Determination of Z Matrices

EEE 306 – FINAL PROJECT

GROUP B1-1B

1006071-74

Objectives

1. Creating a system that can take as input at least a six bus system.

2. Find the Z matrices, that is positive sequence matrix (Z_1), negative sequence matrix (Z_2) and zero sequence matrix (Z_0).

Approach to the Solution

Take the system as input in database (with a specific schema).

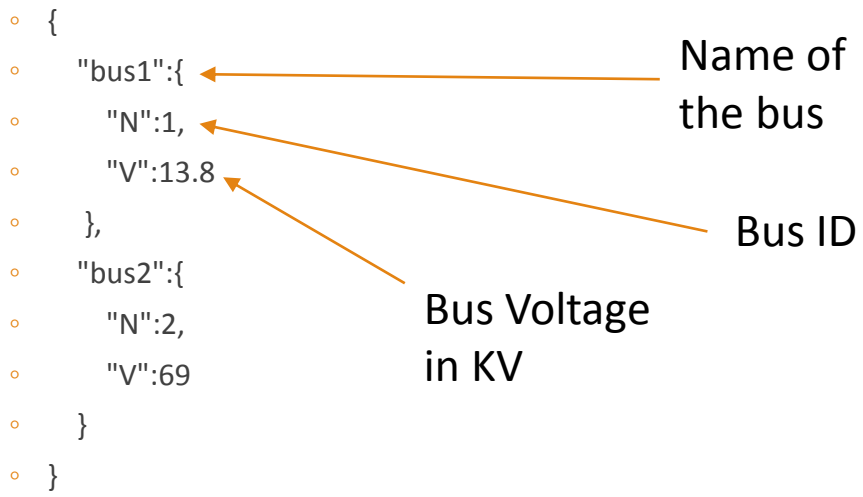
Load the system into memory and create positive and zero sequence graph of the network.

Use the Zbus building algorithm on the graph to obtain the Z_1, Z_2 and Z_0 matrices.

Assumptions

- All the elements are balanced.
- All impedance data are given in per phase equivalent.
- There are no regulating transformers in the network (for which Z_{bus} is asymmetric).

Database Schema



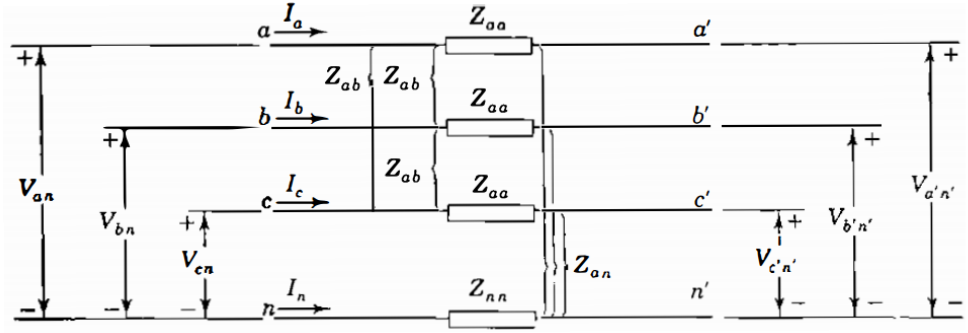
The database used is an open standard known as **JavaScript Object Notation**. Some of the properties of such schema is:

- Each curly braces { } there is a structure inside it.
- Each elements in the structure has a (key, value) pair.
  - For example, “N” is a key, and “1” is it’s value.
  - For the base structure “bus1” is a key and the structure that defines the bus is a value.
- Base structure does not have any key.
- A key can be any string that can be name of a variable in the programming environment. In our case MATLAB.
- Value can be string or numeric.

Each network is described by the following files:

- busdata.json
- transformerdata.json
- generatordata.json
- linedata.json
- loaddata.json

Transmission Line



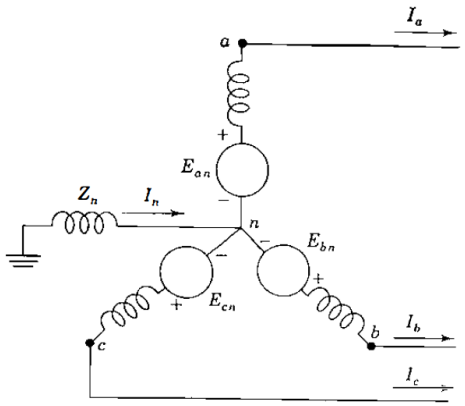
Z_{aa} = Balanced transmission line impedance
Z_{ab} = Mutual Impedance between a, b, c phase
Z_{nn} = Impedance of neutral line
Z_{an} = Mutual Impedance between a, b, c line and neutral

$Z_0 = Z_{aa} + 2\,Z_{ab} + 3\,Z_{nn} - 6\,Z_{an}$
$Z_1 = Z_2 = Z_{aa} - Z_{ab}$

In database:

```
"L34":{
      "bus1": 2,
      "bus2": 3,
      "Raa" : 0,
      "Xaa" : 0.2,
      "Xab" : 0.05,
      "Xan" : 0.08333,
      "Rnn" : 0,
      "Xnn" : 0.1
   }
```

Synchronous Machine



$Z_0 = Z - 2\,Z_m + 3\,Z_n$

$Z_1 = Z_2 = Z + 2\,Z_m$

Z = Machine Impedance

Z_m = Mutual Impedance

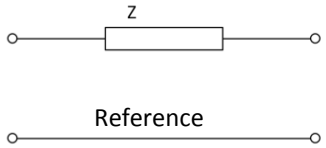
Z_n = Neutral to reference impedance

In Database (one machine is shown):


```
"g2":{
    "bus": 4,
    "rated_kv": 13.8,
    "rated_mva": 200,
    "sub_tr_R": 0,
    "sub_tr_X": 0.14667,
    "sub_tr_M": 0.05333,
    "tr_R": 0,
    "tr_X": 0,
    "tr_M": 0,
    "R": 0.01,
    "X": 0.12,
    "M": 0,
    "winding": "Yg",
    "Rn": 0,
    "Xn": 0.05,
    "activeGeneration_MVA": 100
  }
```

Fixed Tap Transformers

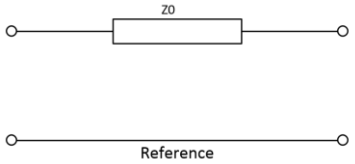
Positive/Negative Sequence Network:



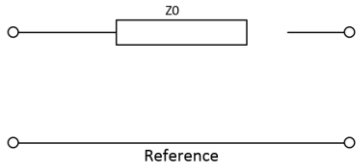
$Z_1 = Z_2 = Z$

Zero Sequence Networks:

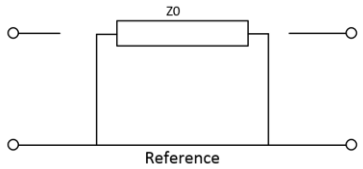
1. Y_g–Y_g:



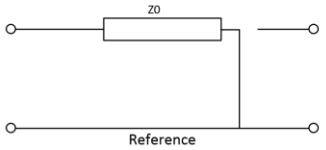
2. Y_g–Y/Y-Δ :



3. Δ - Δ :

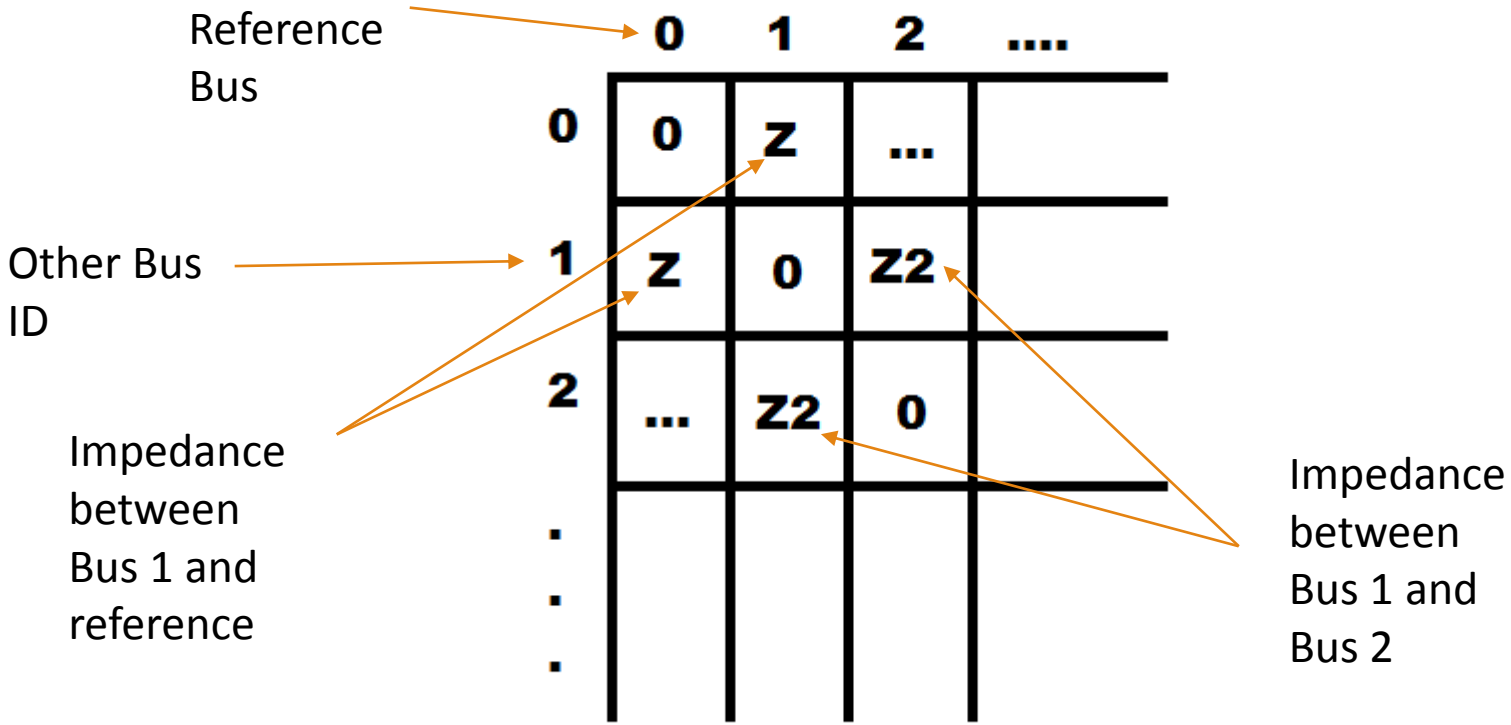


4. Y_g - Δ :



1. $Z_0 = Z + 3 Z_N + 3 Z_n$
2. $Z_0 = Z + 3 Z_N$ or $Z_0 = Z + 3 Z_n$ (A new bus at floating impedance is created in the zero sequence network)
3. $Z_0 = Z$ (Can be neglected in the network)
4. $Z_0 = Z + 3 Z_N$ or $Z_0 = Z + 3 Z_n$

Creating the Network Graph



- The algorithm for building network graph goes through all the information given, one by one.
- For each element Z0, Z1 (or Z2) impedance is added in their respective graph.
- For the floating impedance (Usually from transformers or synchronous machines) in Z0 network, a new node is created in the corresponding network graph.

Building Z_1, Z_2 And Z_0 Matrices

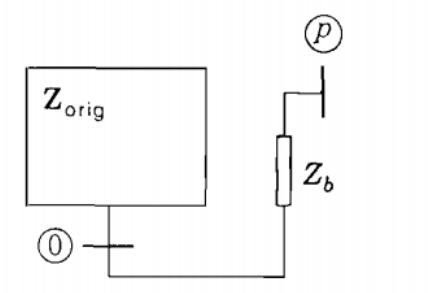
The following approaches are taken for all sequence networks (Z_1 and Z_2 matrices are equal, so calculating one should suffice):

1. First, the impedances connected to the reference are dealt with (Case 1).

2. Then all other buses which has a impedance between two of them are processed (Case 2 & Case 3). Kron reduction is used where necessary.

Z Matrices: Case 1

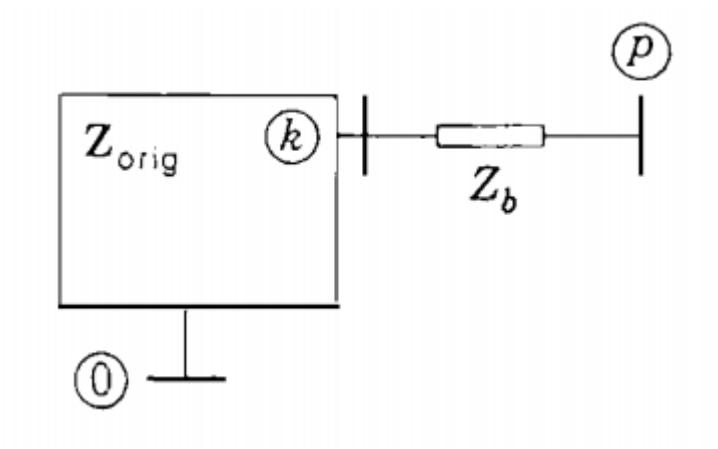
Adding a impedance to new bus from reference:



1. Add a new column and row (assuming k) in Z_{bus} matrix.
2. All elements are zero initialized.
3. $Z_{kk} = Z_b$

Z Matrices: Case 2

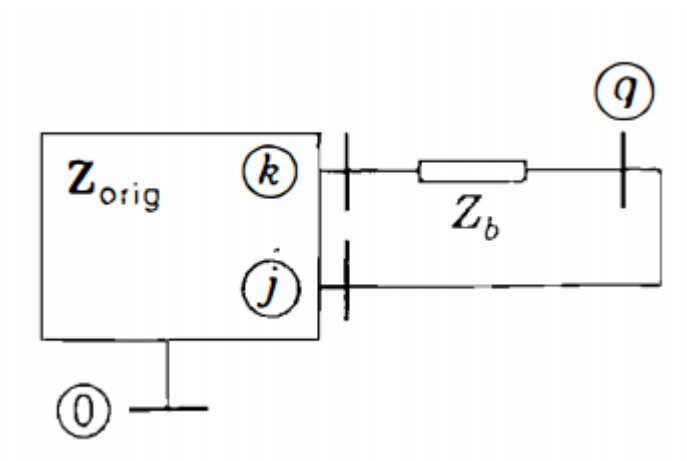
Adding branch Z_b from existing bus k to a new bus p



1. Create a new column and row in Z_{bus} matrix
2. Copy column k and row k into new column p and row p respectively
3. $Z_{pp} = Z_{kk} + Z_b$

Z Matrices: Case 3

Adding branch Z_b from existing bus k to a existing bus j



1. Add temporary node q.
2. Copy (column k-column j) to column q and copy (row k – row j) to row q.
3. $Z_{qq} = Z_{jj} + Z_{kk} – 2\ Z_{jk} + Z_b$
4. Use Kron reduction.

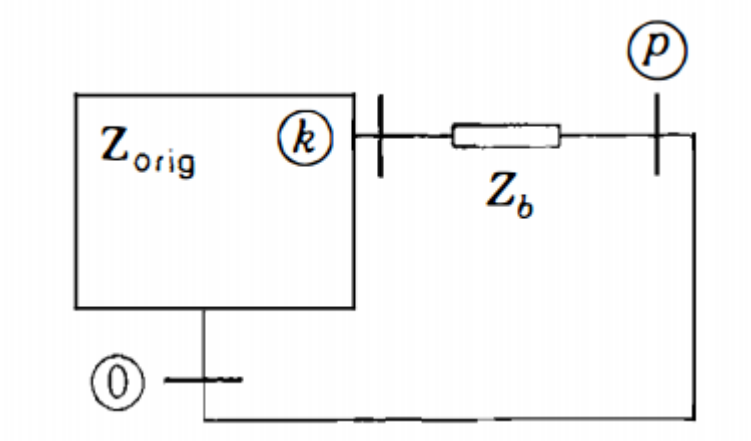
   For all index other than q:

   $$Z_{hi(new)} = Z_{hi} - Z_{hq}\ Z_{qi} / Z_{qq}$$

5. Delete node q.

Z Matrices: Case X

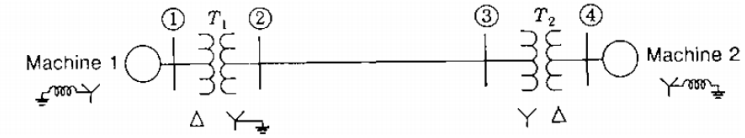
Adding a impedance to an existing bus from reference:



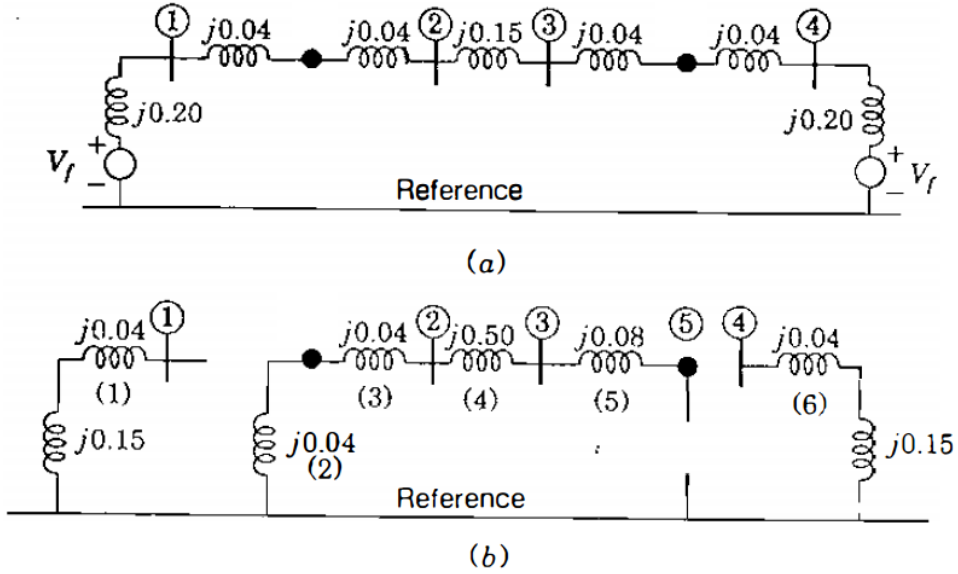
This case is not considered because we have already considered all the impedances from reference to bus in first step. For which, all such impedances are considered in case 1.

Tests: 4 Bus System

This system is taken from the book ‘Power System Analysis’ (Indian Edition) by John J. Grainger and William D. Stevenson, Jr. Chapter 12, Example 12.1.

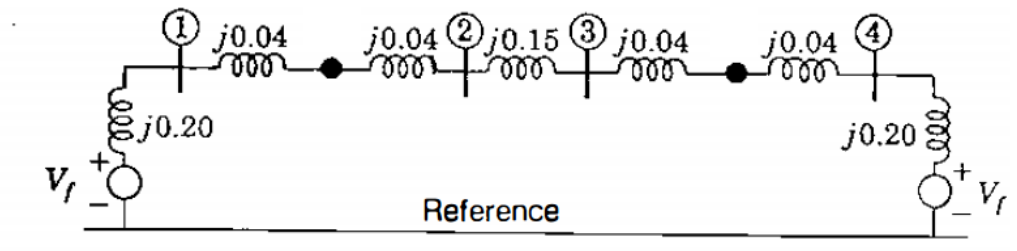


One Line Diagram (Above)
Positive Sequence Network (Top Right)
Zero Sequence Network (Bottom Right)



Tests: 4 Bus System (Network Graph)

Positive Sequence Graph:



	0	1	2	3	5
0	0	0 + 0.2000i	0	0	0 + 0.2000i
1	0 + 0.2000i	0	0 + 0.0800i	0	0
2	0	0 + 0.0800i	0	0 + 0.1500i	0
3	0	0	0 + 0.1500i	0	0 + 0.0800i
4	0 + 0.2000i	0	0	0 + 0.0800i	0

Tests: 4 Bus System (Z_1)

Calculated $Z_1 = Z_2$:

	1	2	3	4
1	0 + 0.1437i	0 + 0.1211i	0 + 0.0789i	0 + 0.0563i
2	0 + 0.1211i	0 + 0.1696i	0 + 0.1104i	0 + 0.0789i
3	0 + 0.0789i	0 + 0.1104i	0 + 0.1696i	0 + 0.1211i
4	0 + 0.0563i	0 + 0.0789i	0 + 0.1211i	0 + 0.1437i

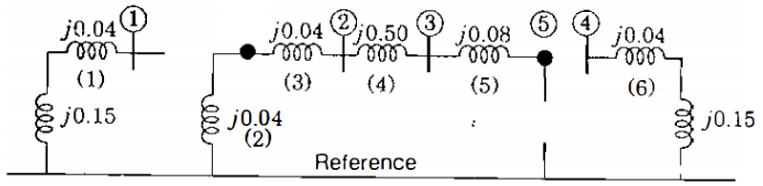
This matches the $Z_{bus}^{(1)}$ of the network:

$$\mathbf{Z}_{\text{bus}}^{(1)} = \mathbf{Z}_{\text{bus}}^{(2)} = \begin{array}{c} \\ ① \\ ② \\ ③ \\ ④ \end{array} \begin{array}{c} \begin{array}{cccc} ① & \bullet & ③ & ④ \end{array} \\ \begin{bmatrix} j0.1437 & j0.1211 & j0.0789 & j0.0563 \\ j0.1211 & j0.1696 & j0.1104 & j0.0789 \\ j0.0789 & j0.1104 & j0.1696 & j0.1211 \\ j0.0563 & j0.0789 & j0.1211 & j0.1437 \end{bmatrix} \end{array}$$

Tests: 4 Bus System (Z_0)

Similarly Z_0 is calculated.

Network Graph:



	0	1	2	3	4	5
0	0	0 + 0.1900i	0 + 0.0800i	0	0 + 0.1900i	0
1	0 + 0.1900i	0	0	0	0	0
2	0 + 0.0800i	0	0	0 + 0.5000i	0	0
3	0	0	0 + 0.5000i	0	0	0 + 0.0800i
4	0 + 0.1900i	0	0	0	0	0
5	0	0	0	0 + 0.0800i	0	0

Z_0 Matrix:

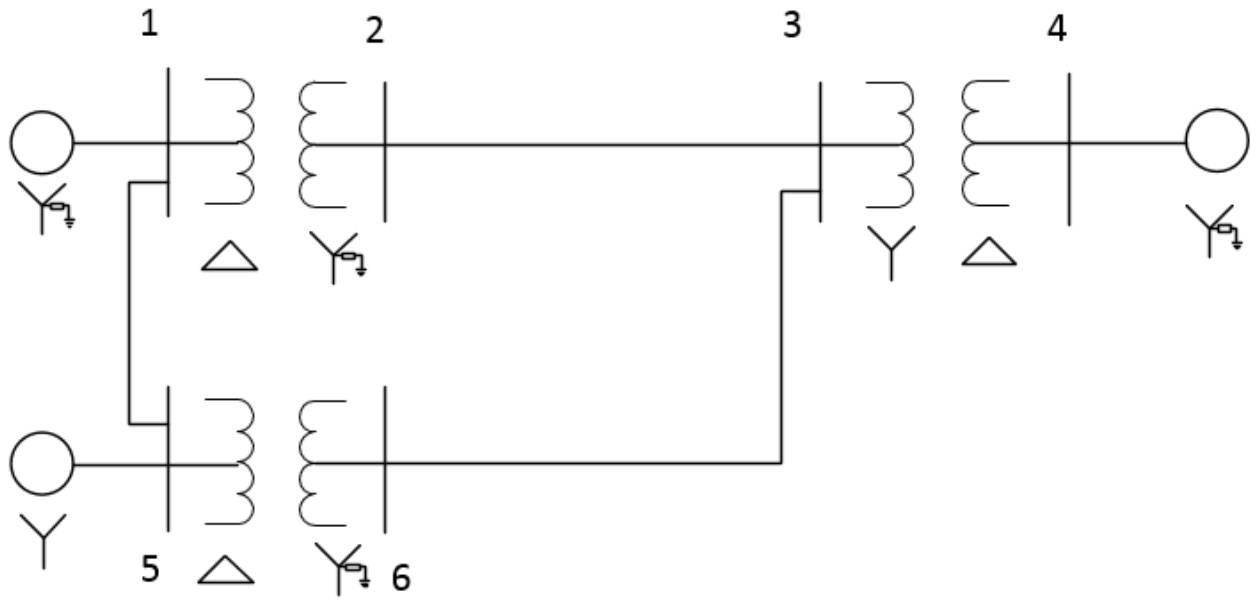
	1	2	3	4
1	0 + 0.1900i	0	0	0
2	0	0 + 0.0800i	0 + 0.0800i	0
3	0	0 + 0.0800i	0 + 0.5800i	0
4	0	0	0	0 + 0.1900i

Which matches the result from the book:

$$\mathbf{Z}_{\text{bus}}^{(0)} = \begin{array}{c} \\ ① \\ ② \\ ③ \\ ④ \end{array} \begin{array}{c} \begin{array}{cccc} ① & ● & ③ & ④ \end{array} \\ \begin{bmatrix} j0.19 & 0 & 0 & 0 \\ 0 & j0.08 & j0.08 & 0 \\ 0 & j0.08 & j0.58 & 0 \\ 0 & 0 & 0 & j0.19 \end{bmatrix} \end{array}.$$

Tests: 6 Bus System

One Line Diagram (System Described in the Database folder: Sample 3):



Tests: 6 Bus System (Results)

Z_1 or Z_2 :

0 + 0.1055i	0 + 0.0885i	0 + 0.0566i	0 + 0.0404i	0 + 0.0541i	0 + 0.0550i
0 + 0.0885i	0 + 0.1374i	0 + 0.0792i	0 + 0.0566i	0 + 0.0550i	0 + 0.0634i
0 + 0.0566i	0 + 0.0792i	0 + 0.1216i	0 + 0.0869i	0 + 0.0566i	0 + 0.0792i
0 + 0.0404i	0 + 0.0566i	0 + 0.0869i	0 + 0.1192i	0 + 0.0404i	0 + 0.0566i
0 + 0.0541i	0 + 0.0550i	0 + 0.0566i	0 + 0.0404i	0 + 0.1055i	0 + 0.0885i
0 + 0.0550i	0 + 0.0634i	0 + 0.0792i	0 + 0.0566i	0 + 0.0885i	0 + 0.1374i

Z_0:

0 + 0.1900i	0	0	0	0 + 0.1900i	0
0	0 + 0.0622i	0 + 0.0400i	0	0	0 + 0.0178i
0	0 + 0.0400i	0 + 0.0900i	0	0	0 + 0.0400i
0	0	0	0 + 0.1900i	0	0
0 + 0.1900i	0	0	0	0 + 0.4180i	0
0	0 + 0.0178i	0 + 0.0400i	0	0	0 + 0.0622i

Thank You

Special Thanks to:
Apratim Roy
Assistant Professor, EEE, BUET
and
Md. Shahadat Hasan Sohel
Lecturer, EEE, BUET

Sincerely,
Mohammad Tariqul Islam, 1006071
Khalid Mahmud, 1006072
Amit Kumar Kundu, 1006073
Naimul Hasan, 1006074

Questions?