer driving range, and less need for cooling. The large reduction of losses at full current gives the possibility of actually slightly increasing the maximum torque of the electric machine.

Timing and finance

The total project time is 9 months. The total project budget is SEK 865 kkr

Executors and collaboration

Torbjörn Thiringer has been the project manager and developed the FEA model of the electric machines. Ali Rabiei has developed the control algorithm and obtained the results from the comparison between the ordinary MTPA and the improved one. Johan Åström has investigated and provided the iron loss calculations.

Papers and publications

Writing of a Journal publication is underway and is estimated to be sent by the end of the project time (30/60)