



PLECS

*DEMO MODEL*

## Direct Flux Vector Control

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## 2.1 Electrical Circuit and Machine Model

The voltage-source inverter (VSI) is modeled as an ideal three-legged bridge with a stiff DC supply. The six IGBTs are switched by means of a space vector modulator to realize the phase voltages commanded by the vector control. A three-phase motor current sensor and a DC link voltage sensor provide feedback to the control algorithm.

The electric machine is of the permanent magnet assisted salient type with  $L_d > L_q$ . It is connected to a frictionless inertia as well as an idealized position and speed sensor.

## 2.2 Controls

The input to the control system is the desired machine torque. In order to optimize the efficiency of the drive, the Maximal Torque Per Ampere (MTPA) block first determines the optimal flux level according to the iterative method described in [4]. Depending on the motor speed and DC link voltage the desired motor flux may have to be further reduced to respect the maximal available inverter voltage. This is achieved by the Flux Weakening block, which also ensures that there is enough voltage margin for the regulators to handle transients.

With the desired flux determined, the set-point for the torque producing current component  $I_{qs}^*$  can be established. Its value may have to be further reduced to ensure that the inverter current limit is respected and the maximal load angle not exceeded. The limit value for  $I_{qs}^*$  is generated by the Current and Load-Angle Limiter block, which also contains a basic PI controller.

The Vector Control block then compares the set-points of flux and current with the actual quantities and calculates the appropriate voltage vector to be applied to the machine. While the control of the flux is fully decoupled, the current control is affected by the flux level and motor speed. A feed-forward term is therefore required to assist the PI in the current/torque path.

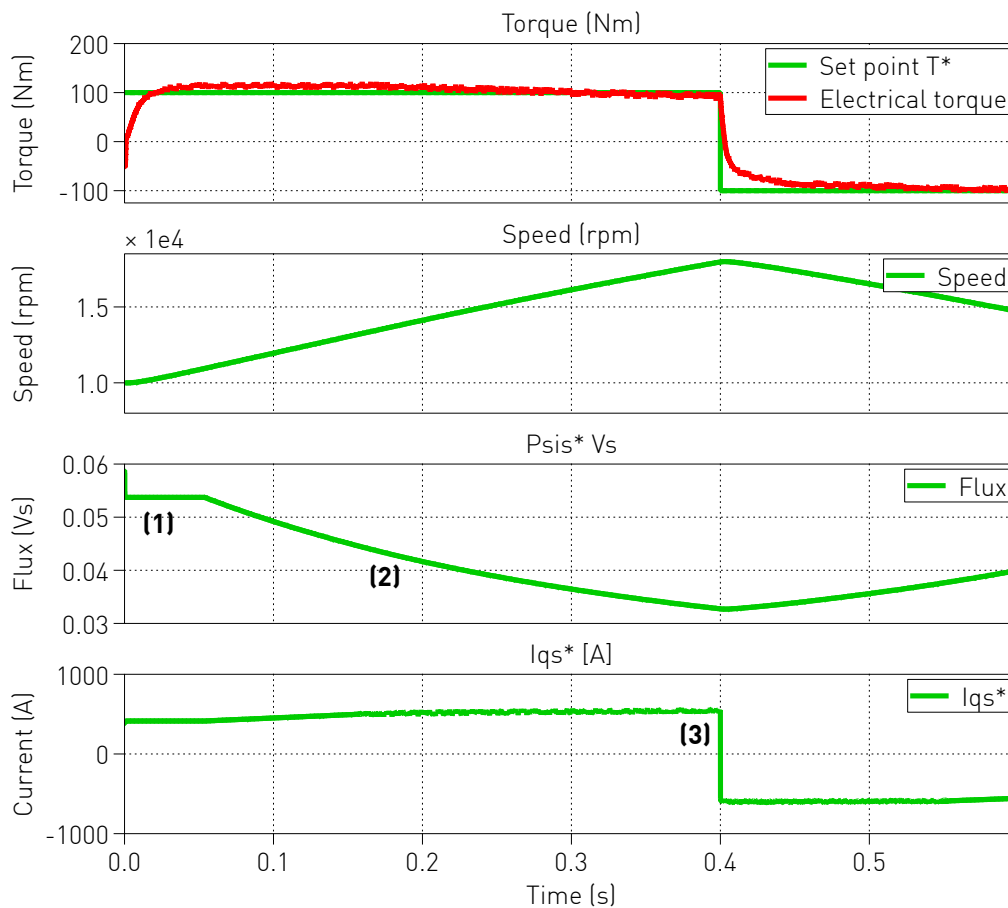
Since the motor flux cannot be directly measured, its amplitude and angle must be estimated by means of an observer. The method described in [5] has been realized for this purpose in the Flux Observer block. The observed flux is a fusion of a current-based magnetic model and a voltage-based integration, with the former being dominant at low speeds where the integration may be inaccurate.

## 3 Simulation

Run the simulation with the model as provided and review the signals in the scope. The results of the simulation are shown in Fig. 2 as a reference. Notice how the torque set-point of  $+100 \text{ N} \cdot \text{m}$  is achieved within the accuracy provided by the Flux Observer. For the first  $-50 \text{ ms}$  (1) the torque can be produced at the ideal MTPA flux level. However, as the machine speed increases beyond the base speed, the flux level has to be reduced and the quadrature current increased (2), until eventually the current limit is reached (3). The torque set-point is subsequently reversed to  $-100 \text{ N} \cdot \text{m}$ , causing the machine to decelerate.

## References

- [1] G. Pellegrino, E. Armando and P. Guglielmi, "Direct Flux Field-Oriented Control of IPM Drives With Variable DC Link in the Field-Weakening Region," in *IEEE Transactions on Industry Applications*, vol. 45, no. 5, pp. 1619-1627, Sept.-Oct. 2009.
- [2] G. Pellegrino, E. Armando and P. Guglielmi, "Direct-Flux Vector Control of IPM Motor Drives in the Maximum Torque Per Voltage Speed Range," in *IEEE Transactions on Industrial Electronics*, vol. 59, no. 10, pp. 3780-3788, Oct. 2012.
- [3] G. Pellegrino, R. I. Bojoi and P. Guglielmi, "Unified Direct-Flux Vector Control for AC Motor Drives," in *IEEE Transactions on Industry Applications*, vol. 47, no. 5, pp. 2093-2102, Sept.-Oct. 2011.



**Figure 2: Simulation results showing different important points at (1), (2) and (3)**

- [4] K. D. Hoang, J. Wang, M. Cyriacks, A. Melkonyan and K. Kriegel, "Feed-forward torque control of interior permanent magnet brushless AC drive for traction applications," 2013 International Electric Machines & Drives Conference, Chicago, IL, 2013, pp. 152-159.
- [5] A. Vagati, M. Pastorelli, G. Franceschini and V. Drogoreanu, "Digital observer-based control of synchronous reluctance motors," Industry Applications Conference, 1997. Thirty-Second IAS Annual Meeting, IAS '97., Conference Record of the 1997 IEEE, New Orleans, LA, 1997, pp. 629-636 vol. 1.

## Revision History:

PLECS 4.3.1      First release

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