Universidade de Coimbra

Departamento de Engenharia Electrotécnica e de Computadores

CONTROLO DIGITAL
Modelo Simulink de Motor DC
Setembro de 2015

Considere um motor DC de ímanes permanentes com parâmetros: Jm=0.05 Kg.m^2; Ra=0.5 Ohm; La=10 mH; Ke=0.5N.m/A; Kf=0.001 N.m.s.

PARTE A: Construa o seguinte modelo em Simulink:

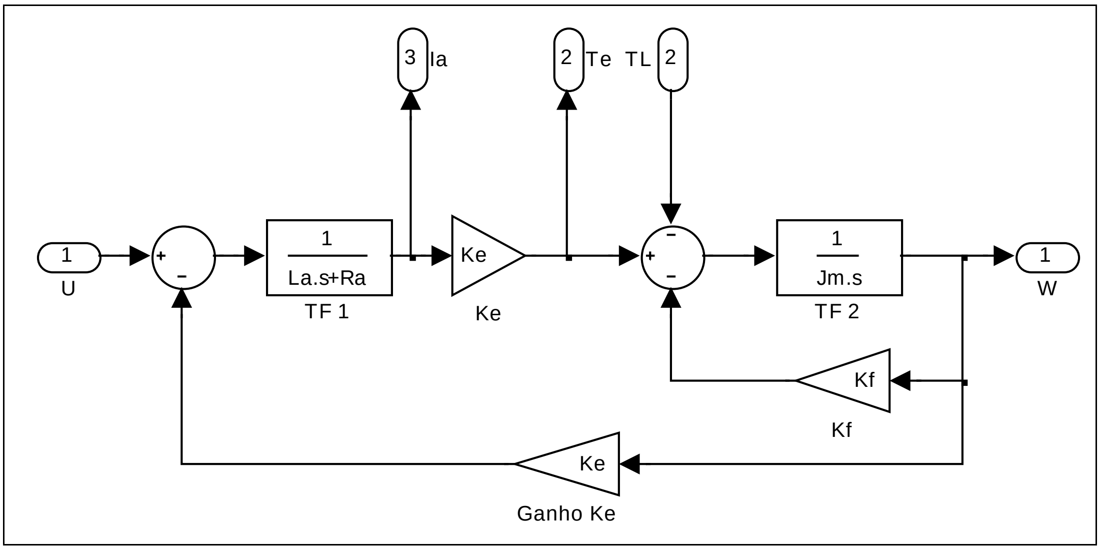


Fig. 1: motor DC controlado por tensão - modelo de circuito do motor DC com entradas (U e TL) e saídas (Ia, Te e velocidade do veio (w) em rad/s).

PARTE B: Construa o seguinte modelo em Simulink:

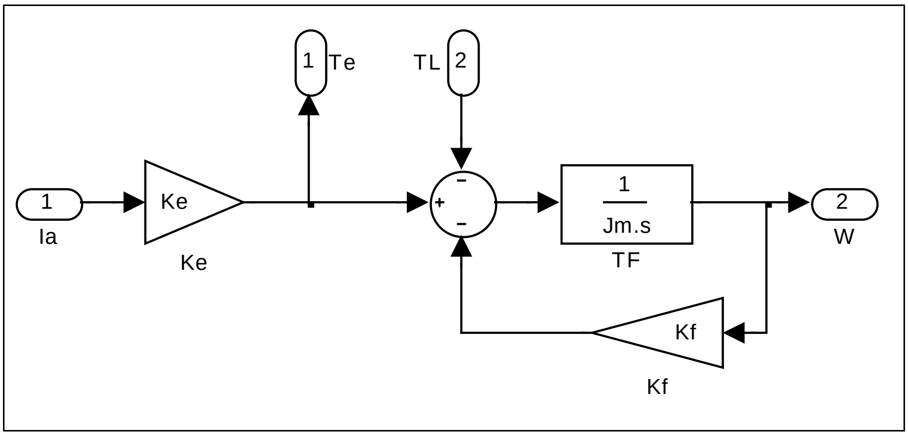
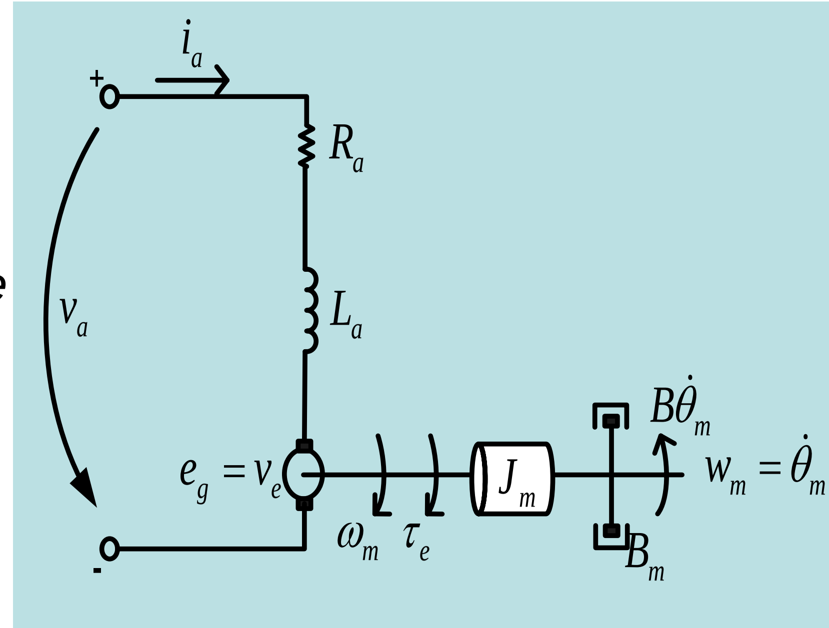


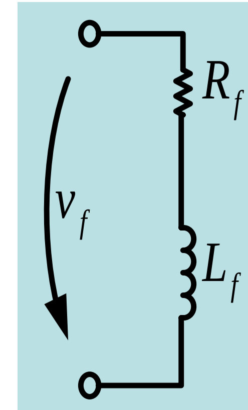
Fig. 2: motor DC controlado por corrente - modelo do motor DC com entrada (Ia e TL) e saídas (Te e velocidade do veio em rad/s).

MODELOS DO MOTOR ELÉCTRICO CC

$$\begin{cases} \tau_e(t) = K \cdot i_a(t) i_f(t) \\ v_e(t) = e_g(t) = K \cdot i_f(t) \omega_m(t) \end{cases}$$

$\tau_e(t)$: *binário gerado electricamente no veio do motor*
$e_g(t)$: *força contra-electromotriz induzida*
K : *constante de acoplamento electromagnético*





***Estas equações não são lineares**. Para as tornar lineares, fazemos i_f=cte (ou i_a=cte) e controlamos a velocidade do veio do motor através da corrente no circuito do rotor (ou corrente do circuito de excitação).*

Quatro configurações básicas:

***1. i_a=cte** (“motor field-controlled”)* $\rightarrow \tau_e(t) = K_{mf} i_f(t); \quad K_{mf} = K \cdot I_a = cte$

1.1 Controlado por corrente de circuito de excitação

1.2 Controlado por tensão de excitação

MODELOS DO MOTOR ELÉCTRICO CC

2. $\mathbf{I}_f$**= cte** (“*motor armature-controlled*”) $\begin{cases} \tau_e(t) = K_{ma} i_a(t); & K_{ma} = KI_f = cte \\ v_e(t) = K_{ma}\omega_m(t) \end{cases}$

2.1 Controlado por corrente do circuito induzido

2.2 Controlado pela tensão aplicada ao circuito do induzido

Motor Controlado pela Tensão Aplicada ao Cicuito do induzido (“Armature-Voltage Controlled”)

$$V_a(s) - V_e(s) = \left(R_a + sL_a\right) I_a(s); \quad \left(V_e(s) \equiv E_g(s)\right)$$

$$\Rightarrow \frac{I_a(s)}{V_a(s) - V_e(s)} = \frac{1}{R_a + sL_a} \qquad (113.1)$$

$$T_e(s) = K_{ma} I_a(s); \qquad (113.2)$$

O movimento do veio do motor (s/carga):

$$J_m \ddot{\theta}_m(t) = \tau_e(t) - B_m \dot{\theta}_m(t)$$

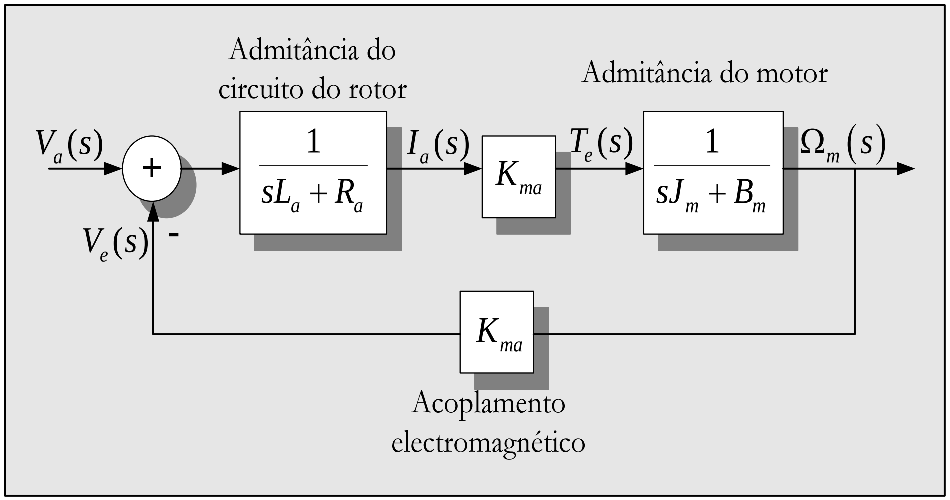
$$(s^2 J_m + B_m s)\theta_m(s) = T_e(s); \; (\Omega_m(s) = s\theta_m(s))$$

$$(sJ_m + B_m)\Omega_m(s) = T_e(s); \; \frac{\Omega_m(s)}{T_e(s)} = \frac{1}{sJ_m + B_m} \qquad (113.4)$$

MODELOS DO MOTOR ELÉCTRICO CC

$$V_e(s) = K_{ma}\Omega_m(s) \qquad (114.1)$$

Em diagrama de blocos (Eqs. (113.1)-(113.3) e (114.1)):



$$\frac{\Omega_m(s)}{V_a(s)} = $$

$$= \frac{K_{ma}}{(R_a + sL_a)(sJ_m + B_m) + K_{ma}^2}$$

A indutância L_a no circuito do induzido é geralmente pequena e pode ser desprezada, resultando:

$$\frac{\Omega_m(s)}{V_a(s)} = \frac{K_{ma}}{(sJ_m R_a + B_m R_a) + K_{ma}^2} \Rightarrow \frac{\Omega_m(s)}{V_a(s)} = \frac{K_1}{s+\alpha} = \frac{K_m}{T_m s + 1}$$

$$K_1 = \frac{K_{ma}}{R_a J_m};\ \alpha = \frac{1}{J_m}\left(B_m + \frac{K_{ma}^2}{R_a}\right)$$

$$T_m = \frac{1}{\alpha} = \frac{R_a J_m}{B_m R_a + K_{ma}^2}; \quad K_m = \frac{K_1}{\alpha} \begin{cases} T_m \rightarrow \text{cte de tempo do motor} \\ K_m \rightarrow \text{ganho DC do motor} \end{cases}$$

MOTOR CC COM CARGA (Incluindo trem de engrenagens)

Diagrama de blocos

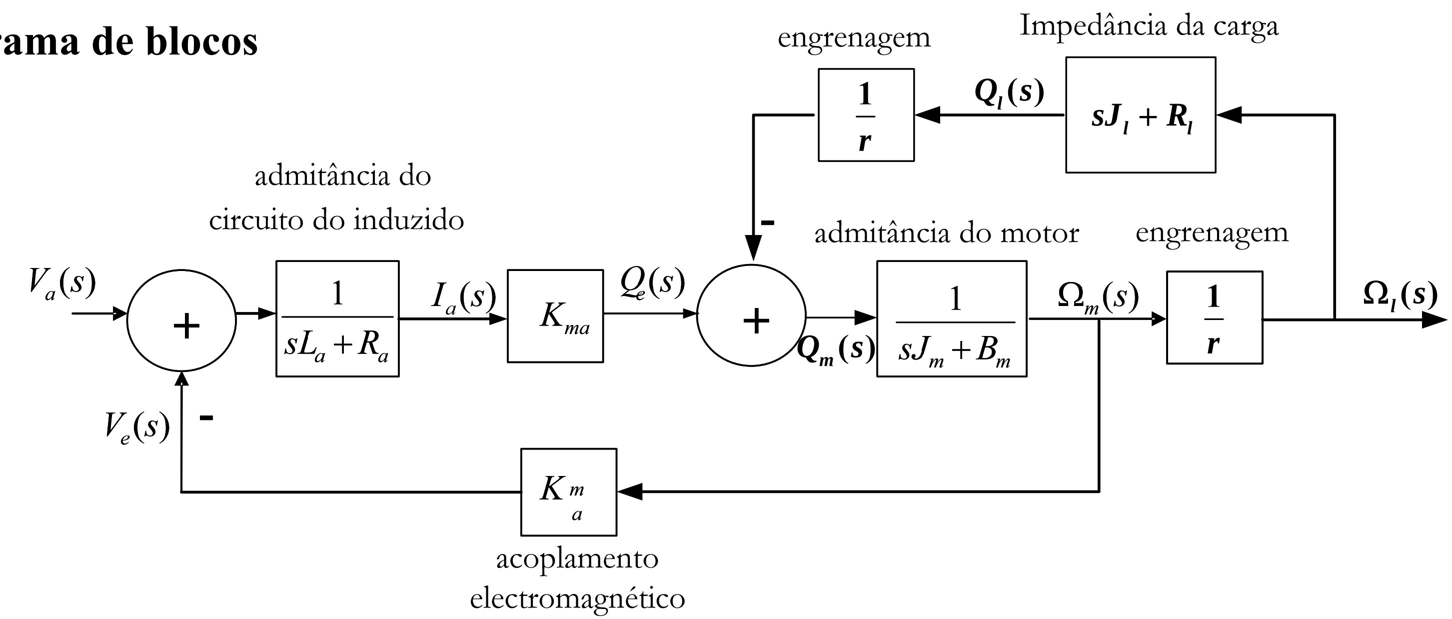
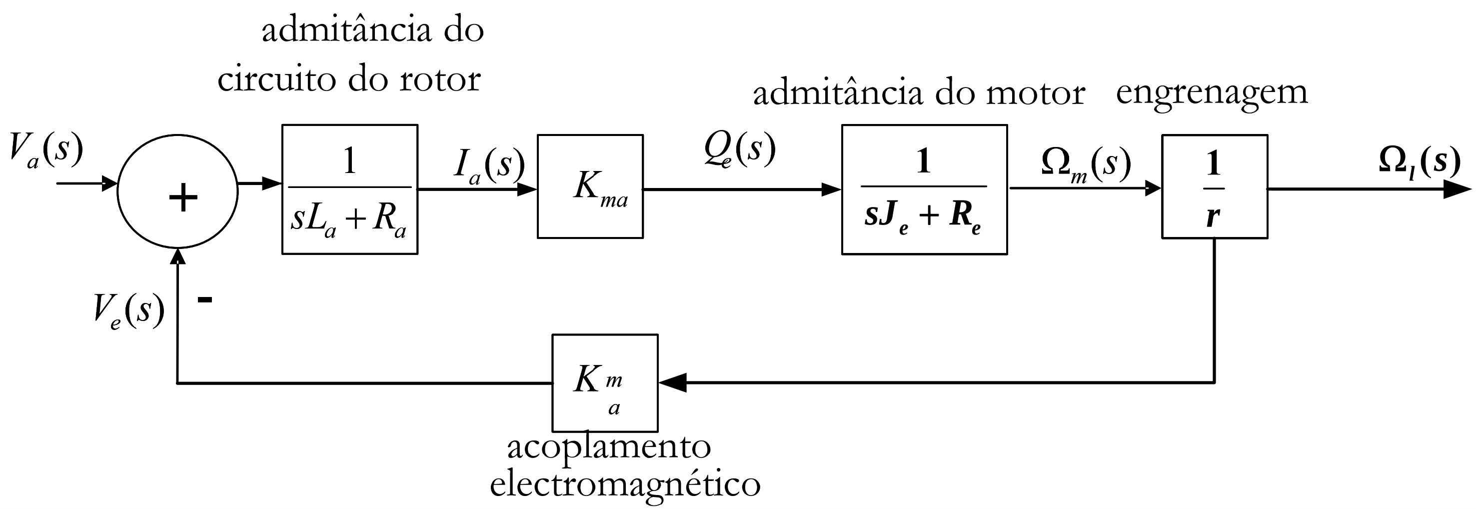


Diagrama de blocos Reduzido



MODELO DE ESTADO (MOTOR CC)

Um modelo de estado para o motor CC controlado pela tensão aplicada ao circuito induzido pode ser o seguinte:

$$\begin{cases} T_m\ddot{\theta}(t) + \dot{\theta}(t) = K_m v_a(t) \\ \ddot{\theta}(t) + \dfrac{1}{T_m}\dot{\theta}(t) = \dfrac{K_m}{T_m} v_a(t) \end{cases}$$

Variáveis de estado : $\begin{cases} x_1 = \theta \rightarrow (\textit{posição do veio do motor}) \\ x_2 = \dot{\theta} \rightarrow (\textit{velocidade do veio do motor}) \end{cases}$

Variável de entrada: $u = v$

Variável de saída: $y = \theta = x_1$

A representação em espaço de estados vem dada por:

$$\dot{x}_1 = x_2$$
$$\dot{x}_2 = -\frac{1}{T_m}x_2 + \frac{K_m}{T_m}u$$

Na forma matricial:

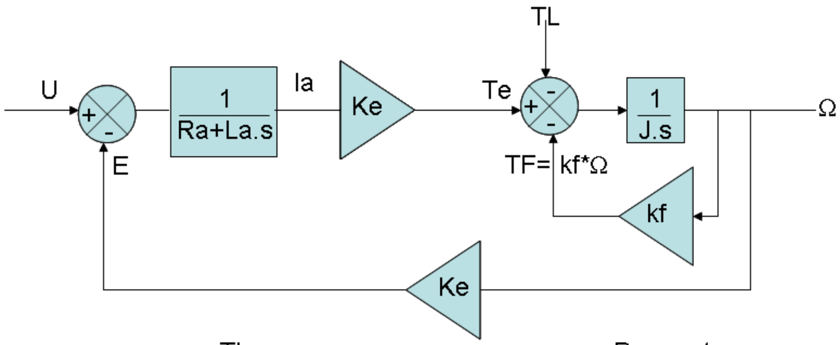
$$\begin{bmatrix} \dot{x}_1 \\ \dot{x}_2 \end{bmatrix} = \begin{bmatrix} 0 & 1 \\ 0 & -\dfrac{1}{T_m} \end{bmatrix} \cdot \begin{bmatrix} x_1 \\ x_2 \end{bmatrix} + \begin{bmatrix} 0 \\ \dfrac{K_m}{T_m} \end{bmatrix} u$$

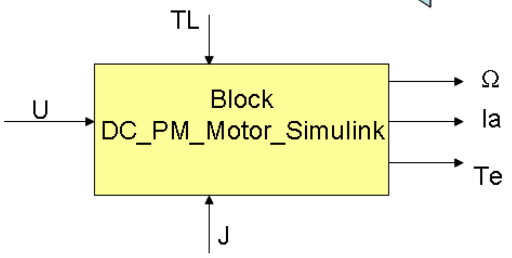
Workshop "Matlab/Simulink in Drives and Power electronics"
Practice 3: DC Motor Control

1- Creation of a DC Permanent Magnet Motor" Simulink block in library.

1.1. Simulation model

We will use the classical model for DC motor with constant excitation.

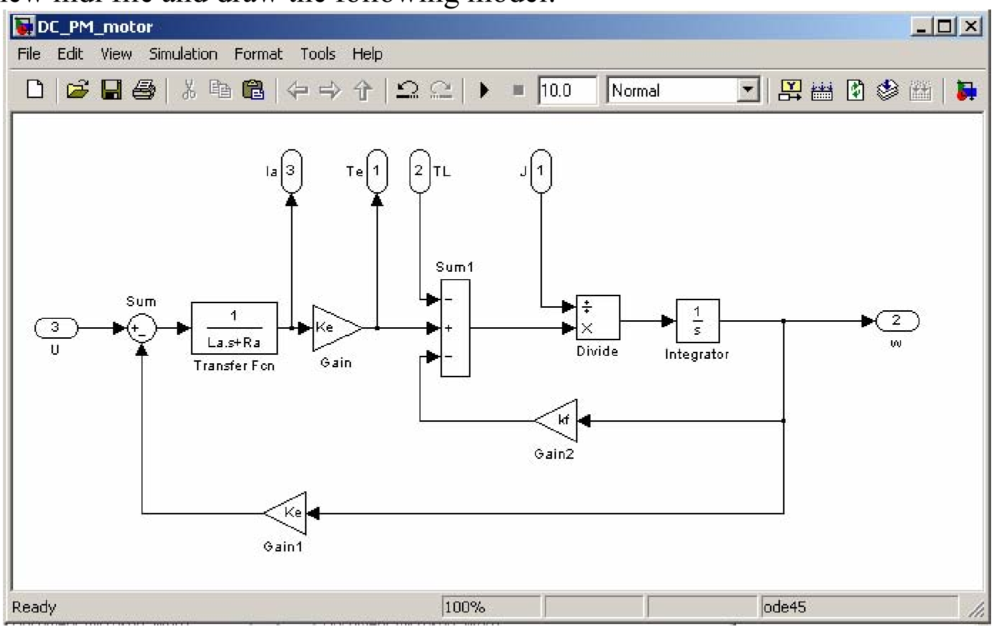




Parameters:
Armature resistance Ra (ohms)
Armature inductance La (H)
Torque constant Ke (N.m/A)
Viscous friction gain kf (N.m.s)

1.2. Simulink translation of the model

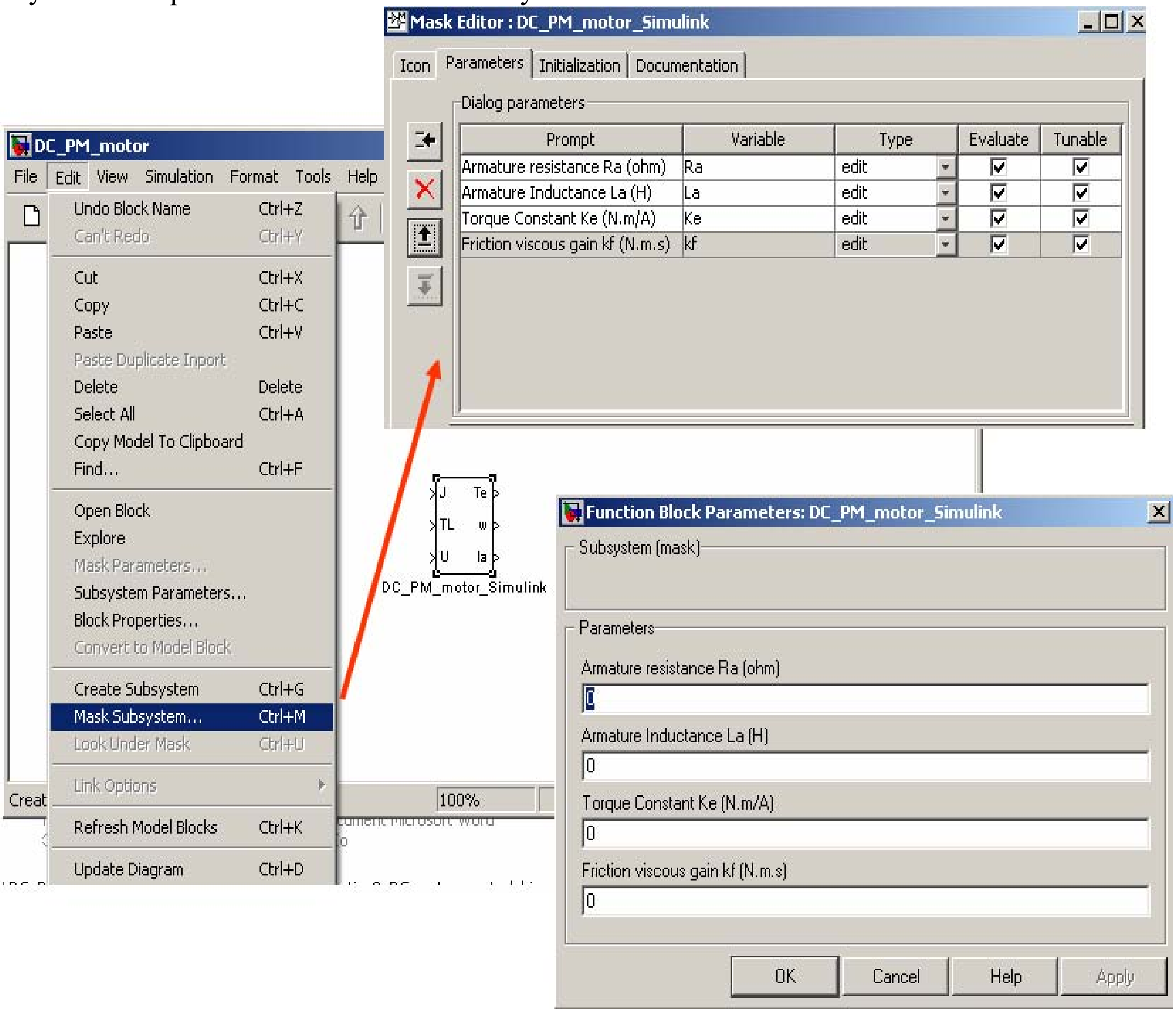
Open a new mdl file and draw the following model:



Save it in the working directory as DC_PM_motor.mdl

1.3. Creating a Function Block with its Function Block Parameters windows

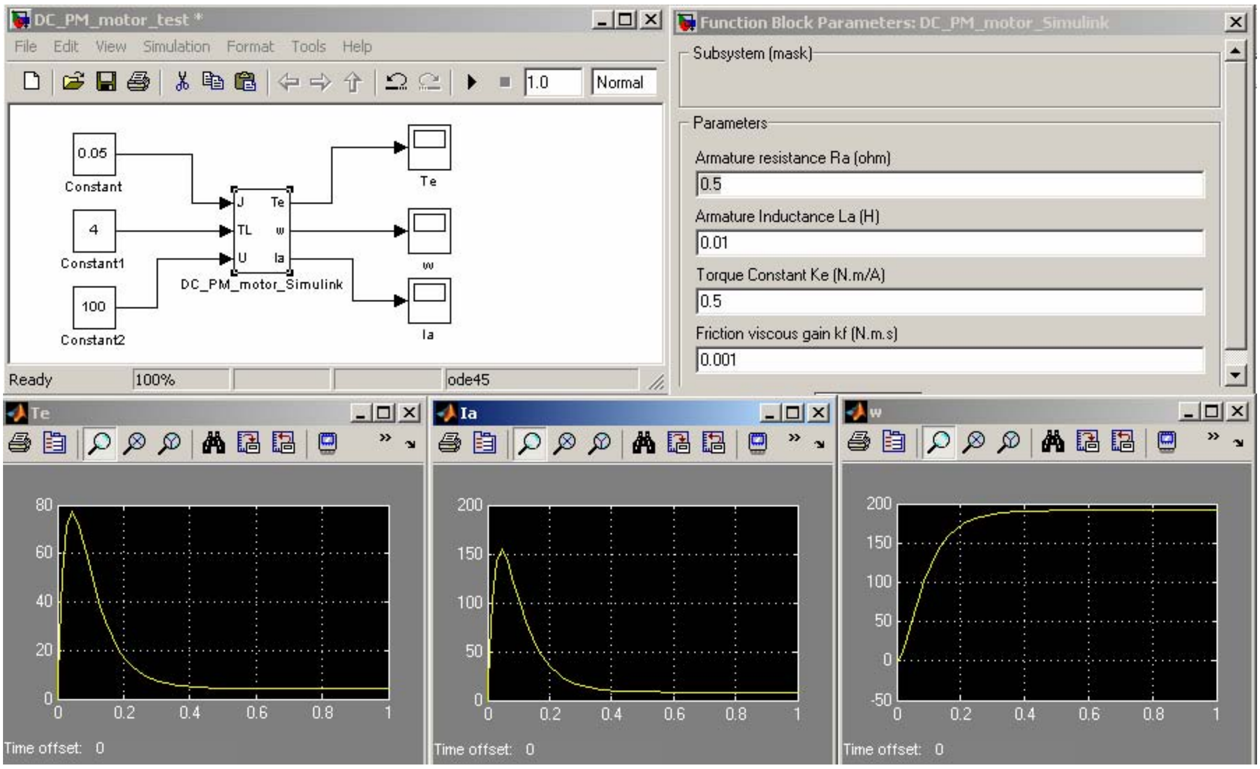
Select all the component of the model and create a subsystem. Remove all the input and output outside the subsystem. Rename the subsystem as DC_PM_motor_Simulink. Select the subsystem and open the windows "Mask Subsystem" from the edit menu.



Save the DC_PM_motor.mdl file

1.4. Testing the Function Block

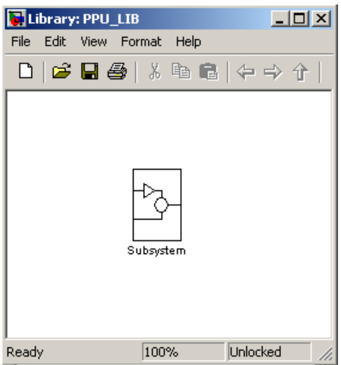
Save the DC_PM_motor.mdl as DC_PM_motor_test.mdl. Connect constant blocks to the inputs U (100 volts), J (0.05 Kg.m^2) and TL (4 N.m), scopes to the outputs w, Ia and Te. Using the Function Block Parameter windows, initialize the internal parameters Ra (0.5 ohm), La (10 mH), Ke (0.5 N.m/A) and kf (0.001 N.m.s).
Start the simulation (End time 1s). The result should be the following:



1.5. Creating a new Simulink library

From the Simulink Library Browsers, open a new library : File/new/library. Save this empty file in a safe place as PPU_LIB.

Create an empty subsystem in the windows PPU_LIB: drag any icon in the windows, select it and create a subsystem. Open the subsystem and remove all the components. Close the subsystem.

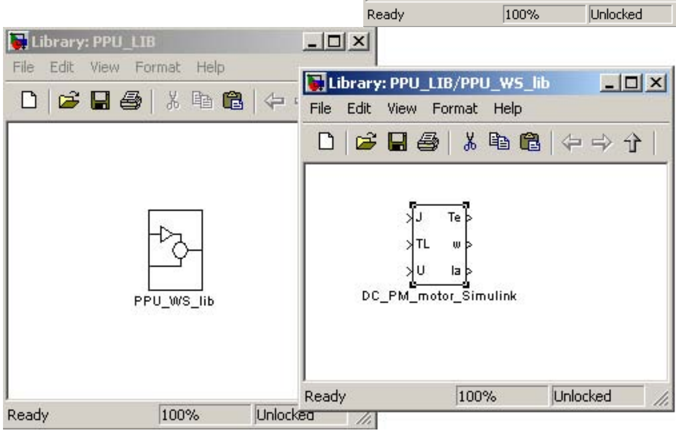


Rename the subsystem as PPU_WS_lib.

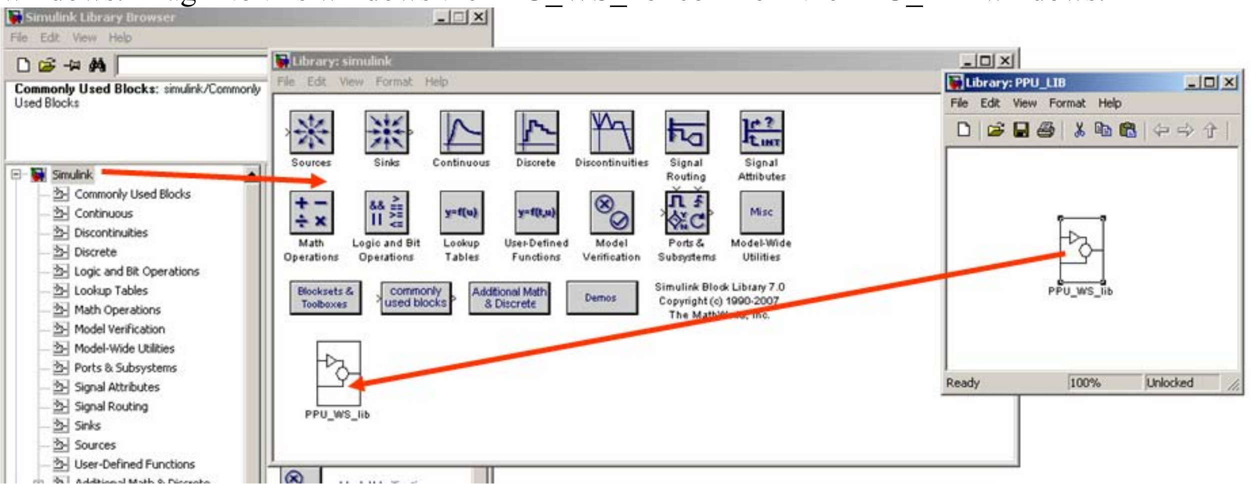
During the workshop, we will use this subsytem PPU_WS_lib as the original folder of our own function blocks.

Copy the function block DC_PM_motor_simulink into the subsystem PPU_WS_lib.

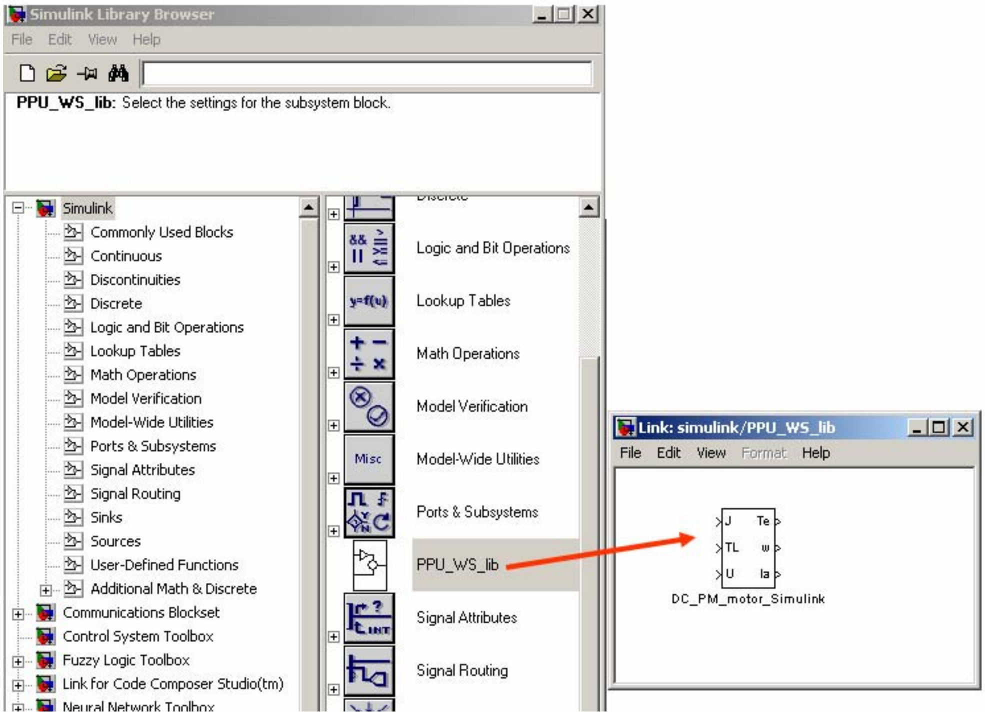
Save all the windows.



From the Simulink Library Browser windows, open (right click)the Library Simulink windows. Drag into this windows the PPU_WS_lib icon from the PPU_LIB windows.



Save the Library Simulink. Close all the windows.
Open the Simulink Library Browser windows. The PPU_WS_lib library is now in the list of the available libraries. Opening the PPU_WS_lib icon allows to access to the DC_PM_motor_Simulink function block.



2- Introduction to the Control Design / Linear Analysis

2.1. 0pen loop model

Using the DC_PM_motor_Simulink function bloc, draw the following open_loop1.mdl model. The internal parameters of the motor are: Ra=0.5, La=0.005, Ke=0.5, kf=0.005. Perform simulation.