Last Comments on Short-Circuit Analysis

1.0 Exam summary

- Work all HW problems and know them;
- Read notes
- Read related book sections

Topics:

1. Symmetrical faults (no book section)
2. Zbus building (9.3-9.6)
3. Fault analysis using Z-bus (9.3, 9.6)
4. Symmetrical components (12.1)
5. Unsymmetrical fault analysis 12.2-12.11)

2.0 Introduction

There are a few issues that I want to "clean up" before moving on to Chapter 13. These issues are:

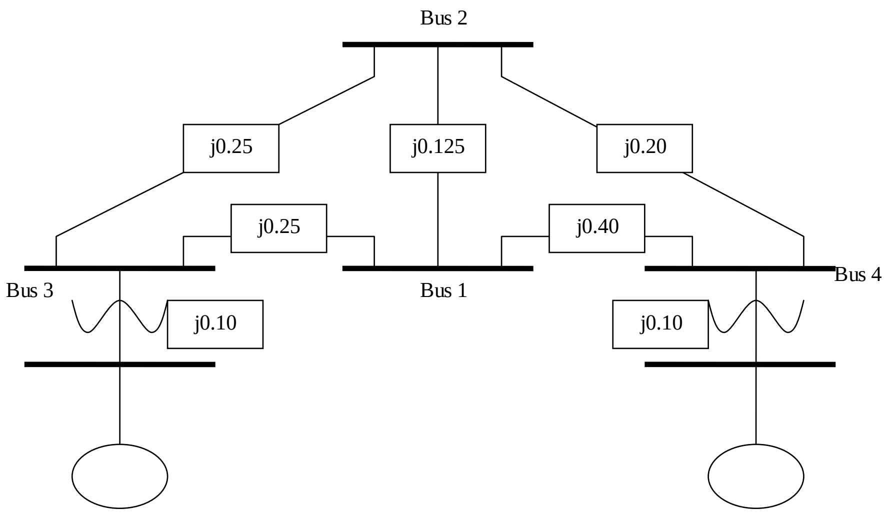
1. Y-bus, Z-bus relation
2. Deriving networks
3. Large-scale system fault studies

These are issues that I feel we have not addressed well enough, and I do not want to leave you with any misconceptions.

3.0 Y-bus, Z-bus relations

Consider the homework #3 assignment, repeated below.

Consider the 4-bus system shown. Both machines have subxient reactances of 0.20 pu (you can combine machine subtransient reactance with the transformer impedance to get a single reactance connecting the machine internal voltage with the network).



a. Construct the Y-bus for this network (should be a 4×4 matrix).

b. Consider that there is a three-phase (symmetrical) fault at bus 2.

- Use LU decomposition to obtain the 2nd column of the Z-bus.
- Compute the subtransient fault current.
- Use (12) to find voltages during fault.
- Use (17) to find the subtransient currents in lines 3-2, 1-2, and 4-2.

Solution:

a). Compute the Y-Bus

$$Y_{bus} = \begin{bmatrix} \frac{1}{j.25}+\frac{1}{j.125}+\frac{1}{j.40} & \frac{-1}{j.125} & \frac{-1}{j.25} & \frac{-1}{j.4} \\ \frac{-1}{j.125} & \frac{1}{j.25}+\frac{1}{j.125}+\frac{1}{j.2} & \frac{-1}{j.25} & \frac{-1}{j.2} \\ \frac{-1}{j.25} & \frac{-1}{j.25} & \frac{1}{j.25}+\frac{1}{j.25}+\frac{1}{j.3} & 0 \\ \frac{-1}{j.4} & \frac{-1}{j.25} & 0 & \frac{1}{j.2}+\frac{1}{j.3}+\frac{1}{j.40} \end{bmatrix}$$

$$Y_{bus} = \begin{bmatrix} -j14.5 & j8 & j4 & j2.5 \\ j8 & -j17 & j4 & j5 \\ j4 & j4 & -j11.3333 & 0 \\ j2.5 & j5 & 0 & -j10.83333 \end{bmatrix}$$

b) For a symmetrical fault at bus 2:

- **Use LU decomposition to obtain the 2nd column of the Z-bus.**

$$Z_2 = \begin{bmatrix} j0.1938 \\ j0.2295 \\ j0.1494 \\ j0.1506 \end{bmatrix}$$

- Compute the subtransient fault current

$$I''_f = \frac{V_f}{Z_{22}} = \frac{1}{j.2295} = -j4.3573pu\_or\_4.3573\angle -90^\circ pu$$

This is where I want to stop with this problem. And here let me as you the following question:

___ The Thevenin impedance for a fault at bus k is the inverse of the Y-bus element in row k, column k.

True or false?

Let's test it in the above example. The Thevenin impedance for a fault at bus 2 is Z_{22}=j0.2295.

The Y-bus element in row 2, column 2 is Y_{22}=-j17.

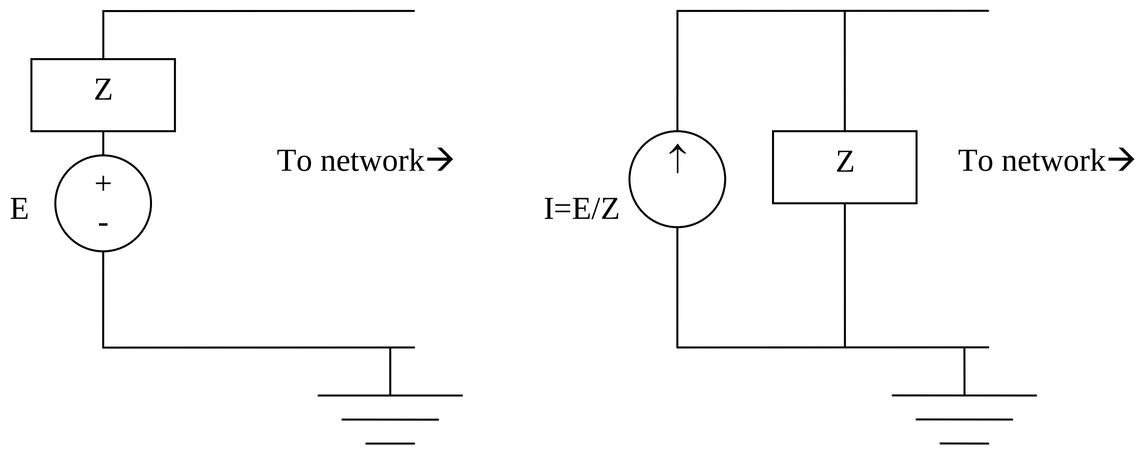
$$\frac{1}{-j17} = j0.0588$$

Clearly, $Z_{22} \neq 1/Y_{22}$. So answer to the T/F question on the quiz is FALSE.

What then, are Y_{22} and Z_{22}?

To answer this question, first assume that all generators in the network are represented by current sources in parallel with the generator reactance (subtransient, transient, or synchronous reactance).

This assumption extends from the concept of source transformation, as shown below.



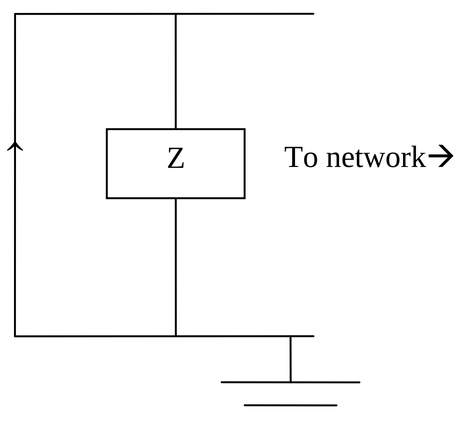
Voltage source model Current source model

So if Z represents the generator reactance plus the transformer reactance (assuming each generator is connected through the network through its own transformer), then we may represent all generators using the current source model as shown.

Now consider the Y-bus for our 4-bus network, and let's write out the second equation in the Y-bus relation I=YV which is the equation corresponding to bus 2. In doing so, you will see that

$$Y_{22} = \left. \frac{I_2}{V_2} \right|_{V_1=V_3=V_4=0}$$

which says that Y_{22} is the ratio of bus 2 current injection to bus 2 voltage when all other buses in the network are shorted. A shorted generator bus will appear as below.

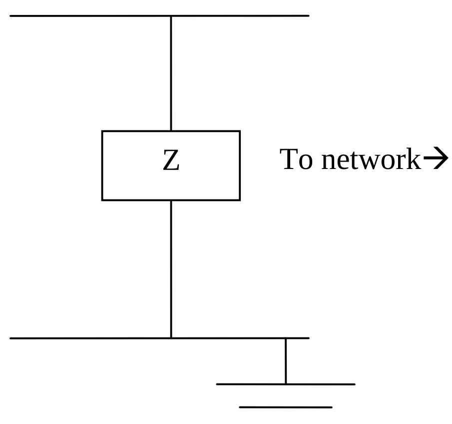


Short circuited load buses are similar.

Likewise, now consider writing the Z-bus for our 4-bus network, and let's write out the second equation in the Z-bus relation V=ZI, which is the equation corresponding to bus 2. In doing so, you will see that

$$Z_{22} = \left.\frac{V_2}{I_2}\right|_{I_1=I_3=I_4=0}$$

which says that Z_{22} is the ratio of the bus 2 voltage to the bus 2 current injection when all other buses are open-circuited. An open circuited generator bus will appear as below.

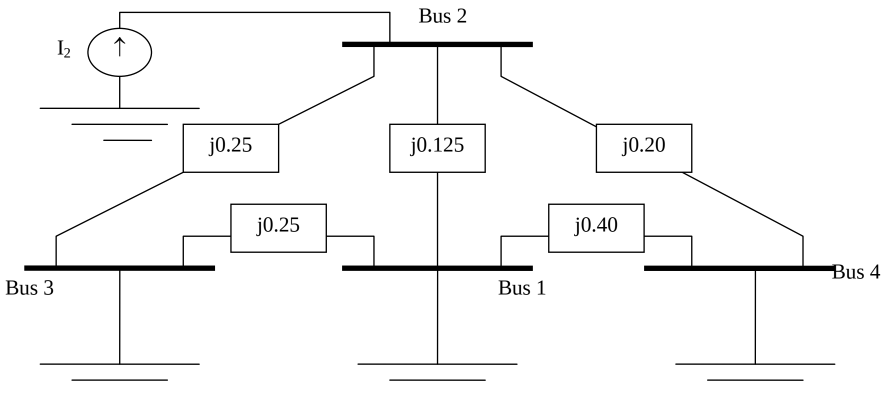


Open-circuiting load buses has no effect on them if loads are represented as constant impedances (as they are in fault studies).

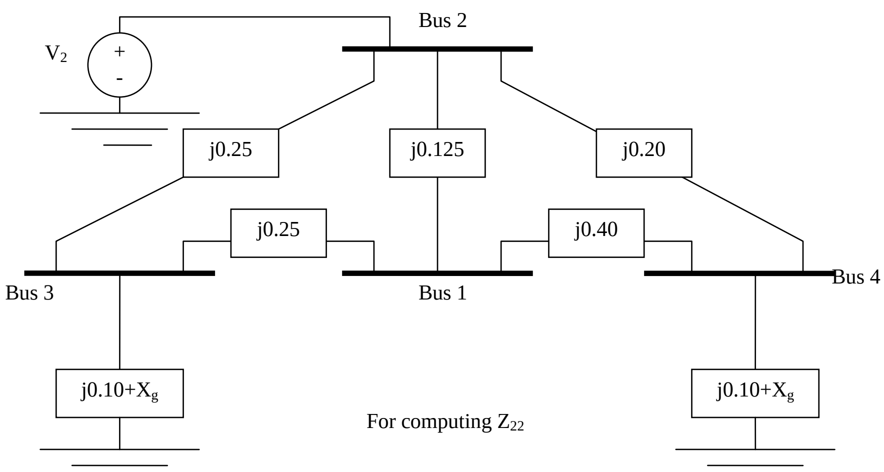
So the Y-bus element for bus k, Y_{kk}, is computed with all other buses shorted.

The Z-bus diagonal element for bus k, Z_{kk}, is computed with all other buses open.

Having all other buses open or all other buses shorted creates two very different networks, so we cannot expect $Z_{kk}=1/Y_{kk}$.



For computing Y_{22}



For computing Z_{22}

But because $\underline{I}=\underline{Y}\underline{V}$ ➔ $\underline{V}=\underline{Z}\underline{I}$, it is true that $\underline{Z}=\underline{Y}^{-1}$.

The upshot of this is that Z_{kk} has an attractive conceptual and practical usefulness in that it is also the Thevenin impedance seen looking into the k^{th} bus.

Unfortunately, Y_{kk} has no corresponding usefulness.

4.0 Deriving networks

I want you to know that in my notes called "Unsymmetrical Fault Analysis 2," I did not perform rigorous derivations of the sequence networks for the different types of faults. I merely looked at the relations between the sequence CURRENTS and developed connections between the sequence networks that were consistent with these relations. Although this is a necessary condition, it is not a sufficient one.

To be rigorous, you also need to look at the relations between the sequence voltages and make sure that the connections between the various networks are also consistent with those. We did not do that, but the text does.

5.0 Large-scale system studies

Section 12.11 and 12.12 are important for understanding how to perform fault analysis studies for large-scale systems.
PLEASE READ THESE SECTIONS!!!!!

I make a few remarks about these sections.

Section 12.11:
Assumptions 1-4 (and associated comments 1-5) on pg. 478 are very important to understand. These assumptions are

1. Neglect load impedances.
2. Neglect shunt elements in lines, xfmrs.
3. Neglect series resistances in all elements.
4. All pre-fault bus voltages are 1.0.

You read the associated comments on pg. 478. I add to them the following question:

➔If all load impedances are neglected, then how is it that there is any current flow at all in the network?

- In the pre-fault network, there is no flow! This fact is consistent with assumption #4.
- In the post-fault network, there is flow but *only due to the fault*.

Therefore, our fault analysis is only going to obtain for us the current in the network due to the fault (and not the composite current of fault current + load current), but this is generally acceptable because, usually,

fault current >> load current

Section 12.12:

Fault analysis of large-scale systems is of course done by computer model based on the above assumptions.

To get the currents into the fault, we must have the positive, negative, and zero-sequence impedances as seen from the fault point. This requires that we obtain the positive, negative, and zero sequence Z-bus diagonal elements.

If we also want fault currents in the lines (so as to size breakers, for example), then we also need positive, negative, and zero sequence Z-bus off-diagonal elements.

There are two ways to obtain what we need.

- Zbus construction using Zbus building algorithm (see notes "Zbus" & Ch. 9).
- Construct Y-bus and use LU.

Note, however, either way, we need to do it three times, once each for

- Positive sequence network
- Negative sequence network
- Zero sequence network

I will hold you responsible for knowing how to do it by constructing Y-bus and using LU. Here, the main things are:

- Positive and negative sequence Y-bus are straightforward.
- Zero-sequence Y-bus must account for transformer connections.

Then for faulted bus k, you use LU three different times, once on each Y-bus, to get the k^{th} column of the Z-bus.

Use the diagonal elements to get the sequence networks, connect them appropriately, and then compute the fault current. Additional information follows from equations given on page 484.