Single Phase Line Examples

\[ \mu s := \frac{s}{10^6} \quad ms := \frac{s}{1000} \]

**Single Phase Transmission Line:**

\[ L' := 1 \, \frac{mH}{km} \quad C' := 11.5 \, \frac{nF}{km} \quad R' := 0 \, \frac{ohm}{km} \quad \text{Length} := 100km \]

\[ \nu := \frac{1}{\sqrt{L' \cdot C'}} \quad \nu = 2.95 \times 10^5 \frac{km}{s} \quad \text{• Just below speed of light} \]

\[ \tau := \frac{\text{Length}}{\nu} \quad \tau = 3.3912 \times 10^{-4} \text{s} \quad \text{• Set step at 10 \mu sec} \]

\[ Z_c := \sqrt{\frac{L'}{C'}} \quad Z_c = 294.88 \Omega \]

![Diagram of single phase transmission line](image-url)
Case 1: Energize line with DC source:

First use a distributed parameter line model:
$V_{dc} := 100\text{kV}$

Switch at receiving end to create a short or open circuit.

Open Circuit:

Sending and receiving end voltage:
Recall $\tau = 0.34$-ms

Start of transition
Open Circuit:
Sending and receiving end current:

Recall that: \( \frac{V_{dc}}{Z_c} = 339.12 \text{ A} \)

Short Circuit:
Sending and receiving end current (sending end voltage same as above, receiving end zero):
Repeat with nonzero resistance:

- Line resistance creates a resistive voltage divider reducing the applied voltage entering the line model at the sending end.

\[
V_{\text{appl}} := 100 \text{kV} \cdot \left( \frac{Z_c}{\frac{R_1' \cdot \text{Length}}{4} + Z_c} \right)
\]

\[V_{\text{appl}} = 99.66 \text{kV}\]

\[V_{\text{rec}} := 2 \cdot V_{\text{appl}} \quad V_{\text{rec}} = 199.32 \text{kV}\]
- $V_{\text{rec}}$ is a little off, due to a second voltage drop in the middle of the line.
  - Let’s look into this in more detail
  - Looking into the resistance + $Z_c$, we get a terminating resistance of:
    $$R_t := Z_c + \frac{R_1 \cdot \text{Length}}{2} \quad R_t = 296.88 \Omega$$

    $$V_{\text{mid-rec}} := V_{\text{appl}} \left[ 1 + \left( \frac{R_t - Z_c}{R_t + Z_c} \right) \right] \quad V_{\text{mid-rec}} = 100\text{-kV}$$

- Then the voltage applied to the second line section of the model again sees a voltage divider:

    $$V_{\text{applied-mid}} := V_{\text{mid-rec}} \left( \frac{Z_c}{R_1 \cdot \text{Length}} + \frac{Z_c}{2} \right) \quad V_{\text{applied-mid}} = 99.33\text{-kV}$$

    The receiving end is open circuited, so the voltage reflection coefficient is:
    $$\Gamma_v := 1$$

    $$V_{\text{rec}} := V_{\text{applied-mid}} \left( 1 + \Gamma_v \right) \quad V_{\text{rec}} = 198.65\text{-kV} \quad \text{Which agrees with the simulation result}$$
Sending and receiving end current:

\[ I_{\text{send}} := \frac{V_{\text{appl}}}{Z_c} \]

\[ I_{\text{send}} = 337.97 \, \text{A} \]

Short Circuit:

Sending and receiving end current:
- **PSCAD Implementation**

![Diagram showing PSCAD implementation of a timed breaker logic with variables and time responses.](image-url)
Choose edit....

**Transmission Line Configuration**

- **Segment Name**: TLine
- **Steady-State Frequency**: 60.0 [Hz]
- **Segment Length**: 100.0 [km]
- **Number of Conductors**: 1
- **Termination Style**: Direct Connection

**Line Model General Data**

- **Name of Line**: TLine
- **Steady State Frequency**: 60.0 [Hz]
- **Length of Line**: 100.0 [km]
- **Number of Conductors**: 1

**Bergeron Model Options**

- **Travel Time Interpolation**: On
- **Reflectionless Line (ie Infinite Length)**: No

**Manual Entry of Y,Z**

- **+ve Sequence R**: 0 [ohm/m]
- **+ve Sequence Travel Time**: 3.3912e-9 [s/m]
- **+ve Sequence Surge Impedance**: 294.88 [ohm]
$Z_c = 294.88 \, \Omega$

\[
\frac{1}{\nu} = 3.3912 \times 10^{-9} \, \text{s/m}
\]

Open Circuit:

![Graph showing current fluctuations with labels 0.3369kA and -0.3369kA]
Now replace the travelling wave line model with pi sections:

Case 1: Energize line with DC source:

Open circuit with a single pi circuit (R = 0):

This will have problems with numerical oscillations in the current waveform due to change in voltage across capacitor. We'll see a possible fix below.
Note that R, L and C entered per unit length and length entered as 100 here. Could have entered length as 1 and entered R*100, L*100, and C*100.
- Currents demonstrate numerical oscillations due to \( \frac{dv}{dt} \) across capacitor.
- Note that the triangle wave is changing each time step.
• Use regular circuit elements, and add a damping resistor for the capacitor by the switch.
• Need to multiply L' and C' time the length of the line now.
• Note that it would be more accurate to include source impedance.

\[
\begin{align*}
L_{pi} &:= L' \cdot 100 \text{km} \quad L_{pi} = 100 \cdot \text{mH} \\
C_{pi} &:= 0.5 \cdot C' \cdot 100 \text{km} \quad C_{pi} = 0.58 \cdot \text{μF}
\end{align*}
\]

• Numerical oscillation damping included in capacitor

Use \(K_s\) recommended by ATPDraw

Simulation timestep

\[
K_s := 0.15 \quad \Delta t := 10 \mu s
\]

\[
R_s := \frac{K_s \cdot \Delta t}{2 \cdot C_{pi}} \quad R_s = 1.3043 \cdot \text{ohm}
\]

Same voltage
Sending end current. Note impact of oscillation damping resistor with the large current spike at just after switch closing

\[ I_{pk\_ss} := 239.71 \text{A} \]

Current looks like a numerical oscillation, but with damping
Repeat with $K_s = 13.33$
(which gives optimal damping, but $R_s = 115.9$ ohm)

$I_{pk_{ss}} := 239.74$A

Smaller initial overshoot (critically damped). In this case
steady-state current not impacted since capacitor with resistor is
across an ideal source, the current actually increases a little..

- Now compare the results with the distributed parameter line model

Voltage waveforms:
- Notice that the pi model has a single frequency that doesn't
  match up with the travel times
- The first two travel time is an ok approximation
We see similar behavior with the currents.

Short line case:

Source and receiving end currents
Zoom in on currents:

Little difference between source and receiving end, no delay.

Compare currents to travelling wave model
EMTDC Implementation

Single Pi Section

Since built-in pi model is three phase
the single phase pi model is made manually

- Results match the ATPDraw
- Don't need the numerical
  oscillation damping resistance
  with the capacitor.

Extending to 5 PI segments:

First section need damping resistor, so build pi manually
Open circuit energization

Voltagess

Currents

Short circuit termination case:
Compare to distributed parameter case

- Better match for travel time
- But not for peaks
### 10 pi sections:

Open circuit termination
Voltage

```
VDC

VSEND
0.0575uF

10mH

10km 10km 10km 10km 10km

VREC
```

![Voltage and Current Waveforms](file dc-10-pi.pl4; x-var t)
Zoomed voltage

Comparison
Short circuit termination

Since built-in pi model is three phase
the single phase pi model is made manually
10 Pi Sections

Since built-in pi model is three phase
the single phase pi model is made manually

PSCAD circuit:

Main: Graphs

y (kV)

0.0050 0.0075 0.0100 0.0125 0.0150 0.0175 0.0200 0.0225 0.0250 0.0275