

Stator flux linkage estimation for direct torque control of permanent magnet synchronous machines

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1 Introduction

The use of highly dynamic electrical drives with permanent magnet synchronous machines (PMSMs) gained a lot of interest due to their high efficiency and reliability. These drives have to provide accurate and fast torque control, for example with direct torque control (DTC). The basic principle is to directly select stator voltage vectors to change the amplitude and the position of the stator flux linkage vector $\underline{\Psi}_s$ according to the differences between actual and reference value for torque and stator flux linkage in a stationary reference frame. As such $\underline{\Psi}_s$ has to be estimated with high accuracy. To this end several estimation methods were compared [1], both for surface and interior geometries of PMSMs [2].

2 Voltage model based methods

Equation (1) could be used for the estimation. The advantages are the independence of rotor position and the dependence on only one parameter (stator resistance R_s). Main problems for open-loop integration are: drift (measurement offset), offset (incorrect initialization) and sensitivity to R_s .

$$\underline{\Psi}_s = \int_0^t (\underline{V}_s - R_s \underline{I}_s) dt + \underline{\Psi}_s|_{t=0} \quad (1)$$

Open-loop low-pass filter (LPF)

An LPF is equivalent with a high-pass filter followed by an integrator, the DC offsets are removed and drift is avoided.

Closed-loop integrator with PCLPF

Closed-loop integrators, have an added stabilizing feedback. A programmable cascade of low-pass filters (PCLPF) resets the integrator removing offset errors.

Closed-loop integrator with PI

Stabilization by input from a PI-compensator, acting on the difference between estimated and reference $\underline{\Psi}_s$.

3 Extended Kalman filter current model

The EKF is used to obtain unmeasurable states (stator flux linkage) by using a model for the dynamical system, measured states and statistics of the system and measurement noise. The selection of the state variables is very important as either stator currents or stator flux linkages can be used. The state vector can be expanded with parameters to reduce the sensitivity to parameter deviations. The selection of the covariance matrices is the main problem here.

4 Results in simulation

Under ideal circumstances all estimators perform very good, also under highly dynamic conditions (except the LPF).

4.1 Influence of measurement disturbances

Voltage and current signal conditioning circuits and analog-to-digital converters can introduce a DC-offset to the measurement. The effect of this disturbance on the estimators is investigated. The LPF does not diverge, but oscillates heavily. The integrator can be stabilized by the PCLPF-reset, however large excursions occur. The PI-stabilized integrator and EKF estimators perform best.

4.2 Influence of parameter variations

There is a large difference in the dependence of the estimator output on R_s . The error of the EKF estimators is very small even for large deviations of R_s . The PI-stabilized integrator gives comparable results. A PCLPF-reset stabilization helps only for higher deviations of R_s . The error with the LPF is bounded but considerable. The EKFs are however also dependent on the synchronous inductance L_s and rotor flux Ψ_f . Although the estimation then still is performed in a sensorless fashion the EKF estimators can not cope with variations in L_s and Ψ_f : the estimation is stable but with considerable deviations. EKFs with added parameter estimation offer a solution, but their design and operation is complicated [2].

4.3 Influence of initial conditions

As an estimated value of the stator flux linkage is used to initialize the stator flux vector estimators, the sensitivity to an error in this initial value has to be considered. Both errors in angle and magnitude are important. In general all estimators remain stable under even quite severe initialization mismatch but with possible large deviations in transient.

5 Conclusions

The EKF-implementations exhibit a lesser dependence on R_s , measurement offset and initial conditions. They are much more complicated to design correctly and their dependence on L_s and Ψ_f should be addressed, which was not mentioned in literature before [1]. Expanding the state vector with parameters increases complexity tremendously [2]. Closed-loop integrator methods can also be very powerful. Given their simplicity voltage model based estimators should not be overlooked. However, a good stator resistance estimation scheme is still needed or desirable. As all methods have advantages and disadvantages, most are usable if the characteristics of the estimator match the application.

References

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