ECE 524 Final Exam Summer 2019

EXAMINATION RULES

1. This is an open-book/open-note take-home exam.
2. I can e-mail a MathCAD file with the exam problems to you if you would like a copy.
3. Do your own work on this examination. You are on your honor. Therefore, you will neither give nor receive aid on this examination, except from the *course* instructor. If you violate this trust, you will receive the grade of zero for this examination.
4. Show all of your work! Make it neat. *No* partial credit will be given if I can not easily follow your work.
5. ***You have 3 days to complete the exam the exam from the time you receive it from your proctor.***
6. ***Pease read and sign the following statement when you finish the exam:***
7. I certify that I have neither given nor have I received any help on this examination, except from the course instructor.

SIGNED: ____

PRINTED NAME:______________________________________

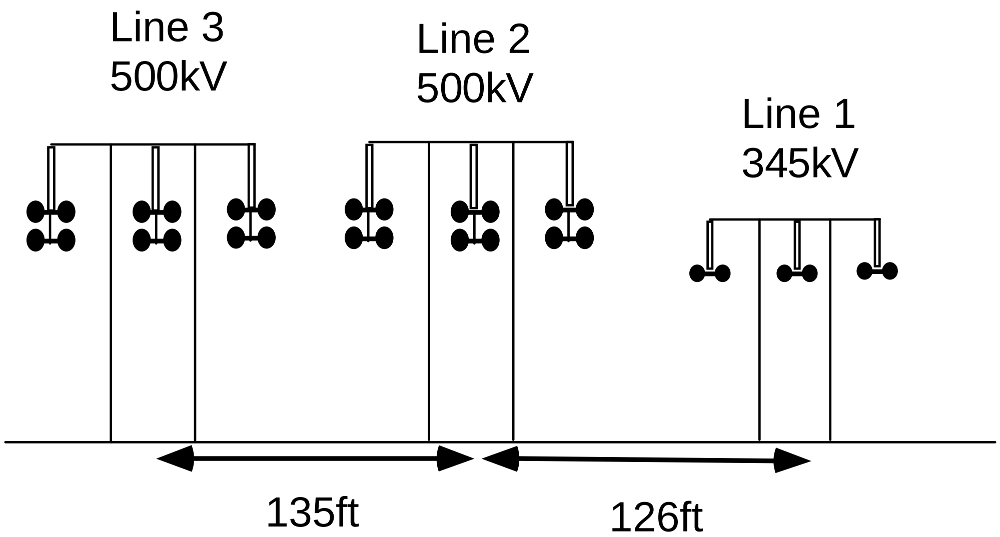
DATE:_______________

1. _____________/48 pts

2. _____________/52 pts

Total: _____________/100 pts

1. (48 pts) The three lines below run in parallel through the length of the same 75 mile corridor.



Line information (earth resistivity = 100 ohm-m:

Line 1: Height at tower = 73ft
Heigth at midspan = 55 ft
Horizontal spacing between adjacent phases = 35 ft
Number of conductors per bundle = 2, positioned as shown above
Bundle spacing = 18 inches
Conductor outside diameter = 1.108in
DC Resistance = 0.12 ohm/mile
Conductor GMR = 0.4476 in

Line 2: Height at tower = 76ft
Heigth at midspan = 33 ft
Horizontal spacing between adjacent phases = 39 ft
Number of conductrs per bundle = 4, positioned as shown above
Bundle spacing = 18 inches
Conductor outside diameter = 0.95in
DC Resistance = 0.15 ohm/mile
Conductor GMR = 0.3876 in

Line 3: Height at tower = 77ft
Heigth at midspan = 33 ft
Horizontal spacing between adjacent phases = 35 ft
Number of conductors per bundle = 4, positioned as shown above
Bundle spacing = 18 inches
Conductor outside diameter = 1.0in
DC Resistance = 0.145 ohm/mile
Conductor GMR = 0.4260 in

Assume that lines 2 and 3 are untransposed. Line 1 is transposed every 25 miles.

Do the following:

A. (14 pts) Create distributed parameter line model (Bergeron) of the coupled circuit for the three lines above using your EMTP program.

Provide a text copy of the line constants output from your program with your solution in addition to providing your simulation model.

Test your lines with ideal sources connected to one end the other end open. Plot the steady-state charging currents.

B. (6 pts) Connect line 1 to an ideal source with V_{LL} = 360kV, line 2 to an ideal source with V_{LL} = 550kV and leave line 3 open at each end. Connect a unity power factor loads to line 1 and line 2, drawing 440A and 830A respectively.

Simulate this and plot the line to neutral and line to line voltages on Line 3.

C. (6 pts) Repeat part B with line 3 grounded through a Y-connected 5 ohm resistance each end. Measure the currents flowing in each phase on line 3

D. (5 pts) Comment on your results from parts B and C. What is the main source of coupling in this case?

E. (12 pts) Now repeat parts B and C with separate simulations with a SLG, LL, DLG andthree phase fault applied at the midpoint of line 2. Plot the sending end currents for all three lines for each case.

F. (5 pts) Comment on your results for part E.

2. (52 pts) Short answer

(a) (9 pts) How accurately can you locate faults using a travelling wave fault locator if your time stamps are accurate to plus or minus 1 microsecond (give an approximate answer in miles giving your assumptions)? Does this change for underground cable, how? Which is modes do you use (first line mode, second line mode, ground mode)? Explain

(b) (6 pts) How much of the power system must be modeled for performing studies to see whether or not a flashover will occur if lightning strikes the ground wire of a transmission tower near the middle of a 100 mile transmission line? Is the lightning strike modelled as a voltage source or a currentsource (explain your answer).

(c) (6 pts) Is a large footing resistance or small footing resistance better for decreasing the chances of a back flashover if lightning strikes the top of a grounded transmission tower? Large or small relative to what?

(d) (7 pts) Insulation coordination studies can be performed using rules of thumb, deterministic studies and statistical studies. What are the trade-offs with these three options?

(e) (7 pts) How do the ground wires impact the phase and modal domain R', L', and C' values for a transmission line used for simulation? Will there still be one ground mode if there are multiple static wires? What difference is there if the ground wire is segmented or continuous, if any?

(f) (7 pts) Under what circumstances would you want to use a frequency dependent distributed parameter line model in an EMTP simulation for overhead lines? How about cables? What does this model represent and why is it useful to use over a single frequency travelling wave (constant parameter) model?

(g) (5 pts) What does BIL stand for? How about BSL? Explain what each represents and how they are used.

(h) (5 pts) Describe how a transformer be modeled for high frequency transient analysis differ from models used for low frequencies? At what frequencies do the differences start to be significant? Does saturation matter more or less as frequency goes up?

Joe Stanley

ECE 524 - FINAL EXAM

In [16]:

```python
# Import Libraries
import numpy as np
import matplotlib.pyplot as plt
import eepower as eep
from eepower import p,n,u,m,k,M

# Define Plotting Function
def atpdataplot(fname,title="",labels=None,xlim=None):
    # Condition Inputs
    if fname[-4:] != ".ADF":
        if fname[-4:] != ".adf":
            fname += ".ADF"
        else:
            fname = fname[:-4] + ".ADF"
    # Load Data from File
    data = np.genfromtxt(fname,delimiter='\t',skip_header=2,unpack=True)
    t_arr = data[0]
    # Plot Data
    for i in range(1,len(data)-1):
        d_set = data[i]
        if labels != None:
            try:
                d_name = labels[i-1]
            except:
                d_name = "Entry "+str(i)
            plt.plot(t_arr,d_set,label=d_name)
        else:
            plt.plot(t_arr,d_set)
    plt.title(title)
    if labels != None:
        plt.legend()
    if xlim != None:
        plt.xlim(xlim)
    plt.show()
```

Problem 1

25MI Section

```
KARD  3  3  4  4  5  5  6  6  7  7  8  8  9  9 10 10 11 11
KARG  1 10  2 11  3 12  4 13  5 14  6 15  7 16  8 17  9 18
KBEG  3  9  3  9  3  9  3  9  3  9  3  9  3  9  3  9  3  9
KEND  8 14  8 14  8 14  8 14  8 14  8 14  8 14  8 14  8 14
KTEX  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1
/BRANCH
VINTAGE, 1
-1IN___AOUT__A             8.46916E-01 9.86461E+02 9.11449E+04-1.25000E+
01 1  9
-2IN___BOUT__B             4.90624E-02 4.90748E+02 1.56156E+05-1.25000E+
01 1  9
-3IN___COUT__C             4.49365E-02 3.66942E+02 1.73129E+05-1.25000E+
01 1  9
-4IN___DOUT__D             3.66310E-02 2.55102E+02 1.81007E+05-1.25000E+
01 1  9
-5IN___EOUT__E             6.03907E-02 2.57172E+02 1.83588E+05-1.25000E+
01 1  9
-6IN___FOUT__F             4.11214E-02 2.15286E+02 1.83313E+05-1.25000E+
01 1  9
-7IN___GOUT__G             3.20448E-02 2.10301E+02 1.83427E+05-1.25000E+
01 1  9
-8IN___HOUT__H             3.23347E-02 1.85518E+02 1.84521E+05-1.25000E+
01 1  9
-9IN___IOUT__I             3.26577E-02 1.89758E+02 1.84403E+05-1.25000E+
01 1  9
VINTAGE, 0
  0.25459016 -0.28578499  0.08062086  0.11335363  0.49452695  0.65633465
  0.05210785 -0.02548649  0.01757359
 -0.00214746 -0.00163171  0.04145063 -0.13972595 -0.04923833  0.06204167
 -0.16262080  0.06901223  0.09035807
  0.25181870 -0.33142966  0.25779302 -0.09576600 -0.78042732  0.20342169
 -0.05807565  0.02129701  0.04525270
 -0.00467529 -0.00052754  0.03048257 -0.05439639 -0.00967506 -0.10185594
 -0.06059491  0.03323815  0.02125391
  0.29453910 -0.41196398  0.43833080 -0.26811116  0.36849689 -0.49857718
 -0.10370434  0.02931978  0.01111147
 -0.01136341  0.02031202 -0.03208499  0.10734132  0.04946835 -0.07362000
  0.10240355 -0.03614565 -0.05935866
  0.37037324  0.09834052 -0.43925563 -0.37782413 -0.00147644  0.08476747
 -0.47998870 -0.43868258 -0.21246403
  0.00599144 -0.01145508 -0.01593004  0.03325380 -0.00237691 -0.09535404
 -0.10177552  0.01062066  0.12740576
  0.34611560 -0.09134549 -0.46304661  0.13528527 -0.00290004 -0.14842598
 -0.21524836  0.51099006  0.51914960
  0.00613417 -0.01411720 -0.01094295  0.06616933 -0.00335852 -0.15321679
  0.13705067  0.11694772 -0.12614246
  0.36417560 -0.27418836 -0.30661142  0.51049916 -0.07210733 -0.32030721
  0.45981282 -0.24912649 -0.35296533
  0.00447504 -0.01467881  0.02502189  0.02133822  0.01961856  0.29737772
```

```
  0.08525134 -0.15550527 -0.01089246
  0.39004670  0.52025682  0.43053543  0.47432008 -0.00247036 -0.03683601
 -0.38423703  0.18381415 -0.26805925
 -0.00584214 -0.00178966 -0.01321173  0.02998290  0.00131018 -0.01076907
  0.04740431 -0.01199024 -0.04511730
  0.33588765  0.40756564  0.19406895 -0.03123462 -0.00054071 -0.00190396
  0.27869281 -0.45116311  0.56514007
  0.00121724  0.01022184  0.00892381 -0.00403456 -0.00039310  0.03272859
 -0.04512903  0.09053997  0.08866530
  0.36078240  0.32820866 -0.07474509 -0.46257608  0.00034969  0.05746154
  0.43398443  0.42267311 -0.32395809
  0.00400714  0.00242172  0.00001289 -0.06035449 -0.00096611  0.03095573
 -0.00786206 -0.11377587 -0.08826399
EOF
ARG, IN___A, IN___B, IN___C, IN___D, IN___E, IN___F, IN___G, IN___H, IN_
__I
ARG, OUT__A, OUT__B, OUT__C, OUT__D, OUT__E, OUT__F, OUT__G, OUT__H, OUT
__I
```

12.5MI Section

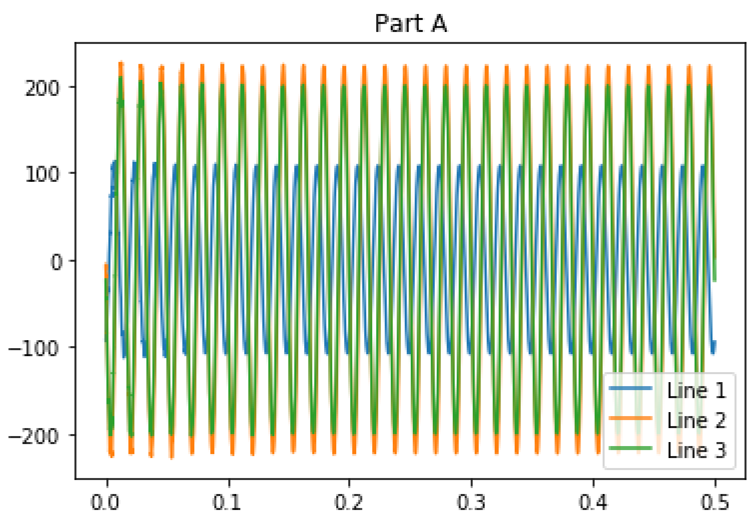
```
KARD  3  3  4  4  5  5  6  6  7  7  8  8  9  9 10 10 11 11
KARG  1 10  2 11  3 12  4 13  5 14  6 15  7 16  8 17  9 18
KBEG  3  9  3  9  3  9  3  9  3  9  3  9  3  9  3  9  3  9
KEND  8 14  8 14  8 14  8 14  8 14  8 14  8 14  8 14  8 14
KTEX  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1
/BRANCH
VINTAGE, 1
-1IN___AOUT__A             8.46916E-01 9.86461E+02 9.11449E+04-1.25000E+
01 1  9
-2IN___BOUT__B             4.90624E-02 4.90748E+02 1.56156E+05-1.25000E+
01 1  9
-3IN___COUT__C             4.49365E-02 3.66942E+02 1.73129E+05-1.25000E+
01 1  9
-4IN___DOUT__D             3.66310E-02 2.55102E+02 1.81007E+05-1.25000E+
01 1  9
-5IN___EOUT__E             6.03907E-02 2.57172E+02 1.83588E+05-1.25000E+
01 1  9
-6IN___FOUT__F             4.11214E-02 2.15286E+02 1.83313E+05-1.25000E+
01 1  9
-7IN___GOUT__G             3.20448E-02 2.10301E+02 1.83427E+05-1.25000E+
01 1  9
-8IN___HOUT__H             3.23347E-02 1.85518E+02 1.84521E+05-1.25000E+
01 1  9
-9IN___IOUT__I             3.26577E-02 1.89758E+02 1.84403E+05-1.25000E+
01 1  9
VINTAGE, 0
  0.25459016 -0.28578499  0.08062086  0.11335363  0.49452695  0.65633465
  0.05210785 -0.02548649  0.01757359
 -0.00214746 -0.00163171  0.04145063 -0.13972595 -0.04923833  0.06204167
 -0.16262080  0.06901223  0.09035807
  0.25181870 -0.33142966  0.25779302 -0.09576600 -0.78042732  0.20342169
 -0.05807565  0.02129701  0.04525270
 -0.00467529 -0.00052754  0.03048257 -0.05439639 -0.00967506 -0.10185594
 -0.06059491  0.03323815  0.02125391
  0.29453910 -0.41196398  0.43833080 -0.26811116  0.36849689 -0.49857718
 -0.10370434  0.02931978  0.01111147
 -0.01136341  0.02031202 -0.03208499  0.10734132  0.04946835 -0.07362000
  0.10240355 -0.03614565 -0.05935866
  0.37037324  0.09834052 -0.43925563 -0.37782413 -0.00147644  0.08476747
 -0.47998870 -0.43868258 -0.21246403
  0.00599144 -0.01145508 -0.01593004  0.03325380 -0.00237691 -0.09535404
 -0.10177552  0.01062066  0.12740576
  0.34611560 -0.09134549 -0.46304661  0.13528527 -0.00290004 -0.14842598
 -0.21524836  0.51099006  0.51914960
  0.00613417 -0.01411720 -0.01094295  0.06616933 -0.00335852 -0.15321679
  0.13705067  0.11694772 -0.12614246
  0.36417560 -0.27418836 -0.30661142  0.51049916 -0.07210733 -0.32030721
  0.45981282 -0.24912649 -0.35296533
  0.00447504 -0.01467881  0.02502189  0.02133822  0.01961856  0.29737772
```

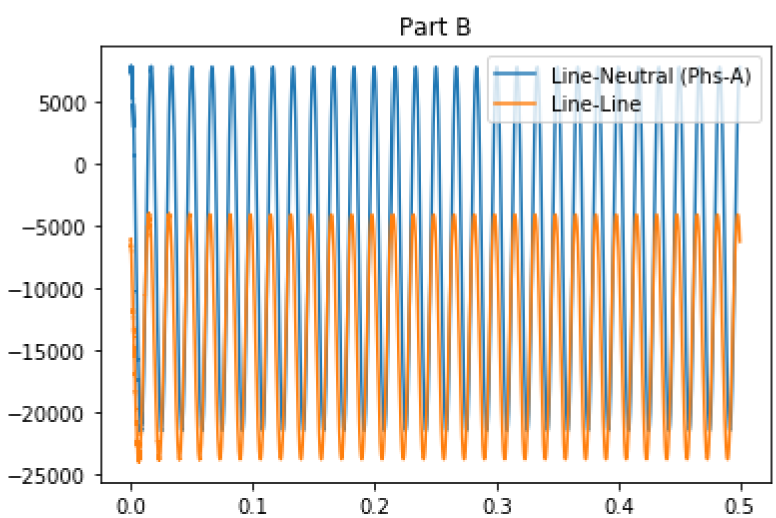
```
  0.08525134 -0.15550527 -0.01089246
  0.39004670  0.52025682  0.43053543  0.47432008 -0.00247036 -0.03683601
 -0.38423703  0.18381415 -0.26805925
 -0.00584214 -0.00178966 -0.01321173  0.02998290  0.00131018 -0.01076907
  0.04740431 -0.01199024 -0.04511730
  0.33588765  0.40756564  0.19406895 -0.03123462 -0.00054071 -0.00190396
  0.27869281 -0.45116311  0.56514007
  0.00121724  0.01022184  0.00892381 -0.00403456 -0.00039310  0.03272859
 -0.04512903  0.09053997  0.08866530
  0.36078240  0.32820866 -0.07474509 -0.46257608  0.00034969  0.05746154
  0.43398443  0.42267311 -0.32395809
  0.00400714  0.00242172  0.00001289 -0.06035449 -0.00096611  0.03095573
 -0.00786206 -0.11377587 -0.08826399
EOF
ARG, IN___A, IN___B, IN___C, IN___D, IN___E, IN___F, IN___G, IN___H, IN_
__I
ARG, OUT__A, OUT__B, OUT__C, OUT__D, OUT__E, OUT__F, OUT__G, OUT__H, OUT
__I
```

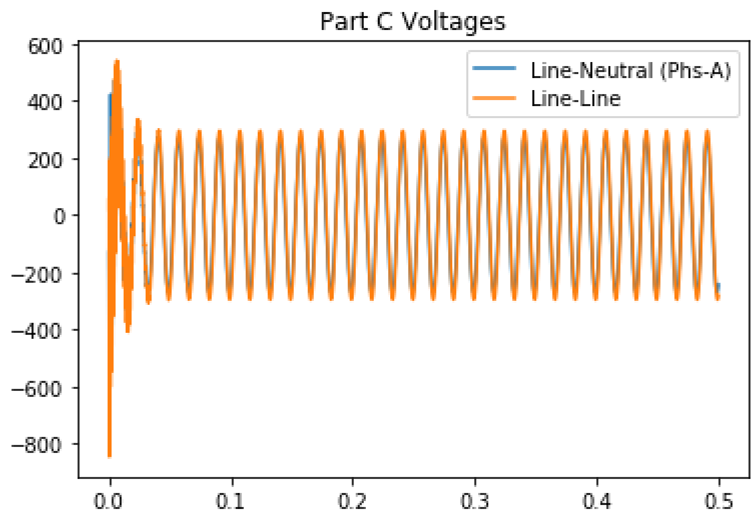
In [21]:

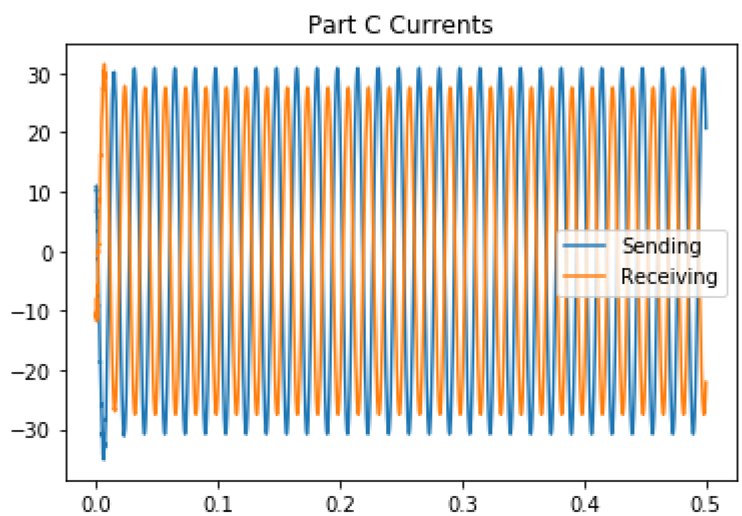
```python
# Calculations
R1 = eep.phaseline(VLL=345*k)/440
print("Load Resistance (Y-Config):",R1,"Ω")
R2 = eep.phaseline(VLL=500*k)/830
print("Load Resistance (Y-Config):",R2,"Ω")

# Plot For Part A
atpdataplot("1_A",title="Part A",labels=["Line 1","Line 2","Line 3"],xlim=No

# Plot For Part B
atpdataplot("1_B",title="Part B",labels=["Line-Neutral (Phs-A)","Line-Line"]

# Plot For Part C
atpdataplot("1_C1",title="Part C Voltages",labels=["Line-Neutral (Phs-A)","L
atpdataplot("1_C2",title="Part C Currents",labels=["Sending","Receiving"],xl
```

```
Load Resistance (Y-Config): 452.69509743277484 Ω
Load Resistance (Y-Config): 347.80136698170224 Ω
```







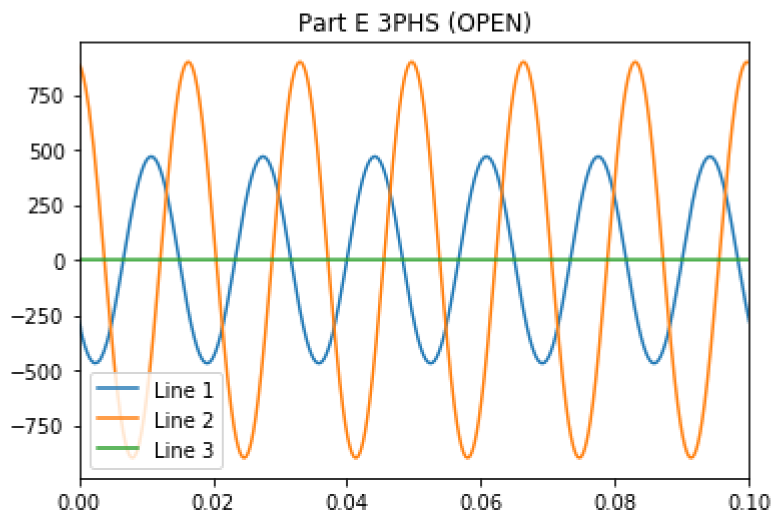


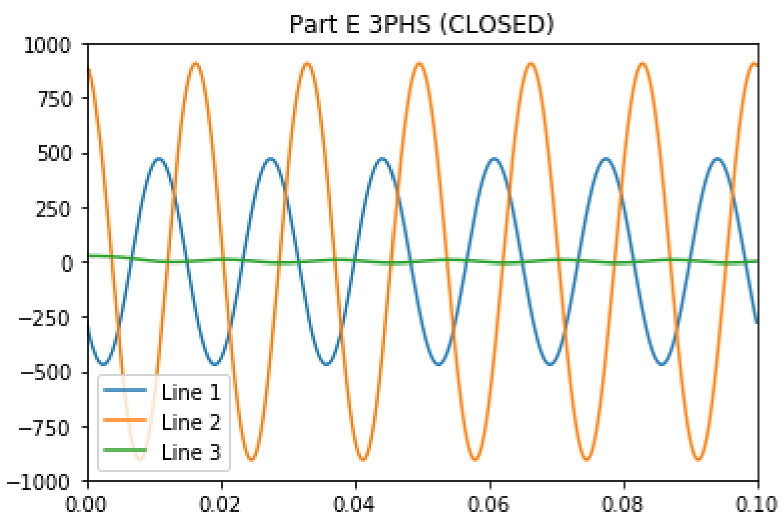
Part D Discussion:

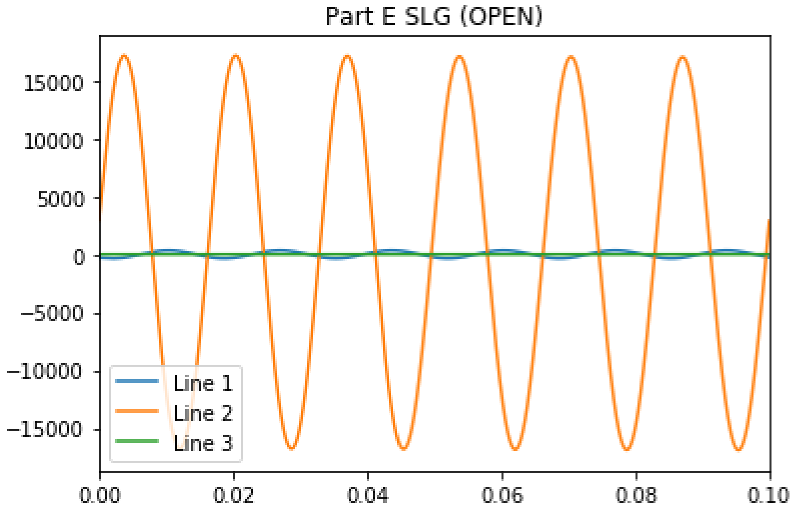
As the differences appear in the results of the system being modeled, it appears that the coupling is largely inductive. I make this deduction based on the fact that without any complete circuit path, the voltages in part B are very large as compared to the grounded case evaluated in part C. In part B, we see very high voltages that are induced entirely by the adjacent lines. In part C, we see the significantly lower voltages due to the ground and phase return paths.

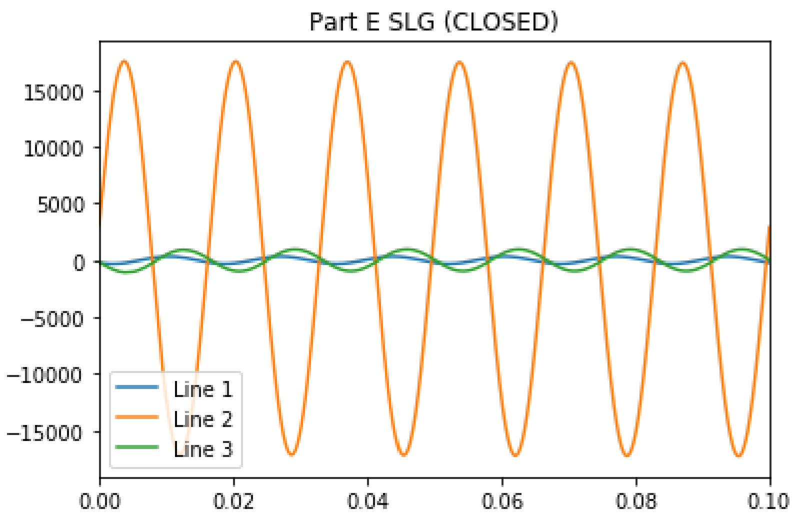
In [22]:

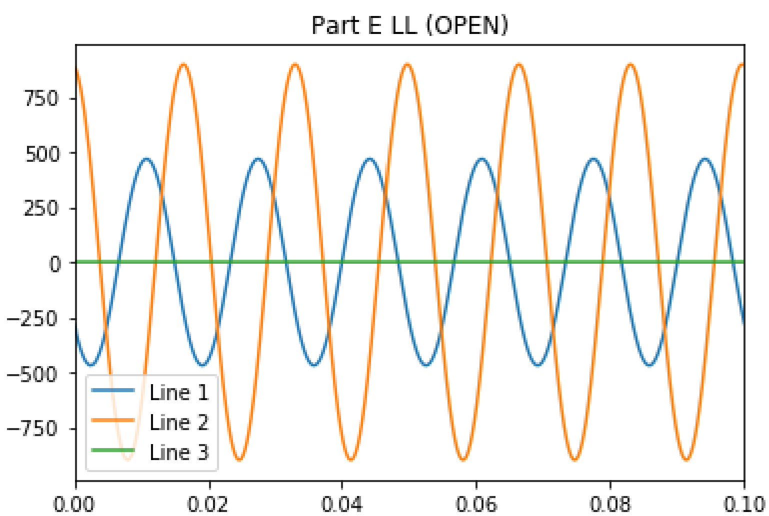
```
# Plot For Part E
atpdataplot("1_E_1_3PHS",title="Part E 3PHS (OPEN)",labels=["Line 1","Line 2
atpdataplot("1_E_2_3PHS",title="Part E 3PHS (CLOSED)",labels=["Line 1","Line
atpdataplot("1_E_1_SLG",title="Part E SLG (OPEN)",labels=["Line 1","Line 2",
atpdataplot("1_E_2_SLG",title="Part E SLG (CLOSED)",labels=["Line 1","Line 2

atpdataplot("1_E_1_LL",title="Part E LL (OPEN)",labels=["Line 1","Line 2","L
atpdataplot("1_E_2_LL",title="Part E LL (CLOSED)",labels=["Line 1","Line 2",
atpdataplot("1_E_1_DLG",title="Part E DLG (OPEN)",labels=["Line 1","Line 2",
atpdataplot("1_E_2_DLG",title="Part E DLG (CLOSED)",labels=["Line 1","Line 2
```

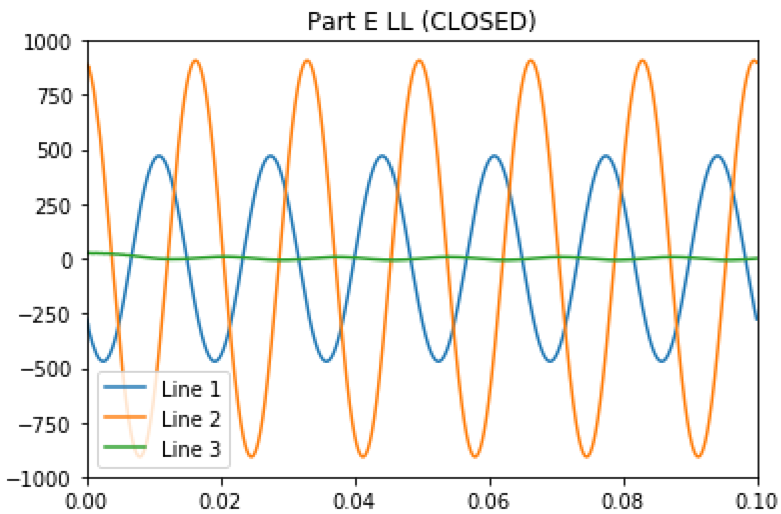


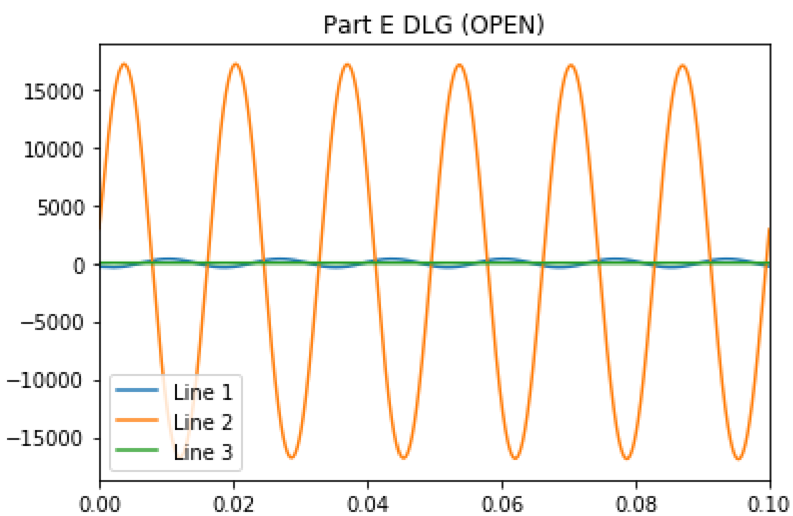


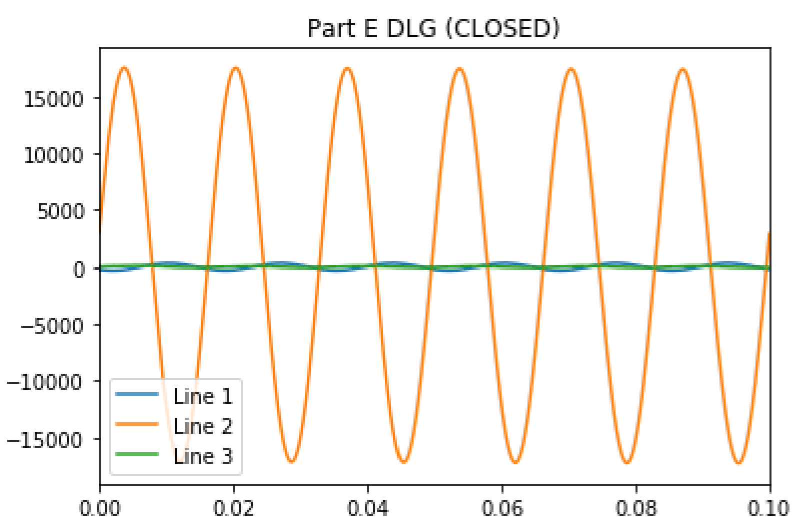

Part E SLG (OPEN)
15000
10000
5000
0
−5000
−10000
−15000
0.00
0.02
0.04
0.06
0.08
0.10
Line 1
Line 2
Line 3


Part E SLG (CLOSED)
15000
10000
5000
0
−5000
−10000
−15000
0.00
0.02
0.04
0.06
0.08
0.10
Line 1
Line 2
Line 3


Part E LL (OPEN)
750
500
250
0
−250
−500
−750
0.00
0.02
0.04
0.06
0.08
0.10
Line 1
Line 2
Line 3







Part F Discussion:

In every case above, we note a coupling factor between the faulted system and the unfaulted systems. Interestingly enough, the SLG Fault seems to have the most effect on the adjacent line.

Problem 2:

A)

Assume that velocity characteristics are as described from Midterm Exam:

$$v_0 = 1.2254 * 10^5 * \frac{mi}{sec}$$
$$v_1 = 1.8213 * 10^5 * \frac{mi}{sec}$$
$$v_2 = 1.8213 * 10^5 * \frac{mi}{sec}$$

In [24]:
```
# Calculate Part A:
dt = 1*u # second
v0 = 1.2254e5 # mi/sec
v1_2 = 1.8212e5 # mi/sec
accuracy = dt*v1_2
print("Accuracy of Location:",accuracy,"mi")
```

```
Accuracy of Location: 0.18212 mi
```

The accuracy of fault location will be different from that of an overhead transmission line due to the inherent difference in propogation velocity, an effect of the difference in cable arangement and cable parameters (R/L/C). Other factors that will affect the accuracy include the variety of underground objects and variation of soil consistency and moisture, among other factors.

We should aim to avoid usage of the ground/zero mode due to the fact that it attenuates and distorts values; instead, we should use the first/(alpha) and second/(beta) line modes. The distortion related to the ground mode comes from factors like those described above. Underground objects and variation in the ground makeup will inevitably distort the methods used for traveling wave detection/location.

B)

To determine flashover characteristics in a lightning strike situation, only the pertinent grounding mechanism needs to be modeled thoroughly, the remaining pieces of the grounding system may be reduced to thevenin equivalent circuits. In the case of the 100 mile transmission line, only the nearby towers and grounding system need to be modeled thoroughly.

The lighting strike should be modeled as a current source. After all, lightning is really just the discharge of electrically charged clouds, and the change of charge over time is current.

C)

Larger footing resistances will actually help to reduce the risk of a back flashover, this is because with the increased resistance, there will be a lower potential difference (voltage) between the ground conductor and the phase conductors. This results in a lower chance of flashover. This resistance must be great compared to the impedance between the tower phase conductor and ground conductor.

D)

1. Rules of Thumb:
    - Easy to apply
    - Quick application
    - Does not account for system specific parameters
    - May over/under estimate the system
2. Deterministic Studies:
    - Requires in-depth system analyis, modeling, and calculation
    - Highly accurate as compared to (1)
    - May largely overstate the insulation requirements
    - Higher than necessary cost due to previous bullet
3. Statistical Studies:
    - Attempt to account for "most likely" requirements
    - Likely will lead to lower costs than (2)
    - Likely will lead to greater accuracy than (1)
    - May not account for all cases
    - May not accurately generate the "most likely" requirements as result of pseudo-randomness

E)

Ground wires affect the R', L', and C' values by providing an object for mutual coupling to occur with. There is always one ground mode, regardless of the number of static wires because of the fact that all ground returns share a common path, and thus common characteristics.

Having a segmented or continuous ground wire will only affect the coupling parameters for the phase conductors. It will not affect the ground mode as there is still one path for the ground return.

F)

Frequency dependent distributed models will be especially useful for switching studies, and for fault studies where multiple lengths of line must be tested and modeled.

Cables will be useful in modeling line interactions and coupling in addition to line charging and faulted line interaction.

G)

- BIL stands for "basic lightning impulse insulation level", and as described in class, it describes: "Rise time of 1.2μsec and decay to 50% in 50μsec"
- BSL stands for "basic switching impulse insulation level", and it describes: "Rise time of 250μsec and decay to 50% in 2500μsec"

Both of these standards are used to describe the ability of equipment and insulation to withstand overvoltages.

H)

Transformers modeled for high-frequency transient analysis must include capacitive characteristics that models designed for low frequency analysis often don't include. This is because of the increased importance of capacitance in high-frequency ranges.

These differences tend to appear in the neighborhood of 20kHz.

Saturation tends to be more important and more prevalent in lower frequency ranges, and as a result, that is why low-frequency transformers tend to be larger in physical size.

In [ ]:
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