EE 4002 – Electric Drives

Q1. A three phase star connected 415V (L-L) 50 Hz 4 pole induction motor (IM) is assumed to have a linear torque-slip characteristic in the slip range 0 to 0.1 when operated with rated voltage and frequency condition. It develops the rated torque of 250 N-m at a slip of 0.08. It is used for a water pump application. Consider the following condition and find out the energy saving in kWh/day that would be possible to obtain if for discharge control instead of a mechanical throttle (where the speed of the IM is not varied) a variable frequency drives (VFD) is used in V/f mode.

The pump characteristics (simplified) are given by the equation:

$H = 0.12732\omega_{mech}$, where H is the pressure head in meters and ω_{mech} is the rotor speed in rad/s and is constant for any discharge (Q).

The system (that means the water delivery system) characteristics are given by the equation:

$H = K_S Q^2$, where H is the pressure head in meters, Q is the discharge in m^3/s (cubic meters per second) and K_S is the system constant that varies with the the position of the throttle. If there is no throttle then $K_S = 460$.

The discharge (Q)requirement of the pump over a day is 0.2 m^3/s for 6 hours (this is without any throttle), 0.15 m^3/s for 6 hours, 0.1 m^3/s for 6 hours and 0.05 m^3/s for 6 hours.

(i) Find the voltage (L-L) and the stator frequency in (Hz) of the IM for each discharge condition when the throttle is used for control of discharge.
(ii) Find the torque to be developed by the machine for each discharge condition when the throttle is used to control the discharge.
(iii) Find the power to be absorbed by the throttle for each discharge condition when the throttle is used to control the discharge.
(iv) Find the power that is actually delivered to the system for each discharge condition when the throttle is used to control the discharge.
(v) Find the torque to be developed by the IM for each discharge condition when the VFD is used to control the discharge.
(vi) Find the rotor speed in rpm of the IM for each discharge condition when the VFD is used to control the discharge.
(vii) Find the voltage (L-L) and the stator frequency in (Hz) of the IM for each discharge condition when the VFD is used for control of discharge.
(viii) Find the energy saving in kWh that would happen if the VFD is used instead of the throttle.

Marks: 4+2+4+4+4+4+4+4=30

Q2. A three phase star connected 415V (L-L) 50 Hz 4 pole induction motor (IM), has a rotor resistance $R_2 = 0.18\ \Omega$ referred to the stator. It is assumed to have a linear torque-slip characteristic in the slip range 0 to 0.06 and the slip at rated torque is 0.03 when operated with rated voltage and frequency.

The speed of the induction motor is controlled by an AC drive that employs Sine-Triangle PWM (known as SPWM) to perform V/f control. The DC bus voltage of the inverter is 700V DC and the switching frequency is 10 kHz. Consider the following operating conditions

(a) 1.5 times the rated torque at starting (b) ½ the rated torque at ½ the rated speed (c) $3/4^{th}$ the rated torque at the rated speed.

Determine (i) the fundamental voltage(RMS, L-L) that the inverter has to produce at the motor terminals and the corresponding stator frequency in Hz in each of the three cases mentioned above. (ii) in the SPWM modulator what has to be the peak of the sinusoidal modulating voltage if the peak of the triangle carrier waveform is 10V in each of the three cases mentioned above

(iii) what are the on time and off time of the three top devices in a switching period in which it has to synthesize the maximum voltage in phase Y for condition (a)?

(iv)What are the on time and off time of the three top devices in a switching period in which it has to synthesize minimum voltage in phase B for condition (c)?

(v) Find the common mode voltage (voltage between the motor neutral and the DC bus middle point (V_{NO}) produced by the inverter in the switching period referred in (iv).

Marks: 4*3+2*3+2*3+2*3+2=32

Q3. A three phase star connected 415V (L-L) 50 Hz 4 pole induction motor (IM), has a rotor resistance $R_2 = 0.12\ \Omega$ referred to the stator. It is assumed to have a linear torque-slip characteristic in the slip range 0 to 0.08 and the slip at rated torque is 0.04 when operated with rated voltage and frequency.

The speed of the induction motor is controlled by an AC drive that employs Space Vector Modulation PWM (known as SVM) to perform V/f control. The switching frequency is 10 kHz. Consider the following operating condition

(a) ½ the rated torque at ½ the rated speed and (b) the rated torque at the rated speed

(i) Find the magnitude $(V)$and frequency (f in Hz) of the voltage vector $(\bar{V} = V\angle\theta), \theta = 2\pi f$ that has to be produced by the three phase inverter in each of the two cases mentioned above.

(ii) What must be the minimum DC bus voltage V_{dc}that will be required to generate the voltage vector of condition (b) so that there is no low frequency harmonics between the line-line voltages?

(iii) Let $V\angle 0$ be defined as the condition when the switch combination of the inverter is such that R phase voltage is $V_{RO} = \frac{Vdc}{2}$, Y phase voltage is $V_{YO} = -\frac{Vdc}{2}$ and B phase voltage is $V_{BO} = -\frac{Vdc}{2}$. Find the ON and OFF duration of the top three switches of the inverter in the switching period in which the space vector is located at an angle 225^0 with respect to the reference vector for the condition mentioned in (a).

(iv) Draw a modulator scheme for digital implementation with specific details such as the value to be loaded to the comparator that would generate the ON-OFF pulses of the three phases of the inverter using a 12 bit up-down counter comparator scheme.

Marks: 4*2+2+3*3+6=25

Q4. A 3ph, 4 pole, 50Hz, star connected 650 V(L-L) induction motor (IM) develops rated torque of 4000N-m at a slip of 4% and maximum torque at a slip of 10%. Ignore all other equivalent circuit parameters except rotor resistance and reactance. Assume that the stator to rotor turns ratio is 1. The slip power recovery drive needs to produce rated torque at all speed between the rated speed and 50% of the rated speed. Consider that the dc link current is harmonic free because the inductance in the dc link has a very large value.

(i) Draw the schematic of a slip power recovery drive system with the provision of a transformer between the 3 phase grid and the thyristor inverter. The grid voltage (V_L)is 650V (L-L) and the voltage at the input to the thyristor is N*V_L .

(ii) For N=1, and when the IM is producing rated torque at 50% of the rated speed , find the DC link current, the DC link voltage, the power recovered, the current returned to the grid by the current source inverter, total current drawn from the grid by the slip power recovery drive and the firing angle of the current source inverter.

(iii) For what value of N the phase of the current returned to the grid by the current source inverter will be 15 degrees (lead) under the condition mentioned above? What will be firing angle of the inverter? What will be the total current drawn from the grid by the current source inverter?

Marks: 4+2*6+(4+2+2)=24

Q5. A 3ph, 4 pole, 50Hz, star connected 650 V(L-L) induction motor (IM) develops rated torque of 4000N-m at a slip of 4% and maximum torque at a slip of 10%. Ignore all other equivalent circuit parameters except rotor resistance and reactance. It is driven by a thyristor based current source inverter that draws power from a three phase supply of 760V (L-L) through a thyristor rectifier. Consider that the dc link current is harmonic free because the inductance in the dc link has a very large value.

(i) Draw the circuit schematic of such a current source inverter system driving an induction machine.

(ii) Find the fundamental component of the stator terminal voltage/per phase, the stator frequency, the dc link current and the firing angle of the thyristor rectifier when the motor operates at half the rated speed with rated torque.

(iii) Find the fundamental component of the stator terminal voltage/per phase, the stator frequency, the dc link current and the firing angle of the thyristor rectifier when the motor operates at the rated speed with ½ the rated torque.

(iv) What value of capacitance must be connected in delta at the induction motor terminals in order to make the load power factor appear as 20 degrees (leading) to the inverter?

Marks: 4+8+8+4=24