

Line Model options in Line Data device

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1 Introduction

The Line-Model module can produce transmission line models for steady state and for time-domain studies. The following line models are available:

- FD: Frequency dependent model, FD model
- CP: Constant-parameter model
- Exact-PI: Exact frequency domain representation of a line at a given frequency, for steady-state and frequency scan simulations
- Wideband: wideband line model

2 FD model

The FD option can be used to generate data fully compatible with the EMTP FD line model for time-domain and steady-state solutions.

This model represents the true nature of a transmission line by modeling the line parameters as distributed and frequency dependent. The line resistance and inductance are evaluated as functions of frequency, as determined by skin effect and ground return conditions. The capacitance is assumed constant. A non-zero constant shunt conductance G (the default value is 0.2×10^{-9} S/km) is included in the model.

The model is based on the approximation by rational functions of the line characteristic impedance Z_c and propagation function A_p , given by the following equations:

$$Z_c = \frac{\sqrt{R + j\omega L}}{\sqrt{G + j\omega C}}$$

$$A_p = e^{-\gamma \ell}$$

$$\gamma = \sqrt{(R + j\omega L)(G + j\omega C)}$$

where ℓ is the line length and R , L , C and G are the line parameters per unit length.

A transformation matrix T_i (also referred to as Q) is used in this model to relate phase and modal quantities.

The main simplification used in this model is the validity of the assumption that a constant real transformation matrix can be used to relate phase and modal quantities over an extended frequency range.

This model can be generated for the following transformation matrices:

- Real T_i** : In the general case of an untransposed line, the elements of the transformation matrix relating phase and modal quantities are complex numbers. Also, the matrix has different values at different frequencies. The FD model, however, makes the approximation of using a constant transformation matrix of real numbers for all frequencies in the modelling interval (default).

The optimum frequency at which to evaluate this real constant transformation matrix can be determined automatically by the program (default option), or the user can specify it using the “Model frequency” option field.

The optimum frequency determination procedure (Find Model frequency automatically) selects an optimum value of frequency for the range of switching transients. This value is based on asymptotic conditions for the particular line under consideration. Typical values are in the range from 500 Hz to 5 kHz with a mean around 1000 Hz. The selection of an optimum value is based on the constancy of T_i within the typical frequency range for switching transients. For studies involving other frequency ranges (lightning, for example) the frequency should be supplied in the “Model frequency” field.

After calling the eigenanalysis functions to evaluate the exact (complex) transformation matrix of the line at one frequency, the matrix is rotated and normalized. The imaginary part is then discarded and the remaining real part is taken as the “correct” transformation matrix to evaluate the line parameters and propagation functions at all frequencies. The errors due to this approximation are estimated in the Q-Error Table listed in the output file.

- **Balanced line:** The line is modelled as perfectly transposed. The diagonal and the off-diagonal elements in the reduced phase matrices (Z_{phase} and Y_{phase}) are averaged out.

The balanced-line transformation matrix used is the generalized Clarke transformation ($\alpha\beta 0$) for an m-phase line.

Unless the line is actually transposed, the results using this option are usually poorer than with the option “Real T_i ”. Check the Q-Error table in the output listing for error indicators.

- **Double circuit line:** This option is only selected for double-circuit lines. The line is modeled as consisting of two separate circuits, each circuit perfectly balanced with respect to itself and to the other circuit.

Under these conditions, the only coupling between the two circuits is zero sequence coupling. A special transformation matrix corresponding to this condition is used.

Unless the transposition scheme of the line approaches the ideal zero coupling condition on which this option is based, better results are usually obtained with the default “Real T_i ” option. Check the Q-Error Table in the output listing for an indication of the errors

The “Frequency range” represents the frequency

2.1 FD model data file format

After entering the remaining data in the “Line length” tab, The Model Data Calculation Function can be invoked from “Save and run this case” data tab to generate the model data file. The model can be used with the FD line model (FD m-phase device) by selecting the model data file after clicking on the “Select data file” button for “Time-domain model data”. It can be used for steady-state and/or time-domain simulations in EMTP.

The FD model data file format for a sample line with 3 propagation modes is shown in Figure 2–1. This is an automatically generated data file; the information below is provided only for documentation purposes.

The following data lines are needed:

- The first line is mandatory. It provides the model data calculation function identification, followed by the model option (FD) and the number of phases.
- The mode sections are identified by the mode number: -1,-2,-3...-N. If N is greater than 9, the following count must be used: -A,-B,-C..... Only the mode identification character is decoded by the actual line model “FD m-phase”. Each mode is associated to a wire on the “FD m-phase” device drawing, from top to bottom.
- The mode identification line is followed by the number of poles in the synthesized characteristic impedance Z_c and the value of Z_c at infinite frequency.

- The next lines contain the residues for the above number of poles.
- The next lines contain the poles.
- The line following the Z_c poles presents the number of poles in the propagation function A_p and the travel time of the mode.
- The above line is followed by the residues of the poles of A_p .
- The residues of A_p are followed by the poles of A_p .
- The line following the last pole data line must be a comment line.
- The above comment line is followed by the always available transformation matrix $Q (T_i)$.
Data is entered as a real matrix rows followed by imaginary matrix rows. Imaginary data is always 0, but present.

It is noticed that the number of modes must be equal to the number of wires (phases) in the device "FD m-phase".

```

C LINE DATA, FD, 3
C Comments start with C
C LINE LENGTH = 2.2200E+02 KM
C TRANSFORMATION MATRIX AT F = 1.0000E+03 HZ
C The following line identifies the mode 1 (-1). The rest of this line is not
C decoded.
-1
    21      4.74462509318108402567E+02
2.283015427021728101D+02  9.575640649554595711D+02  2.013381477094321212D+02
6.061618998688145439D+02 -6.972729233161383036D+02  6.760451094099685143D+00
8.363043587952587643D+01  1.591355321753289900D+02  6.493018039972242832D+02
1.833223774853337545D+03  5.577558121371023844D+03  1.679503983644356776D+04
3.939444222663762048D+04  1.120239009613241506D+05  2.293957712303487351D+05
5.992245960304505425D+05  1.359085399919180200D+06  3.495434180024222005D+06
1.102754796920852736D+07  1.898582910228958726D+07  1.044347249584238678D+08
3.184377308326697461D-03  1.142659741453015743D+00  1.410247054729613758D+00
1.747385523651275863D+00  1.780662486687028201D+00  2.218827200258786547D+00
4.023109927718707013D+00  6.502239502807383609D+00  2.083985460432543846D+01
5.876541140540180663D+01  1.823876732116725918D+02  5.640593991713492414D+02
1.402308099704432834D+03  4.075276323700988542D+03  8.963552488252842522D+03
2.410076505448365424D+04  5.787837305888934497D+04  1.562438177227384003D+05
5.140558334568240098D+05  1.832975845465427265D+06  1.019662353574014083D+07
    15      8.68087756699963456440E-04
2.446998953943564067D-05  1.101009379493385482D-01  2.729248310394779331D+00
1.163007709687541746D+00  1.330734909971337743D+01  7.270670599628982700D+01
9.703362572893102822D+01  2.288976028807581997D+02  5.706582308417526974D+02
5.873835810335974202D+03 -4.097508590341319177D+03  5.637155913727347070D+03
1.318633359546961449D+07 -1.321907020431305282D+07  2.433651981372164664D+04
1.985692975945386671D-02  2.159004563804076327D+01  2.350104352106030774D+02
2.515290357548743714D+02  5.765320412212246310D+02  1.309900558085271314D+03
1.870063871129507561D+03  3.001329244557226502D+03  3.984777264224765531D+03
5.937139251138488362D+03  6.065781934721424477D+03  1.163051851448095294D+04
1.990879557630283671D+04  1.992851726727190180D+04  2.981838019691102454D+04
-2
    14      2.72613957709204953517E+02
2.040928261573570808D+02  7.320340772647377889D+02  5.023996315103571533D+02
-2.447593159557985132D+02  4.070538193429653973D+01  5.386497094030494814D+00
2.716602807009862772D+02  5.259885608101141088D+02  1.204394272070120593D+02
1.015066436643730441D+02  1.272919440633899768D+02  1.181570571087700898D+02
3.410575508383083616D+03  1.402412764259435644D+05
2.827959091350378332D-03  1.100817723982985941D+00  1.468275521513094706D+00
1.657482856979041186D+00  2.067723976098531313D+00  2.509486139975520391D+00
4.585938122269856088D+00  8.520899497580858295D+00  9.624728164528338681D+00
1.457422452929704804D+01  2.403005241314601648D+01  3.912960424422755779D+01
1.791302848959001267D+03  7.388337549133962602D+04
    18      7.48652637550797027920E-04
3.379262809620548266D-05  2.790741898524098583D-02  2.437873410569479660D+01
2.524031108790083167D+01  4.032006639563203976D+02  2.244921419547969435D+03
1.646662359713069964D+04  3.528314876257380820D+04  5.797372924111800239D+04
6.756604360794900276D+04  1.230227615342034958D+06  -7.470853275939022424D+05
1.0436570010148488500D+08 -1.039677783588729799D+08  1.802076085009829104D+08
-1.814829657466953099D+08  1.576599275564814918D+07  -1.555168685457617417D+07

```

```

1.985225811826055523D-02 5.364714604810082221D+00 2.326199818676640916D+03
4.862941501813475952D+03 1.866557005247363486D+04 5.062422393492590345D+04
1.568762917443446931D+05 2.928418220667541609D+05 4.255624537142930785D+05
5.303951584052367834D+05 1.180557654378241627D+06 1.357218238814550918D+06
3.255399028247645125D+06 3.258623832750257105D+06 4.515348206166080199D+06
4.519821118733711541D+06 1.173308270877454057D+07 1.174470552294277214D+07
-3 1. -2 3
14 2.85812087797527453858E+02
2.068440416608754333D+02 7.434328788502074303D+02 6.141129744727347770D+02
-3.345703266681347259D+02 2.989634922878786227D+01 1.122342424280733475D+01
2.390496148121008844D+02 1.323054560993927225D+03 -6.484703783012250824D+02
1.128252634702326986D+02 1.301301011621264081D+02 1.247322428001669010D+02
1.957136191849841271D+04 2.984413252458497416D+06
2.867346487667737139D-03 1.099862837404594895D+00 1.480922641108804783D+00
1.650797701824323616D+00 2.039787231411344326D+00 2.491273901704059490D+00
4.341853487766006658D+00 8.903535913660869383D+00 9.283443531905913204D+00
1.461053974519216681D+01 2.397836184835597706D+01 3.982334892028816853D+01
1.001535962164031116D+04 1.534036532459646463D+06
15 7.42260779552304772975E-04
3.281517460210861976D-05 4.231843588743761791D-02 3.429455764932136219D+01
5.064001014999667660D+01 5.677989071445322224D+02 3.702826389013024254D+03
2.777021501646843171D+04 3.266723665610918033D+04 5.183239686396404286D+05
-1.329557821802375656D+04 -1.399472376895410998D+05 3.849242295078294724D+07
-3.893168894298432767D+07 8.090281889140170533D+05 -7.996364033324117772D+05
1.985274803339131394D-02 7.319178322505369039D+00 2.927930125718939053D+03
8.458745237649192859D+03 2.242598200799151527D+04 6.291347434485757549D+04
1.556321095858299814D+05 2.199676019453247718D+05 4.256247426522265305D+05
4.662550907182482770D+05 6.317486660880415002D+05 9.898985434087131871D+05
9.908791387987753842D+05 1.324181025567296334D+07 1.325492761823427491D+07
C Q MATRIX BY ROWS (IMAGINARY PART = 0)
0.57764932 -0.41240739 0.70710678
0.00000000 0.00000000 0.00000000
0.57663209 0.81227413 0.00000000
0.00000000 0.00000000 0.00000000
0.57764932 -0.41240739 -0.70710678
0.00000000 0.00000000 0.00000000

```

Figure 2-1 FD model data file format

3 CP model

The CP model (constant parameter line model) assumes that the line parameters R, L and C are constant, as calculated at the requested frequency in the “Model frequency” field. The model considers L and C to be distributed (ideal line) and R to be lumped at three places (line ends R/4 and line middle R/2). The shunt conductance G is taken as zero.

The frequency dependence of the line parameters (represented in the FD model) is an important factor for the accurate simulation of waveform and peak values. However, the CP model is very robust, simple and fast. It also provides a good alternative for a first approximation analysis.

This model can be generated for the following transformation matrices:

- **Real T_i** : A constant real transformation matrix is calculated at a frequency determined automatically by the program (“Find Model frequency automatically”) or specified in the “Model frequency” field. The automatic procedure is similar to the FD model.
- **Balanced line**: The line is modeled as perfectly transposed. The balanced-line transformation matrix used is the generalized Clarke transformation ($\alpha\beta 0$) for an m-phase line. In this case the frequency data is applicable only to modal parameters.
- **Double circuit line**: This option is only selected for double-circuit lines. The line is modeled as consisting of two separate circuits, each circuit perfectly balanced with respect to itself and to the other circuit.

Under these conditions, the only coupling between the two circuits is zero sequence coupling. A special transformation matrix corresponding to this condition is used. In this case the frequency data is applicable only to modal parameters.

3.1 CP model data file format

After entering the remaining data in the “Line length” tab, The Model Data Calculation Function can be invoked from “Save and run this case” data tab to generate the model data file. The model can be used with the CP line model (CP m-phase device) by selecting the model data file (also called “model file”) through the “Load data file” option in the device data. It can be used for all simulation options of this device. The format of this file can be found in the documentation of the CP m-phase device.

4 Exact PI model

The Exact PI (also called pi-exact) model is used for steady-state or frequency scan solutions; it is not valid for time-domain simulations. This model is an exact lumped-impedance multiphase representation of the line as seen from its end points. The parameters of the model are different for different frequencies.

The model data produced for this option is given in terms of a Y-matrix representation that includes the series and shunt branches of the multiphase pi model.

This model can be generated for the following transformation matrices:

- ❑ **Complex T_i** : Since the exact-pi model is produced in phase quantities, it is not subject to the transformation matrix modeling constraints of transients line models. The exact complex transformation matrix can then be correctly used at each frequency at which the pi model is requested (default).
- ❑ **Balanced**: The line is modeled as perfectly transposed. The balanced-line transformation matrix used is the generalized Clarke transformation ($\alpha\beta 0$) for an m-phase line.
- ❑ **Double circuit line**: This option is only selected for double-circuit lines. The line is modeled as consisting of two separate circuits, each circuit perfectly balanced with respect to itself and to the other circuit. Under these conditions, the only coupling between the two circuits is zero sequence coupling. A special transformation matrix corresponding to this condition is used.

This model is capable to generate the frequency parameters based on a logarithmic or linear scale. On output, the model data file (“model file”) contains the matrices $Y_{series}(\omega)$ and $Y_{shunt}(\omega)$ (see Figure 4–1 below) at every frequency requested in “Frequency range”. Note that the specified “Frequency range” must be identical to the one chosen through the “Frequency scan” option in EMTPWorks Simulation Options.

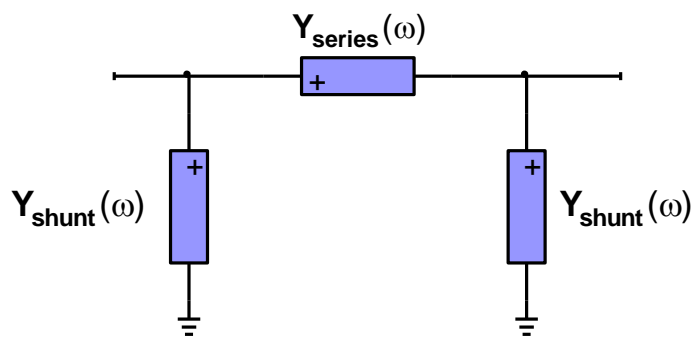


Figure 4–1 Circuit representation of Exact PI model

After entering the remaining data in the “Line length” tab, The Model Data Calculation Function can be invoked from “Save and run this case” data tab to generate the model data file. The model can be used with the FD line model (FD m-phase device) by selecting the model data file after clicking on the “Select data file” button for “Frequency-domain model data”. It can be used for steady-state or for frequency scan simulations in EMTP.

The FD model data file format for a sample line with 3 propagation modes is shown in Figure 4–2. This is an automatically generated data file; the information below is provided only for documentation purposes.

The first line is mandatory. It provides the model data calculation function identification, followed by the model option (EXACT-PI) and the number of phases.

The series-real, series-imaginary, shunt-real and shunt-imaginary matrix elements become available at each frequency given before the first line of series-real data.

```

C LINE DATA, EXACT-PI, 3
C          === PI-EXACT LINE EQUIVALENTS ===
C
C          MATRICES SHOWN AS  Y(1,1) Y(2,1) Y(2,2) Y(3,1) Y(3,2) Y(3,3)
C          Y(4,1) Y(4,2) ..... IN MHOS.
C
1.00000E-01 HZ.  ---> SERIES-REAL:
2.72319E-01 -5.37172E-03  2.72283E-01 -5.32792E-03 -5.37172E-03  2.72319E-01
---> SERIES-IMAG:
-2.52228E-02 -1.49066E-02 -2.52098E-02 -1.45653E-02 -1.49066E-02 -2.52228E-02
---> SHUNT -REAL:
2.22003E-08 -9.32865E-14  2.22003E-08 -6.52650E-14 -9.32865E-14  2.22003E-08
---> SHUNT -IMAG:
7.29282E-07 -1.14220E-07  7.43737E-07 -8.55898E-08 -1.14220E-07  7.29282E-07
C
1.25893E-01 HZ.  ---> SERIES-REAL:
2.69874E-01 -7.60179E-03  2.69821E-01 -7.53400E-03 -7.60179E-03  2.69874E-01
---> SERIES-IMAG:
-3.07600E-02 -1.77793E-02 -3.07361E-02 -1.73546E-02 -1.77793E-02 -3.07600E-02
---> SHUNT -REAL:
2.22005E-08 -1.47461E-13  2.22006E-08 -1.03038E-13 -1.47461E-13  2.22005E-08
---> SHUNT -IMAG:
9.18111E-07 -1.43795E-07  9.36309E-07 -1.07751E-07 -1.43795E-07  9.18111E-07
C
1.58489E-01 HZ.  ---> SERIES-REAL:
2.66439E-01 -1.06952E-02  2.66362E-01 -1.05911E-02 -1.06952E-02  2.66439E-01
---> SERIES-IMAG:
-3.71792E-02 -2.08517E-02 -3.71358E-02 -2.03258E-02 -2.08517E-02 -3.71792E-02
---> SHUNT -REAL:
2.22008E-08 -2.32927E-13  2.22009E-08 -1.62499E-13 -2.32927E-13  2.22008E-08
---> SHUNT -IMAG:
1.15583E-06 -1.81027E-07  1.17874E-06 -1.35651E-07 -1.81027E-07  1.15583E-06
C
.....

```

Figure 4–2 Exact PI model data file format