Controlled Three-Phase Drives

Tutorial 10: Direct Torque Control (DTC) of Induction Machine

Machine Parameter:

Inertia :	$J = 0{,}02$ kgm^2	Pole pair number:	$p = 2$
Main Inductance:	$L_m = 116$ mH	Leakage Inductances:	$L_{\sigma s} = L_{\sigma r} = 6{,}24$ mH
Stator Resistance:	$R_s = 1{,}154\ \Omega$	Rotor Resistance:	$R_r = 0{,}916\ \Omega$
Nominal quantities:	$T_n = 30$ Nm, $f_n = 50$ Hz, $I_n = 20$ A und $U_n = 400$ V		

Exercise 1: Modeling of Induction Machine in rotor flux oriented coordinates

1. Set up the rotor flux oriented motor model of the induction machine in MATLAB/Simulink using the below mathematical equations and the diagram.
   Hint: Please use the template file **"Motor_model_IM.mdl"**
2. Verify the functionality of your created motor model by simulating the acceleration behavior of the machine. To do so, apply a three-phase voltage (U_n, f_n) to the machine.
3. How does the behavior of the machine change when applying a load torque $m_L \neq 0$ Nm at the time $t = 0.5$ s? In this context, apply the load torque $m_L = m_n$ and determine the corresponding slip.

Exercise 2: Direct Torque Control (DTC) of Induction Machine

Set up a Direct Torque Control for the induction machine in Matlab/Simulink. To do so, proceed as follows:
Hint: Please use the template file **"DTC_IM.mdl"**

1. At first, design a stator-flux observer using the voltage model of the induction machine in stator-fixed coordinates α/β. The output variables of the observer should be the stator flux $\underline{\Psi}_{s,\alpha\beta}$, the magnitude of the stator flux $|\underline{\Psi}_{s,\alpha\beta}|$ and the torque T.
2. Implement a sector detection algorithm as MATLAB-*function* within the DTC-block. Based on the α/β- components of the stator flux $\underline{\Psi}_{s,\alpha\beta}$, the algorithm should be able to determine the sector (1..6) in which the current stator flux pointer is located in. To do so, complete the m-file *„Sector_Detection_DTC.m“*
3. Integrate a switching table in the DTC-block (the file *„Switching_Table_DTC.m*“ can be used as template). Based on the detected sector and depending on the outputs of the hysteresis controls for stator flux and torque, the switching table chooses the voltage vector to be applied to the machine.
4. Investigate the behavior of the controlled system at constant speed. Therefore, a fixed speed of $n = 0.5\, n_{synch}$, a stator flux reference of $\psi_s^* = \psi_{s,N}$ and a reference torque step of $T^*(t = 0s) = 0.1\, T_N$ and $T^*(t = 0.25s) = 0.9\, T_N$ shall be assumed.

Helpful notes for the tutorial

Induction Machine model in rotor flux oriented coordinates

$$\sigma L_S \cdot \frac{di_{Sd}}{dt} + \rho R_S \cdot i_{Sd} = u_{Sd} + \frac{L_m \cdot R_R}{L_R^2} \cdot \psi_R + \omega_{FS} \cdot \sigma L_S \cdot i_{Sq}$$

$$\sigma L_S \cdot \frac{di_{Sq}}{dt} + \rho R_S \cdot i_{Sq} = u_{Sq} - \omega_{RS} \cdot \frac{L_m}{L_R} \cdot \psi_R - \omega_{FS} \cdot \sigma L_S \cdot i_{Sd}$$

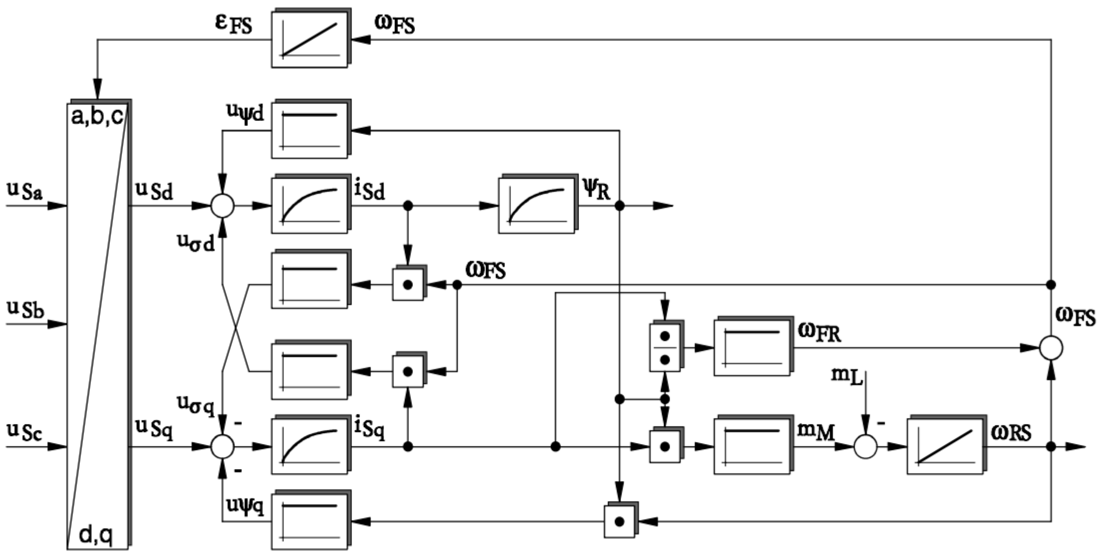
$$\frac{L_R}{R_R} \cdot \frac{d\psi_R}{dt} + \psi_R = L_m \cdot i_{Sd} \qquad \frac{J}{p} \cdot \frac{d\omega_{RS}}{dt} = m_M - m_L$$

$$\omega_{FS} = \frac{R_R \cdot L_m}{L_R} \cdot \frac{i_{Sq}}{\psi_R} + \omega_{RS} \qquad m_M = \frac{3}{2} \cdot p \cdot \frac{L_m}{L_R} \cdot \psi_R \cdot i_{Sq}$$

with the resistance number ρ:

$$\rho = 1 + \frac{L_m^2}{L_r^2} \frac{R_R}{R_S}$$

Diagram of Induction Machine in rotor flux oriented coordinates



Voltage model of the Induction Machine in stator oriented coordinates:

$$\underline{u}_s = \frac{d\underline{\psi}_s}{dt} + R_s \underline{i}_s$$

Torque equation:

$$T = \frac{3}{2} p * \operatorname{Im}\left\{\bar{\underline{\psi}}_s \underline{i}_s\right\}$$