ELE385

HOMEWORK 6

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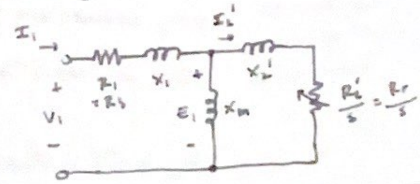
① A 3ϕ, 280V, 60Hz, 20HP, 4-pole induction motor has the following equivalent circuit parameters



IEEE EQ. CKT. MODEL.

$R_1 = R_s = 0.12\Omega$ $\qquad X_s = X_r = 0.25\Omega$

$R_2' = R_r = 0.1\Omega$ $\qquad X_m = 10.0\Omega$

The rotational loss is 400W. For 5% slip, determine

A MOTOR SPEED (rpm & rad/s)

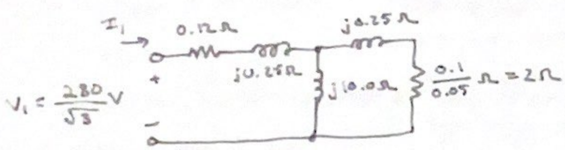
For a four-pole induction motor $n_s = \frac{120 f_s}{p} = \frac{120(60Hz)}{4} = 1800 \text{ rpm} \longrightarrow 188.496 \text{ rad/s}$

$(s = 1 - \frac{n_m}{n_s})$ Given a 5% slip, $s = 0.05$, $n_m = (1-s)n_s = (1-0.05)(1800\text{rpm}) = 1710 \text{ rpm}$

converting to rad/s $\Rightarrow \frac{1710 \text{ rot.}}{1 \text{ min.}}\left(\frac{2\pi \text{ rad.}}{1 \text{ rot.}}\right)\left(\frac{1 \text{ min}}{60 \text{ s}}\right) = 179.1 \text{ rad/s} \Rightarrow \boxed{n_m = 1710 \text{rpm} = 179.1 \text{ rad/s}}$

B MOTOR CURRENT

To find the motor current, we need to draw the IEEE equivalent ckt. where the input voltage to a single motor phase $V_1 = \frac{V_L}{\sqrt{3}} = V_p$ assuming a wye configuration.



Here we can find the equivalent impedance looking into V_1

$$\Rightarrow Z_{eq} = 0.12\Omega + j0.25\Omega + \left[j10.0\Omega \,||\, (2 + j0.25\Omega)\right]$$

$$= 0.12 + j0.25 + \frac{j10(2+j0.25)}{j10 + 2 + j0.25}$$

$$= 1.95 + j0.85\Omega = 2.13\angle 23.6^\circ \Omega$$

$$\Rightarrow I_1 = \frac{V_1}{Z_{eq}} = \frac{280/\sqrt{3}}{2.13\angle 23.6^\circ} = \boxed{75.8\angle -23.6^\circ A}$$

$\hookrightarrow \phi = \cos^{-1}(pf) = -23.6^\circ$

C STATOR COPPER LOSS

$$P_{s,cu} = 3 I_1^2 R_1 = 3(75.8)^2(0.12) = \boxed{2.068 kW}$$

magnitude squared

$^{or}\ P_{in} = 3V_P I pf \ldots$

D AIRGAP POWER

Since we are not given the core losses in the stator, the only power loss from the input is in stator copper losses. First we need to find P_{in} applied at the stator terminals.

$$P_{in} = \sqrt{3}\, V_L I\, pf = \sqrt{3}(280V)(75.8A)\cos(-23.6°)$$

$$= 33686.5W$$

$$\Rightarrow P_{ag} = P_{in} - P_{s,cu} = 33686.5W - 2068W = \overset{\text{airgap power}}{\boxed{31618.5W}}$$

E ROTOR COPPER LOSS

The rotor copper loss is found via applying slip to the airgap power, according to the textbook,

$$P_{r,cu} = sP_{ag} = (0.05)(31618.5W) = \boxed{1581W}$$

F THE SHAFT POWER

The shaft power P_{out} is the mechanical power P_{mech} after rotor copper loss and friction & windage loss (we are not provided rotor core losses). First we need P_{mech}

$\uparrow P_{f,w}$

$$\Rightarrow P_{mech} = (1-s)P_{ag} = (1-0.05)(31618.5W) = 30037.5W$$

$$\Rightarrow P_{out} = P_{mech} - P_{f,w} = 30037.5W - 400W = \boxed{29637.5W} \approx 40 Hp.$$

G DEVELOPED TORQUE & SHAFT TORQUE

(Eq. 5.52) from the textbook has $T_{mech} = P_{ag}/\omega_{syn}$ for ω_{syn} is the angular velocity of n_s as found in part A, $\omega_{syn} = 188.5\,rad/s$.

$$T_{developed} = \frac{P_{ag}}{\omega_{syn}} = \frac{31618.5W}{188.5\,rad/s} = \boxed{168\ N\cdot m}$$

But some torque is lost to rotational losses ∴

$$T_{shaft} = \frac{P_{out}}{\omega_{syn}} = \frac{29637.5W}{188.5\,rad/s} = \boxed{157\,N\cdot m}$$

H EFFICIENCY

$$\eta = \frac{P_{out}}{P_{in}} \times 100\% = \frac{29637.5W}{33686.5W} \times 100\% = \boxed{87.98\%\ \text{efficient}}$$

(2) Designing an electric water pumping station in rural Southern Illinois.

- Water pump requires 50HP motor to run @ 1700-1800rpm.

- Pumping station located at end of 2-mile 3ϕ 12.47kV/7.2kV wye-connected line w/ sufficient capacity. Voltage reg. is a concern.

- Limited budget, so initial construction and operating costs are a concern.

- The water district is socially conscience, concerned of environmental impact, and prefers U.S. made products.

* motor & xf options provided in HW6 P-SET

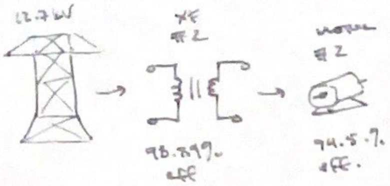
[A] Which distribution transformer and pump motor would you use for the design? Explain in terms of the system's electric needs, efficiency, cost, and environmental and global impact.

I would choose Motor #2 from Japan. This is a middle ground choice in terms of cost at \$4,200, which is \$1,300 cheaper than the less efficient American make, but more efficient than the cheaper Chinese alternative. The 88.1% efficiency on the American motor just isn't good enough when the cheaper Japanese motor is 94.8% efficient just at 50% load. Also, the American motor is class D, which does not fit the application when either a class B or C is available — the Motor 2 is class C. Environmentally, motor 2 is the most obvious as its the most efficient at converting electrical energy to mechanical work. Globally, using Japanese products in the U.S. is good for trade. Also Motor 2 lands in the rpm range, Motor 3 does not by a longshot.

In order to withstand Motor #2's power needs, $S = (460V)(58.3\,FLA) = 26.7kVA$ when operating at full-load, we'd need to use Transformer #2 from Germany. With the cost savings of using the Japanese motor over the Chinese, we can invest slightly more into the German transformer which gives the 50kVA headroom we need. The US. 25kVA transformer just isn't enough to drive a 26.7kVA motor. Also Transformer #2 is ~1% more efficient than the U.S. motor, which is better for the environment.

There are most likely plenty of U.S. options better suited for this application, but purely basing off cost, efficiency, and electrical needs, the U.S. options given are impractical.

B Assuming wire losses are negligible, what is the overall efficiency of your design @ full-load?



Since the transformer is 98.89% efficient, the 94.5% @full-load motor can only be that efficient starting from the 98.89% efficiency

$\therefore \eta_{total} = 98.89\% \times 94.5\%$

$= \boxed{93.45\% \text{ efficient at full-load}}$

(3) In a factory the following loads are:

$\boxed{\text{Induction motors}}$: 1000HP, 0.7pf, 85% eff.

$\boxed{\text{Lighting \& heating}}$: 100kW

A 3ϕ synchronous motor is installed to provide 300HP to a new process. The motor operates at 92% eff.

A Determine kVA of motor if the overall factory power factor is to be raised to 0.95.

Induction motor to kVA $\Rightarrow \underbrace{(1000HP)\left(\frac{746W}{1HP}\right)}_{P_{out}} = 746kW \xrightarrow{\div 85\% \text{ eff}} 877647W$ (input) $= P_{ind.}$

We can get the reactive power from the ind. motors since pf = 0.7

$S_{ind.} = \frac{P_{ind.}}{pf} = 1.25MVA \rightarrow Q_{ind} = \sqrt{(1.25M)^2 - (877647)^2} = 895379 \text{ VAR}$

The light/heat load needs $P_{lh} = 100kW$, $Q_{lh} = 0VAR$

The total active power in the factory is $P_{fact} = 877647W + 100kW + \underbrace{\frac{(300HP)(746\ W/HP)}{0.92}}_{P_{sync}}$ ← efficiency

$= 1.221MW$

Convert P_{fact} to apparent power $S_{fact} = \frac{P_{fact}}{0.95} = 1.285MVA$ (pf)

Find the reactive part of $S_{fact} = (1.285MVA)\sin(\cos^{-1}(0.95)) = 401293VAR$

So our sync motor needs to compensate for the difference $895379VAR - 401293VAR = \underline{494086VAR}$ $= Q_{sync}$

Combining to get the sync motor's apparent power $S_{sync} = \sqrt{P_{sync}^2 + Q_{sync}^2} = \sqrt{\left(\frac{300 \cdot 746}{.92}\right)^2 + (494086)^2}$ ($= 243kW$)

$= \boxed{551 kVA}$

B Power Factor

$pf = \frac{P_{sync}}{S_{sync}} = \frac{243261W}{551kW} = \boxed{0.442 \text{ lead}}$ ← lead b/c balancing inductive load...