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XXXVII Cycle

Sensorless Control of Electric Vehicle Traction IPMSM

Andras Holczer

Supervisor: Prof. Radu Bojoi

Research context and motivation

- Sensorless control of electric drives can eliminate the use of position sensor during operation, thus increasing reliability and decreasing cost of the drive. Many methods have been proposed and commercialized in industrial applications such as fans and pumps. Encoder is normally used in case of electric vehicle (EV) traction application, hence sensorless control provides backup in case of encoder failure. The aim of the research is to develop sensorless control on the whole operating speed range for EV traction interior permanent magnet synchronous motor (IPMSM). EV motor is likely to work under heavy saturation, thus linear techniques need modification to ensure accurate current control with high bandwidth.

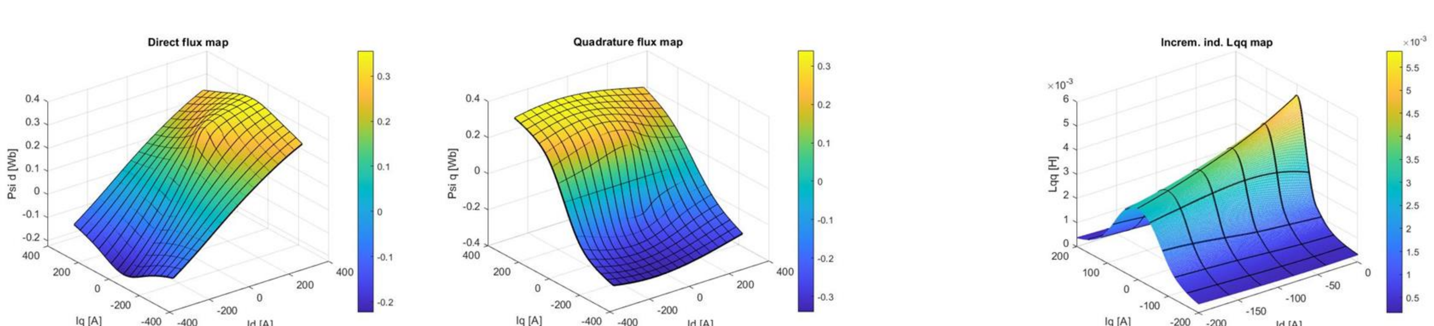
- The research involves many aspects of sensorless control, such as switching on-the-fly (transition from encoder-based to sensorless operation), transition from saliency-based to model-based method, and utilizing the flux and inductance maps for the improvement of electrical angle and speed demodulation.

- The research focuses on sensorless control of IPMSM, since most manufacturers use this type of motor due to its high power and torque density, for instance Chevrolet Bolt and Volt, BMW i3, Toyota Prius, Nissan LEAF, Tesla 3 rear motor.

Addressed research questions/problems

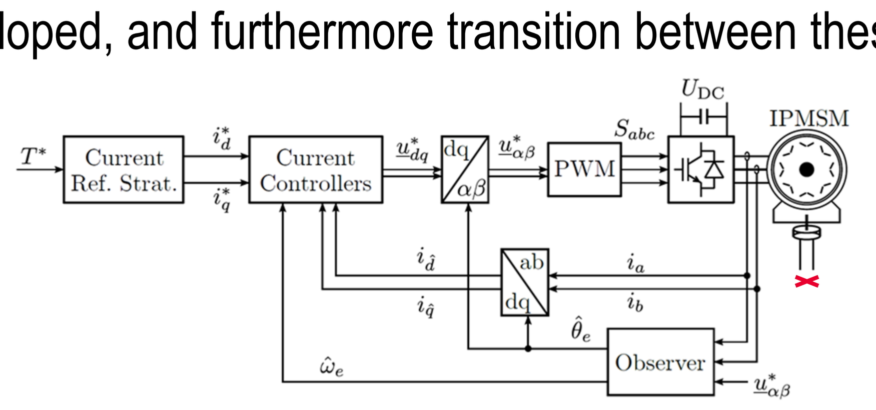
- The research addresses the peculiarities of EV traction motors and their effect on sensorless control. High drive quality (current harmonics, torque ripple, control bandwidth) is not crucial for industrial application, the main objective of sensorless control is price reduction of the product while maintaining functionality. In case of traction application, the main goal is to provide backup in case of encoder failure while maintaining high drive quality. Thus considering switching on-the-fly is important part of the research, and taking into account machine nonlinearity is necessary to avoid harmonics and to achieve accurate current control with high bandwidth.

- Magnetic saturation and cross-coupling effects have to be taken into account in sensorless angle and speed observer design, since machine parameters vary due to saturation. The nonlinear magnetic characteristics of the machine imposes limitations on sensorless control capabilities, which has to be analyzed in order to ensure control stability.

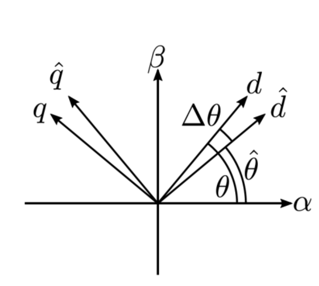


Flux maps and incremental inductance L_{qq} map of Toyota Prius 2017.

- The EV traction motor needs to operate on wide speed range hence both saliency-based control at low speed and model-based control at middle and high speed have to be developed, and furthermore transition between these methods.



Sensorless control block diagram.



Real and estimated dq frames.

Submitted and published works

Novel contributions

- Many novel algorithms have been implemented, tested and compared. Nonlinear modifications were applied to sensorless control techniques using the flux and incremental inductance maps of the simulated EV traction motor.
- Lookup table based nonlinear model of Toyota Prius IPMSM motor was used for the simulations and for the analysis of limitations imposed by the machine characteristics.

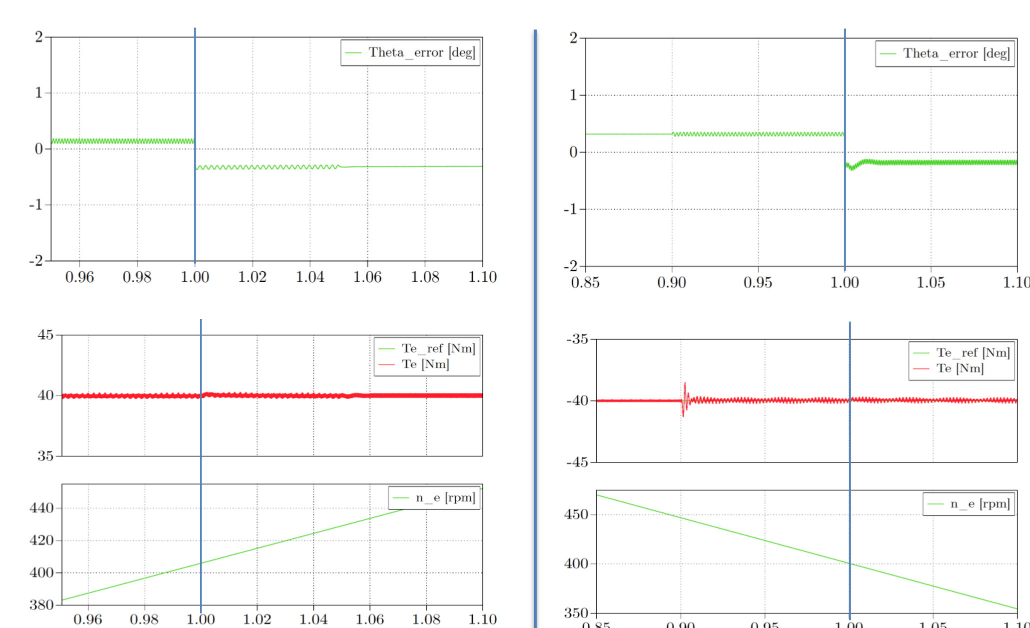
- In traction application typically MTPA current reference strategy is used to minimize copper losses. Following the MTPA curve, the saliency ratio quickly becomes too small for saliency-based method with increasing torque reference. By modifying the current reference strategy to maximum torque per saliency ratio method, higher electromagnetic torque can be achieved for a given saliency ratio. Although copper losses increase, the overall losses do not increase a lot, since current reference is only modified at low speed low power operation where saliency-based methods are used.

Adopted methodologies

- The research focuses on peculiarities of EV traction IPMSM, and therefore nonlinear models are used instead of too simple linear models.
- The control is first tested in simulation taking into account non-ideal factors in the drive, such as inverter distortions, current measurement error and control delays.
- Experimental validation of the control algorithms will be done in PoliTo lab.

- The developed control methods and relating techniques were implemented and tested in PLECS.

- The transition from HFI to flux observer and from flux observer to HFI shows the operation of sensorless control on the whole speed range.



Transition from HFI to flux observer. Transition from flux observer to HFI.

Future work

- Investigation of saliency-based sensorless control methods that do not generate torque ripple for sinusoidal HFI injection.
- Analysis of square-wave HFI based sensorless control focusing on effects of non-ideal factors on the angle estimation accuracy.

- Laboratory work in Turin to experimentally test the polarity detection methods, high-frequency injection based methods, flux observers, and the sensorless operation on the whole speed range.
- Investigate the conditions of switching on-the-fly in case of encoder failure, difficulties are expected for saliency-based methods.

- Publication of an overview paper and other research outputs supported by measurements.

List of attended classes

- 01RGBRV – Optimization methods for engineering problems (7/6/2022, 30h)
- 03OYCIV – Hybrid propulsion systems (30/6/2022, 15h)
- 01DOBRV – Mathematical-physical theory of electromagnetism (11/7/2022, 15h)
- 01LEVRV – Power system economics (7/9/2022, 16h)
- 01DOARV – Electrical demand management (23/09/2022, 25h)
- 11 soft skill courses (42h)