

EE4001 Study Questions – ED Chapter 12

Summer 2005

Problem 1

- (a) Sketch the wiring diagram of the star-delta starter for inrush control of the induction machine. [3 marks]
- (b) The specification table for Westinghouse induction motors is provided as an attachment (see page 6). Consider the 22 kW, four-pole machine with 400 V (line-line), 50 Hz applied. What is the direct-on-line starting current when a star-delta starter is used? [3 marks]
- (c) A four-pole star-connected motor outputs 40 Nm at 1746 RPM when supplied by a 60 Hz line-line voltage of 440 V and a phase current of 10.39 A lagging at a power factor of 0.866. The series resistance is 1.5 Ω .
- (i) By maintaining a constant field flux, what are the electrical line voltage, current, frequency, and power factor sourced from the inverter, when developing 50% of the rated torque at 50% of the rated speed?
- (ii) Determine values for the slip frequency, line current and power factor required to ensure constant-power operation of the machine at twice the rated speed.

Use the formula $slope = \frac{V_{ph,rated} - R_S \cdot I_{R,rated}}{f_{rated}}$ for low-voltage boost.

[14 marks]

[Ans. (b) 162A, (c) (i) 220.1 V, 30 Hz, 0.654, (ii) 1.8 Hz, 9.37 A, 0.96]

- (d) Incorporating low-voltage boost, determine approximate values for the starting frequency, current, and voltage in order to supply 150% of rated torque at startup.

[Ans. 2.7 Hz, 51.2 V, 14.5 A]

Summer 2004

Problem 2

- (a) Sketch the wiring diagram of the star-delta starter for inrush control of the induction machine. [4 marks]
- (b) A four-pole star-connected induction motor interfaces a mechanical load to the 400 V (line-line) 50 Hz power grid (via gearing, contactor and breaker). The machine has the following per-phase equivalent circuit parameters:
 $R_S = 20 \text{ m}\Omega$, $L_{LS} = 0.2 \text{ mH}$, $L_M = 7.2 \text{ mH}$, $L_{LR}' = 0.3 \text{ mH}$, and $R_R' = 35 \text{ m}\Omega$.
- (i) Which motor parameters limit the startup current and what value of peak startup current do you expect?
- (ii) How much greater would the startup current be if the machine was started in a delta configuration.
- A power electronics inverter is now integrated into the system and the motor is connected in star. The motor develops an electromagnetic torque (including friction and windage) of 865 Nm at 1453.5 rpm when supplied by a voltage-source PWM inverter supplying a 50 Hz line-line voltage of 400 V and line current of 225 A lagging at a power factor of 0.89.
- (iii) Calculate the minimum dc link voltage for the voltage-source inverter.
- (iv) By maintaining a constant airgap flux, what are the electrical line voltage, current, and frequency, and power factor sourced from the inverter, when developing 25 % of the rated torque at 25 % of the rated speed? Also calculate the modulation index for this operating point.
- (iv) Determine approximate values for the starting electrical line voltage, current, and frequency in order to supply 150% of rated torque at startup.

Use the formula $slope = \frac{V_{ph,rated} - R_S \cdot I_{R,rated}}{f_{rated}}$ for low-voltage boost.

[16 marks]

[Ans: 1390 Arms (about 7 times rated!); 2408 Arms; 654 Vdc, 100 V, 114.2 A, 12.5 Hz, 0.439, 28.7 V, 317 A, 2.326 Hz]

Problem 3

Note various wiring circuits for soft-start, volts/hertz control, etc.

A four-pole motor outputs 40 Nm at 1440 rpm when supplied by a 50 Hz line-line voltage of 400 V and phase current of 10 A lagging at a power factor of 0.88. The series resistance is 1.5 Ω . Neglecting voltage boost and maintaining a constant field flux, what are the approximate slip and electrical frequencies when outputting 20 Nm at 800 rpm. Calculate the minimum dc link voltage for the voltage-source inverter.

Incorporating voltage boost, determine approximate values for the starting frequency, current, and voltage in order to supply 150% of rated torque at startup. Calculate the modulation index (ratio of peak control voltage to peak triangular voltage) at this voltage.

[Ans: 0.5 Hz, 27.67 Hz, 653 Vdc, 3 Hz, 13.2 A, 56.9 V, 14.2%]

Problem 4

Consider the Westinghouse 22 kW, 8-pole machine with 400 V (line-line), 50 Hz.

(i) What are the initial starting line current and torque for a direct-on-line start?

A volts/hertz controller with voltage boost is integrated into the delta-wired drive. The series resistance is estimated to be 0.43 Ω .

(ii) Determine approximate values for the starting frequency, current, and voltage in order to supply the specified starting torque.

(iii) Maintaining rated airgap flux, what are the electrical line voltage, current, frequency, and power factor sourced from the inverter, when developing 50 % of the rated torque at 75 % of the rated speed?

Use the formula $slope = \frac{V_{ph,rated} - R_S \cdot I_{R,rated}}{f_{rated}}$ for low-voltage boost.

[Ans. 350.5 A, 604.8 Nm, 2.8 Hz, 99.9 A, 45.6 V, 296.5, 41.8 A, 37.2 Hz, 0.545]

Summer 2006

Problem 5

(a) Sketch the wiring diagram for the volts/hertz control of the induction machine.

[4 marks]

(b) Consider the Westinghouse 75 kW, 4-pole machine with 400 V (line-line), 50 Hz.

(i) What are the initial starting line current and torque for a direct-on-line start?

A volts/hertz controller with voltage boost is integrated into the delta-wired drive. The series resistance is estimated to be 117 m Ω .

(ii) Determine approximate values for the starting frequency, current, and voltage in order to supply the specified starting torque.

(iii) Maintaining rated airgap flux, what are the electrical line voltage, current, frequency, and power factor sourced from the inverter, when operating as a **generator** developing 100 % of the rated torque at 50 % of the rated speed?

Use the formula $slope = \frac{V_{ph,rated} - R_S \cdot I_{R,rated}}{f_{rated}}$ for low-voltage boost.

[16 marks]

[Ans. 949 A, 1205 Nm, 1.25 Hz, 292.4 A, 29.1 V, 198 V, 130 A, 24.25 Hz, 0.88]