ECGR 2254 – Project 1

Due: Friday 10/4/2019 – 12PM

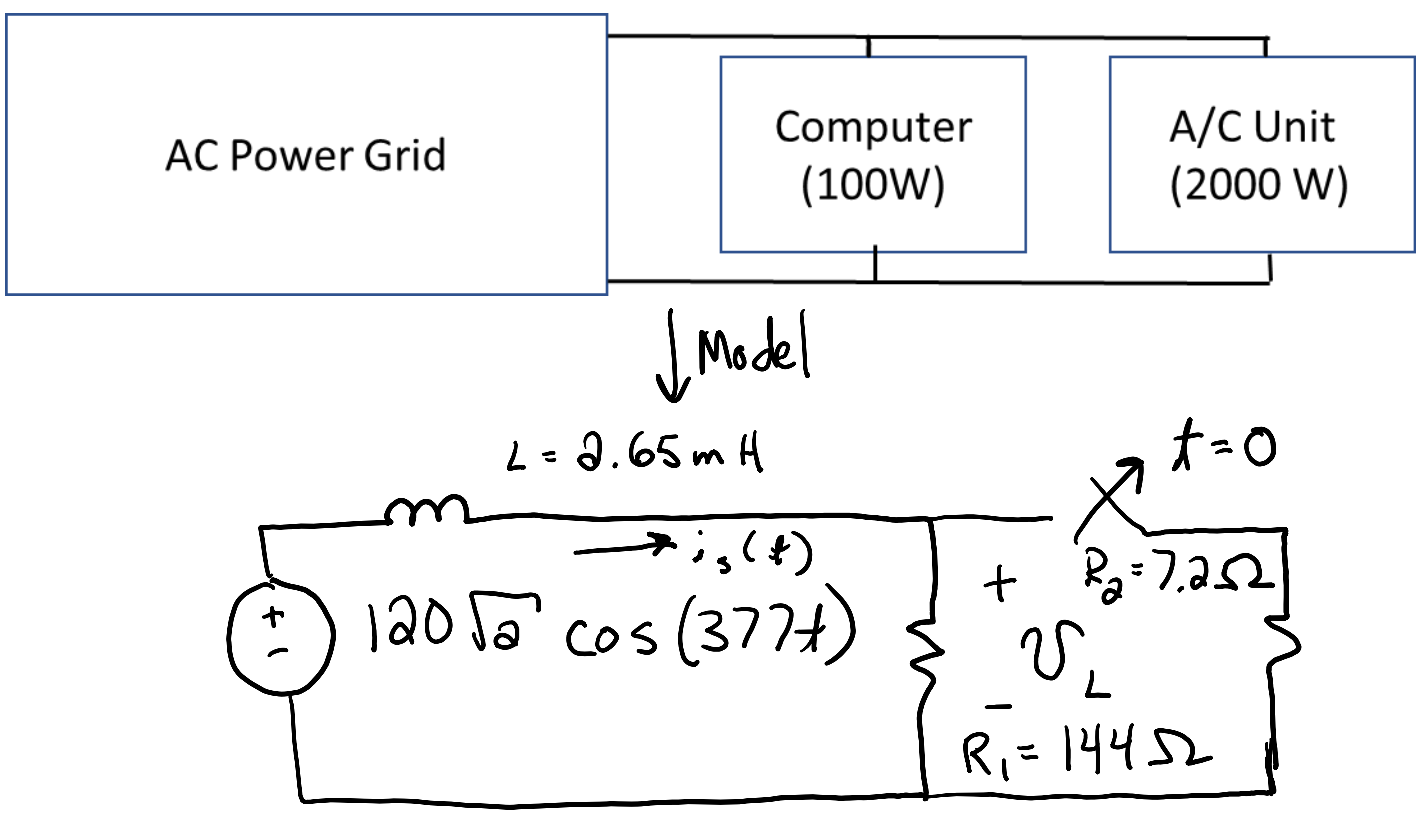
Please note the following:

- **Provide a neatly written report that describes your process. For example, in problem 1, part c, carefully describe how you chose your time step, mixing words and equations as needed. You don't need to write a lot, but someone who knows what you're doing (i.e. me) should be able to follow your logic.**
- **You do not need to type up a report. A neat, hand-written report is sufficient.**
- **Please identify your collaborators (i.e. two or three people with whom you worked on the project). Each person should submit a unique report, and you do not have to collaborate. That said, I think it's highly likely that you will talk to others, and you should cite that. Working with others is a good way to learn, as long as you re not copying.**

Problem 1 – Surge Suppression

When computers and sensitive equipment are connected to a power system, they often have "surge supressors." These devices are designed to absorb excess voltages that can exist in the power system and destroy equipment.

In this problem, you are given the simple circuit shown below, which is a reasonable model for the power-distribution system in your house. The AC grid is represented by a Thevenin equivalent circuit consisting of a voltage source and a 2.65mH inductor. Two loads are connected in parallel. One load is a computer (represented by a 144Ohm resistor) and the other is an air-conditioner (represented by the 7.2Ohm resistor).



The circuit has been operating in steady-state for a long time before $t = 0$. At that time, the switch shown is opened and the current flowing to the motor stops flowing.

a) Use impedance/phasor analysis to determine a function for the current $i_S(t)$ before $t = 0$. Use this expression to determine and explicit numeric value for $i_S(0)$. ***I stress that you should use phasor/impedance analysis. Do not waste time solving the complete differential equation.***
b) Write a differential equation that allows you to solve for $i_S(t)$ after $t = 0$.
c) Write a MATLAB program that allows you to plot the voltage $v_L(t)$ after $t = 0$. Carefully describe how you:
    a. Discretized the equation
    b. How you chose the time step
d) What is the maximum value of the voltage v_L? Include an appropriately labeled plot of $v_L(t)$ in your report.

Normally, engineers simply worry about steady-state operating conditions. This problem should show why it makes sense to use impedance analysis for steady-state operation and why it makes sense to use *numeric simulation to solve for transient conditions*. This sort of transient analysis must be performed when designing a product that must be connected to a grid. Such calculations (and related tests) are needed to have a product approved by UL (Underwriter's Laboratories). Knowing the peak voltage v_L, an engineer would choose a transient voltage suppressor that would clamp the voltage to an upper value much lower than the value calculated here.

Problem 2 – Digital Filtering

For this problem, you must also download the file named "problem2.wav." This file contains some corrupted digital audio. A 60Hz "hum" has somehow corrupted the file. You must remove it.

To start this problem, you must download the file "problem2.wav" and place it in your working directory. This directory should be the same as the one from which you are running your scripts. You can load this file with the following command:

```
>> [y,Fs] = audioread('problem2.wav');
```

There are two outputs:

- y: This is a vector containing the audio file data.
- Fs: This is the sampling frequency in Hz. 1/Fs is the amount of time that passes between each point in the audio file.

Before listening to the sound, scale the file by a factor of 3:

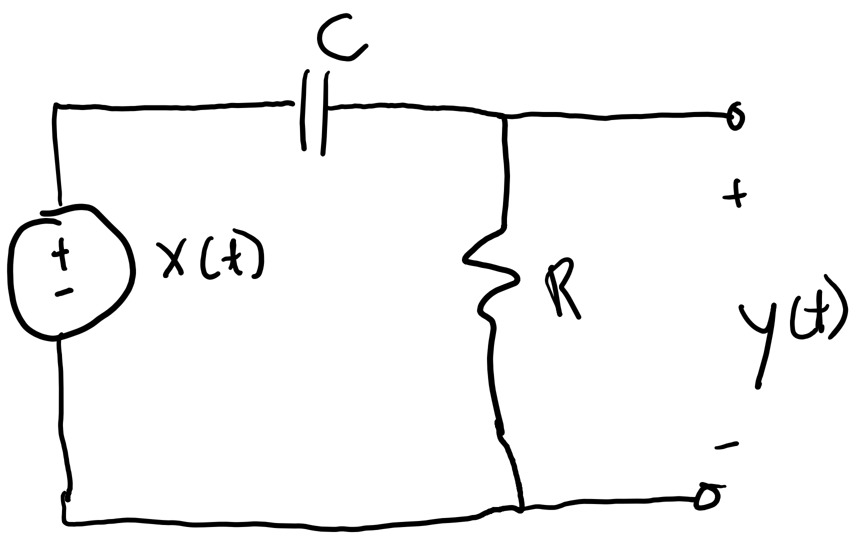
```
>> x = y*3;
```

To listen to the sound, use the following command:

```
>> sound(x,Fs);
```

You will hear the 60Hz distortion. We will now remove it.

a) Since most audio signals are above 60Hz, we will attempt to clean the signal up using a "high pass" filter. To create this digital filter, we are going to make a digital analog to the following circuit:



In this circuit, the audio signal can be thought of as the input voltage source $x(t)$ and the filtered audio can be though of as the output voltage $y(t)$. $R = 1$ Ohm and $C = 318.3\mu F$.

Write a differential equation that solves for $y(t)$.

b) Discretize this equation using a step size based on Fs. Explain your process.
c) Write a MATLAB script that filters the audio signal x. The output will be y. Play y using the command sound(y,Fs). The audio should sound much clearer.
d) Using subplot, show the input x(t) and the output y(t). It should be clear that this is a large signal that has been removed.

Problem 3

You are given the following differential equation:

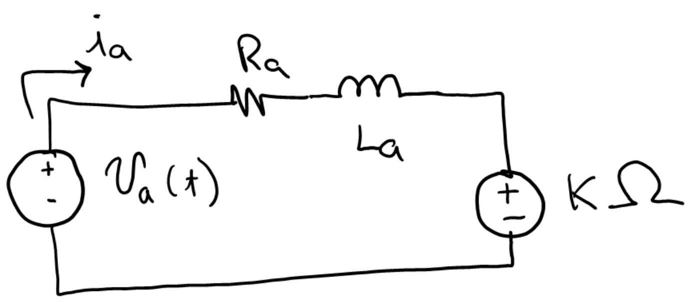
$$\frac{d^2y}{dt^2} + 2\frac{dy}{dt} + 4y = 5\cos\left(10t + 30^\circ\right)$$

With the initial conditions $y(0) = 0$ and $y'(0) = 2$.

a) Determine the transient solution $y_c(t)$ in terms of the constants C_1 and C_2. What type of response does this system have (i.e. under, over, critically damped?)
b) Discretize this equation as shown in class and discussed in section 7.5 in the text. Carefully describe your process.
c) Write a MATLAB script that solves the equations in part a. Carefully choose your time step. Use the nature of the transient response to help you determine the time step.
d) Solve for the complete solution by hand using complex exponentials as we've described in class.
e) Using MATLAB, plot your answers from c and d on the same axes. They should look almost identical.

Problem 4

You are given a DC motor the controls a robot arm. The circuit model for the DC motor is shown below:



The variable Ω is the speed of the motor in rad/sec. Note that the model includes a speed-dependent voltage source.

The mechanical component of the motor is represented by Newton's Second Law for rotation, which states:

$$(Moment\ of\ Inertia) \times (Angular\ Acceleration) = Net\ Torque$$

Mathematically, this is:

$$J\frac{d\Omega}{dt} = Ki_a - \beta\Omega$$

Where:

- β: Damping ratio
- J: Moment of inertia
- K: Motor constant

The motor you are controlling is connected to a robot arm, and it has the following parameter values:

- $L = 0.01\ H$
- $R = 3.38\ Ohms$
- $K = 0.029\ Vs/rad$
- $J = 2 \times 10^{-4}\ kg\ m^2$
- $beta = 0.5 \times 10^{-5}\ Nms/rad$

Please do the following:

a) Determine a differential equation for $i_a(t)$ from analyzing the electrical circuit.
b) Discretize the two differential equations (the one for $i_a(t)$ and the one for $\Omega(t)$).
c) Write a MATLAB script that shows the response for both the speed and the current in response to $v_a(t) = 10u(t)$. Your result should include subplots with both $i_a(t)$ and $\Omega(t)$.

   Choose the time step carefully by examining the two differential equations. Assume that speed is zero in the electrical differential equation and the current is zero in the mechanical differential equation. Compare the time constants to determine an appropriate time step.

d) Now, you are going to provide a position controller for the DC motor. In this case, we want to control the angle of the machine. This means we need to add one more differential equation:

$$\Omega = \frac{d\theta}{dt}$$

   Add this differential equation to your previous code and modify it. Include subplots with $i_a(t)$, $\Omega(t)$, and $\theta(t)$.

e) To create a position controller, we need to add a little feedback to our system. To make this happen, we want the voltage applied to the motor to depend upon the difference between the desired angle and the actual angle. We write this like so:

$$v_a(t) = K_{p\theta}(\theta_{ref} - \theta(t))$$

   In this equation:

   - θ_{ref}: The desired angle
   - θ: The actual angle
   - $K_{p\theta}$: An adjustment factor

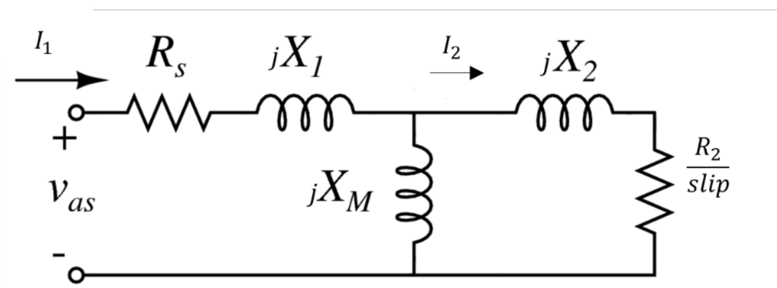
   In this case, you should do the following. Assume you want $\theta_{ref} = 45$ degrees (or $\pi/4$ radians). Initially, $\theta(0) = 0$ degrees. Start with $K_{p\theta} = 1$. At each time step, update the voltage $v_a(t)$ using the equation above.

   Create the appropriate code and generate a plot that shows $\theta(t)$ for 50 seconds.

f) The result you found in part d should be extremely underdamped. This is somewhat undesirable. The result shows that the rotor position will fluctuate around its final position, which is a situation that can cause extreme mechanical fatigue in a real system. Think how you can fix this by changing $K_{p\theta}$. Should you use a smaller or larger $K_{p\theta}$? Experiment and find a good choice that produces an overdamped result. Explain why a smaller or larger $K_{p\theta}$ makes intuitive sense. (Note that by smaller, I mean fractional. Do not chose a value for $K_{p\theta} < 0$). To answer this, you might want to examine different signals such as $\theta_{ref} - \theta(t)$.

Problem 5

You are given an induction motor, which is an AC motor. It has the following equivalent circuit:



The motor is connected to a 2300V AC voltage source at 60Hz. You are told the following about the induction motor circuit:

- Since the machine is connected to a 60Hz voltage source, we model the inductances as reactances (i.e.$j\omega L = jX_L$). In this case, you are told directly what the X values are in Ohms assuming $\omega = 2\pi 60$ rad/sec. (see below).
- One of the resistances depends upon what is known as slip. Slip is defined as follows:

$$slip = \frac{2\pi 30 - \Omega(t)}{2\pi 30},$$

  where $\Omega(t)$ is the motor speed. The full speed of the motor is $\Omega = 2\pi 30$ rad/sec. If the motor reaches this full speed, the slip becomes 0 and thus the resistance becomes infinite and the current i_2 becomes zero. Don't worry about the physics. What matters for you is that one of the resistances depends upon the speed of the motor.

You are given the following parameters:

- $R_s = 0.262\ Ohms$
- $X_1 = 1.206\ Ohms$
- $X_M = 54.02\ Ohms$
- $X_2 = 1.206\ Ohms$
- $R_2 = 0.187\ Ohms$

The mechanical portion of the induction motor is also governed by Newton's Second Law. In this case, we have:

$$J\frac{d\Omega}{dt} = T_m - \beta\Omega(t)^2$$

In this case, the torque T_m produced by the motor is

$$T_m = \frac{3|I_2|^2\left(\frac{R_2}{slip}\right)}{2\pi 30}$$

Note that $|I_2|$ is the magnitude of the phasor.

You are also given the following mechanical parameters:

- $J = 63.87$
- $\beta = 0.2565$

a) To solve this problem, first use mesh analysis to write two equations that will solve for the phasors I_1 and I_2 at any given speed. Note that you can solve this simply using impedance/phasor analysis. (I'm only asking you to write the equations here – you cannot solve them until you have computed the speed).

b) Discretize the differential equation.

c) Write a MATLAB script that allows you to plot the speed $\Omega(t)$ and the current phasor I_1. To approach this problem, I suggest you do the following at each time step:

- Step 1: Compute slip
- Step 2: Solve the system of equations you found in part a.
- Step 3: Use the result from solving the system of equations to determine T_m.
- Step 4: Find $\Omega(t + \Delta t)$.

In this case, use $\Delta t = 0.001$s.

d) Generate plots showing $\Omega(t)$ and the current phasor I_1 for 10 seconds.

This type of analysis is often used to analyze what happens during motor starting. You should notice that the current is quite large when the speed is increasing, and then it decreases as the motor reaches steady-state.