In this exercise you’ll write a Matlab program to perform unsymmetrical fault studies. Fault simulation programs use phasor calculations, so currents are always stated in RMS amps. You can use ASPEN to check your results. Be aware of some of the following assumptions/limitations:

- Only the ac component of the current is calculated (dc component is neglected).
- In a simplistic fault study, all generators, lines, and transformers are represented as a series reactance. If the system voltages are at 0°, the angle of the fault current is therefore always -90°. If such a simplifying assumption is made, it is not possible to consider resistive effects like the X/R ratio, which is important in the specification of circuit breakers, nor to determine the actual angle of the fault current, which is important in setting protective relays. Also, results are conservative, as neglecting resistance will result in slightly larger magnitude fault currents than actual.
- Pre-fault load currents may or may not be included. In order to include them, you need to run a pre-fault load flow to establish what the load currents are. If pre-fault load currents are neglected, all source voltages are in the positive sequence network and are assumed to be equal to the pre-fault Thevenin voltage (you can assume 1.05 /0° pu if you want worst-case fault currents). (This may be quite different than the actual voltages obtained from a power flow program). Otherwise, pre-fault bus voltages should be according to what was solved for by the loadflow program.
- Standard Y-Δ and Δ-Y 30° phase shift transformers have low-voltage currents and voltages which lag their high-side companions by 30°. Some simulation programs do not let you select non-standard phase shifts. In your program, you should be able to handle any possible phase shift. (Note that both two-winding and three-winding transformers and transformers with non-standard phase shifts can be simulated in programs such as ASPEN).

A 5-bus system, taken from Chapter 9 of the Glover text, is to be studied here:

<table>
<thead>
<tr>
<th>Table 9.1</th>
<th>BUS</th>
<th>( x_q ) per unit</th>
<th>( x_{q1} = x_{q2} ) per unit</th>
<th>( x_1 ) per unit</th>
<th>NEUTRAL REACTANCE ( x_n ) per unit</th>
</tr>
</thead>
<tbody>
<tr>
<td>Synchronous machine data for Example 9.8</td>
<td>1</td>
<td>0.06</td>
<td>0.18</td>
<td>0.18</td>
<td>0</td>
</tr>
<tr>
<td></td>
<td>3</td>
<td>0.02</td>
<td>0.09</td>
<td>0.09</td>
<td>0.01</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Table 9.2</th>
<th>BUS-TO-BUS</th>
<th>( x_q ) per unit</th>
<th>( x_1 ) per unit</th>
</tr>
</thead>
<tbody>
<tr>
<td>Line data for Example 9.8</td>
<td>2-4</td>
<td>1.2</td>
<td>0.4</td>
</tr>
<tr>
<td></td>
<td>2-5</td>
<td>0.6</td>
<td>0.2</td>
</tr>
<tr>
<td></td>
<td>4-5</td>
<td>0.3</td>
<td>0.1</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Table 9.3</th>
<th>LOW-VOLTAGE (connection)</th>
<th>HIGH-VOLTAGE (connection)</th>
<th>LEAKAGE REACTANCE</th>
<th>NEUTRAL REACTANCE</th>
</tr>
</thead>
<tbody>
<tr>
<td>Transformer data for Example 9.8</td>
<td>Bus</td>
<td>(Y)</td>
<td>(Y)</td>
<td>per unit</td>
</tr>
<tr>
<td>1 (Δ)</td>
<td>5</td>
<td>0.08</td>
<td>0</td>
<td></td>
</tr>
<tr>
<td>3 (Δ)</td>
<td>4</td>
<td>0.04</td>
<td>0</td>
<td></td>
</tr>
</tbody>
</table>
1) The first 3 steps of this part can should be done before doing any programming.
   - Sketch out a one-line diagram of the system described above.
   - Sketch out the zero, positive, and negative sequence networks. Label all impedances.
   - Obtain the sequence impedance values for the above networks. Show positive and negative
     sequence phase shifts in the transformers.
   - Enter the system parameters into a modified .cdf file that can be read by Matlab.

2) Referring to lecture notes, program Matlab so that it a) opens the .cdf file, reads the bus and
branch data, and obtains pre-fault voltages by running the loadflow, b) makes use of add’l
branch and generator data to build sequence admittance matrices for fault calculations. Include
+/- sequence phase shifts for transformers. You must include the reference bus of each sequence
network as a separate node in each of the sequence networks. c) add code to program so that it
can, for any given type of fault (3-ph, LG, LL, LLG) at any bus, use augmentation method to
properly connect sequence networks and calculate sequence voltages and fault current at fault
location, and finally d) print out results of phase and sequence voltages at every bus and phase
and sequence currents in every branch (printout format can be very similar to loadflow printout).

2) Assuming a pre-fault voltage of 1.05 /0° per unit and a fault impedance of 0.0 + j0.0 per unit,
run the following simulations for each bus and print out the current and bus voltage information.
   - Simulate a 3-phase balanced fault.
   - Simulate a L-L fault.
   - Remove j0.01 per unit reactance in the neutrals of G3 and re-run the L-G fault cases. (This
type of neutral reactor is sometimes called a Peterson coil).

3) Inspect the results. Answer the following questions in your report:
   - For all 4 types of faults at bus 2 (the simulations with the neutral reactors), determine the line
currents on the generator side of the transformers. (The transformers have a standard 30°
phase shift).
   - Determine the current in the neutral of G3 for a L-N fault, with and without the neutral
reactor. How much effect does this coil have on the fault currents "out on the system?"
   - For a fault at a given bus, which type of fault seems to result in the highest magnitude of
fault current? Explain in terms of the connection of the sequence networks and in terms of
the relative Thevenized values of $Z_0$, $Z_1$ and $Z_2$ at the fault location.
   - If you need to know the worst-case fault current so you can specify station post insulators
that have a sufficient cantilever strength and so a structural engineer can design the bus
supports, and so circuit breakers can be specified, which type of fault would you pick? Is
it dangerous to generalize without knowing the system parameters? Such design is often
based on the 3φ fault current. Do you agree with this practice?

4) Write a brief report summary. Point out any limitations or problems you are aware of in terms
of your program or the assumptions made in doing this study. Specify which buses may have
fault currents which are too high for circuit breakers to interrupt. Make recommendations on
possible system modifications and operating strategies, based on the results of this study.

In your report, outline any problems you had, interpret the results, and make important
conclusions/recommendations about this system. For example, are there any extremely high fault
currents (too high to interrupt) or low fault currents (too low to detect reliably), how would you limit
them, how would you recommend reconfiguring the system, would you move or add circuit breakers
to provide better protection, etc. Try to provide as much insight as possible.