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:

$R_{foot} := 30ohm$ $Z_{c\_gw} := 520ohm$

$H_{tower} := 40m$ $Z_{c\_tower} := 135ohm$

$H_{conductor} := 0.75 \cdot H_{tower}$ $H_{conductor} = 30\,m$

$D_{span} := 280m$

Define speed of light:

$\mu_o := 4 \cdot \pi \cdot 10^{-7} \frac{H}{m}$ $\varepsilon_o := 8.854 \cdot 10^{-12} \frac{F}{m}$

$c := \frac{1}{\sqrt{\mu_o \cdot \varepsilon_o}}$ $c = 3 \times 10^5 \frac{km}{sec}$

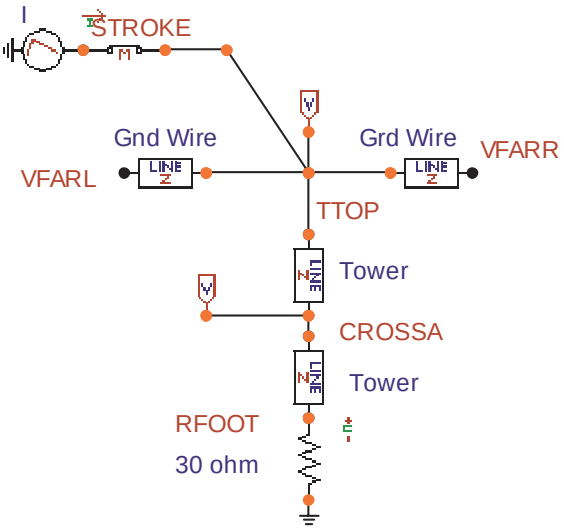
$v_{gw} := c$

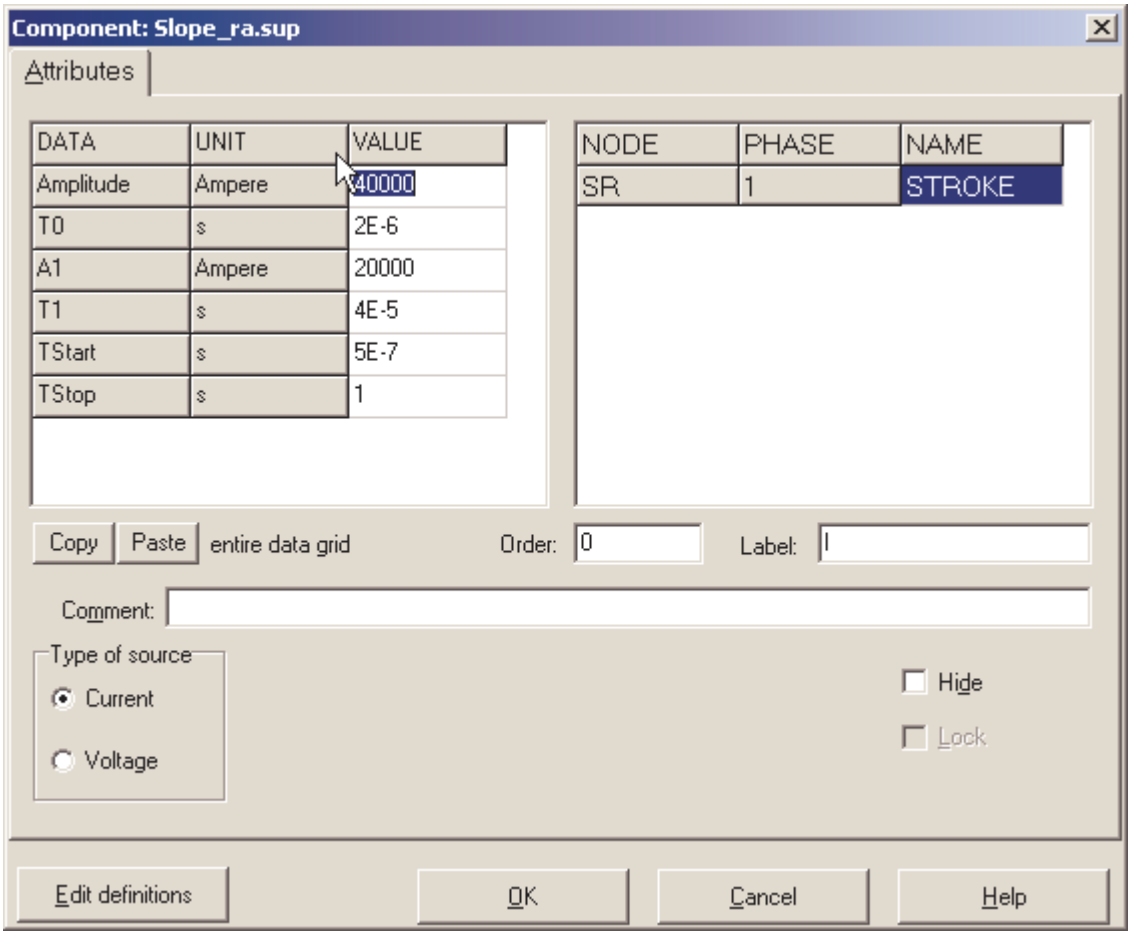
$v_{tower} := 0.85 \cdot c$ $v_{tower} = 2.5483 \times 10^5 \frac{km}{sec}$

$\mu sec := 10^{-6} \cdot sec$

(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



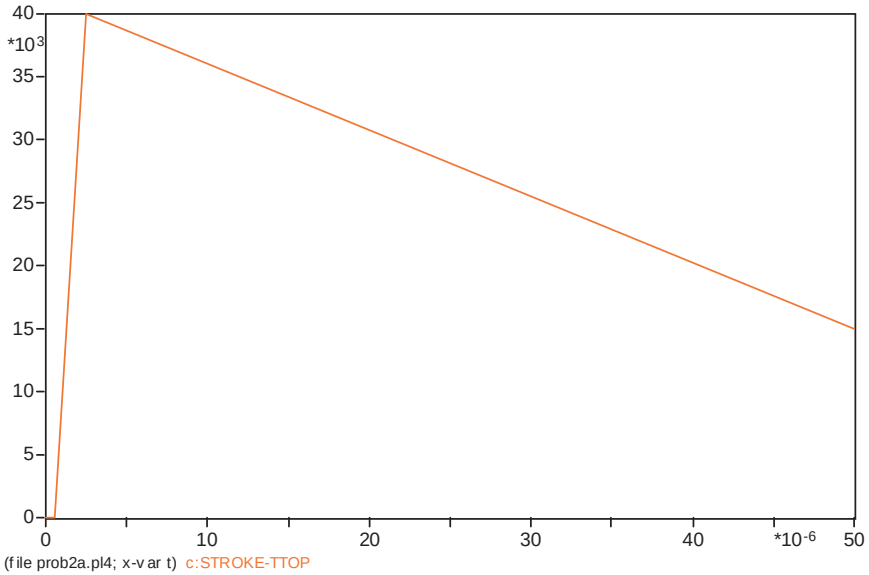


ATP Data File

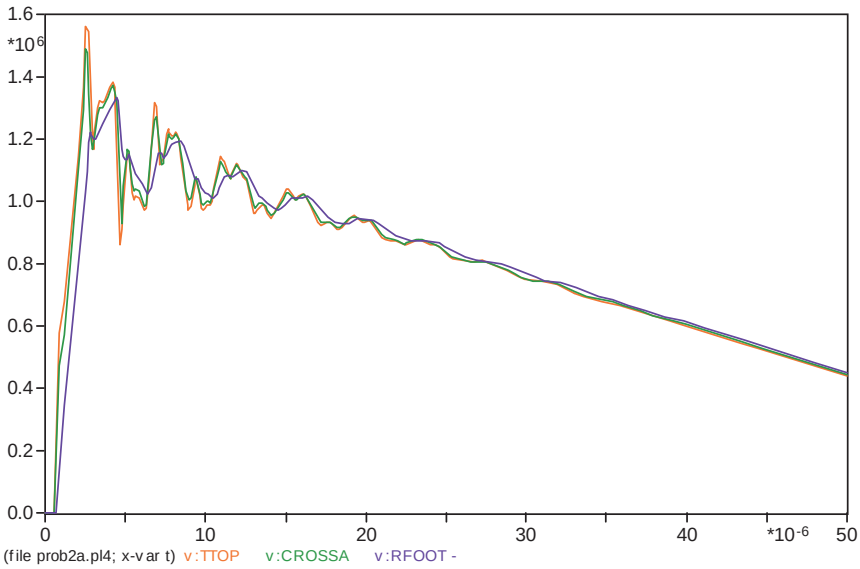
```
BEGIN NEW DATA CASE
C -----------------------------------------------------
C Generated by ATPDRAW  January, Wednesday 4, 2006
C A Bonneville Power Administration program
C Programmed by H. K. Høidalen at SEfAS - NORWAY 1994-2003
C -----------------------------------------------------
C  dT  >< Tmax >< Xopt >< Copt >
  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 345678901234567890123456789012345678901234567890123456789012345678901234567890
/BRANCH
C < n 1>< n 2><ref1><ref2>< R  >< L  >< C  >
C < n 1>< n 2><ref1><ref2>< R  >< A  >< B  ><Leng><><>0
-1CROSSARFOOT                     135.2.55E8   30. 1 0                          0
  RFOOT                      30.                                                2

-1VFARL TTOP                      520.  3.E8  280. 1 0                          0
-1TTOP  VFARR                     520.  3.E8  280. 1 0                          0
-1TTOP  CROSSA                    135.2.55E8   10. 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.E-5     5.E-7        1.
/OUTPUT
  TTOP  CROSSA
BLANK BRANCH
```

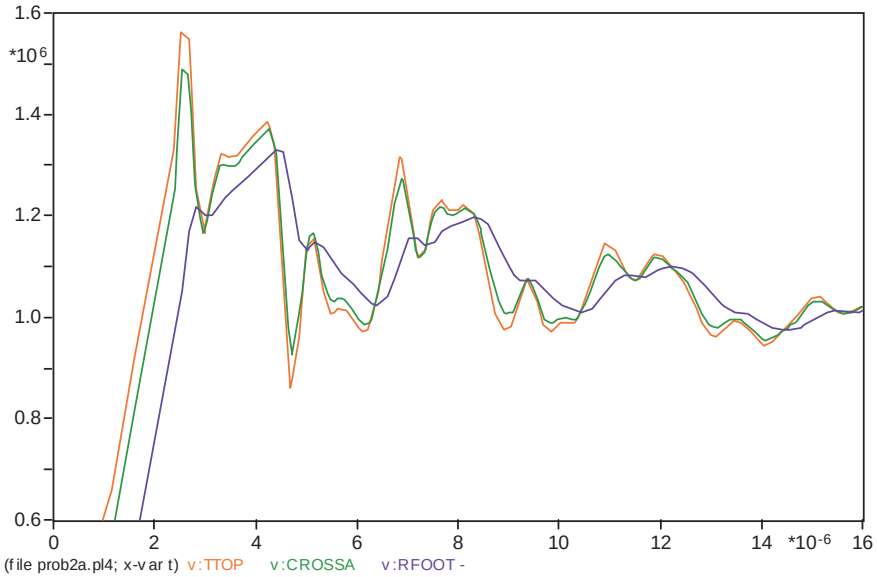
Plot of lightning current:



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.

$V_{peak\_top} := 1.5609 \cdot 10^3 kV$ at $t_{top} := 2.5075 \mu sec$

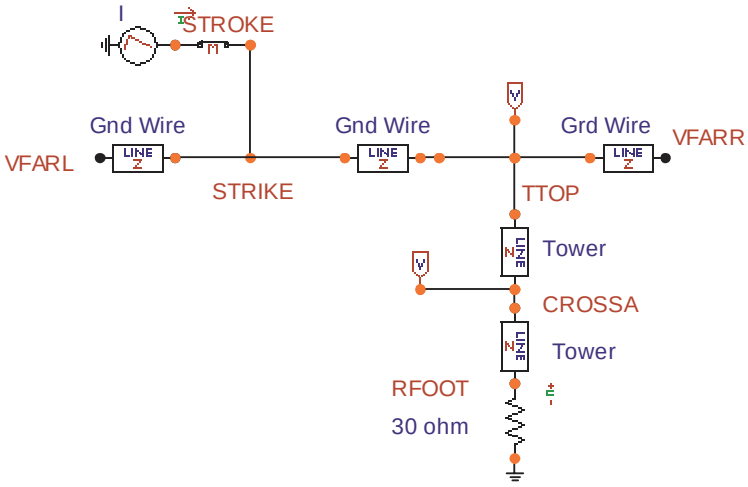
$V_{peak\_crossarm} := 1.4876 \cdot 10^3 kV$ at $t_{cross} := 2.5400 \mu sec$

$V_{peak\_foot} := 1.3294 \cdot 10^3 kV$ at $t_{foot} := 4.3275 \mu sec$

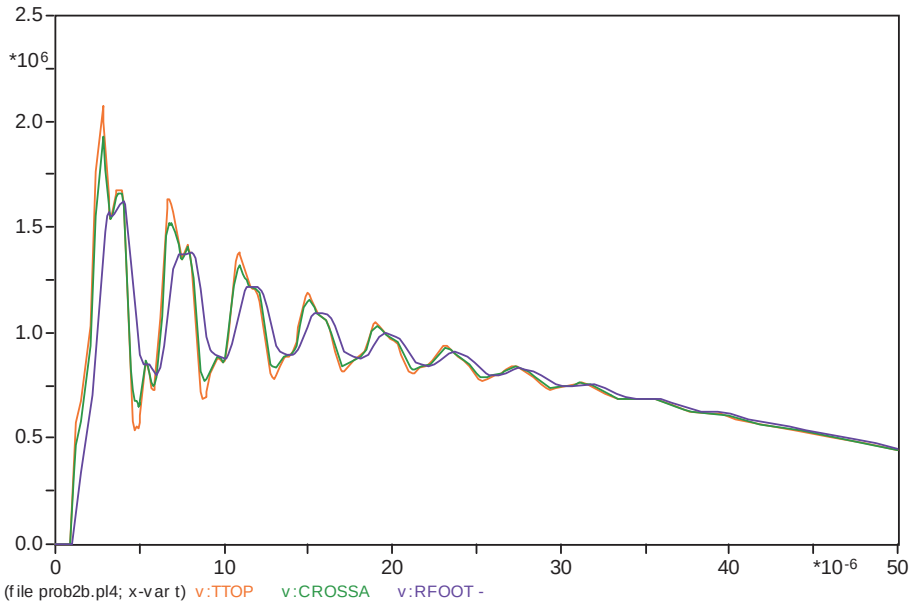
Note that this is actually the second relative peak in this waveform

(b) Repeat of the lightning strike occurs 100m away from the tower top (in either direction).

ATP Draw Circuit Diagram

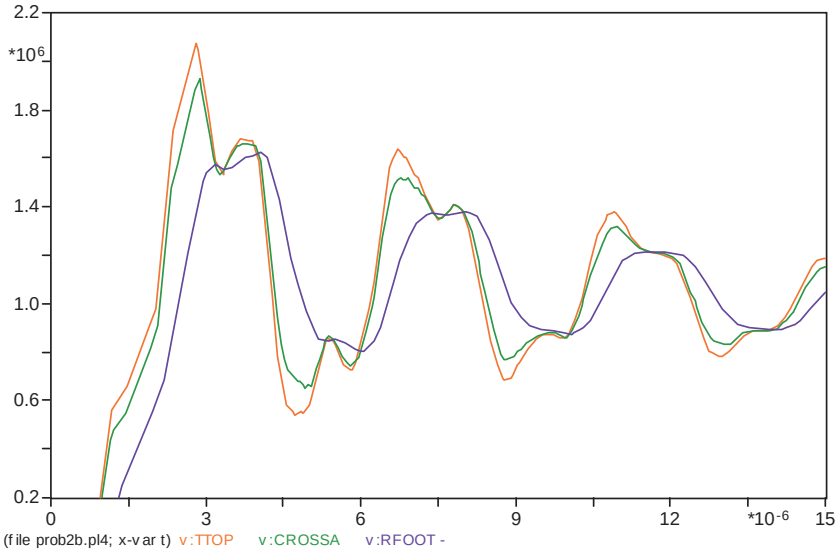


Voltages at tower top, cross arm and footing resistance.



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.

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

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

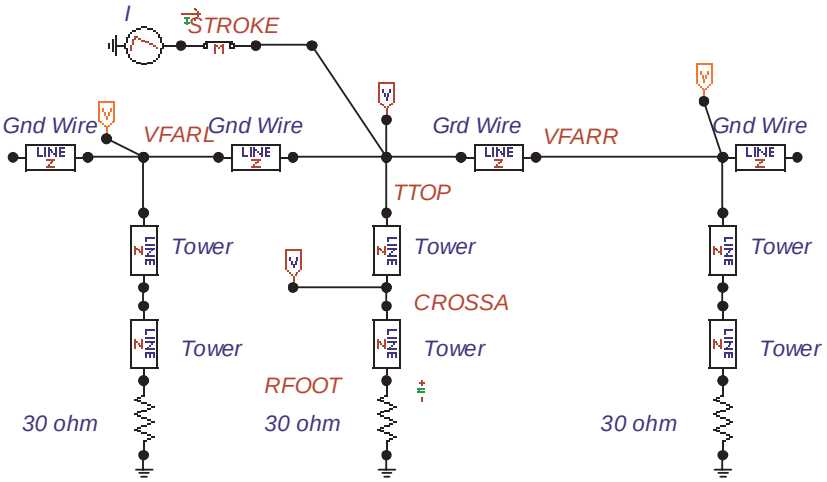
$V_{peak\_crossarm} := 1.9251 \cdot 10^3 kV$ at $t_{cross} := 2.8650 \mu sec$

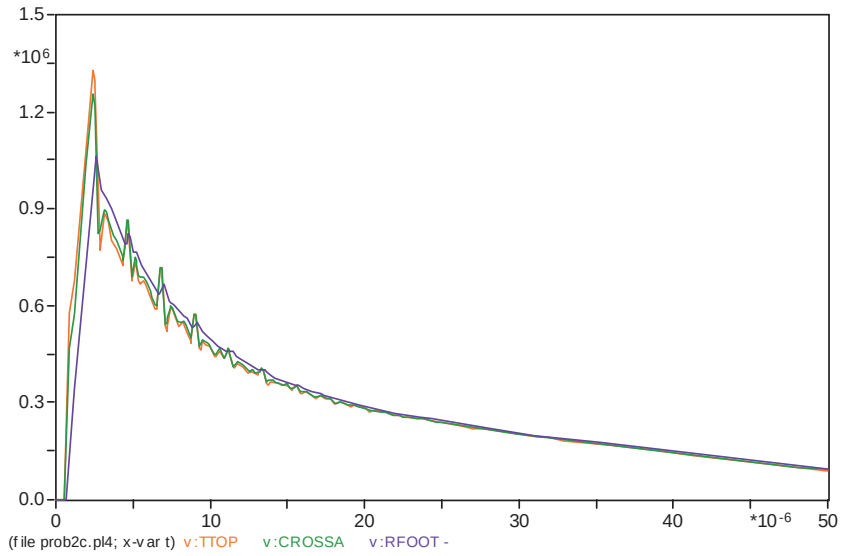
$V_{peak\_foot} := 1.6244 \cdot 10^3 kV$ at $t_{foot} := 4.0525 \mu sec$

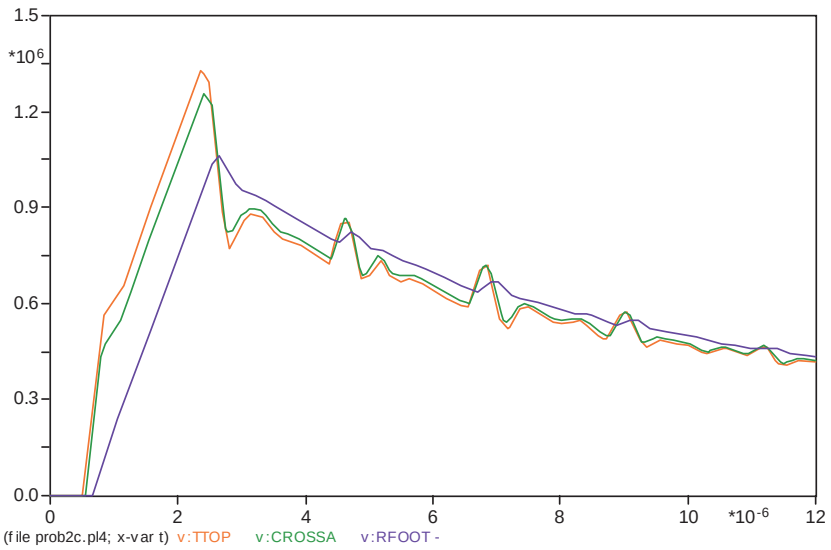
Note that this is actually the second relative peak in this waveform, but it is earlier than the last case.

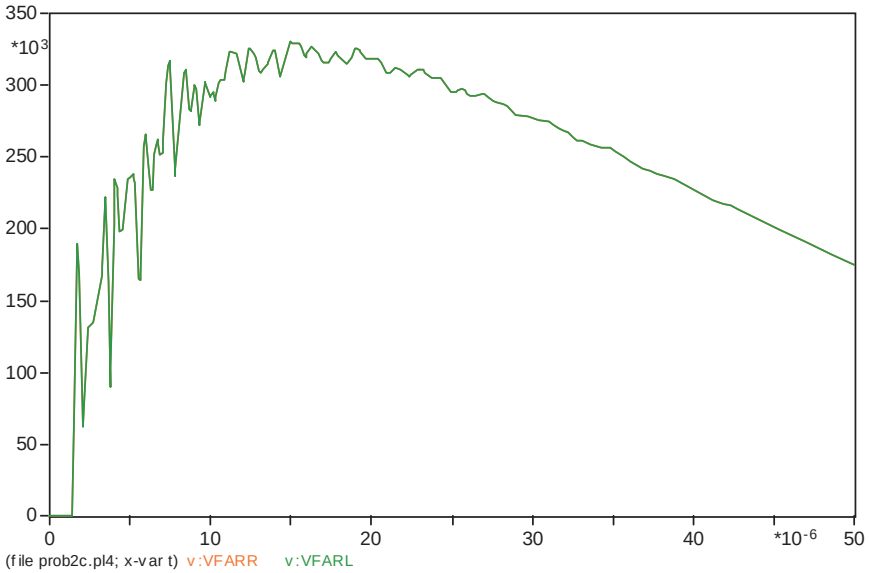
(c) Repeat part (a) if the adjacent towers are each grounded, with the same ground strap characterist and the same footing resistances.

- For this case, we will just model the adjactent 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.

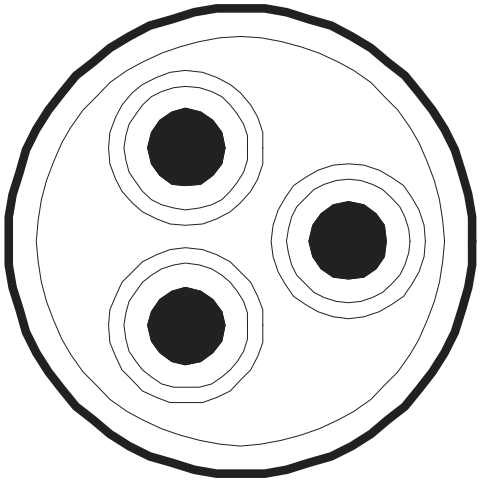

I
STROKE
Gnd Wire
VFARL
Gnd Wire
Grd Wire
VFARR
Gnd Wire
TTOP
Tower
Tower
Tower
CROSSA
Tower
Tower
Tower
RFOOT
30 ohm
30 ohm
30 ohm


1.5
*10^6
1.2
0.9
0.6
0.3
0.0
0
10
20
30
40
*10^-6
50
(file prob2c.pl4; x-var t) v:TTOP v:CROSSA v:RFOOT -


1.5
*10^6
1.2
0.9
0.6
0.3
0.0
0
2
4
6
8
10
*10^-6
12
(file prob2c.pl4; x-var t) v:TTOP v:CROSSA v:RFOOT -


350
*10^3
300
250
200
150
100
50
0
0
10
20
30
40
*10^-6
50
(file prob2c.pl4; x-var t) v:VFARR v:VFARL

Typical cable data: 15 kV underground pipe type cable below at 60 Hz. Assume the sheaths are grounded and the pipe are grounded.



Inner Pipe Diameter = 3.48 in.
Outer Pipe Diameter = 3.58 in.
Outer Jacket Diameter = 4.1 in.
Resistivity of pipe = 2.828E-8 ohm-m
Relative permeability of pipe = 1.0
Relative permittivity inside pipe = 1.0
Relative permittivity of jacket = 3.5
Angle to phase 1 = 0 degrees
Radius to center phase 1 = 0.81 in
Angle to phase 2 = 120 degrees
Radius to center phase 2 = 0.81 in
Angle to phase 3 = -120 degrees
Radius to center phase 3 = 0.81 in
Depth of center of pipe = 1 meter

SC cable inner radius = 0 in
SC core, diameter = 0.8 in
SC Sheath inner diameter = 1.324 in
SC Sheath outer diameter = 1.4 in
Resistivity SC Core = 1.724E-8 ohm-m
Relative permeability of core = 1.0
Relative permeability of insulator 1 = 1.0
Relative permittivity of insulator 1 = 3.5
Resistivity sheath = 1.724E-8 ohm-m
Relative permeability of sheath = 1.0