Tutorial Sheet 7 - Three Phase Induction Motor

1. A 3-phase induction motor runs at almost 1,200 rpm at no-load and 1,140 rpm at full load when supplied with power from a 60 Hz, 3-phase line.
   a) How many poles does the motor have?
   b) What is the percent slip at full load?
   c) What is the corresponding frequency of the rotor voltages?
   d) What is the corresponding speed (i) of the rotor field with respect to the rotor? (ii) of the rotor field with respect to the stator? (iii) of the rotor field with respect to the stator field?
   e) What speed would the rotor have at a slip of 10 percent?
   f) What is the rotor frequency at this speed?
   g) Repeat part d for a slip of 10 percent. [Ans: (a) 6, (b) 5%, (c) 3 Hz, (d) 60 rpm, 1200 rpm, 0, (e) 1080 rpm, (f) 6 Hz, (g) 120 rpm, 1200 rpm, 0]

2. A 3-phase, Y-connected, 480-V (line-to-line), 30-hp, 60-Hz, 4-pole induction motor has the following equivalent-circuit constants in ohms per phase referred to the stator:

   $R1 = 0.24, R2 = 0.20, X1 = 1.3, X2 = 1.2, X_m = 37.$

   The total friction, windage and core losses may be assumed constant at 1340W. The motor connected directly to a 480-V. source. Compute the speed, shaft output torque in N-m, power in hp, efficiency, stator current and power factor for a slip of 2 percent.

   [Ans: 1764 rpm, 95.90 N-m, 23.75 hp, 88.7%, 27.17 A, 0.88 (lagging)]

3. A 460-V, 4-pole, 50-hp, 60-Hz, Y-connected, 3-phase induction motor develops its full-load induced torque at 3.8 percent slip when operating at 60Hz and 460V. The per phase impedances of the motor are:

$r_1 = 0.33\Omega$	$X_m = 30\Omega$
$x_1 = 0.42\Omega$	$x_2' = 0.42\Omega$

   Mechanical, core, and stray losses may be neglected in this problem.
   a) Find the value of the rotor resistance r_2'
   b) Find T_{max}, s_{max}, and the rotor speed at maximum torque for this motor.
   c) Find the starting torque of this motor. [Ans: (a) 0.171 Ω, 0.0068 Ω, (b) 448 N-m, 0.191, (c) 198 N-m]

4. A 460V, 100-hp, 4-pole, Δ-connected, 60-Hz, 3-phase induction motor has a full-load slip of 5 percent, an efficiency of 92 percent, and a power factor of 0.87 (lagging). At start-up the motor develops 1.9 times the full-load torque but draws 8.5 times the rated current at the rated voltage. This motor is to be started with reduced voltage.
   (a) What should be the reduced supply voltage so that the starting torque is equal to the rated torque of the motor?
   (b) What will be the motor starting current at this voltage? [Ans: (a) 333 V, (b) 716A]

5. An induction motor has an efficiency of 0.9 when the load is 50 hp. At this load, the stator copper and rotor copper loss each equals the iron loss. The mechanical losses are one-third of the no load loss. Calculate the slip. [Ans: 0.03]

Dated : 18th October, 2019

6. A 3-phase induction motor has a 4-pole, star-connected stator winding. The motor runs on a 50-c/s supply with 200V between lines. The rotor resistance and standstill reactance per phase are 0.1Ω and 0.9Ω respectively. The ratio of rotor to stator turns is 0.67. Calculate: (a) total torque at 4% slip; (b) total mechanical power at 4% slip; (c) maximum torque; (d) speed at maximum torque; (e) maximum mechanical power. Neglect stator impedance. [Ans: (a) 40.48 N-m, (b) 6.1 kW, (c) 63 N-m, (d) 1333 rpm, (e) 8.9 kW]

7. A 3-phase induction motor with star-connected rotor has an induced electromotive force of 60V between slip-rings at standstill on open-circuit with normal voltage applied to the stator. The resistance and standstill reactance of each rotor phase are 0.6 Ω and 4Ω respectively. Calculate the current per phase in the rotor:
   a) when at standstill and connected to a star-connected rheostat of resistance 5Ω and reactance 2Ω per phase;
   b) when running short-circuited with 4% slip. [Ans: (a) 4.22A; (b) 2.22A]

8. The rotor of a 6-pole, 50c/s, slip-ring induction motor has a resistance of 0.2Ω per phase, and runs at 960 rev per min on full load. Calculate the approximate resistance per phase of a rotor rheostat such that the speed is reduced to 800 rev per min for full-load torque. [Ans: 0.8Ω]

9. When operated at rated voltage and frequency, a 3-phase squirrel cage induction motor delivers full load at a slip of 5% and develops a maximum torque of 250% of full load torque at a slip of 25%. Neglecting core loss and rotational losses and assuming that the resistances and inductances of the motor are constant, determine the starting torque (at rated voltage and frequency) of the motor expressed as percentage of the full load torque. [Ans: 121.67%]

10. A 500-hp wound rotor induction motor, with its slip rings short-circuited has the following properties:
    Full load slip =1.5%
    Rotor I^2R at full load torque = 5.69 kW
    Slip at maximum torque = 6.0%
    Rotor current at maximum torque = 2.82 I_{2fl}, where I_{2fl} is the full load rotor current
    Torque at 20% slip = 1.20 Tfl, where Tfl is the full-load torque
    Rotor current at 20% slip = 3.95 I_{2fl}
    If the rotor-circuit resistance is increased to $5R_{rotor}$ by connecting non-inductive resistance in series with each rotor slip-ring, determine:
    a) the slip at which the motor will develop the same full-load torque,
    b) the total rotor circuit I^2R loss at full-load torque,
    c) the horse power output at full-load torque,
    d) the slip at maximum torque,
    e) the rotor current at maximum torque,
    f) the starting torque,
    g) the rotor current at starting.
    Express the torques and rotor currents in per unit based on their full-load values.
    [Ans: (a) 7.5%, (b) 28.45 kW, (c) 470 hp, (d) 30%, (e) 2.82 pu, (f) 1.20 pu, (g) 3.95 pu]

11. A 220-V, 3-phase, 4-pole, 60-Hz squirrel cage induction motor develops a maximum internal torque of 250 percent of full load torque at a slip of 16 percent when operated at rated voltage and frequency. If the effect of stator resistance is neglected, determine the maximum internal torque that this motor would develop if it were operated at 200 V and 50 Hz. Under these conditions, at what speed (in rpm) would the maximum torque be developed? [Ans: 2.975 pu, 1212 rpm]

Dated : 18th October, 2019

12. For a 25-hp, 230-V, 3-phase, 60-Hz squirrel cage motor operated at rated voltage and frequency, the rotor I^2R loss at maximum torque is 9.0 times that at full-load torque, and the slip at full-load torque is 0.03. Stator resistance and rotational losses may be neglected and the reactance's and rotor resistance assumed to remain constant. Find (a) the slip at maximum torque, (b) the maximum torque, (c) the starting torque. Express the torques in per unit of full-load torque. [Ans: (a) 12.4%, (b) 2.18 pu, (c) 0.53 pu]

13. A Δ-connected, 50-hp, 480-V (line-to-line), 3-phase, 6-pole, 60-Hz squirrel cage induction motor has the following equivalent-circuit parameters in ohm per phase Y:

$$r1 = 0.13,\ r2/ = 0.12,\ x1 = 0.75,\ x2/ = 0.72,\ x_m = 23.$$

(a) Calculate the starting current and internal starting torque for this motor connected directly to a 480V source.

(b) In order to limit the starting current, it is proposed to connect the stator winding in Y for starting and then to switch to the Δ connection for normal operation. This type of starting method is commonly referred to as Y-Δ starting. Calculate the starting current and internal starting torque under this Y-Δ stating method. [Ans: (a) 565.98 A, 287.61 N-m, (b) 188.66 A, 95.87 N-m]

14. The following data apply to a 70-hp, 2300-V, 3-phase, 4-pole, 60-Hz squirrel cage induction motor:

No-load test at rated frequency and voltage:

Line current	= 4.1A
3-phase power	= 1550W

Blocked-rotor test at 15Hz:

Line voltage	= 268V
Line current	= 25A
3-phase power	= 9600W

Stator-resistance between phase terminals = 5.80Ω

Compute the stator current and power factor, horse-power output, and efficiency when this motor is operating at rated voltage and frequency at a slip of 3 percent. [Ans: 16.8 A, 0.92 (lagging), 75.15 hp, 90.8%]

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