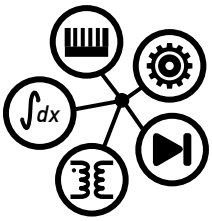

PLECS

DEMO MODEL

Lookup Table-Based PMSM

Last updated in PLECS 4.3.1

1 Overview

This example shows an inverter-fed, 8-pole, non-linear permanent-magnet synchronous machine (PMSM) configured with Finite Element Analysis (FEA) data. The FEA data was generated for a Toyota Prius motor model in Infolytica's MotorSolve platform.

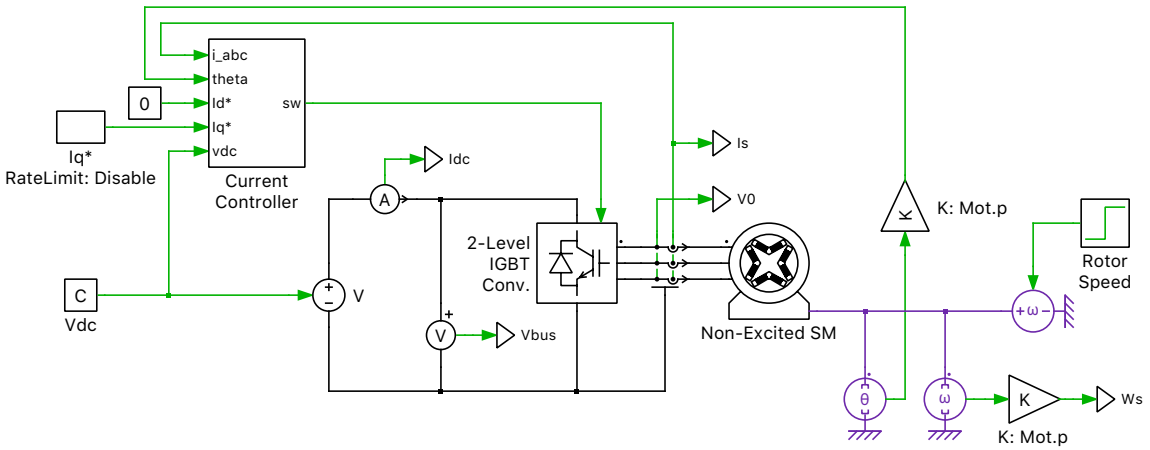

Figure 1: Electrical Circuit of Look-up table based PMSM

Note This model contains model initialization commands that are accessible from:

PLECS Standalone: The menu **Simulation + Simulation Parameters... + Initializations**

PLECS Blockset: Right click in the **Simulink model window + Model Properties + Callbacks + InitFcn***

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2 Model

The **Non-Excited Synchronous Machine** enables the use of look-up tables to configure the machine. These look-up tables can be obtained from FEA tools such as Infolytica's MotorSolve platform. The look-up table approach allows the incorporation of machine saturation and cross-saturation effects. A more detailed description of the non-linear PMSM can be found in the component description of the Non-Excited Synchronous Machine (Lookup) in the PLECS component library.

The machine is operated at constant speed to study the performance of the current controller. This is achieved by connecting a **Rotational Speed (Controlled)** source to the mechanical terminal of a PLECS machine model. The machine inertia must be set to $0\,\mathrm{N\,m\,s^2}$ to operate the machine with a speed source.

The inverter circuit is modeled as an ideal **IGBT Converter (3ph)** with a stiff $200\,\mathrm{V\,DC}$ supply. A "Digital Synchronous Frame Regulator" [1] is used for the closed-loop control of the currents. The machine mechanical speed, mechanical angle, and stator currents are measured. The mechanical speed and angle are scaled by the number of pole-pairs to determine the electrical speed and angle, respectively.

Direct and quadrature current setpoints are provided to the "Current Controller". This controller is decoupled based on motor speed and also includes state-limiting and anti-windup mechanisms. Typically Proportional-Integral (PI) controllers are used for current regulation in the d- and q-axes. The gains of the controllers and the system decoupling are based on the motor parameters: motor speed, motor incremental inductance (L_d and L_q), and stator resistance. For a machine driven into saturation the L_d

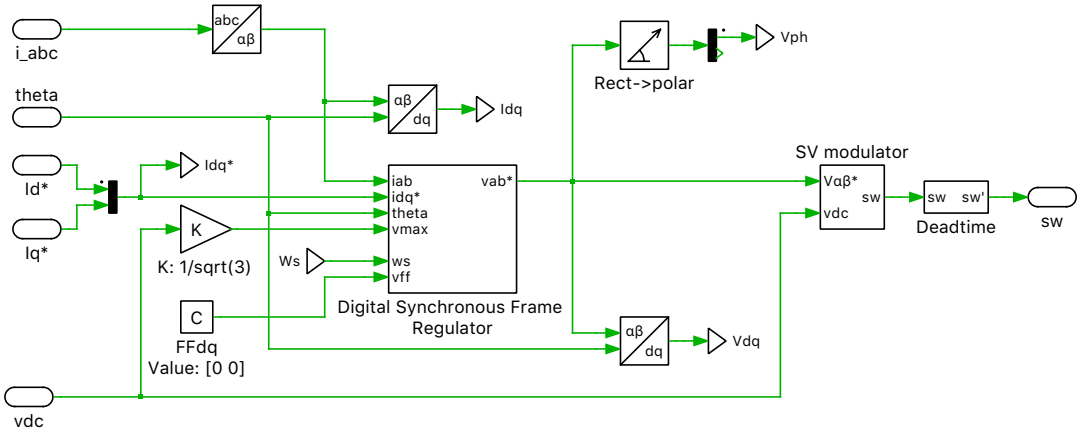

Figure 2: Controls of Look-up table based PMSM

and L_q values change. In this demonstration, the machine inductance in the saturation region is used for the controller design.

The three stator phase currents are being measured for closed-loop control. These are then transformed to direct-quadrature (DQ) values inside the regulator and are compared to their setpoints. The **Space Vector PWM** component is used to generate the output voltage of the inverter.

The direct current setpoint (I_d^*) is held constant at $0\,\mathrm{A}$. The quadrature current setpoint (I_q^*) is set to increase from $20\,\mathrm{A}$ to $130\,\mathrm{A}$ at $0.2\,\mathrm{s}$. In this simulation all the torque is produced by the magnetizing q-axis current and reluctance torque is maintained at $0\,\mathrm{N\,m}$.

3 Simulation

Initially the q-axis current in the system is ramped up from $0\,\mathrm{A}$ to $20\,\mathrm{A}$. The d-axis current is regulated at $0\,\mathrm{A}$. At $0.2\,\mathrm{s}$, the q-axis current is increased to $130\,\mathrm{A}$. See Fig. 3. The q-axis flux linkage increases and the machine is driven into saturation as seen in Fig. 4

As the machine is driven into saturation the incremental inductance values change. The changing machine incremental inductance and fixed current controller gains introduce a mismatch in the decoupling term and PI regulator performance. This causes d-axis current to deviate from the $0\,\mathrm{A}$ setpoint as the q-axis current setpoint is stepped from $20\,\mathrm{A}$ to $130\,\mathrm{A}$ at $0.2\,\mathrm{s}$. See Fig. 3.

In this demonstration, the motor torque is produced entirely by the q-axis magnetizing current. The reluctance torque is maintained at $0\,\mathrm{N\,m}$. At $0.35\,\mathrm{s}$, the rotor speed is increased from $42\,\mathrm{rad\,/\,s}$ to $50\,\mathrm{rad\,/\,s}$. See Fig. 5. The current regulator maintains the q- and d-axis currents at the desired level, thus regulating the electrical torque through the speed change transient.

The step in the q-axis current setpoint at $0.2\,\mathrm{s}$ introduces a step change in the q-axis current error. The current errors in the d- and q-axes are used in decoupling the d- and q-axes in the synchronous frame regulator. The mismatch in the decoupling parameter and the machine incremental inductances (due to saturation) causes the d-axis current to deviate from the $0\,\mathrm{A}$ setpoint. One solution is to use look-up tables for the decoupling parameter and PI gains to optimize machine performance.

An alternative is to limit the rate of change in the current setpoint. By introducing a rate limit of $10\,\mathrm{A}$ per millisecond, the magnitude of the q-axis error decreases. Thus, the effects of a mismatch in the decoupling parameter and the changing machine incremental inductances are reduced. This causes the d-axis current deviation due to change in the q-axis current setpoint to decrease.

Enable the rate limiter for the q-axis current setpoint generator and rerun the simulation. Observe the effect of the rate limiter on the d-axis current as the q-axis current setpoint is changed from $20\,\mathrm{A}$ to $130\,\mathrm{A}$ at $0.2\,\mathrm{s}$. See Fig. 7.

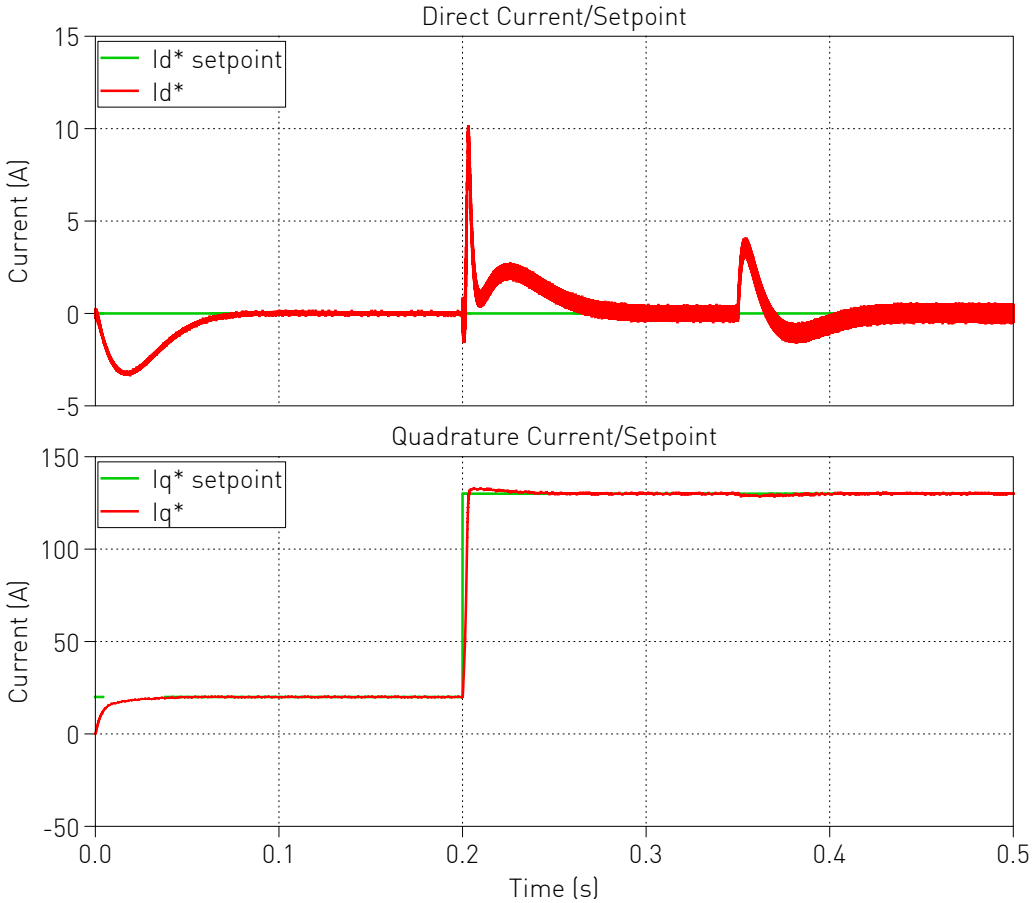

Figure 3: Plots of d-axis and q-axis currents with rate limiter disabled

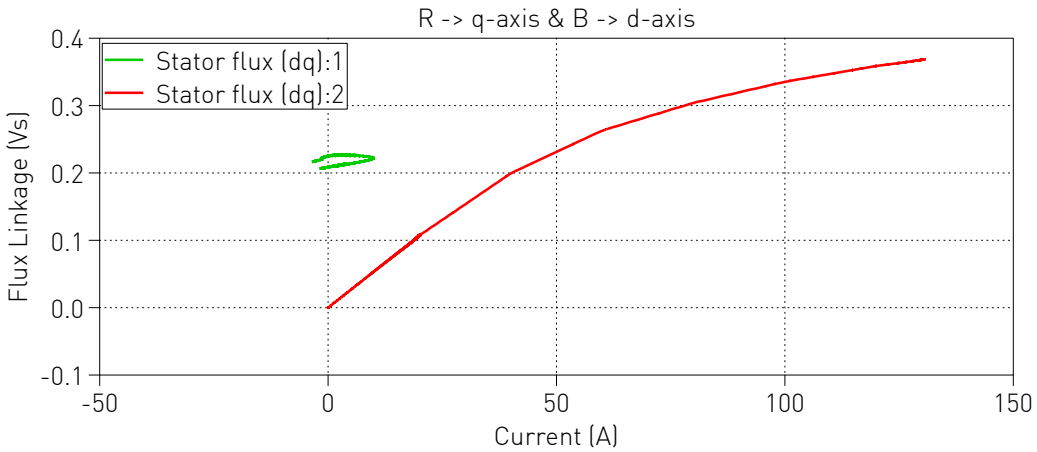

Figure 4: Plot of flux linkage vs current

4 Conclusion

This model highlights a non-linear permanent-magnet synchronous machine (PMSM) configured with FEA, showcasing a few PLECS control domain components. For more models highlighting the control domain, please use the filter feature of the **PLECS Demo Models** library.

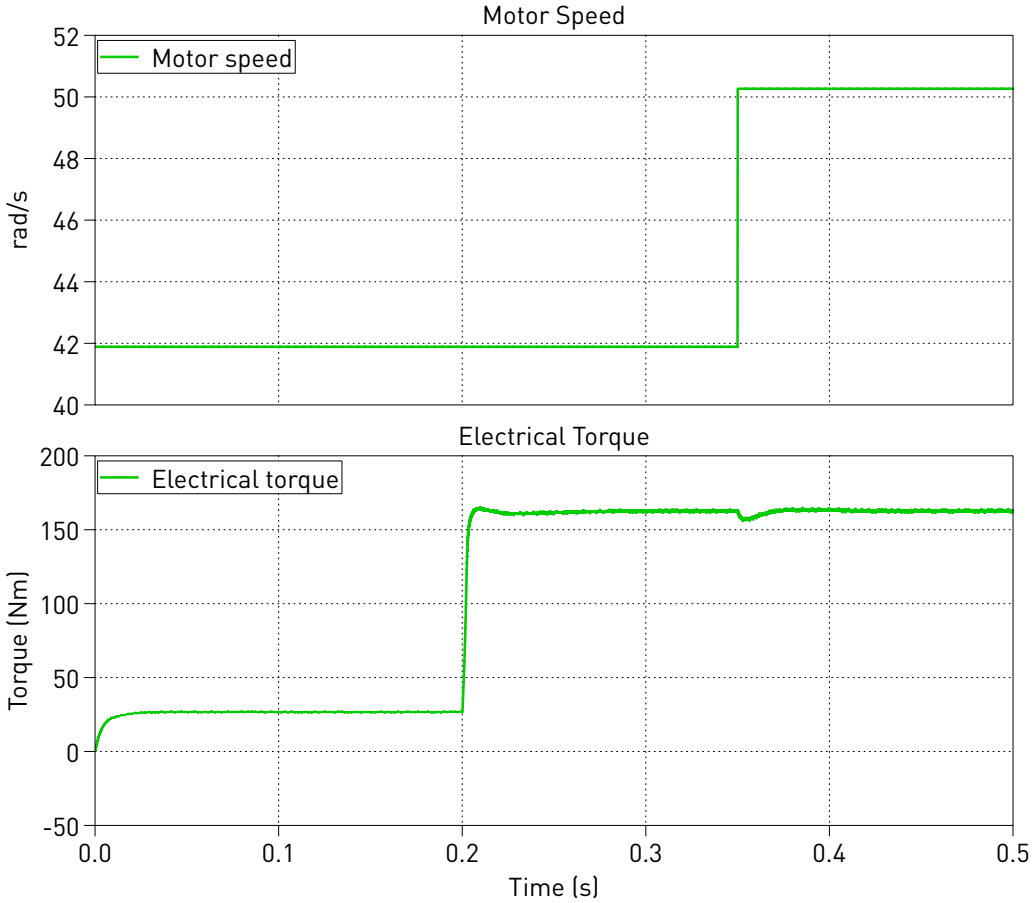

Figure 5: Plots of motor speed and electrical torque, motor and DC currents

References

[1] F. Briz, A. Diez, M. W. Degner and R. D. Lorenz, "Current and flux regulation in field-weakening operation [of induction motors]," in *IEEE Transactions on Industry Applications*, vol. 37, no. 1, pp. 42-50, Jan.-Feb. 2001. Click to access online: IEEE Xplore webpage.

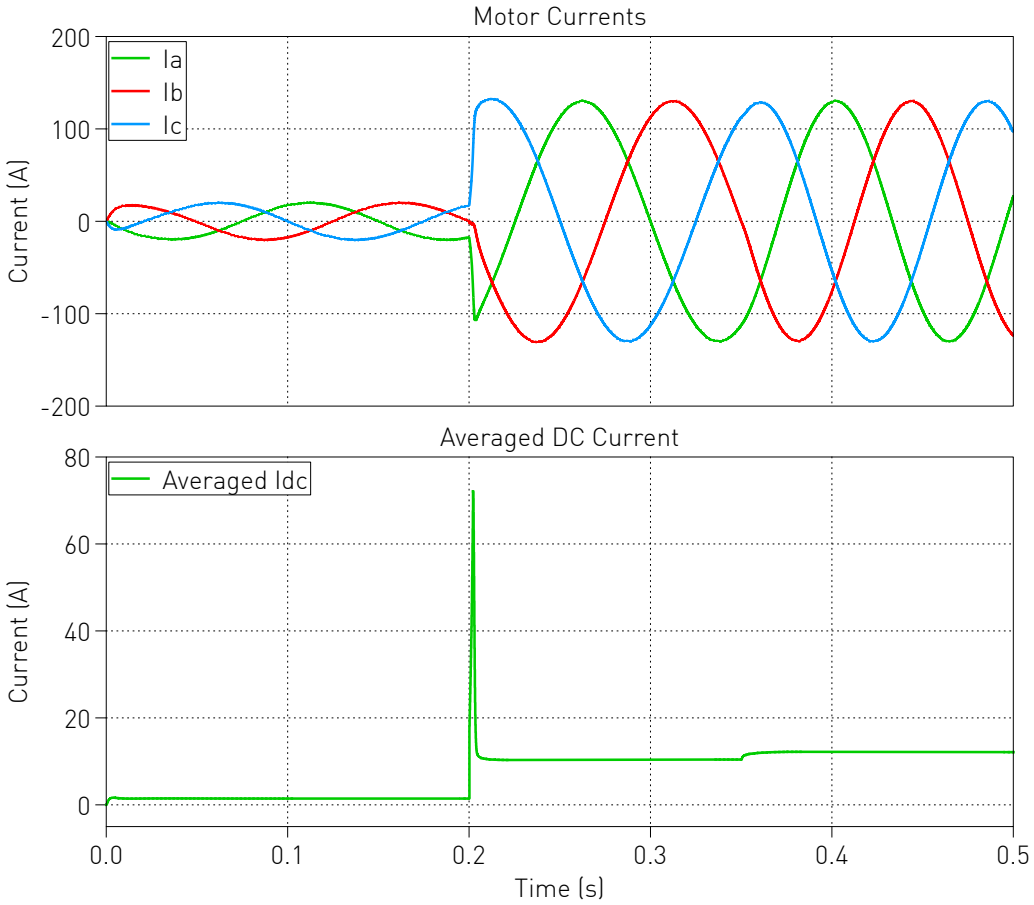

Figure 6: Plots of motor current and averaged DC current

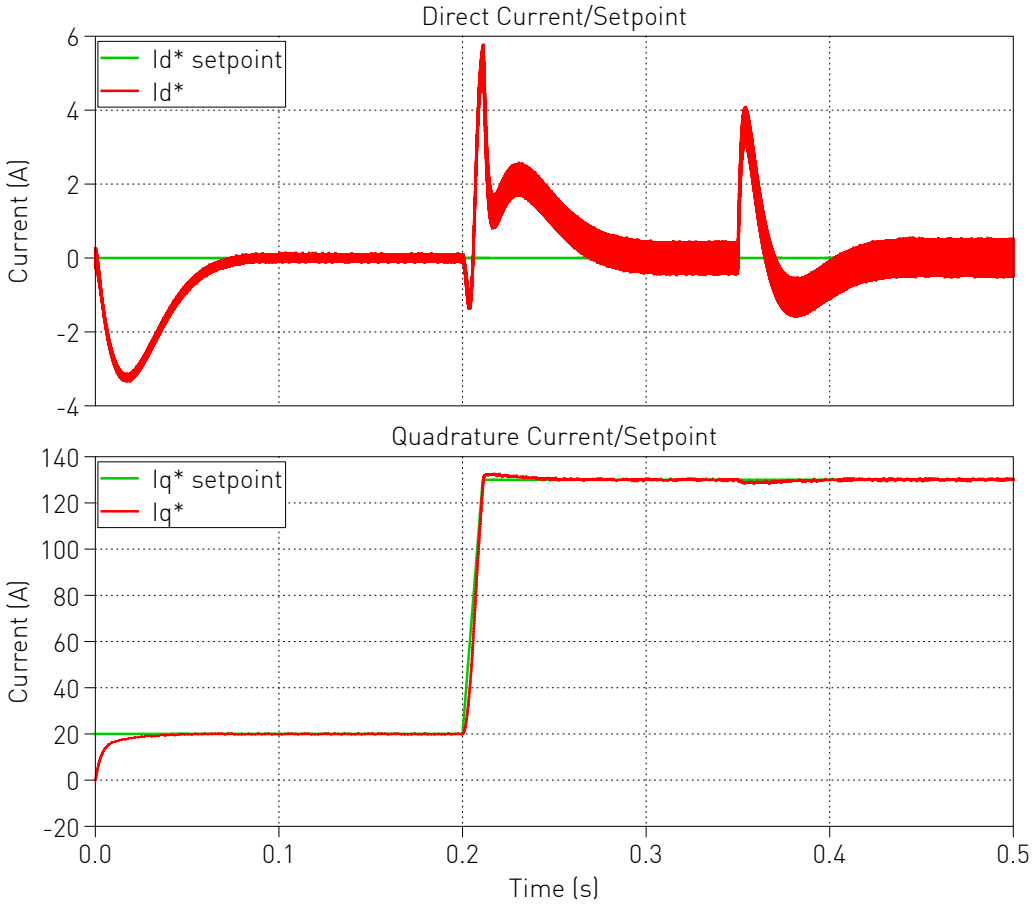

Figure 7: Plots of d-axis and q-axis currents with rate limiter enabled

Revision History:

PLECS 4.3.1	First release

How to Contact Plexim:

☎	+41 44 533 51 00	Phone
	+41 44 533 51 01	Fax
✉	Plexim GmbH Technoparkstrasse 1 8005 Zurich Switzerland	Mail
@	`info@plexim.com`	Email
	`http://www.plexim.com`	Web

PLECS Demo Model