DYNAMIC MODELING OF DC ELECTRIC MACHINES

By

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Course: Electric Machines and Drives.

Program: Electric Vehicle Propulsion and Control (E-PiCo).

March, 2024.

Objective: Implement the dynamic model of the separately-excited DC motor with the following specifications on MATLAB/SIMULINK:

$R_a = 0.5\ \Omega$, $L_a = 0.003\text{H}$, and

$K_b = 0.8$ V/rad/sec, is driving a load of $J = 0.0167\,\text{kg-m}^2$, $B_1 = 0.01$ N·m/rad/sec

(a) Plot the output speed from no-load starting until it reaches its steady state. The motor is supplied with a DC voltage source of 220-V.

(b) Repeat part (a) when the starting torque is 100 N.m.

Methodology:

The differential (dynamic) Equation of the separately-excited DC motor will be implemented in the Simulink environment.

$$\begin{cases} V_{in} = E_a + R_a i_a + L_a \dfrac{di_a}{dt} \\ J\dfrac{d\omega_m}{dt} + B_1\omega_m = T_e - T_L \end{cases}$$

Where: $E_a = K_a\varphi\omega_m = K_e\omega_m,\ T_e = \frac{E_a i_a}{\omega_m} = K_e i_a = K_t i_a$

Substituting $E_a = K_e\omega_m$ and, $T_e = K_e i_a$ in the differential equation above;

$$\frac{di_a}{dt} = \frac{1}{L_a}(V_{in} - K_e\omega_m - R_a i_a)$$

$$\frac{d\omega_m}{dt} = \frac{1}{J}(K_t i_a - T_L - B_1\omega_m)$$

Therefore, we can implement the dynamic model as shown in Figure 1:

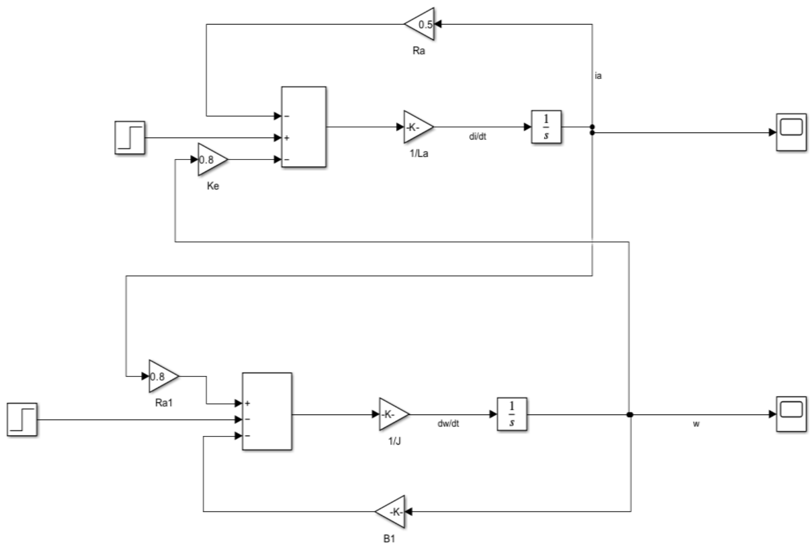

Fig. 1: Simulink Model of a DC Electric Machine

Results:

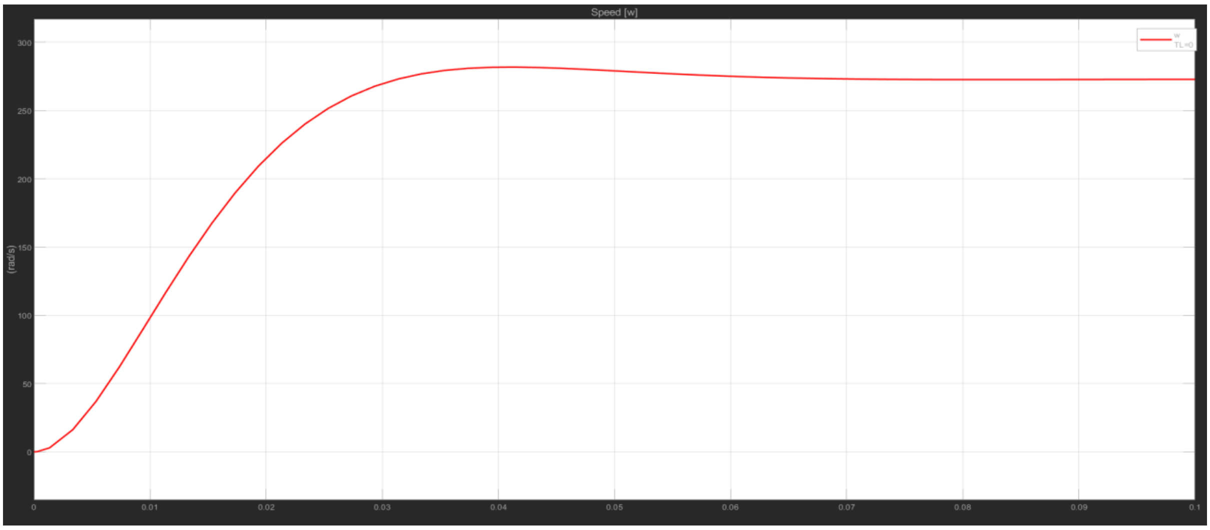

Fig. 2: The output speed from no-load starting until it reaches its steady state.

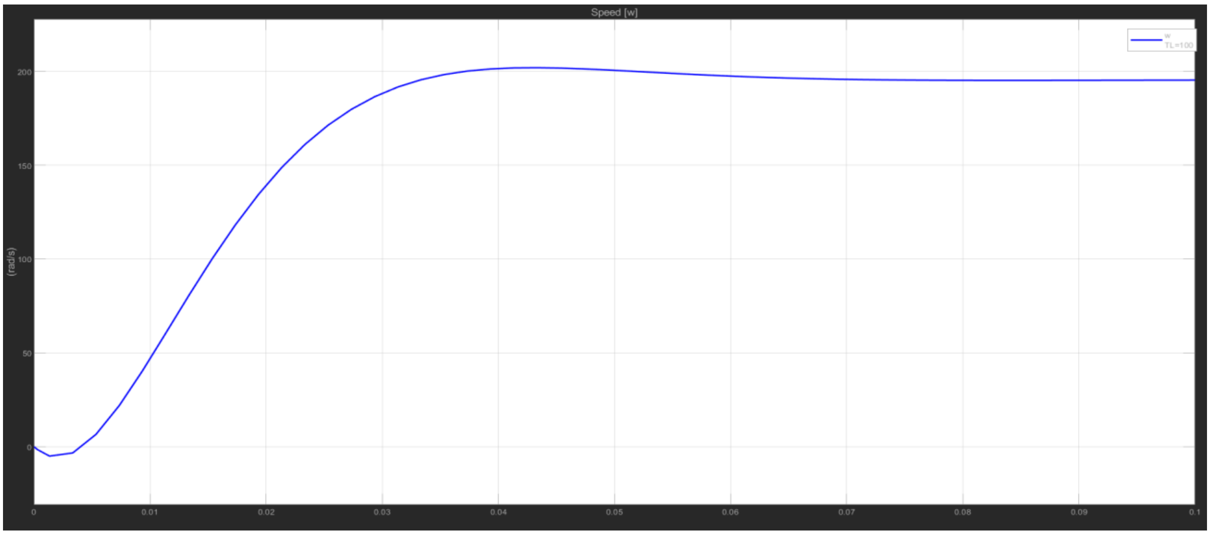

Fig. 3: The output speed when the starting Torque is 100N.m

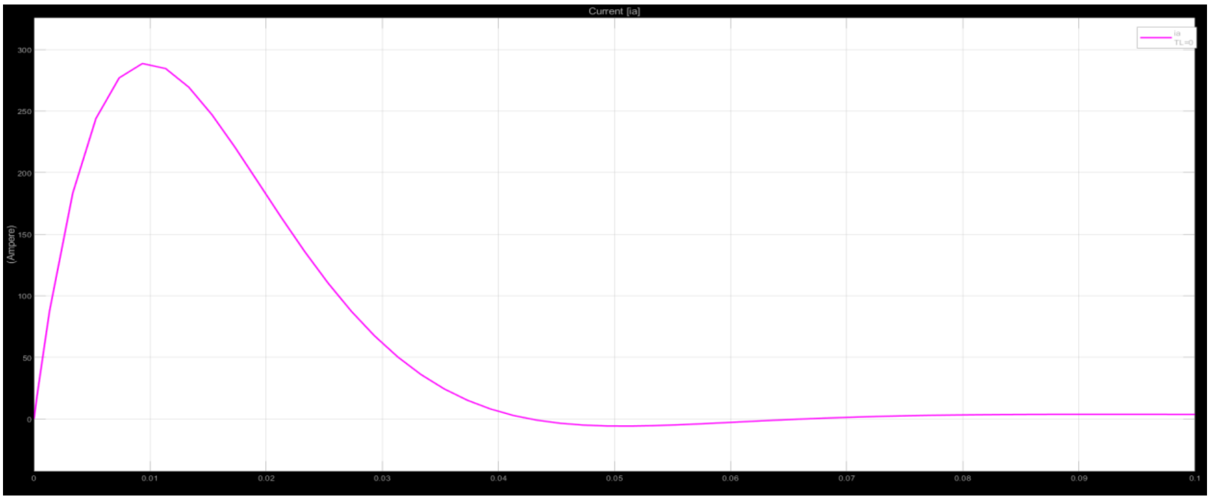

Fig. 4: Armature current at no-load condition

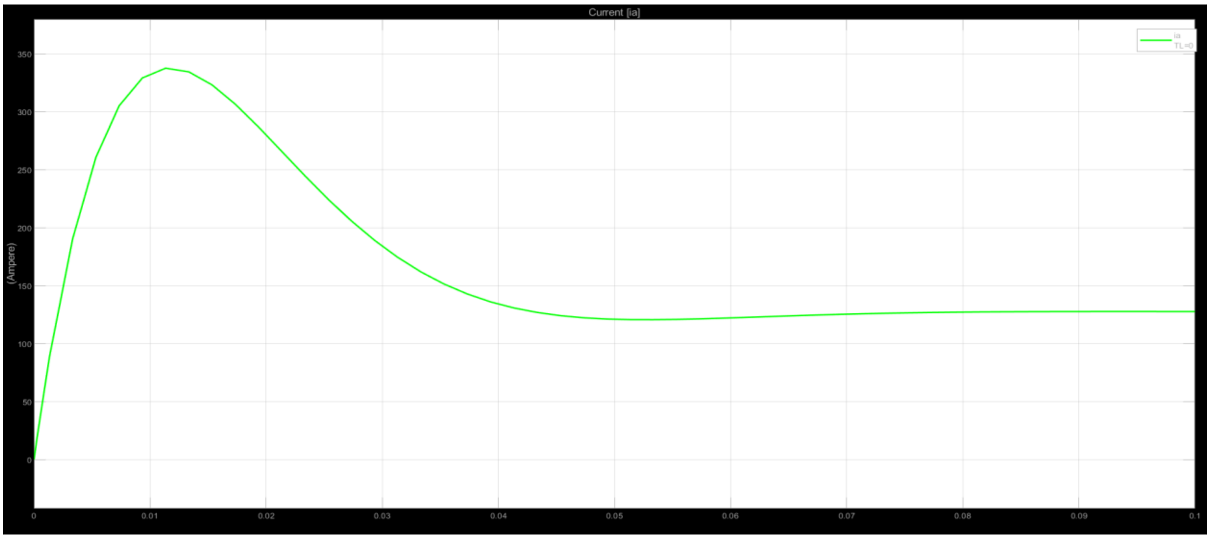

Fig. 5: Armature current when the starting Torque is 100N.m

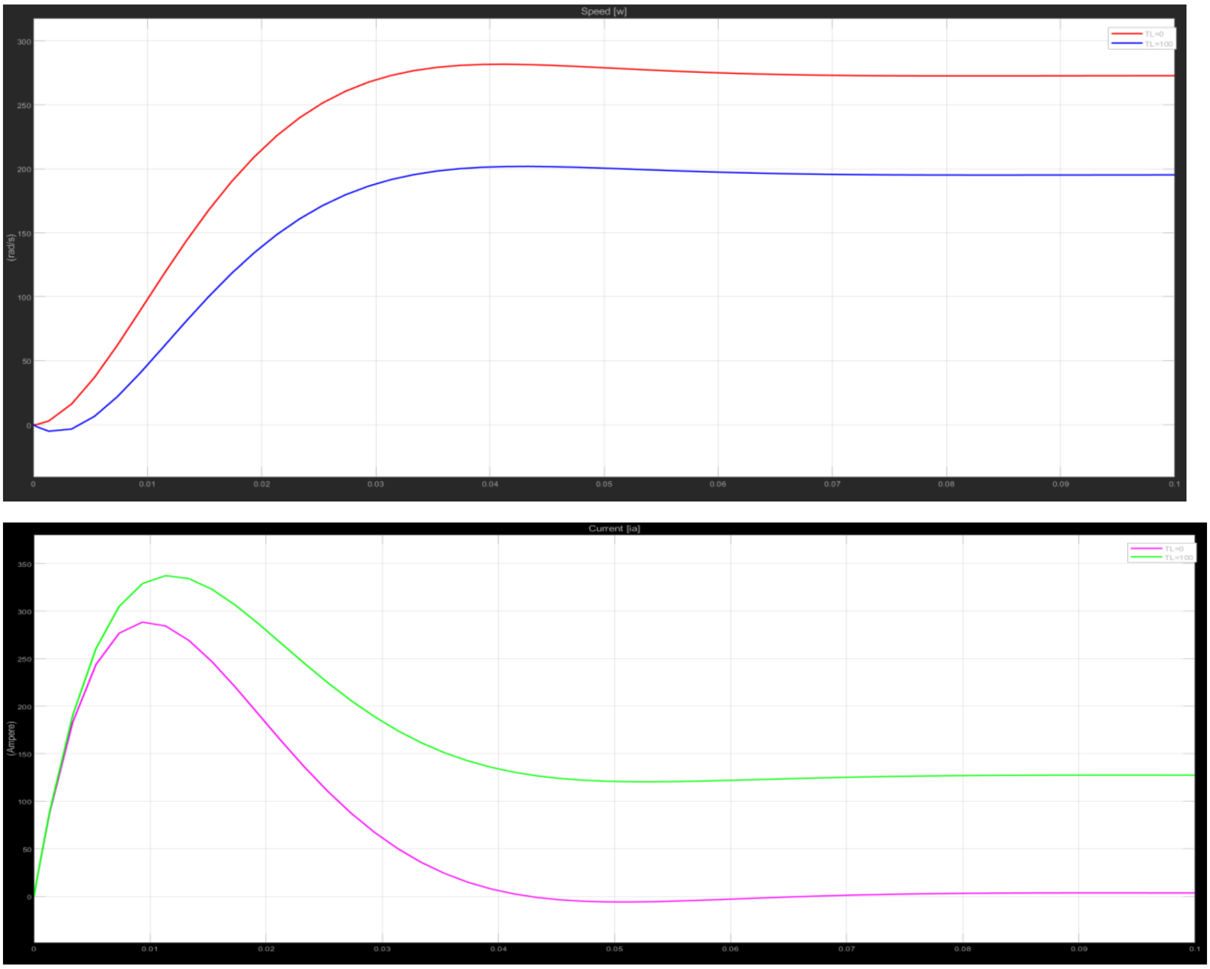

Fig. 6: Combined Simulation Results

Discussion:

- When the load torque is zero, the steady-state armature current is also zero. Conversely, when the load torque is 100 Nm, the armature current becomes a positive steady-state value. This is due to the motor's design, which remains unchanged regardless of load conditions. The motor's separately-excited characteristic means that the field current is unaffected by variations in armature current and load torque. Therefore, the electromagnetic torque is directly proportional to the armature current, which, in turn, is proportional to the load torque in the steady state.

- The observed overshoot in the current response during the transient state is a direct consequence of the motor's need for an electromagnetic torque that exceeds the load torque to accelerate the rotor. This requirement results in a current magnitude during startup that is higher than the steady-state current.

- As the motor transitions to steady state, the speed stabilizes, potentially after experiencing overshoot, at a point where the electromagnetic torque balances with the load torque. This equilibrium marks the motor's entry into steady operation.

- In steady-state operation, it is observed that motors subjected to higher load torques operate at lower speeds. This can be explained through the lens of power conservation. Given that the motor's power output remains constant, an increase in speed leads to a reduction in electromagnetic torque.