**Lightning Example**

Consider a transmission line with towers that are 40m tall and spaced 280m apart. Assume that there is a single shield wire with a characteristic impedance of 520 ohm and assume that the tower ground strap has a characteristic impedance of 135 ohm and the tower has a footing resistance of 30 ohm. Assume a propagation velocity of the speed of light for the ground wires and 0.85 times the speed of light for the tower ground strap. Assume that the phase conductors are 75% of the way up the tower and that the ground wire is segmented and open at the top of each of the adjacent towers.

Consider the case of a lightning strike where the current rises to 40kA in 2 μs and falls to 20kA after 40 μs.

Define parameters:

- \( R_{\text{foot}} := 30 \text{ohm} \)
- \( Z_{\text{c_gw}} := 520 \text{ohm} \)
- \( H_{\text{tower}} := 40 \text{m} \)
- \( Z_{\text{c_tower}} := 135 \text{ohm} \)
- \( H_{\text{conductor}} := 0.75 \cdot H_{\text{tower}} \)
- \( H_{\text{conductor}} = 30 \text{m} \)
- \( D_{\text{span}} := 280 \text{m} \)

Define speed of light:

- \( \mu := 4 \cdot \pi \cdot 10^{-7} \frac{\text{H}}{\text{m}} \)
- \( \varepsilon := 8.854 \cdot 10^{-12} \frac{\text{F}}{\text{m}} \)
- \( c := \frac{1}{\sqrt{\mu \cdot \varepsilon}} \)
- \( c = 3 \times 10^8 \frac{\text{km}}{\text{sec}} \)
- \( \nu_{\text{gw}} := c \)
- \( \nu_{\text{tower}} := 0.85 \cdot c \)
- \( \nu_{\text{tower}} = 2.5483 \times 10^5 \frac{\text{km}}{\text{sec}} \)
- \( \mu_{\text{sec}} := 10^{-6} \cdot \text{sec} \)
(a) Find the peak voltage at the tower top, the bottom of the tower and at the conductor height if the lightning strike the top of the tower.

ATPDraw Schematic

Component: Slope_ra.sup

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<thead>
<tr>
<th>DATA</th>
<th>UNIT</th>
<th>VALUE</th>
<th>NODE</th>
<th>PHASE</th>
<th>NAME</th>
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Comment:

Type of source:
- Current
- Voltage
ATP Data File

BEGIN NEW DATA CASE
C --------------------------------------------------------
C Generated by ATPDRAW April, Wednesday 25, 2012
C A Bonneville Power Administration program
C by H. K. Høidalen at SEfAS/NTNU - NORWAY 1994-2009
C --------------------------------------------------------
C  dT  >< Tmax >< Xopt >< Copt ><Epsiln>
   2.5E-9   5.E-5
       500       1       0       0       0       0       0       1       0
C  1         2         3         4         5         6         7         8
C 34567890123456789012345678901234567890123456789012345678901234567890
/BRANCH
C < n1 >< n2 ><ref1><ref2>< R  >< L  >< C  >
C < n1 >< n2 ><ref1><ref2>< R  >< A  >< B  ><Leng><><>0
RFOOT                      30.                                               2
-1CROSSARFOOT                     135.2.55E8   30. 1 0                         0
-1ITTOP CROSSA                   135.2.55E8   10. 1 0                         0
-1VFARL TTOP                     520.  3.E8  280. 1 0                         0
-1ITTOP VFARR                    520.  3.E8  280. 1 0                         0
/SWITCH
C < n 1>< n 2>< Tclose ><Top/Tde ><   Ie   ><Vf/CLOP ><  type  >
   STROKETTOP              MEASURING                1
/SOURCE
C < n 1><> Ampl.  >< Freq.  ><Phase/T0>< A1  >< T1  >< TSTART >< TSTOP >
13STROKE-1                     4.E4               2.E-6               2.E4     4.2E-5     1.
/OUTPUT
   TTOP CROSSA
BLANK BRANCH

Plot of lightning current:
Voltages at tower top, cross arm and footing resistance.

As one would expect, the top shows the biggest peaks in voltage. Note also the time delay in the voltage at the footing resistor.

\[
V_{\text{peak\_top}} := 1.5609 \times 10^3 \text{kV} \quad \text{at} \quad t_{\text{top}} := 2.5075 \mu\text{sec}
\]

\[
V_{\text{peak\_crossarm}} := 1.4876 \times 10^3 \text{kV} \quad \text{at} \quad t_{\text{cross}} := 2.5400 \mu\text{sec}
\]

\[
V_{\text{peak\_foot}} := 1.3294 \times 10^3 \text{kV} \quad \text{at} \quad t_{\text{foot}} := 4.3275 \mu\text{sec}
\]

Note that this is actually the second relative peak in this waveform.
(b) Repeat of the lightning strike occurs 100m away from the tower top (in either direction).

ATP Draw Circuit Diagram

![Diagram of tower, cross arm, and footing with ground wires and strike point.]

Voltages at tower top, cross arm and footing resistance.

Note that the peak voltages are higher in this case.
Zoom in on peak of voltage waveform:

Again, the top shows the biggest peaks in voltage. Note also the time delay in the voltage at the footing resistor.

\[ V_{\text{peak\_top}} := 2.0707 \cdot 10^3 \text{kV} \quad \text{at} \quad t_{\text{top}} := 2.8275 \mu\text{sec} \]

Note that the time to the peak is delayed, due to travel time along the ground wire.

\[ V_{\text{peak\_crossarm}} := 1.9251 \cdot 10^3 \text{kV} \quad \text{at} \quad t_{\text{cross}} := 2.8650 \mu\text{sec} \]

\[ V_{\text{peak\_foot}} := 1.6244 \cdot 10^3 \text{kV} \quad \text{at} \quad t_{\text{foot}} := 4.0525 \mu\text{sec} \]

Note that this is actually the second relative peak in this waveform, but it is earlier than the last case.

(c) Repeat part (a) if the adjacent towers are each grounded, with the same ground strap characteristics and the same footing resistances.

- For this case, we will just model the adjacent towers in detail, since we aren't concerned with waiting for further reflections to come back.
- We do model both ground wires at the top of each though.
(a) Find the peak voltage at the tower top, the bottom of the tower and at the conductor height if the lightning strike the top of the tower.

PSCAD Schematic from file Lightning1.psc

Notes:
- Note the transmission line models used for the ground straps and static wires
- PSCAD requires a terminating impedance at the end of a line, it can't be open circuited. A very large resistance has been placed at the end of the line
Current surge source dialog box:

Plot of lightning current:

Voltages at tower top, cross arm and footing resistance.
Zoom in on peak of voltage waveform:

As one would expect, the top shows the biggest peaks in voltage. Note also the time delay in the voltage at the footing resistor.

\[
V_{\text{peak\_top}} := 1.5609 \times 10^3 \text{kV} \quad \text{at} \quad t_{\text{top}} := 2.5075 \mu\text{sec}
\]

\[
V_{\text{peak\_crossarm}} := 1.4876 \times 10^3 \text{kV} \quad \text{at} \quad t_{\text{cross}} := 2.5400 \mu\text{sec}
\]

\[
V_{\text{peak\_foot}} := 1.3294 \times 10^3 \text{kV} \quad \text{at} \quad t_{\text{foot}} := 4.3275 \mu\text{sec}
\]

Note that this is actually the second relative peak in this waveform.
(b) Repeat of the lightning strike occurs 100m away from the tower top (in either direction).

PSCAD Circuit Diagram from file Lightning2.psc

Simple Lightning Surge:
\[ I = 40kA T1 * t - C1(t-T1) \]
Voltages at tower top, cross arm and footing resistance.

Note that the peak voltages are higher in this case.

Zoom in on peak of voltage waveform:

Again, the top shows the biggest peaks in voltage. Note also the time delay in the voltage at the footing resistor.

\[ V_{\text{peak\_top}} := 2.0707 \cdot 10^3 \text{kV} \quad \text{at} \quad t_{\text{top}} := 2.8275 \mu\text{sec} \]

Note that the time to the peak is delayed, due to travel time along the ground wire.

\[ V_{\text{peak\_crossarm}} := 1.9251 \cdot 10^3 \text{kV} \quad \text{at} \quad t_{\text{cross}} := 2.8650 \mu\text{sec} \]

\[ V_{\text{peak\_foot}} := 1.6244 \cdot 10^3 \text{kV} \quad \text{at} \quad t_{\text{foot}} := 4.0525 \mu\text{sec} \]

Note that this is actually the second relative peak in this waveform, but it is earlier than the last case.
(c) Repeat part (a) if the adjacent towers are each grounded, with the same ground strap characteristics and the same footing resistances.

- For this case, we will just model the adjacent towers in detail, since we aren't concerned with waiting for further reflections to come back.
- We do model both ground wires at the top of each though.
- The model includes the static wires beyond the next tower as well, terminated with a very large resistance
- From file Lightning3.psc
Voltages at tower top, cross arm and footing resistance.

- Zoomed voltages at tower top, cross arm and footing resistance.
- Note that the peak voltage is significantly lower than the other cases

Voltages at tops of the next towers to the left and right
• Now add the phase conductors to the model. Closest to case 3 above
• Note that this is simplified to illustrate how to model
Compare cross arm voltage to case 3:

Voltages on the footing resistors of the other uprights:
Phase conductor voltages (with cross arm level on ground strap)

- Same voltages without the lightning strike:
Phase Currents Don't show much effect

Zoom on one phase:
Now add voltage dependent flashover switches:

Switch voltages:
Phase currents (between towers):

Phase voltages at Bus 2 (closer bus)
Phase Currents at Bus 2:

(file ltngcase4.pl4; x-var t)  
\begin{align*}
\text{c:SWRA} & \quad \text{-BUS2A} \\
\text{c:SWRB} & \quad \text{-BUS2B} \\
\text{c:SWRC} & \quad \text{-BUS2C}
\end{align*}