EE 374 – ELECTRICAL EQUIPMENT AND APPLICATIONS TERM PROJECT REPORT

2019-2020 SPRING

Calculating the Electrical Parameters of HV Transmission Lines

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INTRODUCTION

Main purpose of this project is calculating the electrical parameters of the HV transmission lines and modelling them with different approachs in MATLAB environemnt. There are three deliverables namely phase-1, phase-2 and phase-3. Each phase is submitted in regular time intervals during the semester. Project will be explained in three subchapters corresponds to chapters.

Phase-1

In this first phase, we were expected to extract the necessary information from given raw data files. Two files were given as inputs; a txt file that contains information about the physical structure and the geometry and a conductor library that contains information about conductor characteristics. First I have determined how should I approach this problem. There were some restrictions about data format. Order of the variables and the number of rows were specified. So I read the txt data row by row. This was the simplest approach. However, writing if statements for each row was a bit time consuming. I am also aware that if there were some changes in the input data order, my approach would fail. I got precise results in the tests and extracted the data succesfully. But I understand that creating a more complex code that can extract data from differently ordered data files would be more helpful in real life applications.

Name	Value
D1AB	3.5057
D1AC	7
D1BC	3.5057
D2AB	3.5057
D2AC	7
D2BC	3.5057
dbundle	0.4000
length	100
line_type	'Rail'
Nbundle	4
Ncircuit	2

Figure 2: Test result for input file 1

Name	Value
D1AB	4
D1AC	8
D1BC	4
D2AB	-1
D2AC	-1
D2BC	-1
dbundle	0.5000
length	125
line_type	'Pheasant'
Nbundle	6
Ncircuit	1

Figure 3: Test result for input file 2

```
Expected output for Example-1:
[2, 4, 0.4, 100, Rail, 3.5057, 7, 3.5057, 3.5057, 7, 3.5057]

Expected output for Example-2:
[1, 6, 0.5, 125, Pheasant, 4, 8, 4, -1, -1, -1]
```

Figure 1: Expected results for phase-1

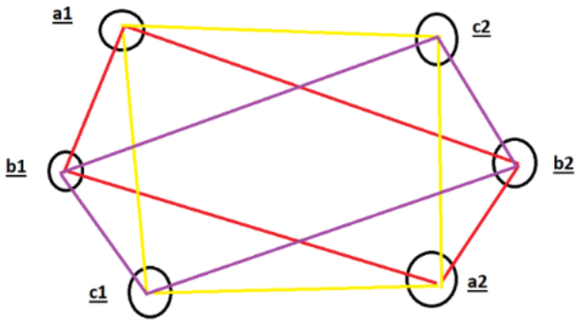
It can be seen that test results are the same as with the expected results. (see fig.1,2,3)

Phase-2

In this phase, we are expected to calculate the electrical parameters of the TM with the extracted data in phase-1. First, I have completed the data extraction. All the necessary data was in the .txt file in phase-1. So I didn't read anything from conductor library. At the beginning of this phase, I've read the data from excel file and completed the data extraction. Then I started with the resistance. It was easy since it does not contain any GMR or GMD calculations. The only tricky part was realizing that there are parallel resistance with the number of Nbundle*Ncircuits. Feet to meter conversion has also carried out.

After calculating the resistance per km value, I calculated the equivalent radius of the bundles. Note that this is an approximation for the future calculations. Since the distance between bundles are much larger than the distances inside the bundle, we are assuming that the distance between the conductors in different bundles is equal to the distance between the centers of bundles. I also assumed that the bundles always form smooth polygons for simplicity. Maximum possible number of the conductors in a bundle is specified as 8. This restriction allowed me to use same approach as in phase-1. I have calculated the equivalent bundle radius for each case. Feet to meter is done again. Note that req calculation is almost the same as the Ds_bundle. Again, I am aware that this is a time consuming but simple way. If I didn't make tha assumptions that are mentioned above, a more complex coding approach would be necessary.

Then, I calculated the GMR value for each phase. I used the distance between the center of bundles and the equivalent bundle radius that I have calculated earlier. Note that req will be used for capacitance calculations instead of Ds_bundle value. GMD calculation was started then. It is calculated by using the distance between phases in the circuits. Note that the effect of earth is also considered for double cct case. Therefore, electrical parameters are calculated with the data extracted from raw data files by the end of this phase. Figures 4,5 and 6 explains the mathematical methods used in phase-2 for GMD, GMR and effecr of eartgh calculations. R, X and B calculations are straightforward. Note that another assumption that I made is that the lines are transposed. This assumption simplifies inductance calculations a lot.



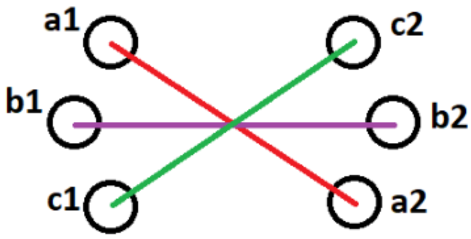
$$GMD = \sqrt[3]{GMD_{AB}GMD_{AC}GMD_{BC}}$$

Each sub-GMDs can be found as geometric mean of the corresponding color:

$$GMD_{AB} = \sqrt[4]{\prod red\ colored\ lines}$$

and similar procedure for other two sub-GMDs.

Figure 4



$$GMR = \sqrt[3]{GMR_{AA}GMR_{BB}GMR_{CC}}$$

Each sub-GMDs can be found as follows:

$$GMR_{AA} = \sqrt{GMR_{bundle} \times red\ line}$$

and similar procedure can be followed for other two sub-GMRs. Same calculations can be repeated for r_eq.

Figure 6

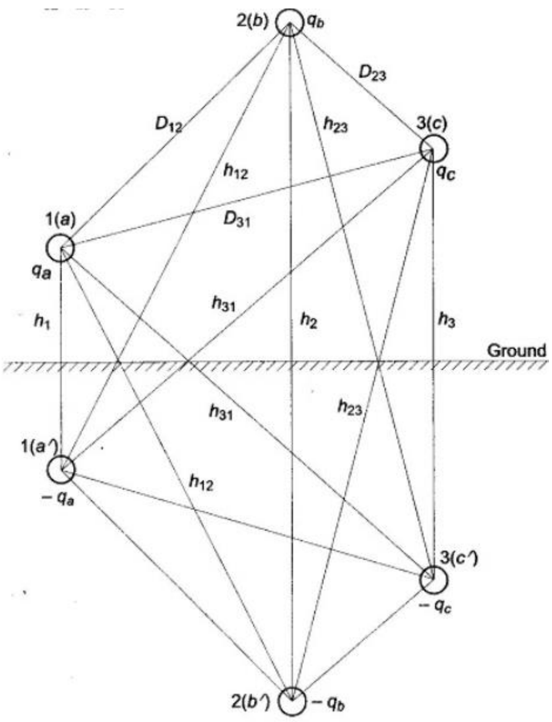


Figure 5

$$C_n = \frac{2\pi k}{\ln \frac{D_{eq}}{r} - \ln\left(\frac{(h_{12}h_{23}h_{31})^{1/3}}{(h_1 h_2 h_3)^{1/3}}\right)} \text{ F/m to neutral} \qquad (3.29a)$$

Test results for phase-2 are as follows;

Workspace

Name	Value
B	1.1593e-05
BBonus	-1
R	0.0077
X	0.0965
XBonus	-1

Figure 7: Test result for input file 1

Workspace

Name	Value
B	6.8139e-06
BBonus	-1
R	0.0078
X	0.1637
XBonus	-1

Figure 8: Test result for input file 2

Expected output for example 1 (without the bonus part):

[0.0077,0.0965,1.1598e-05,-1,-1]

Expected output for example 2 (without the bonus part):

[0.0078,0.1637,6.8170e-06,-1,-1]

Note that test results are sufficiently close to the expected results. There is some error in the B values. I think that this error is due to some mistake in the effect of earth or req calculation. I could not find out the mistake yet. Since I wrote my code in a simple but long manner, it is hard to find misakes and debug. I will most probably write more compact codes in the future. Also, creating sub-function modules would increase the readability of the code.

Phase-3

In this final stage, we are expected to use the electrical parameters that are calculated in phase-2 and employ the proper model for the transmission line. For this purpose, I have used both long line and medium line models. First, series resistance and shunt admittance is calculated since these values are used in both models. Employing the nominal-pi was easy becaues it is a simple model.

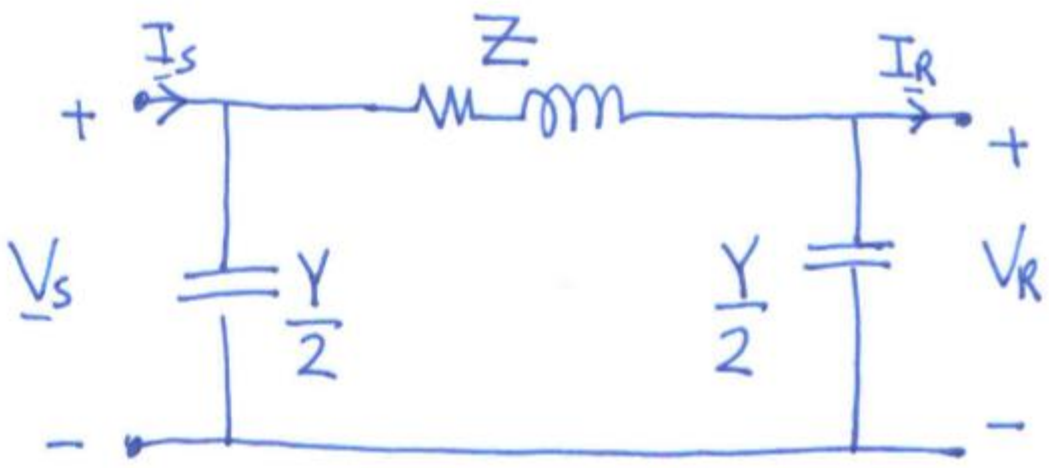


Figure 9: Nominal-pi model

This model is a good approximation up to 240 km length lines. Since the lines in our test cases are shorter than the 240 km, I am expecting that either long or medium line models will give precise results.

In long line model, we are considering the effect of the propagation constant and the characterstic impedance. This model is suitable for lines longer than 240 km. However, I am expecting to get precise results for lines shorter than the 240 km. I used directly the final equations for the A, B, C and D parameters for both long line and moedium line models. I will test both models with very short and long lines and observe the difference.

Name	Value
Al	0.9944 + 0.0004i
Am	0.9944 + 0.0004i
Bl	0.7715 + 9.6319i
Bm	0.7744 + 9.6497i
Cl	-0.0000 + 0.0012i
Cm	-0.0000 + 0.0012i
Dl	0.9944 + 0.0004i
Dm	0.9944 + 0.0004i
length	100

Figure 11: Test result for input file 1

Name	Value
Al	0.9913 + 0.0004i
Am	0.9913 + 0.0004i
Bl	0.9665 + 20.4034i
Bm	0.9722 + 20.4626i
Cl	-1.1734e-07 + 8.4926e-04i
Cm	-1.7632e-07 + 8.4802e-04i
Dl	0.9913 + 0.0004i
Dm	0.9913 + 0.0004i
length	125

Figure 10: Test result for input file 2

Line length for the input-1 is 100km and 125km for input-2. It is obvious that both medium and long line models give the precise results for the lines that shorter than 240 km. So we can conclude using nominal-pi model for lines up to 240 km, which is way simpler, is safe.

Now, let’s try much more longer lines. For example 400, 500 and 700 km. I will modify the input files 1 and 2. Let’s start with input file-1

Name	Value
Al	0.9118 + 0.0070i
Am	0.9105 + 0.0072i
Bl	2.9151 + 37.4644i
Bm	3.0975 + 38.5989i
Cl	-0.0000 + 0.0045i
Cm	-0.0000 + 0.0044i
Dl	0.9118 + 0.0070i
Dm	0.9105 + 0.0072i
length	400

Figure 13: Test result for input-1, 400 km

Name	Value
Al	0.8633 + 0.0107i
Am	0.8601 + 0.0112i
Bl	3.5183 + 46.0438i
Bm	3.8719 + 48.2487i
Cl	-0.0000 + 0.0055i
Cm	-0.0000 + 0.0054i
Dl	0.8633 + 0.0107i
Dm	0.8601 + 0.0112i
length	500

Figure 12: input-1, 500 km

Name	Value
Al	0.7380 + 0.0200i
Am	0.7258 + 0.0220i
Bl	4.4697 + 61.5777i
Bm	5.4207 + 67.5482i
Cl	-0.0001 + 0.0074i
Cm	-0.0001 + 0.0070i
Dl	0.7380 + 0.0200i
Dm	0.7258 + 0.0220i
length	700

Figure 15: input-1, 700 km

Name	Value
Al	2.7666 - 9.3130i
Am	-2.7411e+03 + 2.2005e+02i
Bl	2.1699e+02 - 8.6471e+02i
Bm	5.4207e+02 + 6.7548e+03i
Cl	0.0342 - 0.1012i
Cm	-8.9329e+01 - 1.1123e+03i
Dl	2.7666 - 9.3130i
Dm	-2.7411e+03 + 2.2005e+02i
length	70000

Figure 14: input-1, 70,000 km

Figures 12, 13 and 14 shows that the difference between nominal-pi and long line model parameters is increasing. This means that as the line length increases, medium line model starts to lose validity. At extremely long distances, results are completely different. So we can conclude that the nominal-pi model is not a proper model for the lines longer than 240 km. We also shown that long line model gives the precise result for relatively short distances.

Sagging in Transmission Lines

Sagging is a physical phenomena that has a strong relationship with the tension on the material. Transmission lines are also exposed to the sagging naturally. Small and large sagging is not desired in transmission line applications. At small sag, tension on the lines would be unsafely high and damage may occur in such conditions. On the other hand, transmission lines may touch to the ground or some trees or make huge swings due to the resonant wind. Short circuit faults may occur is such swing moments. There is an optimum point for the line sag and this point is calculated with some basic mathematical equations. I will exculde the maths but we can conclude that amount of sag increases with the ambient temperature, wind load and the material aging. Let’s conclude the electrical effects of sagging;

- Faults may occur due to contact with the external objects or other phases.
- Total amount of conductor between two stationary towers would increase with increasing line sag. This means that line resistance is increasing with the sagging. So,

more sag means power more loss. Increasing amount of conductor would also increase the investment cost.

Temperature and Resistance Relationship

Temperature is defined as the average kinetic energy that particles have in any material. We also know that the particles of solid materials vibrate due to their kinetic energy. So we can say that more temperature means more vibration. When we create a current in a metal, we actually create a charge density difference between two points and the free electrons in the metal start moving from one pont to another. While they are moving, some scattering occurs due to random vibration of positively charged particles. As we increase the temperature, positively charged particles vibrate more. As they vibrate more, they collide with the flowing electrons and the some kinetic energy is dissipated as heat as a result of these collisions. Therefore, we can conclude that the resistance increases with increasing temperature, due to atomic structure of material. So, we model the resistance as a temperature dependent parameter.

CONCLUSIONS

In this project, we calculated the transmission line parameters starting from the given raw data files. During the project, we are exposed both theoretical and practical problems. Working on the project in such a long time interval, and advancing synchronously with the lectures was very helpful. At the end of this project, I understand that how transmission line parameters calculated and how the validity of employed model changes with respect to the application. I've also learnt the effect of sagging and temperature on the line parameters. I think I have gained a lot of experience about the transmission line modelling