EE 56◎ – Electric Machines and Drives

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Homework #1 – Due November 2nd, 2020

Analysis and Modeling of a Wound Field DC Machine and Drive

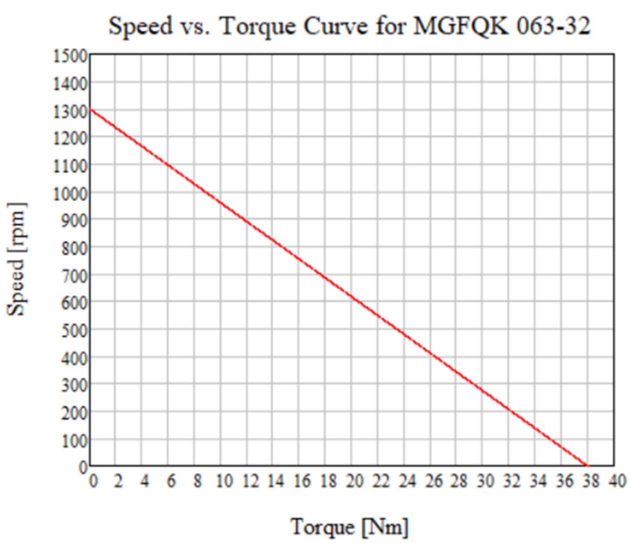
The consulting company that you are working for has been hired by an industrial manufacturer which has used DC motors for the past 100 years. This company is not interested in changing their motor technology, and has asked you to analyze/simulate the performance of these machines in new applications. They have selected the two motors from Lenze, one small machine (1 kW) and one large machine (90.8 kW). The data for each motor is given in the appendix.

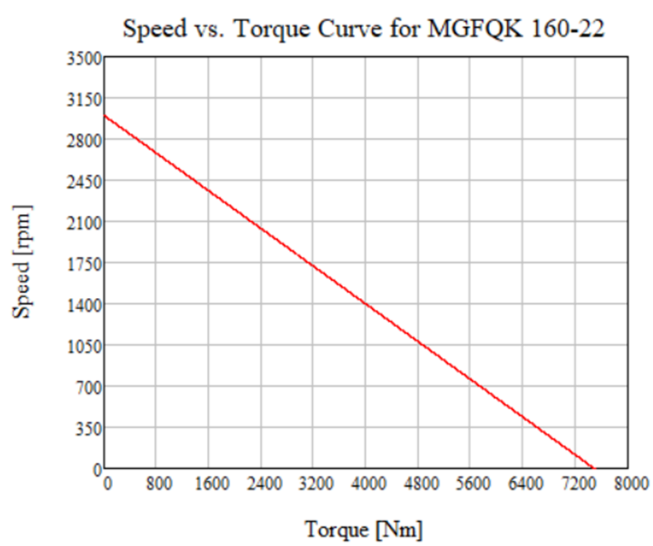
Selected Motors:

Lenze Motor	MGFQK 063-32 – 1 kW	MGFQK 160-22 – 90.8 Kw

In order to evaluate the performance of the motors, you will look at the following properties:

1. Speed vs. Torque Curves (that you generate from the given data)





2. Start-up Transient Behavior with Ideal Voltage Source
   a. Eigenvalue Analysis

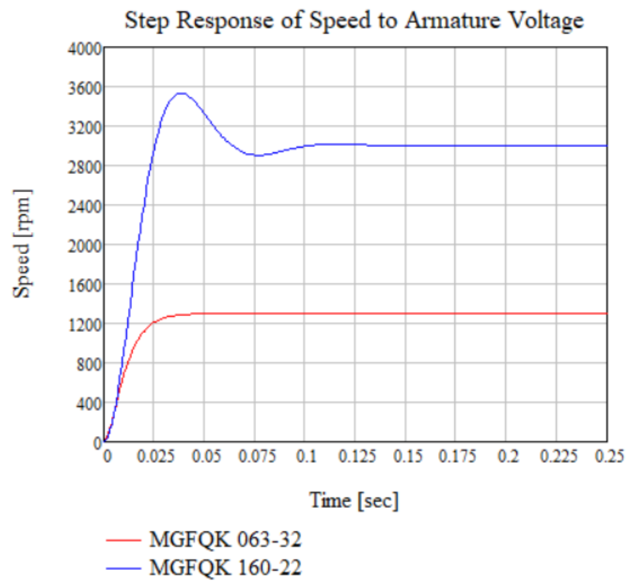
$$EVs(K_{e1}, R_{a1}, L_{a1}, J_{m1}, b_{m1}) = \begin{pmatrix} -33.921 \\ -23.478 \end{pmatrix} \cdot Hz$$

Eigenvalues for MGFQK 063-32

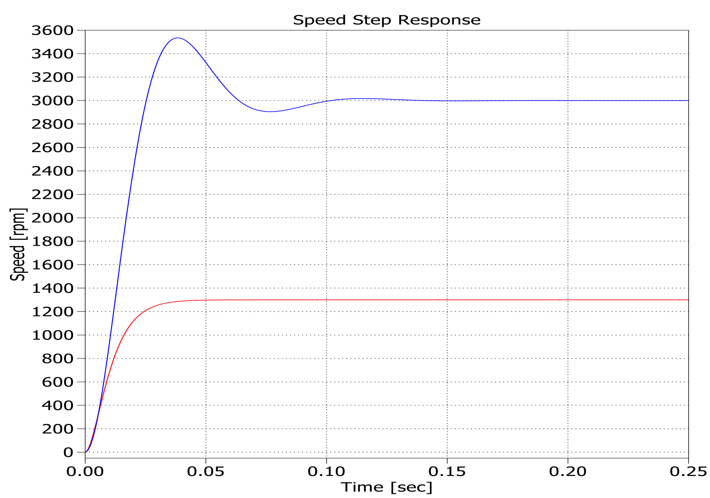
$$EVs(K_{e2}, R_{a2}, L_{a2}, J_{m2}, b_{m2}) = \begin{pmatrix} -7.162 + 13.046i \\ -7.162 - 13.046i \end{pmatrix} \cdot Hz$$

Eigenvalues for MGFQK 160-22

b. Step Response



Or from PLECS



3. Compare the behavior of the DC Motor with a PWM DC Drive to the analysis above.

To do:

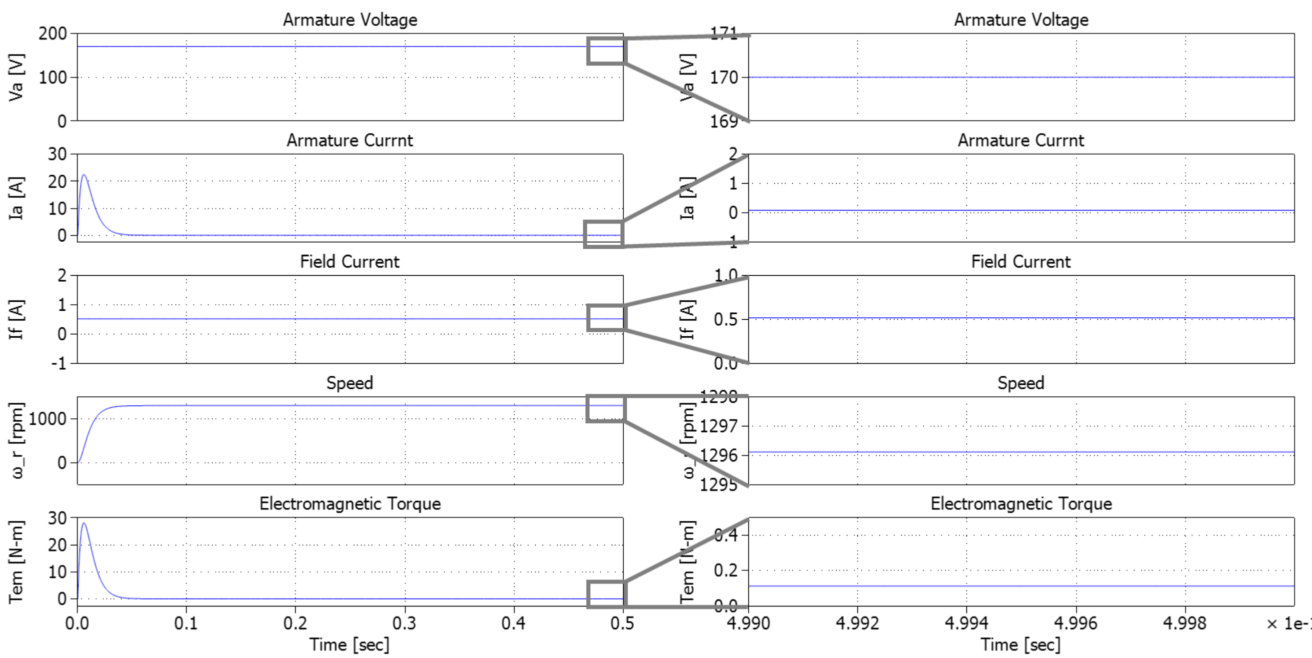
a. Develop the analytical speed vs. torque curves for both motors (speed on the y-axis).
b. Assume the field current is initially at its rated value and apply a step (zero to rated voltage) to the armature. Using an ideal voltage source, simulate the following conditions:

Lenze Motor	MGFQK 063-32 – 1 kW	MGFQK 160-22 – 90.8 Kw
Armature Voltage	170V	460V
Load Torque – case 1	0.1 Nm	1 Nm
Load Torque – case 2	7 Nm	300 Nm

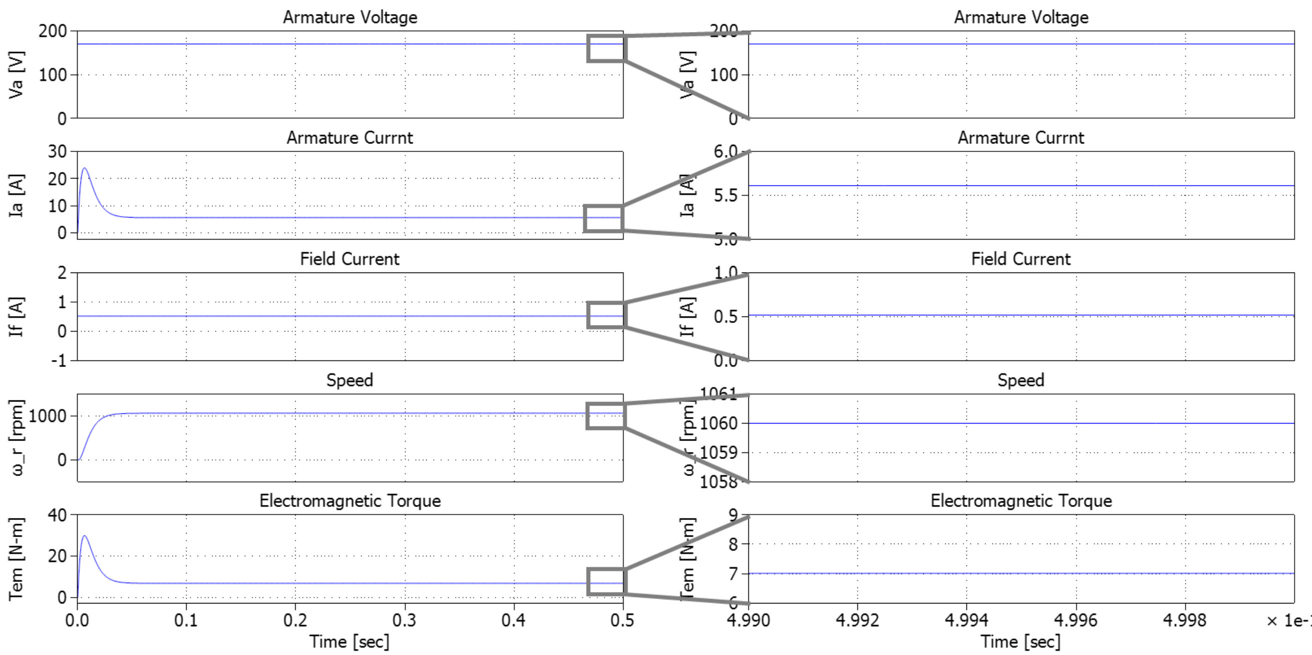
Simulate:

i. The armature current
ii. The speed of the motor
iii. The electromagnetic torque

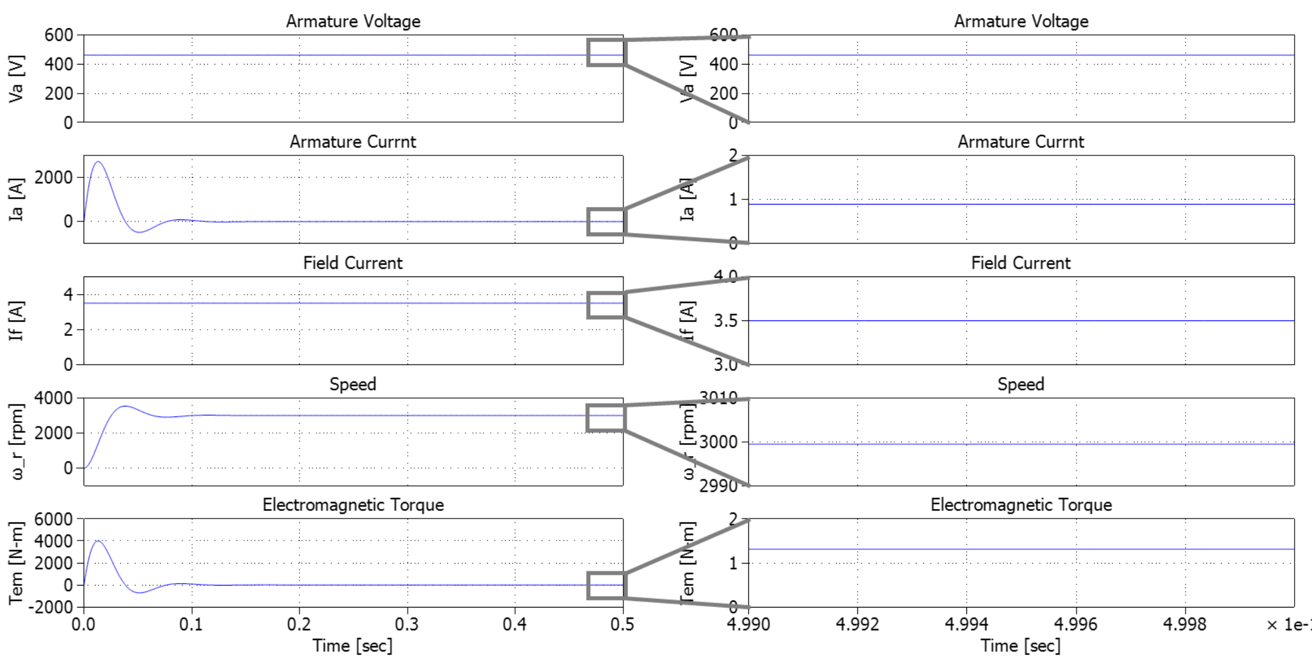
Case 1 – Motor 1



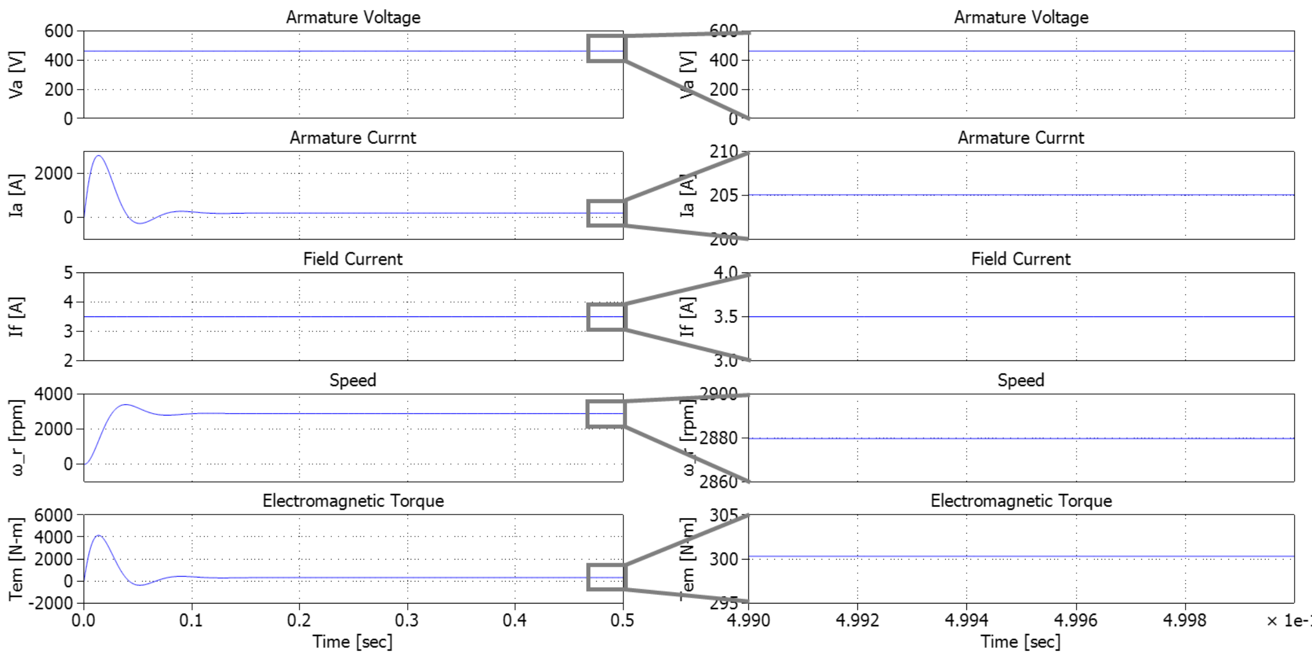
Case 2 – Motor 1



Case 1 – Motor 2



Case 2 – Motor 2



c. Calculate the eigenvalues of each motor. Does the step response yield the expected shape? Answer: yes, the small motor has real eigenvalues and doesn't show any overshoot. The large motor has complex eigenvalues and therefore has overshoot.

$$EVs(K_{e1}, R_{a1}, L_{a1}, J_{m1}, b_{m1}) = \begin{pmatrix} -33.921 \\ -23.478 \end{pmatrix} \cdot Hz$$ *Eigenvalues for MGFQK 063-32*

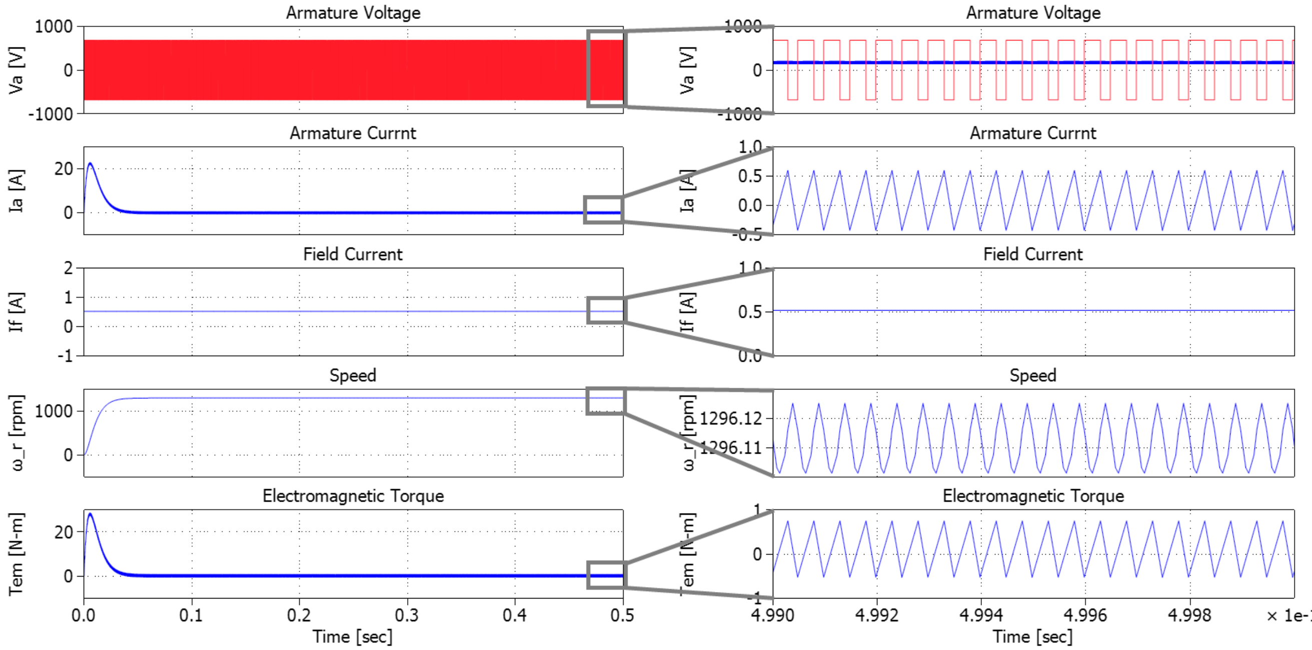
$$EVs(K_{e2}, R_{a2}, L_{a2}, J_{m2}, b_{m2}) = \begin{pmatrix} -7.162 + 13.046i \\ -7.162 - 13.046i \end{pmatrix} \cdot Hz$$ *Eigenvalues for MGFQK 160-22*

d. Using a PWM controlled H-bridge inverter, simulate the motor operation at the conditions of part b and compare.

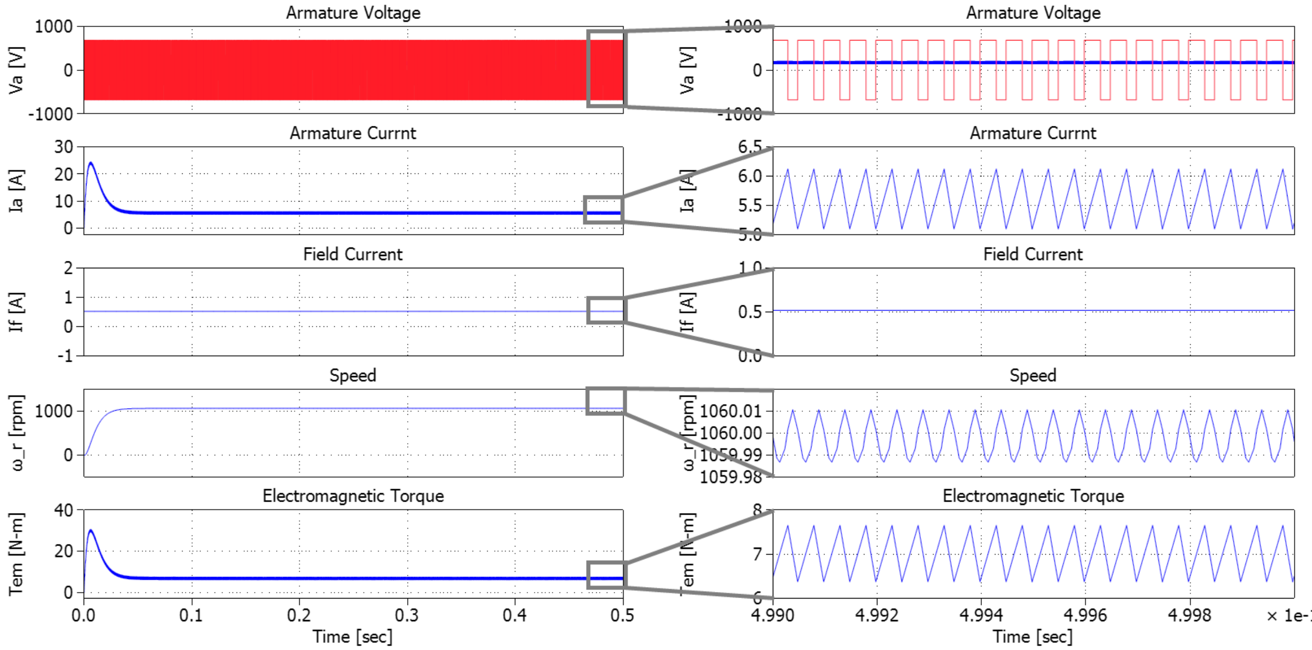
Simulate:

i. An H-bridge inverter with a bus voltage of 680Vdc.
ii. Control the inverter using pulse width modulation to achieve the required armature voltage for each motor.
iii. Plot the steady state speed and armature current.
iv. Does the speed and current correspond with the analysis above? Yes, very closely

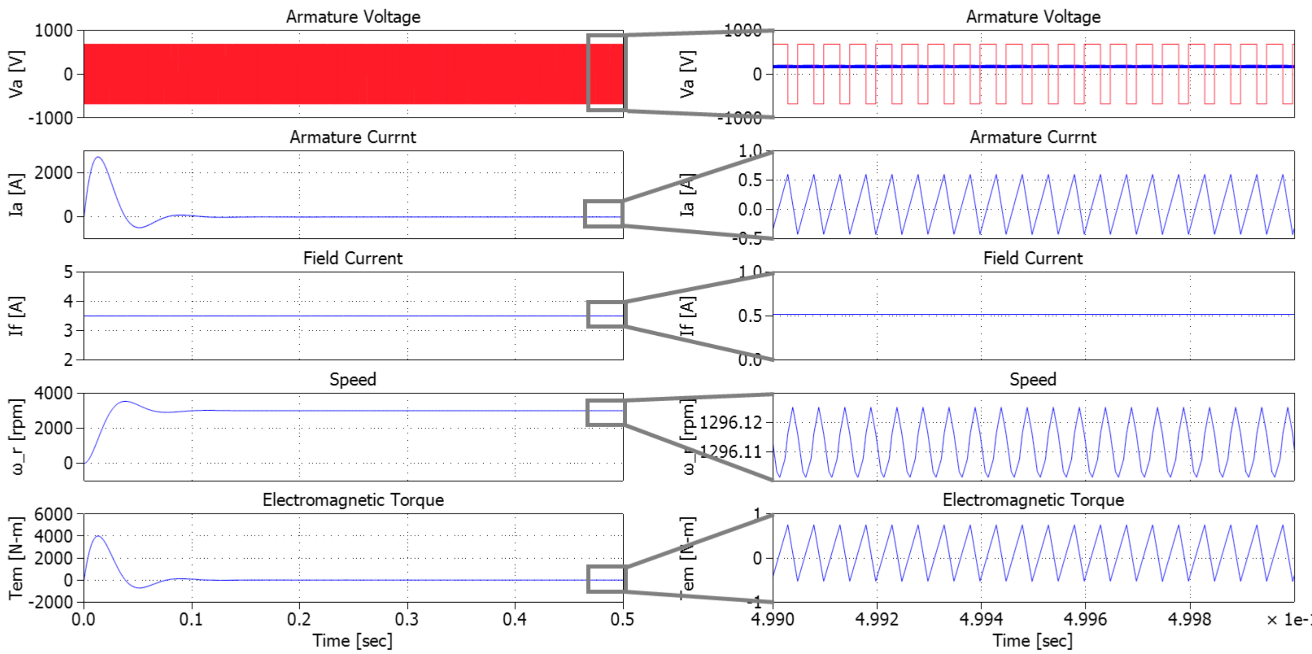
Case 1 – Motor 1



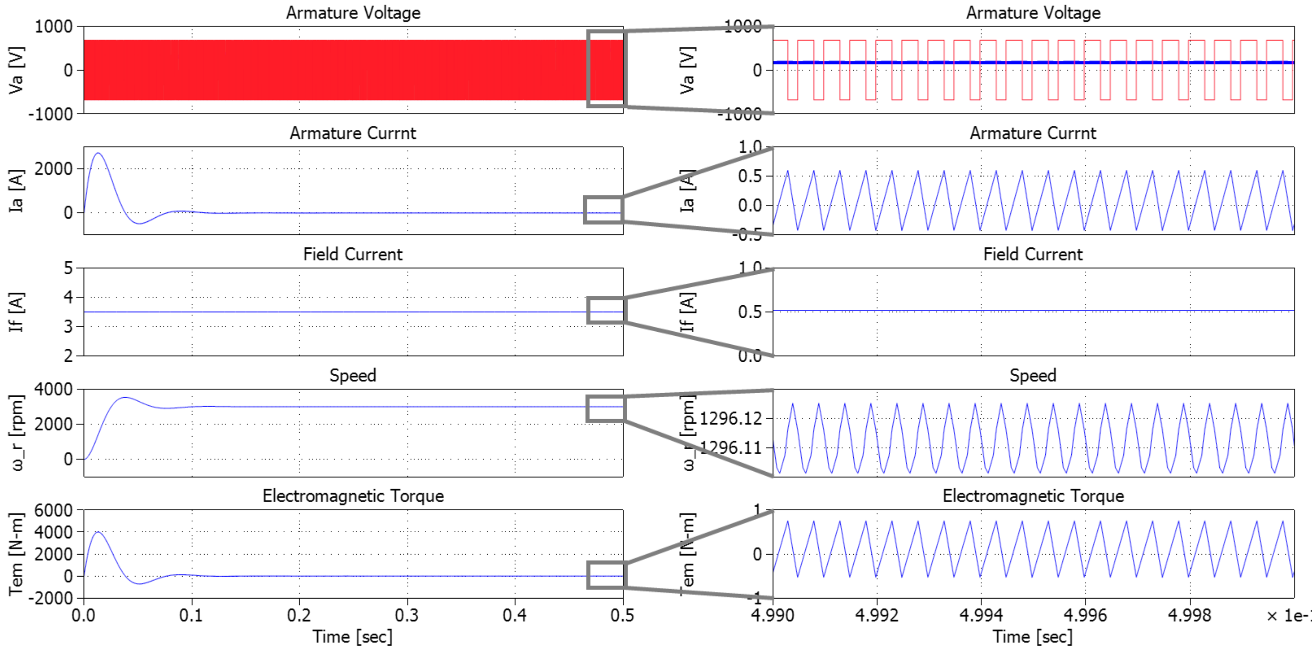
Case 2 – Motor 1



Case 1 – Motor 2



Case 2 – Motor 2



Hand in:

1. Appropriately detailed discussion of important results and comparative findings not to exceed 4 pages. Use appendices for derivations, these are not counted toward the limit.
2. Include plots detailing the analysis and simulation.
3. Your PLECS model.

Motor I

MGFQK 063-32

Technical data

Data refers to: – Form factor – Enclosure – Cooling (forced ventilation) – Continuous operation – Insulation class	F_F = 1.05 IP 23s IC 06 S1 F
Total weight Inertia	m = 19 kg J = 0.0032 kgm²
Field excitation	U_F = 210 V I_F = 1.0 A U_F = 360 V I_F = 0.52 A
A-side bearing B-side bearing	6204-2RSR-C3 6204-2RSR-C3
Carbon brushes	a) 6.3 x 16 x 20
Permissible shaft load for L/2 and n_N – reinforced bearing	F_r = 750 N F_a = 400 N F_{rr} = 1100 N
Fan variant	220–240 V, 50–60 Hz, 0.39 A 380–460 V, 50–60 Hz, 0.11 A
Cooling variant	IC 26 IC 17/37
Cooling air volume Pressure drop	65 m³/h 70 Pa

P	Speed n at voltage				n_F	n_{Mech}	M	I_{AN}	I_{Amax}	L_A	R_a125°	Carbon brushes	
kW	min⁻¹				min⁻¹		Nm	A	A	mH	Ω	Quantity	Variant
	170 V	280 V	–	–									
0.33	400	–	–	–	1300	4500	7.0	5.3	15	57.5	19.4	4	a
0.85	–	1150	–	–	3450	4500	6.9	5.3	15	57.5	19.4	4	a
0.5	750	–	–	–	2250	4500	7.0	5.7	17	39.7	13.26	4	a
1.1	–	1650	–	–	4500	4500	6.9	5.7	17	39.7	13.26	4	a
0.75	1000	–	–	–	3000	4500	7.0	8.0	24	26.5	8.5	4	a
1.5	–	2100	–	–	4500	4500	6.9	8.0	24	26.5	8.5	4	a
1.0	1300	–	–	–	3900	4500	7.0	10.2	30	15.5	5.59	4	a
2.0	–	2700	–	–	4500	4500	7.0	10.2	30	15.5	5.59	4	a

Assume a field inductance of 15 mH and a motor damping $10^{-4}\,\frac{N\cdot m}{rad/sec}$

Motor II

MGFQK 160-22

Technical data

Data refers to: – Form factor – Enclosure – Cooling (forced ventilation) – Continuous operation – Insulation class	 F_F = 1.05 IP 23s IC 06 S1 F
Total weight Inertia	m = 250 kg J = 0.2452 kgm²
Field excitation	U_F = 210 V I_F = 6.2 A U_F = 360 V I_F = 3.5 A
A-side bearing B-side bearing	6312-2RSR-C3 6312-2RSR-C3
Carbon brushes	a) 12.5 x 25 x 32 b) 12.5 x 25 x 32 ZW
Permissible shaft load for L/2 and n_N – reinforced bearing	F_r = 4950 N F_a = 3580 N F_{rr} = 9700 N
Fan variant	345–540 V, 50–60 Hz, 1.4 A
Cooling variant	IC 26 IC 17/37 IC 0666
Cooling air volume Pressure drop	1300 m³/h 500 Pa

P	Speed n at voltage				n_F	n_{Mech}	M	I_{AN}	I_{Amax}	L_A	R_a125º	Carbon brushes	
kW	min⁻¹				min⁻¹		Nm	A	A	mH	Ω	Quantity	Variant
	420 V	460 V	–	–									
25.1	820	–	–	–	2450	3600	292	72	180	9.2	0.884	4	a
27.9	–	900	–	–	2700	3600	292	72	180	9.2	0.884	4	a
33.7	1100	–	–	–	3300	3600	295	93	232	5.6	0.50	8	a
37.3	–	1200	–	–	3600	3600	295	93	232	5.6	0.50	8	a
40.8	1300	–	–	–	3600	3600	300	111	275	4.1	0.368	8	a
45.0	–	1450	–	–	3600	3600	300	111	275	4.1	0.368	8	a
49.2	1550	–	–	–	3600	3600	298	132	330	2.8	0.260	8	a
54.4	–	1750	–	–	3600	3600	298	132	330	2.8	0.260	8	a
62.0	2000	–	–	–	3600	3600	293	163	410	1.8	0.16	12	b
68.2	–	2200	–	–	3600	3600	293	163	410	1.8	0.16	12	b
83.0	**2750**	**–**	–	–	3600	3600	289	215	540	1.0	0.09	12	a
90.8	–	**3000**	–	–	3600	3600	289	215	540	1.0	0.09	12	a

Assume a field inductance of 150 mH and a motor damping $10^{-3}\,\frac{N\cdot m}{rad/_{sec}}$