Previous note: The readers should not expect to obtain in these exercises the exact same waveforms and values of the book. The cables used in these examples have very similar parameters, so that, the study and analyse of the simulations is easier. However, in the book the parameters were often changed in order to highlight one or more aspects of the phenomenon under study.

The name of the PSCAD file correspondent to the exercises is given between brackets.

Exercises

1 – Switching of a single-phase cable ('switching_single')

i) Energise the cable using the default configuration. Check the voltage in the current at the sending end, middle and receiving end
ii) Repeat the simulation, but decrease the switching instant of the CB in 5ms to 0.1s

Notice that the voltage, current and frequency are larger when the cable is energised at peak voltage.
Notice also the magnitude of the voltage increases from the sending end to the receiving end, whereas the magnitude of the current decreases.
For the cable energised at peak voltage, check the time at which the wave reaches the receiving and sending end and the reflection factors (remember to compensate for the losses).

2 – Switching of a three-phase cable with both-ends bonding ('switching_both_ends')

i) Energise the cable using the default configuration. Check the voltage in the current at the sending end, middle and receiving end
ii) Repeat the simulation, but deactivate the single-pole option in the CB
iii) Try to export the waveforms and plot the modal current and voltages (consider the system to be fully decoupled when writing the transformation matrices);

Notice that the voltage at the sending end of the second and third phase to be energised is not exactly 0V at the energisation instant. Notice also that the peak voltage is not exactly the same in the three-phases when using synchronise switching
There is a small jump in the voltage at the middle of the cable a little after 0.1055s. This voltage jump is the arrival of the intersheath mode. Compare the velocity of this mode with the one of the coaxial modes. Confirm that the intersheath mode affects the current in the screen, but does not affect the current in the conductor
Change the values of the grounding resistances and see how it affects the intersheath mode

3 - Switching of a three-phase cable with cross-bonding ('switching_cross')

i) Energise the cable using the default configuration. Check the voltage in the current at the different measuring points
ii) Repeat the simulation, but deactivate the single-pole option in the CB
iv) Try to export the waveforms and plot the modal current and voltages (consider the system to be fully decoupled when writing the transformation matrices);
v) Try to repeat the simulations for the file 'switching_cross2', where the cable has two major-sections

Compare the peak voltage at the cable receiving end with the one of the previous exercise.

Compare the peak times for the voltage at the receiving end. Notice that there is a voltage decrease at approximately 0.10586s (the peak instant for a cable bonded in both-ends), but much smaller than for a cable bonded in both-ends. As a result, the voltage waves arriving after this instant are high enough to increase the voltage over the previous peak, which was expected to be the largest one

Analyse the voltage in the point E_mid_b1 (middle of the first minor-section). There is a voltage jump at approximately 0.10514s and another at approximately 0.10517s. The first is the coaxial mode that was reflected in the first cross-point, whereas the second is the intersheath mode generated at the switching instant

Compare the voltage waveform in the other two phases for both bonding configurations. Notice that for the cross-bonded cable, it appears a voltage in the other two phases at the end of the first minor-section

4 – Energisation of cables in parallel ('switching_parallel')

i) Run the simulation and compare the current frequency and peak magnitude for the energisation of the first cable and for the energisation of the second cable

ii) Increase the network short-circuit power, i.e., decrease the inductance, and repeat the simulations. Notice that as the inductance decreases, i.e., the short-circuit power increases, the waveforms get to be more alike

5 – Zero-missing phenomenon ('zero_missing')

i) Run the simulation and check the current in the cable sending end, shunt reactor and circuit breaker. Notice that the current in the cable and shunt reactor are virtually in phase opposition.

ii) See how many seconds it takes until the current in the CB crosses zero

iii) Repeat the simulation with the shunt reactor installed in the receiving end of the cable. You should notice a strong reduction in the duration of the zero-missing phenomenon, the reason for that is that the cable resistance helps damping the DC component

iv) Put the shunt reactor in the sending end and change its inductance to 0.833H (approximately 100% reactive power compensation). Run the simulation and notice that the current in the circuit breaker has almost no AC component and the duration of zero-missing increases. Repeat the simulation with a pre-insertion resistor of 190Ω. Notice that the DC component is virtually all damped in 10ms. Repeat the simulation for different values of the pre-insertion resistor, try both very large and very low values

6 – De-energisation of a cable and shunt rector ('de_ener_equal_coup' and 'de_ener_diff_coup')

The two models are equivalent, with the difference residing in the value of the mutual inductance between the phases of the shunt reactor. In the first case the mutual coupling is equal for all phases, whereas in the second it is different between the phases.

i) Run the simulation for both files. Notice that the energy stored in the system is damped slower when the shunt reactor is installed at the middle of the cable. Notice that there is a slight overvoltage in the second phase to be disconnected when the couplings are equal and in two phases when the couplings are different. At last, notice that the low frequency components and how are they are more pronounced when the couplings are different

ii) Disconnect the shunt reactor from the system and run one the simulation again. Notice that the voltage is now a decaying DC wave instead of an AC wave oscillating at resonance frequency.

iii) Run the simulation for different coupling factors and see how the frequency changes

7 – Simple TRV (‘TRV_simple’)

Run the simulation and see that the voltage at the terminals of the CB varies between 0 and 2pu after the disconnection.

8 – Restrike of a cable bonded at both ends (‘restrike_multi_runs’)

Run the simulation with and without multiple runs. See how the magnitude of the peak voltage after the restrike can change so much for small variations in the restrike instant (check file ‘peak_volt’ in the folder correspondent to the simulation file).
Remember that the voltage at the CB terminals is larger at the restrike instant and leads to larger overvoltages and larger variations in the waveforms than for a normal energisation.

9 – Restrike of a cable for different bonding configurations (‘restrike_bondings’)

Similar to the previous exercise, but the objective is now to see that the bonding configuration can have a large influence in the waveforms and peak voltage. Thus, check for different reclosing instants the waveforms and the magnitude of the peak voltage after the restrike for the different bonding configurations. As explained in the book it is expected that the overvoltage is larger for a cross-bonded cable than for a cable bonded at both-ends. The magnitude of the overvoltage depends also on the number of major-sections and their lengths, but contrary to before it cannot be said that the overvoltage increases when the number of major-sections increases.

Note: The snapshot function can be used to speed up the simulation.

10 – Energisation and restrike of a cable-OHL hybrid line (‘hybrid_line_res’)

It is similar to the two previous exercises, but with an OHL. Besides repeating the previous exercises for this system, try to switch the OHL with the cable and notice how the voltage is larger when the OHL is installed after the cable, because of the differences in the surge impedances
Analyse also the influence of the bonding configuration as done in the previous exercise.
You can also try to replicate the other hybrid configurations shown in the book.

Note: You can use the snapshot function to speed up the simulation.

11 – Series resonance between a cable and a transformer (‘series_resonance’)

i) Run the simulation using the default configuration and analyse the waveforms, both magnitude and duration of the transient, for the three examples
ii) See how the network strength can influence the transient waveforms (the weakest the network the larger the transient).

Because of the interaction between the transformer’s inductance and the cable’s capacitance we can see a transient at resonance frequency.
We can also see that if another cable is connected to the busbar the transient becomes different, depending on how strong the network is.

At last, notice for the example where only one cable is present that it is indifferent if the transformer is energised together with the cable or if the cable is energised after, the same does not happen in the other two examples.

12 – Parallel resonance between a cable and a transformer ('parallel_resonance')

i) Run the simulation using the default configuration and analyse the waveforms, both magnitude and duration of the transient.
ii) Repeat the exercise for different cable lengths and/or the short-circuit powers.
iii) Change the energisation instant and energise the cable at peak voltage.
iv) Disable the transformer saturation and notice how the transient disappear (no inrush currents).

The transient appears because of the inrush current generated when the transformer is energised. If those currents match the resonance frequency of the system there is an overvoltage. Thus, the phenomenon happens in weak network and/or when the transformer is connected to a long cable, so that the resonance point of the system is at a low frequency.
Consequently, if the saturation is not enable, there is no transient, as there are not generated any inrush currents.

13 – Ferroresonance ('Ferroresonance')

i) Run the simulation using the default configuration and analyse the waveforms, both magnitude and duration of the transient for both examples. Notice that the overvoltage seems almost unpredictable for the delta-star connection.
ii) Explain why there is an overvoltage in one case and not in the other, being the only difference the grounding of the transformer (because of the return path as shown in the book).
iii) Repeat the simulation for other malfunctions of the CB.

14 – Fault in a single-phase OHL ('fault_OHL')

i) Run the simulation and check the tooth-shape waveform in the voltage.
ii) Try to run a normal de-energisation of the OHL (i.e., without the fault) and see that the tooth-shape waveform is no longer present.
iii) Change the fault location and see how that affects the waveform shape.

The objective of this simulation is just to show the voltage at different points of the line during the fault. Thus, check the voltage at more than one point during the fault.

15 - Fault in a single-phase cable ('fault_single')

i) Run the simulation using the default configuration and see how the value of the grounding resistances affects the magnitude of the current during the fault. Check also that the magnitude of the DC component is virtually not affected by the grounding resistance, but the phase angle is.
ii) Change the fault resistance and see how the magnitude of the DC component is affected and also the magnitude of the total current (when the fault resistance increases there is less current flowing into the ground, thus, the DC component decreases).
iii) Check the magnitude of the current in the screen of the cable for different grounding resistances. As expected, the larger the resistance the lower the current flowing in the screen.

You should be able to understand why the phase angle and magnitude of the current during the fault change when the value of the grounding resistances and fault resistances change. Always remember that the return current flows both in the ground and in screen of the cable, and that the lower the impedance of the screen and of the ground the larger the current.

16 – Fault in a cable bonded at both-ends (‘fault_both_ends’)

The currents and voltages are measured in all the points of the cable line. Moreover, the cable is divided into six-sections of equal length in order to analyse the travelling time, magnitude and phase of the waveforms during the fault and after its clearing. The objective of the simulation is to help the readers to understand the description and explanations given in book. Thus, instead of proposing several tasks, it is proposed to run the simulation side-by-side with the explanation given in the book, to stop in the parts that raised more doubts and try to use the simulation for answering those doubts.

i) Run the simulation using the default configuration.
ii) Change the value of the grounding resistance and see how the waveforms are affected.
iii) Change the fault location and see how the waveforms are affected.
iv) Try to export the waveforms and plot the modal current and voltages (consider the system to be fully decoupled when writing the transformation matrices).

17 - Fault in a cross-bonded cable with two major-sections (‘fault_cross_bond’)

This exercise is almost identical to the previous exercise, with some extra steps.

i) Repeat the steps of the previous exercise.
ii) Compare the waveforms of this configuration with the cable bonded at both-ends.
iii) Try to run simulation with the fault on the second major-section and analyse the differences between both.
iv) Change the way how the grounding of the screens is made (ex. a resistor to ground in each screen instead of a short-circuit between the three and a common resistance to the ground) and see how the waveforms are affected. This is usually irrelevant for other transients, but it influences the waveforms during a fault.