# EE 30372, Spring 2019 

Final Exam
7 May, 2019

Show all your work and your answers clearly on the test pages. In any plots and sketches, label and include units (if possible) on anything that might be of interest. You are each allowed one two-sided 8.5 by 11 inch page of formulae for reference. Calculators may be used only for simple trigonometric and (complex variable) arithmetic operations. For full credit, simplify your answers as much as possible. As usual, three-phase voltages are given as line-to-line by default, and powers in three-phase are given as the total among the three phases.

Problem 1 (15)

Problem 2 (25) $\qquad$

Problem 3 (40) $\qquad$

Problem 4 (20) $\qquad$

Total (10-)

Name

1. ( 15 pts.$)$


Above is a per-phase equivalent circuit model of a Y-connected, three-phase induction motor, operating at $60 \mathrm{~Hz}, 600 \mathrm{~V}$. The parameters are $X_{1}=2 \Omega, R_{1}=1 \Omega, X_{M}=25 \Omega, X_{2}=1 \Omega$ and $R_{2}=1 \Omega$. At its rated load, it has mechanical speed of 1140 rpm . The mechanical losses are 500 W and core losses 700 W . Find, at rated load, (a) the number of poles in the windings and the rotor slip; (b) the power crossing the stator/rotor air gap, $P_{A G}$; (c) the induced torque; (d) the output horsepower and (e) the motor's efficiency.
2. You need to transport 800 MW of power to a city that is 200 miles away from your power plant. Fortunately, the receiving end has committed to investing in a large, variable capacitor bank to keep the power factor of its load at 1.0 , but will require exactly rated line voltage at the input to its transformers. Find how this would work out if you use a 765 kV AC line to transport this power. Even though this is a bit long, use the medium-length model for the line, and use the parameters found in Table 3-1 on your handouts.
(a) (10 pts.) Find the real (wattage) power loss in this line and the line's voltage regulation.
(b) (8 pts.) Sketch an accurate phasor diagram for the line in the state described above. Include all our usual voltage and current information on the diagram. Note that in this twoport model, the current we'll need is what we've called the "line" current through the series impedances.
(c) (7 pts.) Find the "charging current" into the line shunt capacitor at the receiving end. Quantify, as precisely as you can, the change in this charging current that will occur if we build bigger towers than specified in Table 3-1, and move the A,B,C phase lines twice as far apart from each other as in that table. (We use the Bundle GMR as conductor radius and GMD as inter-conductor distance.) As always, support your answer with your best analysis and reasoning.
3. Below are the per-unit bus admittance and impedance matrices for the three symmetric components of a 3-phase power system. The system has $S_{\text {base } 3 \phi}=2 \mathrm{MVA}$, and $V_{\text {LLbase }}$ of 5 kV at all of the buses. Assume that in normal, balanced operation, the system behaves according to the positive-sequence parameters. All transmission lines are short; that is they have line shunt capacitance modeled as zero.
$\mathbf{Y}_{0}=\left(\begin{array}{ccc}-j 5 & 0 & 0 \\ 0 & -j 10 & j 4 \\ 0 & j 4 & -j 4\end{array}\right) \mathbf{Y}_{1}=\left(\begin{array}{ccc}-j 4 & j 2 & j 1 \\ j 2 & -j 4 & j 1 \\ j 1 & j 1 & -j 5\end{array}\right) \mathbf{Y}_{2}=\left(\begin{array}{ccc}-j 5 & j 2 & j 1 \\ j 2 & -j 6 & j 4 \\ j 1 & j 4 & -j 10\end{array}\right)$
$\mathbf{Z}_{0}=\left(\begin{array}{ccc}j 0.2 & 0 & 0 \\ 0 & j 0.17 & j 0.17 \\ 0 & j 0.17 & j 0.42\end{array}\right) \mathbf{Z}_{1}=\left(\begin{array}{ccc}j 0.40 & j 0.23 & j 0.13 \\ j 0.23 & j 0.40 & j 0.13 \\ j 0.13 & j 0.13 & j 0.25\end{array}\right) \mathbf{Z}_{2}=\left(\begin{array}{ccc}j 0.28 & j 0.15 & j 0.09 \\ j 0.15 & j 0.31 & j 0.14 \\ j 0.09 & j 0.14 & j 0.16\end{array}\right)$
(a) (10 pts.) Construct a single per-phase, positive-sequence diagram of a system which would have these matrices as its representation. Indicate all circuit component values (for balanced operation state only) in the form of impedances (in $p u$ ). Assume that between each bus and each of its connected transmission lines, there is a transformer. Draw at each bus a symbolic representation of these transformers' wiring connections that matches our set of matrices above. Include also a neutral line with appropriate connections in your sketch and label all buses. Use the available space on this page to make it easier to read you diagram.
(b) (10 pts.) The system is operating with a balanced, light load such that all buses have voltage approximately $1.0 \angle 0^{\circ} \mathrm{pu}$. A double line-to-ground fault (lines B and C) occurs at bus 2 . Find the fault currents in all phases ( $\mathrm{A}, \mathrm{B}, \mathrm{C}$ ) at bus 2 (in p.u.).
(c) (10 pts.) Compute the voltage $V_{A N}$ (in actual voltage) at bus 1 during the fault of part (b).
(d) (10 pts.) Find C-phase current from bus 1 to bus 2 (in actual amps) during the fault.

4. (20 pts.) Above is a one-line diagram of a three-bus, balanced three-phase system in which bus 1 is slack at voltage $1.0 \angle 0^{\circ} V$, bus 2 requires power of $\mathrm{P}=0.4 \mathrm{pu}$ and supplies $\mathrm{Q}=$ 0.2 pu and bus 3 requires $\mathrm{P}=0.6 \mathrm{pu}$ and $\mathrm{Q}=0.4 \mathrm{pu}$. The line quantities given are per-unit admittances. Using our simple, direct calculations and reasonable approximations without appeal to iterative techniques, specify voltages for buses 2 and 3 which approximate this power flow setting and would form a useful initial estimate of the state of the system. Credit will depend on the relative accuracy and analytic support for your choices, but perfection is not expected. Find the net complex power actually flowing into bus 2 from the rest of the system if your voltages were to precisely describe the system state.

