The state equations listed in Figure 4 of the appendix are implemented in PLECS. Responses from the stator phase currents, rotor phase currents, rotor speed, and electromagnetic torque are provided.

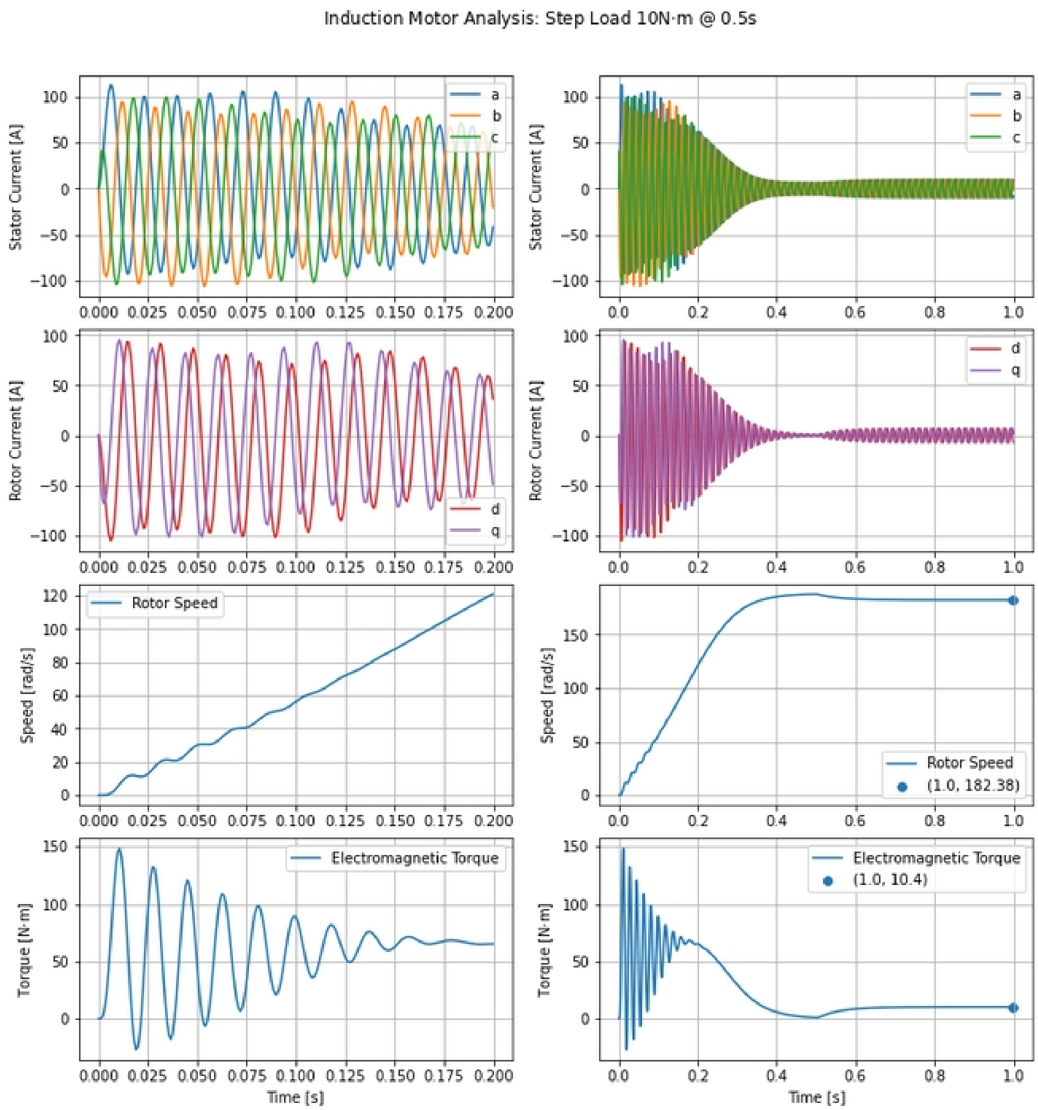

Fig. 1. Analysis Induction Motor: Step Load 10N·m at 0.5 seconds

In Figure 1, the transient response is shown on the left side and the step response (with transient) is shown on the right. The stator phase currents are phase shifted by 120 degrees as expected. Also, the dq rotor currents are separated by 90 degrees as expected. The rotor speed ramps up with small oscillations and follows an underdamped response. The steady state rotor speed is 182.38 rad/s. The electromagnetic torque oscillates greatly before 0.2 seconds and then follows an underdamped response. The steady state torque is 10.4 N·m.

The previous analysis is compared with the induction motor provided by PLECS.

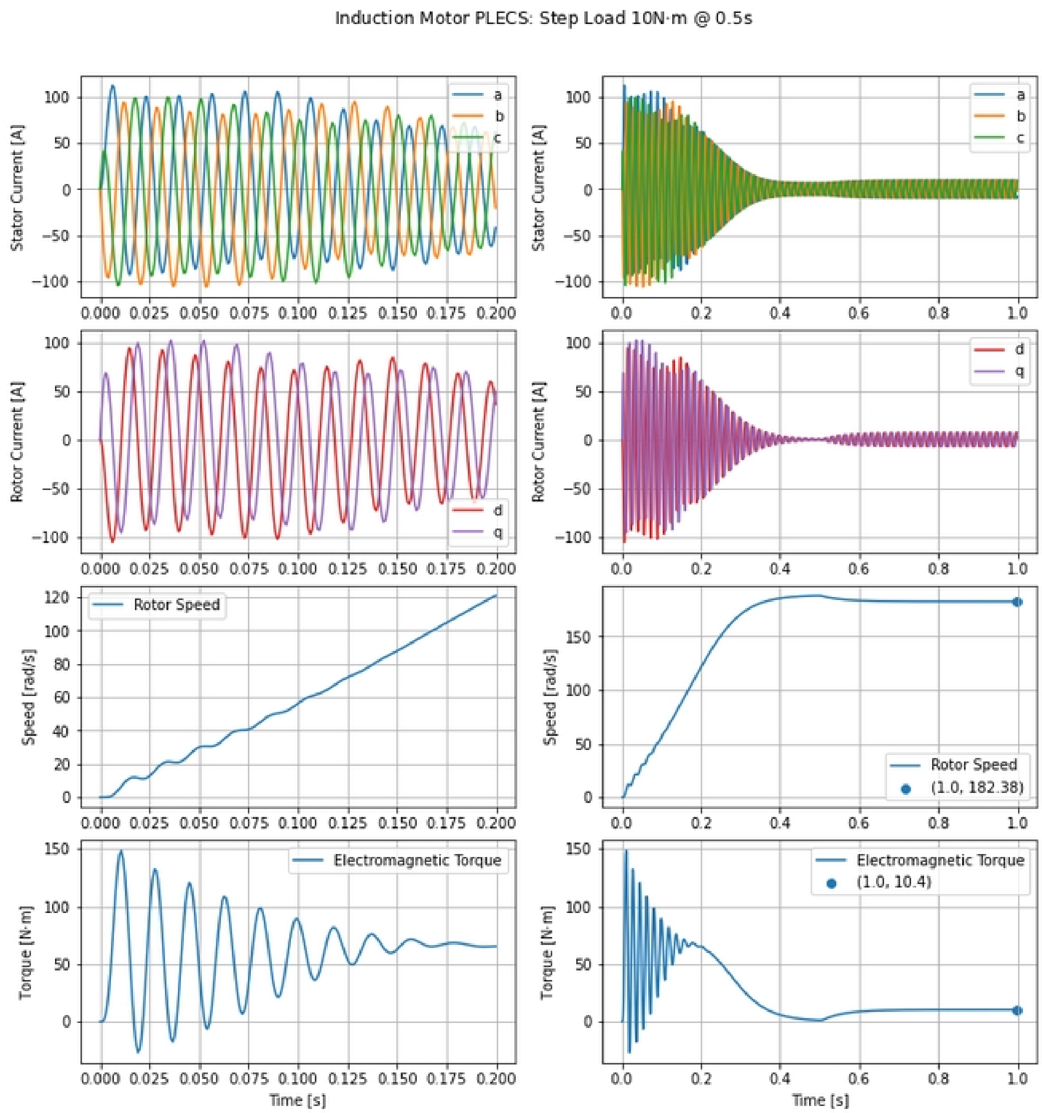

Fig. 2. PLECS Induction Motor: Step Load 10N·m at 0.5 seconds

The simulations from the PLECS models strongly agree with the previous analysis. Both the rotor speed and the electromagnetic torque follow an underdamped response. The steady state rotor speed is 182.38 rad/s and the steady state electromagnetic torque is 10.4 N·m. Note, these are the same values found in the analysis previously. Comparing the rotor phase currents, the analysis currents are shifted 180 degrees from the PLECS model. This is an expected result due to the abc - dq transformation.

$$e^{-j\pi} = -1 \; ; \; e^{-j0} = 1 \tag{1}$$

The transient rotor phase currents are provided for comparison.

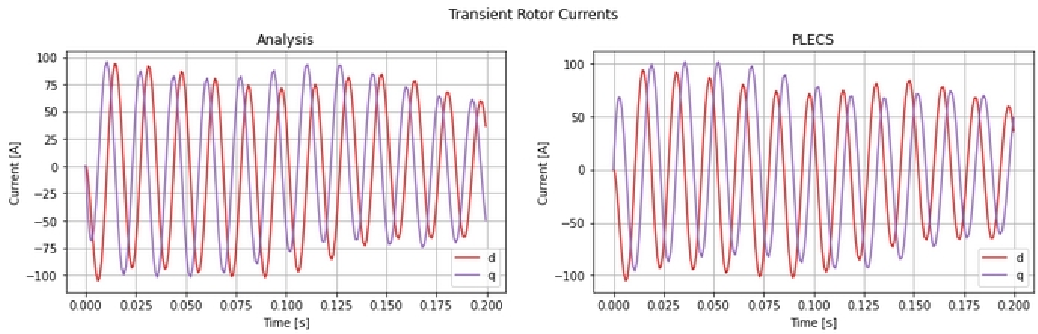

Fig.3 . Transient Rotor Phase Currents (dq)

All abc – dq transformations were calculated using the Clarke transformations.

Appendix

Equation Summary for Simulation:

The following is a listing of state equations which can be used in simulating an AC machine:

$$p\lambda_{qs}^{s} = v_{qs}^{s} - r_s i_{qs}^{s}$$

$$p\lambda_{ds}^{s} = v_{ds}^{s} - r_s i_{ds}^{s}$$

$$p\lambda_{qr}^{s} = v_{qr}^{s} - r_r i_{qr}^{s} + \omega_r \lambda_{dr}^{s}$$

$$p\lambda_{dr}^{s} = v_{dr}^{s} - r_r i_{dr}^{s} - \omega_r \lambda_{qr}^{s}$$

$$T_e = \frac{3}{2}\frac{P}{2} L_m (i_{qs}^{s} i_{dr}^{s} - i_{qr}^{s} i_{ds}^{s})$$

where

$$\lambda_{qs}^{s} = L_s i_{qs}^{s} + L_m i_{qr}^{s}$$

$$\lambda_{ds}^{s} = L_s i_{ds}^{s} + L_m i_{dr}^{s}$$

$$\lambda_{qr}^{s} = L_r i_{qr}^{s} + L_m i_{qs}^{s}$$

$$\lambda_{dr}^{s} = L_r i_{dr}^{s} + L_m i_{ds}^{s}$$

so

$$i_{qs}^{s} = \frac{1}{\sigma L_s}\left(\lambda_{qs}^{s} - \frac{L_m}{L_r}\lambda_{qr}^{s}\right) \qquad \sigma = 1 - \frac{L_m^2}{L_s L_r} \text{ (coupling factor)}$$

$$i_{ds}^{s} = \frac{1}{\sigma L_s}\left(\lambda_{ds}^{s} - \frac{L_m}{L_r}\lambda_{dr}^{s}\right)$$

$$i_{qr}^{s} = \frac{1}{L_r}\left(1 + \frac{L_m^2}{\sigma L_r L_s}\right)\lambda_{qr}^{s} - \frac{L_m}{\sigma L_r L_s}\lambda_{qs}^{s}$$

$$i_{dr}^{s} = \frac{1}{L_r}\left(1 + \frac{L_m^2}{\sigma L_r L_s}\right)\lambda_{dr}^{s} - \frac{L_m}{\sigma L_r L_s}\lambda_{ds}^{s}$$

Fig. 4. AC Machine State Equations