3. Overhead transmission lines and under ground cables

For modelling these, the followings are applicable, where each has respective limited applicability:
Reactance only:
- For very low frequency only, power frequency for overhead transmission line and usually not applicable for cables which have large capacitances.

Pi (□) type:
- Mostly for power frequency for transmission line and cable.
- High reliability, easy to check the parameters due phase domain parameters applied.
- Moderate efficiency in calculation

Distributed parameter line for fixed frequency:
- Applicable to any frequency of phenomena.
- High efficiency in calculation
- Restriction in calculation step time, which is to be shorter than the shortest travel time of the line in the relevant system.
- For very short line together with longer line(s) in the relevant system, "pi" type is recommended.
- Frequency dependent model is only applicable to overhead line.

3.1 Overhead transmission line

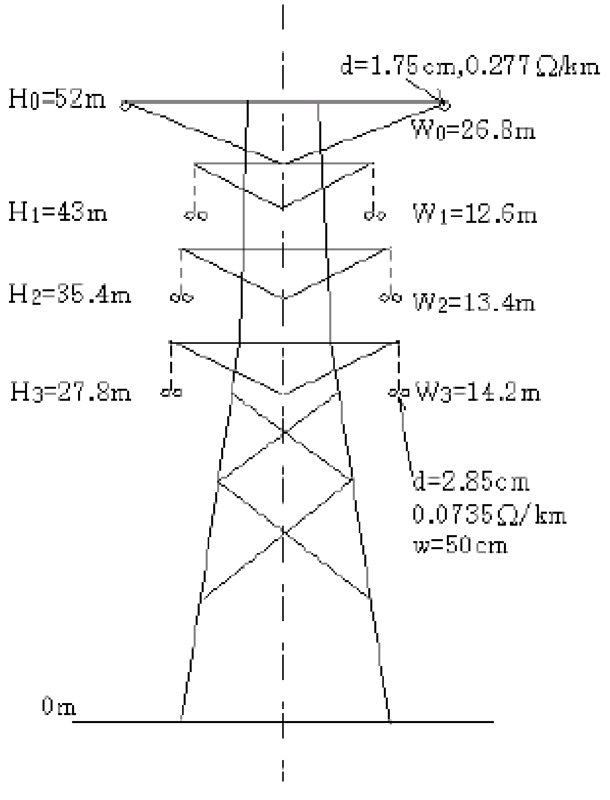


Fig. 3.1 Overhead transmission line
300kV, 410mm^2 X 2 conductor

As an example, an overhead transmission line, as shown in Fig. 3.1, is examined, where the length is 10km. For more detailed parameters not shown in the figure, see the attached data files and Role Book regarding LINE CONSTANTS.
Such double-circuited lines are widely applied to 300kV systems.
For most generalized applications, distributed parameter models of three kinds are calculated using LINE CONSTANTS in ATP-EMTP.:
- Non-transposed model at 50Hz of frequency.
- Non-transposed model at 5000Hz of frequency
- Perfectly transposed model at 5000Hz.

The calculated PCH data, which can be directly introduced to transient calculation data files, are shown in Table 3.1.

In two kinds of non-transposed ones, parameters are written in mode domain, not in phase domain though node names are written in phase domain. The first line of each model corresponds to mainly zero sequence (to ground) mode. Between 50Hz and 5000Hz parameters,
these parameters are of great difference due to skin effect of the earth. Another lines correspond to mainly within lines ones and the differences by both frequencies are not so significantly large.
The matrix shown in the lower part is for converting between mode and phase domains. Between two frequencies, the difference of the matrixes is not so large.

Table 3.1 Overhead transmission line calculated PCH files (three kinds)

Non-transposed line, at 50Hz of calculation frequency

```
$VINTAGE, 1
-1AIN    AOUT                3.08405E-01 1.23649E+03 1.96222E+05-1.00000E+01 1   6
-2BIN    BOUT                3.72190E-02 3.76364E+02 2.93981E+05-1.00000E+01 1   6
-3CIN    COUT                3.74378E-02 4.13688E+02 2.95288E+05-1.00000E+01 1   6
-4DIN    DOUT                3.71066E-02 3.30485E+02 2.96742E+05-1.00000E+01 1   6
-5EIN    EOUT                3.71076E-02 2.96376E+02 2.96764E+05-1.00000E+01 1   6
-6FIN    FOUT                3.71962E-02 3.03602E+02 2.96899E+05-1.00000E+01 1   6
$VINTAGE, 0
  0.42714729 -0.50189676 -0.38348530 -0.50508244 -0.32915364 -0.28463998
  0.00000000  0.00000000  0.00000000  0.00000000  0.00000000  0.00000000
  0.34577854  0.00303391 -0.45336195 -0.00909599  0.54123438  0.57848337
  0.00000000  0.00000000  0.00000000  0.00000000  0.00000000  0.00000000
  0.44495213  0.49808678 -0.38392964  0.49478176 -0.31420252 -0.29040846
  0.00000000  0.00000000  0.00000000  0.00000000  0.00000000  0.00000000
  0.42714729 -0.50189676  0.38348530  0.50508244  0.32915364 -0.28463998
  0.00000000  0.00000000  0.00000000  0.00000000  0.00000000  0.00000000
  0.34577854  0.00303391  0.45336195  0.00909599 -0.54123438  0.57848337
  0.00000000  0.00000000  0.00000000  0.00000000  0.00000000  0.00000000
  0.44495213  0.49808678  0.38392964 -0.49478176  0.31420252 -0.29040846
  0.00000000  0.00000000  0.00000000  0.00000000  0.00000000  0.00000000
```

Non-transposed line, 5000Hz of calculation frequency

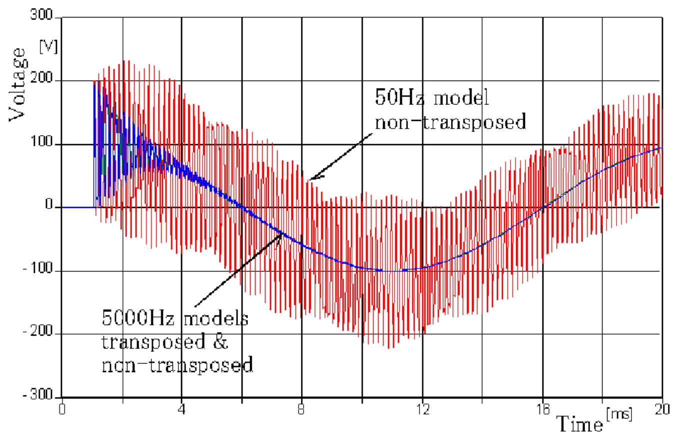
```
$VINTAGE, 1
-1AIN    AOUT                1.68898E+01 9.96835E+02 2.43326E+05-1.00000E+01 1   6
-2BIN    BOUT                2.47858E-01 3.73899E+02 2.95857E+05-1.00000E+01 1   6
-3CIN    COUT                2.14015E-01 3.99901E+02 2.96846E+05-1.00000E+01 1   6
-4DIN    DOUT                1.72252E-01 3.32000E+02 2.98783E+05-1.00000E+01 1   6
-5EIN    EOUT                1.66822E-01 3.01512E+02 2.99037E+05-1.00000E+01 1   6
-6FIN    FOUT                1.66670E-01 2.97406E+02 2.99030E+05-1.00000E+01 1   6
$VINTAGE, 0
  0.44926416 -0.49240961 -0.53662334 -0.43826428 -0.28546871  0.23810826
  0.00000000  0.00000000  0.00000000  0.00000000  0.00000000  0.00000000
  0.34343632  0.00782395 -0.32045636  0.08677428  0.57901886 -0.59985617
  0.00000000  0.00000000  0.00000000  0.00000000  0.00000000  0.00000000
  0.42451526  0.50741655 -0.33067071  0.54808270 -0.28852170  0.28892392
  0.00000000  0.00000000  0.00000000  0.00000000  0.00000000  0.00000000
  0.44926416 -0.49240961  0.53662334  0.43826428 -0.28546871 -0.23810826
  0.00000000  0.00000000  0.00000000  0.00000000  0.00000000  0.00000000
  0.34343632  0.00782395  0.32045636 -0.08677428  0.57901886  0.59985617
  0.00000000  0.00000000  0.00000000  0.00000000  0.00000000  0.00000000
  0.42451526  0.50741655  0.33067071 -0.54808270 -0.28852170 -0.28892392
  0.00000000  0.00000000  0.00000000  0.00000000  0.00000000  0.00000000
```

Transposed line, 5000Hz of calculation frequency

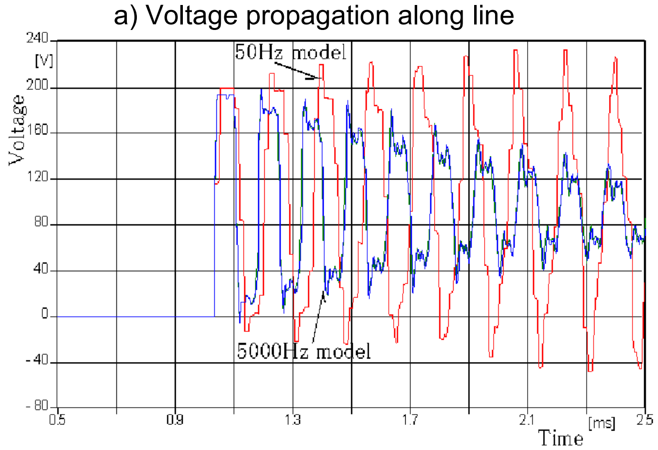
```
$VINTAGE, 1
-1AIN    AOUT                1.71429E+01 1.00950E+03 2.43056E+05 1.00000E+01 1
-2BIN    BOUT                1.86518E-01 3.39087E+02 2.95339E+05 1.00000E+01 1
-3CIN    COUT
-4DIN    DOUT
-5EIN    EOUT
-6FIN    FOUT
$VINTAGE, -1,
```

For transposed line, only zero sequence and positive sequence parameters are given. Mode translation is fixed, so no matrix is necessary. The first and second lines correspond to zero and positive/negative sequence parameters respectively. For transmission line positive sequence parameters is identical to negative ones.

As an example typically showing the differences between these three models, power frequency COS wave shape voltage, the amplitude of which is 100V, is applied from one side of each model transmission line and the other end voltage is calculated. The initial step of the voltage involves high frequency components; so examining wide range of frequency response is expected.



a) Voltage propagation along line



b) Ditto, enlargement of the initial part

Fig. 3.2 Voltage propagation comparison by 3 type of line models

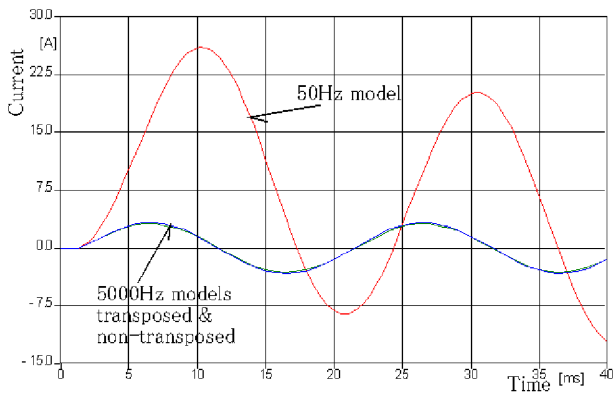


Fig. 3.3 Short circuit currents by 3 models

The calculated result is shown in Fig. 3.2. For power frequency component three kinds of models show almost the same results. But for high frequency one, the difference is great, less damping in 50Hz model. Between transposed and non-transposed modes the difference is negligible. So, simplified transformed model seems to be applicable in most cases.

In b), which is the enlargement of the initial part, 50Hz model shows lower frequency of response, which corresponds to higher inductance of line in lower frequency.

The wave shape somehow angular and seems to be not realistic. This is due to the modelling principle, where the damping is represented by series connected lump resistors at both ends and also at the middle point.

As another example, short circuit current calculation is shown in Fig. 3.3, where sinusoidal wave shape of voltage is applied from one terminal and the other end is earthed, i.e.single phase grounding fault case. By 50Hz model, at least the power frequency component seems to be appropriate. The damping of d.c. component might be necessary to be re-calculated applying very low frequency model.

By 5000Hz models, both transposed and non-transposed ones, the results are quite un-realistic, most probably due to extremely high damping.

In line-to-line mode, i.e. applying a voltage in to one phase and reversed polarity one to the other phase, these differences are significantly small. Readers are strongly recommended to try with your self.

Anyhow, selecting an appropriate frequency as the calculation basis in LINE CONSTANTS is extremely important.

Note:

- As an extreme example, let's take up SLF (see the previous chapter) breaking case. Up to the current interruption, power frequency current flows, therefore, power frequency model is to be applied. Then afterwards, TRV of several tens kHz is created by the reflection in the relevant short line. Of cause, line model based on several tens kHz is to be applied. Therefore, two steps of calculation, in principle, are to be done. This seems to be complicated, so application of current injection seems to be more appropriate. Firstly power frequency SLF current is calculated and then, the

current is to be injected.
Now, let's step in to **Frequency dependent** model.
As the most popularly and widely used modelling for overhead transmission lines, JMARTI (Jose Marti) set up routine is took up. Also, in this case, calculations for transmission line shown in Fig. 3.1, 10km in length, are done. In modelling calculation, various parameters are calculated, based on "frequency by frequency" in mode domain. One example is shown in Fig. 3.4, where propagation constants of various modes of propagating waves vs. frequency are shown. Mode 6, representing great damping in high frequency range, mainly corresponds to zero sequence mode. Also surge impedances and travelling times are calculated.

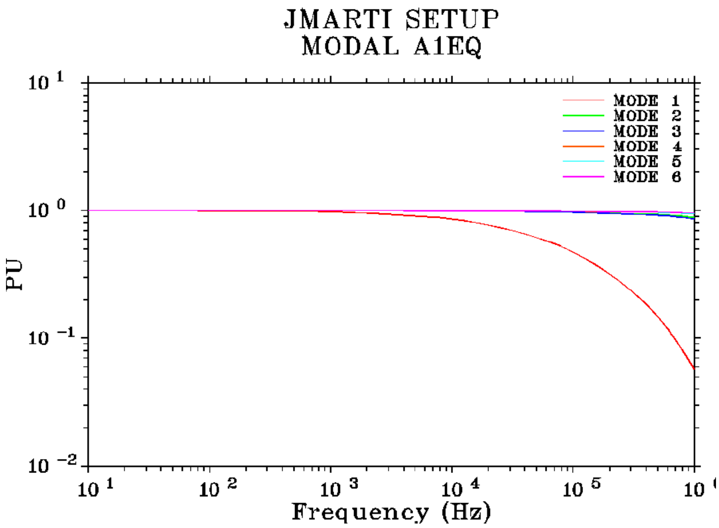


Fig.3.4 Propagation constants of various mode of waves (damping)

Note:
- Such figures are easily obtained by PARAM command in GTPPLOT. For details, see HLP file and GTPPLOT.PDF file attached to GTPPLOT.

In the set up routine, three kinds of frequencies are input, i.e. for mode matrix calculation, for steady state calculation and the lower limit frequency of the frequency range. Of cause upper limit, also, is input. For mode matrix calculation, only one frequency is applied. In principle, the mode matrix depends on frequency so, for other than the specified frequency, errors might be introduced. As shown before, the matrix dose not varies so much depend on the frequency, the errors are kept within permissible range, so experiences show.
Five kinds of frequency sets are applied as for f_m (mode matrix), f_s (steady state) & f_l (lower limit).:

- No. 1	line	f_m = 50Hz	f_s = 50Hz	f_l = 10Hz
- No. 2	line	500Hz	50Hz	10Hz
- No. 3	line	5000Hz	50Hz	10Hz
- No. 4	line	50000Hz	50Hz	10Hz
- No. X	line	1MHz	100kHz	0.1Hz (for wide range up to 10MHz)

For details of the input data, see attached data files, DATA3-06 ----- DATA3-09, and DATA3-0X. The output PCH files (line parameters in JMARTI models) by these data files are calculated which should be checked by your self-calculations. The PCH files are directly used in transient calculation data files alike by LINE CONSTANTS.

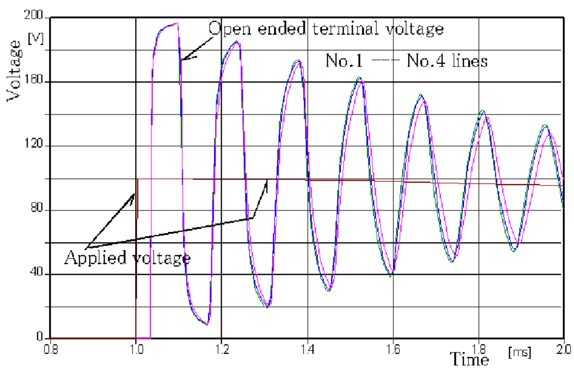


Fig. 3.5 Injecting step-&-cosine wave voltage

For some very simple cases, examples are shown next. In Fig. 3.5, step and cosine shape voltage is injected from one end of the lines and the other open ended terminal voltages are calculated. The condition is almost the same as in Fig. 3.2, where LINE CONSTANTS model is applied The end terminal voltage wave shapes seem quite appropriate, in values, damping, rounded shapes contrasting to angular ones in LINE CONSTANTS, shown in Fig. 3.2, finite front steepness. Depending on frequencies, which are the base of characteristics, differences are negligible. Calculating high frequency of voltage phenomena,

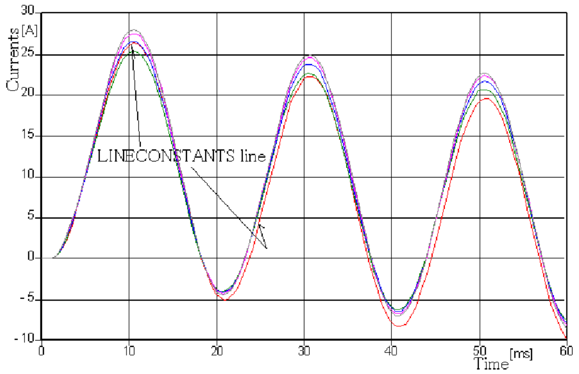


Fig. 3.6 Short circuit current --- 1LG

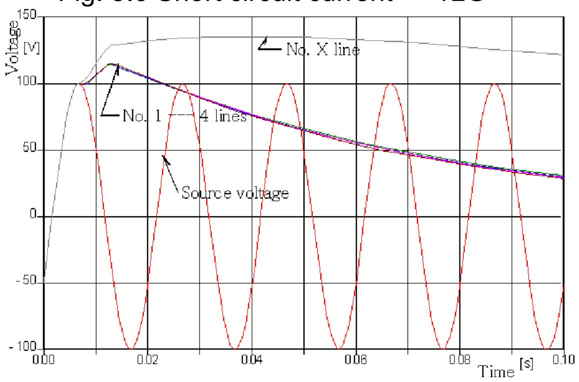


Fig. 3.7 No-load line dropping

JMARTI models seem to be just appropriate, at least for over-head transmission lines.

In the next example (Fig. 3.6) short circuit currents in one line to ground fault cases are shown. Sine wave shape of voltage is applied to one-side terminals, so both AC and damping DC components are involved. Result applying LINTCONSTANTS, where, considering the damping time constant in DC component, 10HZ of calculation basis frequency is applied, is also shown. Experience shows this is most reliable. Results by JMARTI, both in amplitudes and damping of DC components, depending on the basis frequency, show not negligible differences. Therefore, for such calculation, JMARTI model is not always appropriate.

In the third example, no-load line dropping (line capacitive charging current breaking) is taken up. Similar phenomena are shown in Fig. 2.7 and 2.8, where LINE CONSTANTS (transposed model) is applied. In Fig. 3.7 line side voltages of the first phase to open are shown. Up to second and third phase opening, the voltages enhance, but variously. After three phase opening, the trapped voltages show significant damping. In the modelling, no conductance is considered, so no damping, i.e. kept constant, is appropriate. Therefore, JMARTI calculation shows significant error. In calculating re-closing over voltages (see the previous chapter), which is the most important application of the method, great care is to be taken as for the trapped voltage which dominates the over voltage.

Another example is shown in Fig. 3.8, where no-load line's capacitive charging currents in various frequency basis models are shown. As the power factor of the capacitive currents, due to the non-transposed asymmetry of the line, three phase currents are not symmetrical. So, the average power factor of three phases is to be taken. By precise calculation from the results, not shown here, the values are:

- +0.03% by LINE CONSTANTS model
- -2.1% --- +3.7% by JMARTI model

Due to non-conductance modelling between phases and to the earth, the power factor is to be very low. So LINE CONSTANTS model is far more appropriate in this case. As the conclusion of frequency dependent model application, great care is to be taken. In some cases, erroneous results may be introduced. To the author's experiences, SEMLYEN and NODA set-ups introduce similar results in most cases.

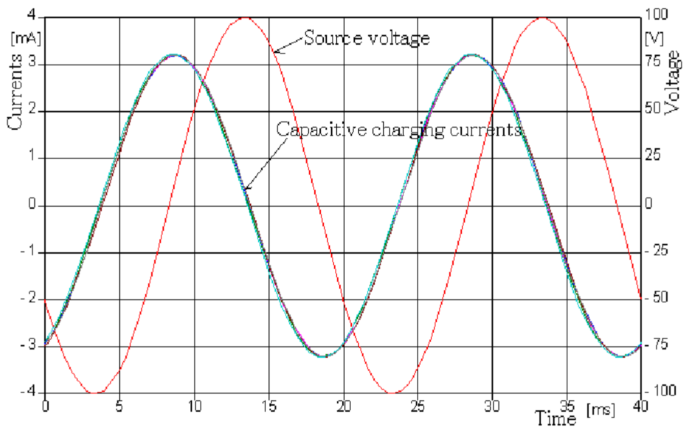


Fig. 3.8 No-load line capacitive charging current

3.2 Under ground cables

First of all, care should be taken that frequency dependent model is not applicable for cables except for gas-insulated cables. The author suppose due to the existence of other than 1.0 of relative permittivity of insulation media. Also, mode matrix is much dependent on frequency. As the supporting programs, both CABLE CONSTANTS and CABLE PARMETERS are available. The later has been recently revised, so this should be more reliable, though the author has not found significant difference between these two.

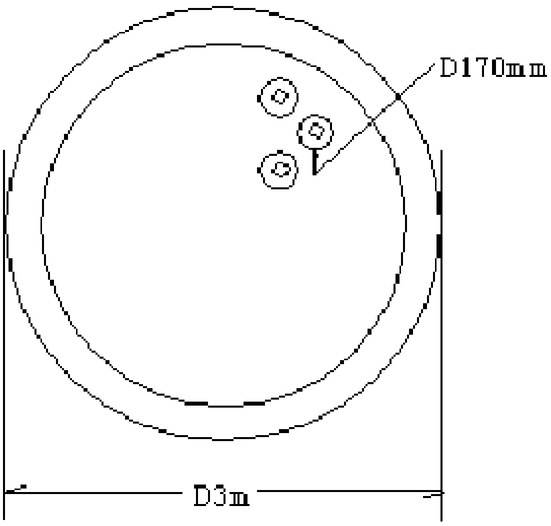


Fig. 3.9 CV cable system layout

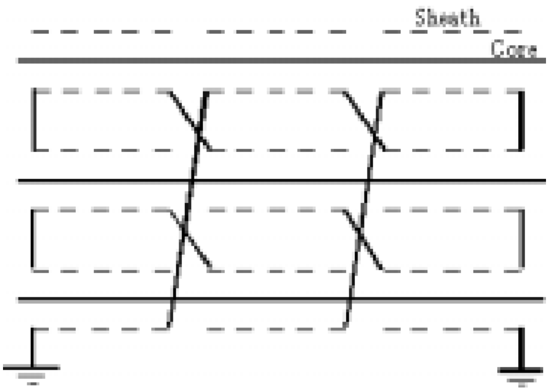


Fig. 3.10 Earth connection of one major Section of a cross-bonded cable

As an example, CV (cross-linked polyethylene insulated) cable system shown in Fig. 3.9 is taken up. The cable is applied to up to 550kV under ground system. As for the detailed dimensions, see attached data file, also referring to ATP Role-book. Three-phase cable system is located in a concrete tube the dimensions of which are arbitral in the data file. The tube is buried in the ground. Each coaxial cable is composed of core conductor, insulation media, sheath conductor, etc. It should be noted the sheath conductor's current capacity is low, so, current in which should be as lower as possible. This means the magnetic field close to the cable is significant.

One total length of cable consists of many major sections, the unit length of which is 1 – 2km. Especially for high and extra high voltage systems, each major section is composed of three minor sections for applying cross-bonded layout in order to reduce the sheath current, see Fig. 3.10. At each connection of minor section, sheath connection is transposed (cross-bonded) and at each major section terminal, three phase sheathes are shunted and earthed.

Here, the effect of cross bond will be demonstrated. As one minor section, 600m length of three-phase cable system is taken up. For power frequency of phenomena calculations, PI-type modelling, parameters of which are calculated at power frequency, seems to be most appropriate. See the attached data file for details. Calculations are done for non-cross bonded cable system, where three minor sections' sheathes are straight connected, and cross-bonded cable system. The typical results are shown in Fig. 3.11. For calculating electro magnetically induced currents, symmetrical three-phase current (1000A) is injected from one terminal and the other end terminal is short-circuited. Therefore, the applied voltage is very low for less electro statically induced current. For electro statically induced current calculation, symmetrical three phase voltage ($\sqrt{2}/\sqrt{3}$ times 550kV) is applied from one terminal and the other end terminal is open circuited. In a) of the figure, three phase injected currents are shown, the crest values are 1000A In b), the magnetically induced sheath currents in non-cross bonded cable are shown, the values are almost the same as the core current ones. In c), One side terminal sheath currents by applying service voltage (550kV) are shown, the values(ca. 50A) are 50% of the major section's capacitive currents due to the both side earthing.

In d) El. magnetically induced currents in cross-bonded cable sheathes are shown, the values of which are dramatically reduced, i.e. from ca. 1000A to less than 100mA.
In e) El statically induced currents in cross bonded cable sheathes are shown, where due to the both end terminal earthing, the three phases' capacitive currents are only partially cancelled, and the values

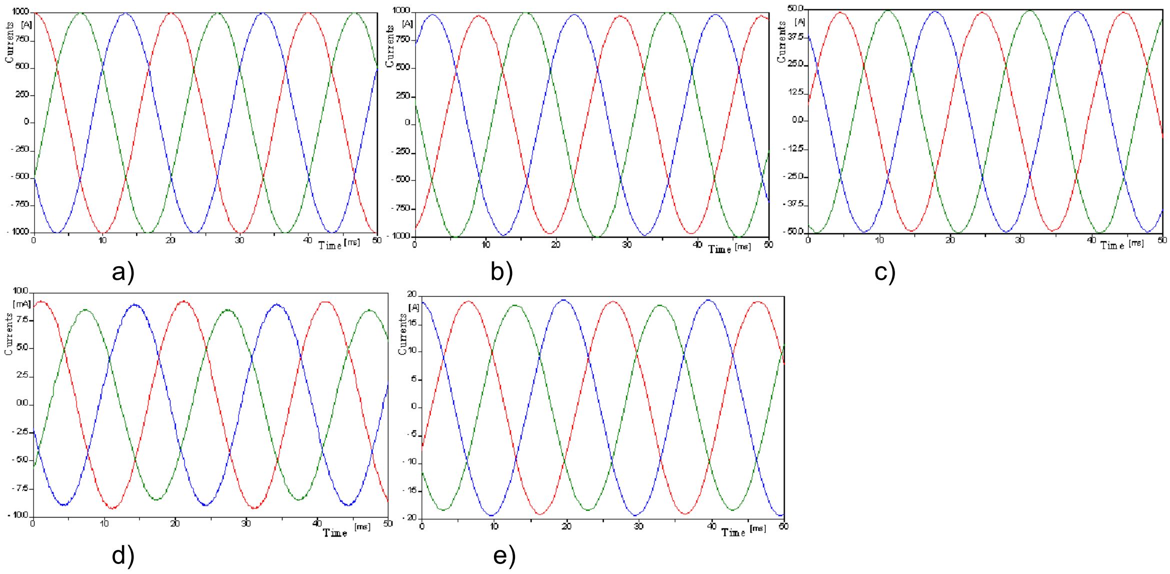


Fig. 3.11 Electro statically/magnetically induced currents in cable sheathes
a) Core currents (1000A) b) Sheath currents in non-cross bonded cable
c) El. statically induced sheath currents in non-cross bonded cable
d) El. magnetically induced sheath currents in cross-bonded cable
e) El. statically induced sheath currents in cross-bonded cable

are ca. 20A, ca. 40% of the non-cross bonded one.

Attached data files for this chapter:
- Data3-01.dat 300kV, 410mm^{2}X2(bundle), 2-circuited, 10km, power frequency distributed parameter PCH calculation in LINE CONSTANTS
- Data3-02.dat Ditto, 5000Hz, Distributed parameter PCH calculation in LINE CONSTANTS
- Data3-04.dat Ditto line, Voltage transient calculation by [step & cosine] voltage, 50Hz, 5000Hz and 5000Hz transposed line parameters.
- Data3-05.dat Ditto lines (three kinds), Short-circuit current calculation under max. asymmetrical (d.c. component) current condition (applying sine wave shape voltage).
- Data3-06.dat Ditto line, JMARTI set-up data, mode frequency=50Hz.
- Data3-07.dat Ditto, mode frequency=500Hz.
- Data3-08.dat Ditto, mode frequency=5000Hz.
- Data3-09.dat Ditto, mode frequency=50000Hz.
- Data3-0X.dat Ditto, mode frequency= 1MHz
- Data3-10.dat Voltage travelling transient calculation, JMARTI (mode frequency=50, 500, 5000, 50000 and 1M Hz) and LINE CONSTANTS (10Hz) lines, applying [step & cosine wave shape voltage].
- Data3-11.dat Short-circuit current calculation in JMARTI (mode frequency=50, 500, 5000, 50000 and 1M Hz) and LINE CONSTANTS (10Hz) lines, with max asymmetry.
- Data3-12.dat Ditto 5 kinds JMARTI lines, trapped DC voltage after breaking capacitive currents.
- Data3-13.dat Ditto 5 kinds JMARTI and one LINE CONSTANTS (50Hz) lines, power frequency capacitive charging current calculation.
- Data3-21.dat 550kV 3-phase CV (cross-linked polyethylene insulated) cable system in a tube,

600m, at 50Hz, PI-type PCH calculation, by CABLE PARAMETERS.
- Data3-22.dat Ditto, but 500Hz, Distributed parameter PCH calculation.
- Data3-23.dat Ditto cable, One major section (three minor sections), non-cross-bonded sheath, Electro-magnetically induced sheath current calculation.
- Data3-24.dat Ditto cable, One major section, Electro-statically induced (capacitive charging) sheath current calculation.
- Data3-25.dat Cross-bonded one major section, ditto parameters, Electro-magnetically induced sheath current calculation.
- Data3-26.dat Ditto one major section, Electro-statically induced sheath current calculation.
- Data3-31.dat One overhead conductor, one under ground cable, 4 under ground earthing mesh conductor, Induced voltage in the cable calculation by L-impulse voltage to overhead conductor application. (Combination of overhead and underground conductors)
- OH-UG3.dat One overhead conductor, 6 underground conductor, one of which is for cable, the other for underground earthing mesh, length=20m, PCH file calculation (distributed parameter type), at 500kHz. (Combination of overhead and underground conductors)
- OH-UG3PI.dat Ditto, but PI type.
- OH-CAB1.dat Coaxial cable in space (actually in very high location), PCH file calculation. Together with PCH by OH-UG3 (above shown), Combination of overhead conductor, underground cable and earthing mesh system is to be represented such as in Data3-31.dat.
- Data3-41.dat Capacitance graded bushing cone elements (total 7 kinds) (coaxial insulation model) PCH file calculation.
- Data3-42.dat Gas insulated bus duct elements (total 7 kinds) PCH file calculation
- Data3-43.dat Capacitance graded bushing sectioning gas insulated bus duct, calculation of voltage distribution around the bushing cone by VFT voltage incoming.
- Data3-44.dat Ditto, but extremely FT voltage incoming.

Appendix 3.1 Combination of overhead line(s) and underground cable(s)
Appendix 3.2 Multi-layer coaxial insulation

Appendix 3.1 Combination of overhead line(s) and under ground conductor(s)

Especially for analysing disturbances in control cables by, e.g. lightning stroke to station conductors or re-striking impulse current, both overhead and under ground conductors are to be included in one analysis domain. In CABLE PARAMETERS, such option is applicable. In Benchmark DC27.DAT, one example is shown, where an overhead and an underground conductors are modelled.
In the present CABLE PARAMETERS in ATP-EMTP, system consists of only one kind of conductors is applicable. So, modelling system with coaxial cable(s), special idea(s) is to be introduced. Let us introduce conductor layout, the cross-sectional view of which is shown in Fig. 3A.1, where one overhead conductor, one cable and four earthing mesh conductors exist. In the system, due to the restriction of present CABLE PARAMETERS, the cable is to be modelled as the same conductor. So, modelling coaxial cable, another coaxial cable in the another domain should be introduced, the sheath of which is electrically connected to the relevant conductor at proper points. Due to negligible penetration through the coaxial cable sheath, this modelling is thought to be appropriate, see Fig. 3A.2. As for the detailed data coding in the modelling, see the attached data files. 60m of the conductor system (segmented to three sections, for obtaining intermediate information if any) and 100m of under ground cable connection are introduced. The ground mesh is earthed at both ends and the sheath of the cable conductor is connected to the ground mesh via appropriate impedance. An impulse voltage (1 MV in crest value, enormous case) is applied to the overhead conductor and various part voltages are calculated. The layout image in longitudinal direction cross sectional view is shown in Fig. 3A.3

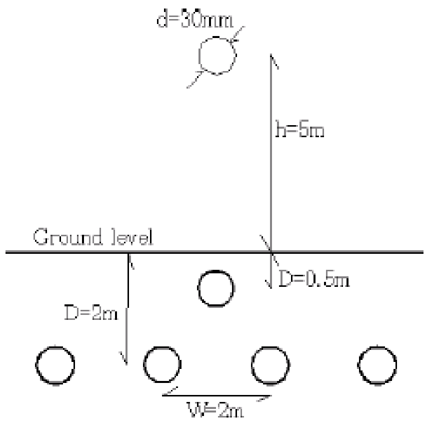


Fig. 3A.1 Conductor layout

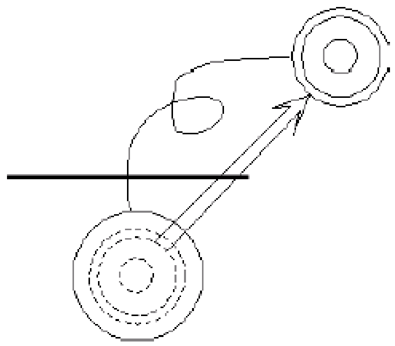


Fig. 3A.2 Imaging underground cable

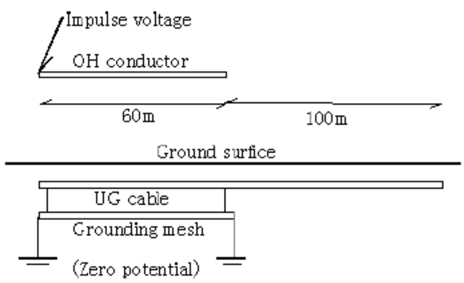
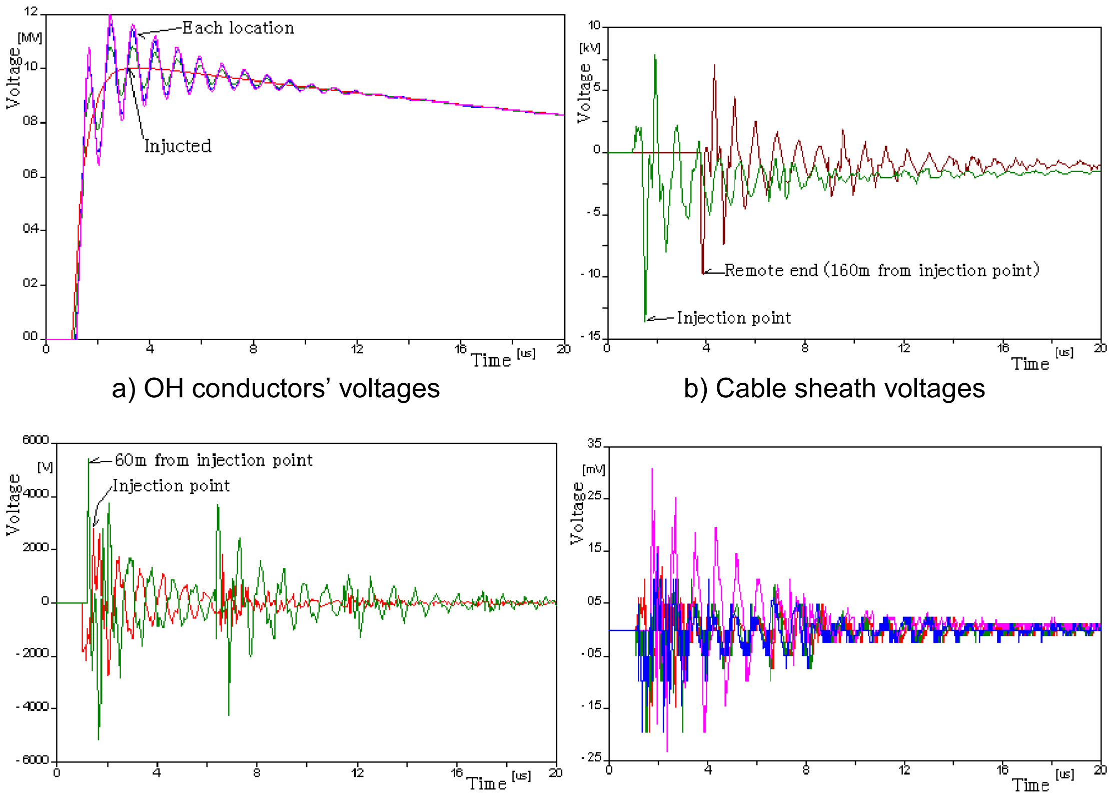


Fig. 3A.3 Longitudinal cross section view

The calculated result summing up is shown in Fig. 3A.4, :
a) 1MV of impulse voltage is applied from a terminal of the overhead conductor. By transmission and reflection, some ripples appear and higher voltages appear.
b) The underground cable sheath voltage, based on the very deep underground, reached to ca. 15kV.
c) The voltage difference between the cable sheath and the grounding mesh is, lower than several kV.
Therefore,
d) The voltage between the underground cable core and the sheath is negligibly low (several mV).
As the conclusion of this case, provide all facilities are earthed to the electrical station underground mesh, the maximum induced voltage in the underground secondary circuits is several kV by 1MV of over-voltage in the outdoor conductor.
Great care should be taken in modelling.



a) OH conductors' voltages b) Cable sheath voltages

c) Cable sheath – ground mesh voltages d) Cable core – sheath voltages

Fig. 3A.4 Underground conductors' induced voltages

Appendix 3.2 Multi-layer coaxial insulation

CABLE PARAMETERS accept up to two-layer coaxial insulation cable. As shown in the previous appendix, due to non-penetration of the transmission wave through the sheath, multi-layer coaxial insulation seems to be represented multiple coaxial cables of respective radii in each domain, the sheathes and cores are connected each other. Fig. 3A.5 shows the concept.

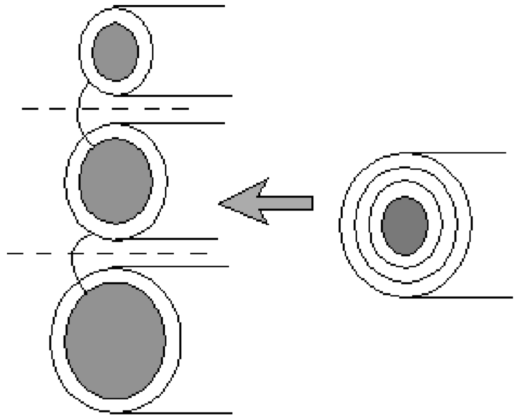


Fig. 3A.5 Multi-layer coaxial insulation representation

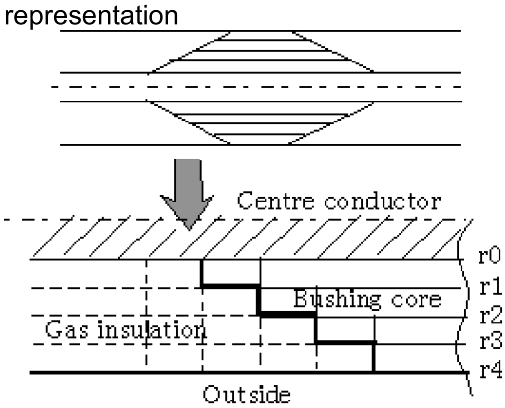
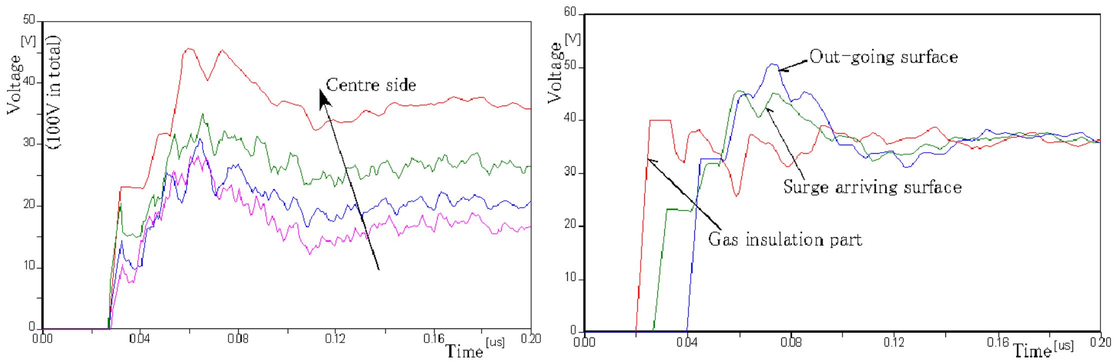


Fig. 3A.6 Modelling capacitance graded bushing

As a typical example, let us take up a capacitance graded bushing in a gas-insulated bus-duct. Due to the difference of length between insulation layers, i.e. travelling time, something may happen in dielectric stress in very fast transient voltage. Fig. 3A.6 shows sectional view in such modeling layout, though very arbitrary. Hopefully we can obtain general tendency in such simplified model. To model cone type bushing, core elements in coaxial insulation with different length are to be introduced. Calculating coaxial insulation elements, overhead coaxial cable in very high position from the ground surface is applicable both for gas insulated bus-duct and bushing core. For detailed dimensions/parameters, see attached data files.

In the surge voltage travelling calculation, VFT voltage is applied from one side of the layout in Fig. 3A.6, and the other side is connected long bus duct. Voltage distribution along the bushing cone surface is calculated. Typical calculated results are shown in Fig. 3A.7. In a) four sections' cone type surface voltage distribution is shown. In the first part, due, most probably, to reflections, slight voltage enhancement appears. In b), highest stressed part, i.e. conductor surface part, detailed voltages are shown. Out-going side voltage shows higher enhancement, which is higher than the applied one (gas insulation part) by approx. 30%.

The calculation shows that cone type capacitance graded bushing in gas insulated bus duct may produce more or less voltage stress concentration by VFT surge coming.



a) Bushing cone surface stress b) Conductor surface part

Fig. 3A.7 Bushing cone surface voltage distribution by VFT surge voltage