EE 30372, Spring 2021
Final Exam
18 May, 2021

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; no programming capabilities are allowed. If your calculator fails you, do your best with manual, possibly approximate calculations. You know that a 30/60/90 triangle has sides of 1/2, sqrt(3)/2 and 1, so that can get you some advance when we're dealing with 120 degree separations of phases. As usual, three-phase voltages are given as line-to-line by default.

Problem 1 (20) ______

Problem 2 (20) ______

Problem 3 (20) ______

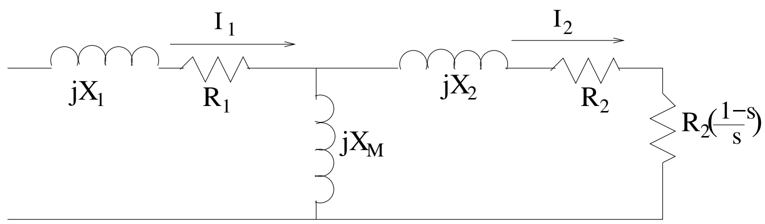
Problem 4 (20) ______

Problem 5 (20) ______

Total (100) ______

Name________________________________

1. Below is a per-phase equivalent circuit model of a Y-connected, three-phase induction machine, operating at 50 Hz, 460V. The parameters are $X_1 = 2\Omega$, $R_1 = 2\Omega$, $X_M = 25\Omega$, $X_2 = 1\Omega$ and $R_2 = 1\Omega$. At its rated load as an induction motor, it has mechanical speed of 1425 rpm. The mechanical losses are 400W and core losses 500W. We have measured some currents at rated load and found $I_1 = 14.69\angle{-41.1^o} A$ and $I_2 = 11.19\angle{-3.58^o} A$.



(a) (13 pts.) Find the number of poles in the windings and, at rated load, the rotor slip, the rotor electrical frequency, and the power converted from electrical to mechanical, P_{conv}

(b) (7 pts.) We learned that dual-fed induction machines such as this one can function as transformers, motors or generators. (This machine has a wound rotor with collectors/ brushes that give us access to the three-phase rotor windings.) Suppose we drive the rotor of this machine at 1800 rpm in order to turn it into a generator. What frequency (relative to the 50Hz, positive-sequence current) will we need to feed into the rotor to synchronize to the 50Hz electrical system at the output?

2. You need to build a line to transport 500 MW of power, consumed with power factor 0.85 lagging, a distance of 150 miles, to allow power exchange between two utilities' service areas. You'll be using a 765kV, 3-phase AC transmission line with specifications matching Table 3.1, attached to your exam. Use the medium-length line model. The receiving end will have the nominal voltage and power factor.

(a) (10 pts.) Find the line current in the series portion of the 2-port line model, the total real power loss of the 3-phase line, and voltage regulation of the line.

(b)(10 pts.) Find the charging current at each end of the line, and the overall reactive power loss of the 3-phase line. Include both the series line losses and shunt capacitive contributions in this loss.

3. (20 pts.) You have been hired to do an energy audit on the Peabody Energy System because it is suspected that someone is stealing power by tapping the 3-phase lines in an out-of-the-way location. To allay this suspicion, you need to account for all the Watts and VARs issuing from, or being absorbed by, all the busses and all those that are consumed by the lines among the busses. That is, when you total the power injected into the system by all the busses and subtract the line losses, you will get zero. Between each pair among the three busses in the system, you have a line of impedance $j0.1\Omega_{pu}$. The voltages at the busses are: $\mathbf{V}_1 = 1.0\angle 0.0^o V_{pu}$, $\mathbf{V}_2 = 1.1\angle{-5.0^o} V_{pu}$, $\mathbf{V}_3 = 0.95\angle 2.0^o V_{pu}$.

   You calculate the line currents and assume they match at the two ends (if someone were stealing power, they likely wouldn't) and carry out your accounting from there. Start by using line currents to compute line losses.

4. Below are the per-unit bus admittance and impedance matrices for the three symmetric components of a 3-phase power system. The system has $S_{base3\phi}$ = 10 MVA, and V_{baseLL} of 20 kV at all of the busses. In normal, balanced operation, the system behaves according to the positive-sequence parameters. All neutral lines are grounded.

$$\mathbf{Y}_0 = \begin{pmatrix} -j5 & 0 & 0 \\ 0 & -j8 & j4 \\ 0 & j4 & -j3 \end{pmatrix} \mathbf{Y}_1 = \begin{pmatrix} -j5 & j2 & j1 \\ j2 & -j4 & j1 \\ j1 & j1 & -j4 \end{pmatrix} \mathbf{Y}_2 = \begin{pmatrix} -j5 & j2 & j1 \\ j2 & -j6 & j4 \\ j1 & j4 & -j7 \end{pmatrix}$$

$$\mathbf{Z}_0 \approx \begin{pmatrix} j0.2 & 0 & 0 \\ 0 & j0.38 & j0.5 \\ 0 & j0.5 & j1.0 \end{pmatrix} \mathbf{Z}_1 \approx \begin{pmatrix} j0.29 & j0.18 & j0.12 \\ j0.18 & j0.38 & j0.14 \\ j0.12 & j0.14 & j0.31 \end{pmatrix} \mathbf{Z}_2 \approx \begin{pmatrix} j0.33 & j0.23 & j0.18 \\ j0.23 & j0.43 & j0.28 \\ j0.18 & j0.28 & j0.33 \end{pmatrix}$$

(a) (10 pts.) The system is lightly loaded before a fault event, with all bus voltages at $1.0\angle 0.0^o V_{pu}$. We then suffer a single line-to-ground fault of the A phase at bus 2. Find the A,B,C fault currents at bus 2 and the A, B, C phase voltages to ground at bus 2 during the fault. Give your voltage values in actual volts, and all A,B,C quantities in polar form.

(b) (10 pts.) Find the A phase voltage (pu is OK here, use polar form) to ground at bus 1 during the fault.

5. A 3-bus power system is represented by the schematic on the following page
(20 pts.) Find the first rows (corresponding to bus number 1) of the bus admittance matrices for the positive and zero-sequence components in this system, in pu with S_{base} of 100 MVA and V_{base} of 13.8kV at bus 1.

The components of the power system have the ratings as follows. Both lines have the same base voltage. Ground lines may be assumed zero impedance, and resistance is neglected throughout the system:

Generator 1(G_1):	100 MVA, 13.8 kV, X_1=0.2 pu, X_2=0.1 pu, X_{g0}=0.05pu
Motor 2(M_2):	100 MVA, 13.8 kV, X_1=0.1 pu, X_2=0.1 pu, X_{g0}=0.05pu
Motor 3 (M_3):	100 MVA, 13.8 kV, X_1=0.1 pu, X_2=0.1 pu, X_{g0}=0.05pu
All $Y-\Delta$ transformers:	100 MVA, 13.8/138 kV, X_1 = 0.05 pu,X_2=0.1 pu, X_0 = 0.1 pu
All $\Delta-\Delta$ transformers:	100 MVA, 13.8/138 kV,X_1 = 0.1 pu,X_2=0.1 pu, X_0 = 0.05 pu
Line 1:	X = 20Ω
Line 2:	X = 30Ω