Database of Power System Parameters for Data Validation in EMTP Studies: Overhead Transmission Line Application

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Abstract - **We are developing a validation engine of "reasonable" transient parameters for power system components. The validation consists of two parts: i) An extensive database of typical parameters of power system components; and ii) A set of algorithms to rebuild some transient data and to check user entered data for physical validity and mathematical consistency. Validation of information is performed hierarchically, according to the sensitivity of the parameters to the specification class. Based on the information supplied, the valuation engine will return a range of typical parameters for the data specified. Each extra information item is optional, but the more of them supplied by the user, the narrower the range of possible viable parameters which the program will return.**

Keywords: EMTP Studies, Validation of Data Entry Parameters, Validation of Overhead Transmission Line Parameters.

I. INTRODUCTION

One of the difficulties in studying power system transients is that the data required for transient modeling is not as familiar to power engineers as the normal steady-state per unit data. Mistakes in entering these data can often lead to completely erroneous transient simulation results. Our concept of the validation engine of reasonable transient parameters for power system components is explained via the example of overhead transmission lines (OHL).

OHL parameters obtained from handbook formulas are given for 60 Hz and are not adequate for transient studies which usually involve higher frequencies. In these studies the resistance and inductance vary as functions of frequency due to skin effects in the earth return and in the conductors. The positive sequence inductance of OHL is practically constant, while the positive sequence resistance due to skin effect in the conductors begins to become important after a few hundred hertz. Zero sequence inductance and resistance are very much frequency dependent due to the earth return characteristic [1].

The complex penetration depth formulas [2] make it easy to obtain closed form expressions for ground return effects which are valid for a large range of frequencies.

The developed data validation engine works as follows. After the user enters the data required by the EMTP input file, he has the option of checking these data via a graphical user interface (GUI). Data checking proceeds in two stages: i) The database of pre-stored typical parameters is consulted; and ii) Parameters not directly in the database are derived from a process of reconstruction using analytical formulas. This paper illustrates this process for the case of overhead transmission lines. Similar processes for the validation of other power system components, like synchronous machines, induction motors, and power transformers are currently under development.

II. VALIDATION OF OVERHEAD TRANSMISSION LINE PARAMETERS

The interface form for the input data validation of a balanced three phase overhead transmission line is shown in Figs 1 and 2. The form gives various choices and outcomes. To choose the sequence parameters mode, the user clicks on the "select" button located at the top in the first row.

After the user enters the data required by the EMTP, he has the option of requesting a "validity check". The check will be based on the model parameters information needed by the EMTP, plus any other additional information which (optionally) may be supplied by the user. For overhead transmission lines this additional information includes: i) Nominal line voltage; ii) Number of conductors per bundle; iii) Tower design; iv) Bundle spacing; v) Ground resistivity; and vi) Frequency.

After the user clicks the "Check" button, the validation engine returns a message indicating if the entered values are not in the expected range and a range of typical parameters for the data specified. This is illustrated in the examples in Figs. 1 and 2.

Supplying all the additional information requested by the validation engine will result in the most accurate parameters range. If only partial additional information is supplied (for example, only the voltage level), the validation engine will return a wider range of typical parameters for the line data.

The validation engine also checks for completeness of the data. For example, for the EMTP option of entering R, Zc, and Tau as the line parameters, it is necessary to also enter the line length. A window with the prompt "length" will pop up in case the user has forgotten to enter this information before clicking on the "Check" button.

The International System of units SI are shown by default, but clicking on the down arrow of the units selection box will change all values to the British system of units.

Sample internal tables of data generated by the validation engine for OHL parameters are shown in Tables 2 to 4. These tables show resistance, inductance and surge impedances for a range of line voltages at 60 Hz and at 10,000 Hz, assuming a ground resistivity of 100 Ω-m.

III. DATABASE DESIGN

A. Parameter validation criteria

In practice, the design voltage level of a transmission line is selected based on the duty of the line within the power system. The most important criteria for this selection are the distance of transmission and the power rating. Standardized voltage levels are defined in international standards IEC 38 and U.S. standards ANSI C 84.1-1982.

The line conductors are selected according to electrical, thermal, mechanical and economic aspects [5].

The type of conductors, the line voltage, bundling and the circuit configuration determine the design of line. Typical choices for each of the standard voltage levels are presented in Table 1.1 and Table 1.2. The base geometries were chosen as average values currently in use for high voltage (HV) and extra-high-voltage (EHV) lines [4]. The average height is equal to the mid-span height plus one-third of the sag [3].

Table. 1.1. Base case, single-circuit OHL

Nominal Voltage (kV)	Line Type	Phase Spacing (m)	GMD (m)	Average Height (m)
138	Hor.	4.25	5.36	10
138	Ver.	3.7	4.8	10
230	Hor.	7.5	9.45	12.5
345	Hor.	7.5	9.45	15
345	Delta	9.5	9.5	12.5
500	Hor.	10	12.6	14
500	Ver.	9	12.8	14
500	Delta	12.8	12.8	14
760	Hor.	14	17.6	18.5
760	Delta	17.6	17.6	18.5
1100	Hor.	18.5	23.3	24
1100	Delta	22	22	24

Table. 1.2. Base case bundle diameters

Conductors per Phase	Bundle Diameters cm	(in)
2	45.7	(18)
3	52.8	(20)
4	61	(24)
6	91.4	(36)
8	101	(40)

B. Database implementation

The database information is stored as a text file in a relational database. This file is a multidimensional matrix defined in the C/C++ language, which contains all the parameter values for a number of conductors, according to the voltage level and the type of line construction. This data was compiled from real cases. The data is organized according to the number of conductors per phase, bundle spacing, type of tower associated with the voltage level, the size of the conductors or/and geometric mean radius (GMR) calculated for different values of bundle spacing, resistance of the conductor, the average height of the tower, the phase spacing or/and geometric mean distances (GMD), and the distance between one conductor and the image (below earth surface) of another conductor.

User data validation (Figs. 1 and 2) is done from the data assembled in this database matrix plus formula calculations based on the earth resistivity and the frequency.

IV. OHL PARAMETER CALCULATIONS FOR FREQUENCY DATA RECONSTRUCTION

The electrical behavior of a transmission line at a specific frequency is described by the system of equations, expressed in phasor form,

$$-[dV/dx] = [Z]\,[I] \qquad (1)$$

$$-[dI/dx] = j\omega[C]\,[V] \qquad (2)$$

A. Series impedance matrix [Z]

The elements of the series impedance matrix *[Z]* in (1) are calculated from the geometry of the line, using the complex penetration depth concept [2] for ground resistivity effects:

$$[Z] = [R(\omega)] + j\omega\,[L(\omega)] \tag{3}$$

In this matrix,

$$Z_{ii} = R^{c}{}_{ii} + j\omega\bar{L}_{ii} \tag{4}$$

$$Z_{ik} = j\omega\bar{L}_{ik} \tag{5}$$

$$\bar{L}_{ii} = \left(\frac{\mu_0}{2\pi}\right)\ln\left(\frac{2\cdot(h_i+\bar{p})}{r_i}\right) = a - jb \tag{6}$$

$$\bar{L}_{ik} = \left(\frac{\mu_0}{2\pi}\right)\ln\left(\frac{D'_{ik}}{d_{ik}}\right) = c - jd \tag{7}$$

$$\bar{p} = \sqrt{\frac{\rho_0}{j\omega\mu_0}} \tag{8}$$

In these formulas $\bar{L}$ indicates complex inductances and $\bar{p}$ represents the complex penetration depth which is added to each y coordinate. The other quantities in these formulas are :

$R^{c}{}_{ii}$ = a.c. resistance of conductor i,
ω = $2\pi f$, angular frequency,
f = frequency in Hz,
h_i = average height above ground of conductor i,
r_i = radius of conductor i,
d_{ik} = direct distance between conductors i and k,
D'_{ik} = distance between conductor i and image below earth surface of conductor k,
ρ_0 = earth resistivity,
μ_0 = earth permeability.

Substituting (6) and (7) into (4) and (5) gives

$$Z_{ii} = R^{c}{}_{ii} + j\omega(a-jb) = (R^{c}{}_{ii} + \omega b) + j\omega a = R_{ii} + j\omega L_{ii} \tag{9}$$

$$Z_{ik} = j\omega(c-jd) = \omega d + j\omega c = R_{ik} + L_{ik} \tag{10}$$

This is a classical result in which the resistance is proportional to frequency and the reactance is defined from an image conductor located at a depth $2\cdot\sqrt{\rho_0/(j\omega\mu_0)}$ meters below the ground [2].

B. Shunt capacitance matrix [C]

The elements of the capacitance matrix *[C]* are determined from Maxwell's potential coefficients,

$$P_{ii} = \frac{1}{2\pi\varepsilon_0}\ln\frac{2h_i}{r_i} \tag{11}$$

$$P_{ik} = \frac{1}{2\pi\varepsilon_0}\ln\frac{D'_{ik}}{d_{ik}} \tag{12}$$

ε_0 = permittivity of free space.

$$[C] = [P]^{-1} \tag{13}$$

C. Positive and zero sequence parameters

Positive and zero sequence impedances are obtained from the averaged self and mutual impedances, with

$$Z_{pos} = Z_{self} - Z_{mutual} \tag{14}$$

$$Z_{zero} = Z_{self} + 2Z_{mutual} \tag{15}$$

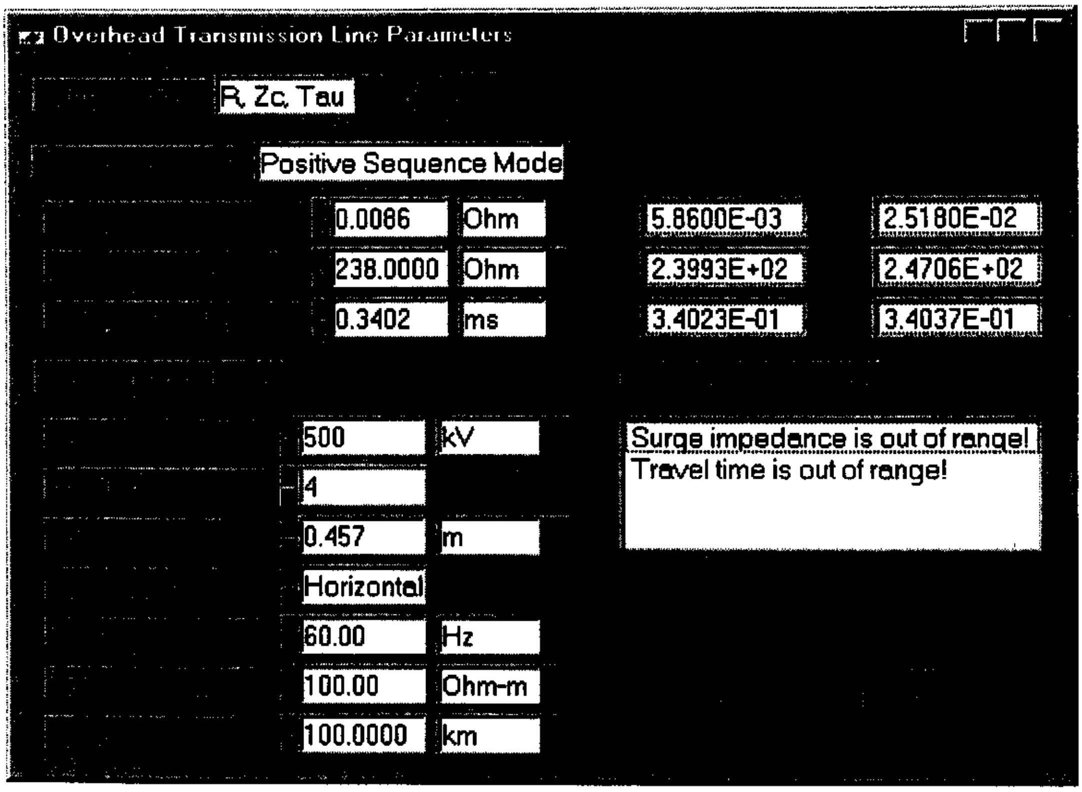
and similarly for the capacitances.

D. Tower geometry

Using typical designs for the reconstruction of the line configuration, one can often arrive at contradictory conditions regarding the line's height and the line's width. A common design requirement that can lead to erroneous reconstruction from tables of typical parameters is the case of towers being as low as possible going through right-of-way corridors that are as narrow as possible. In testing some of these cases, using the average height and the actual distance among conductors in horizontal line configurations resulted in rebuilt capacitances which appeared as reasonable in the validity checks but which resulted in wave speeds

$$v = \frac{1}{\sqrt{LC}} \tag{16}$$

greater then the speed of light (300 km/ms). The validation engine's extra checks for physical feasibility were able to detect these conditions.


Overhead Transmission Line Parameters

R, Zc, Tau

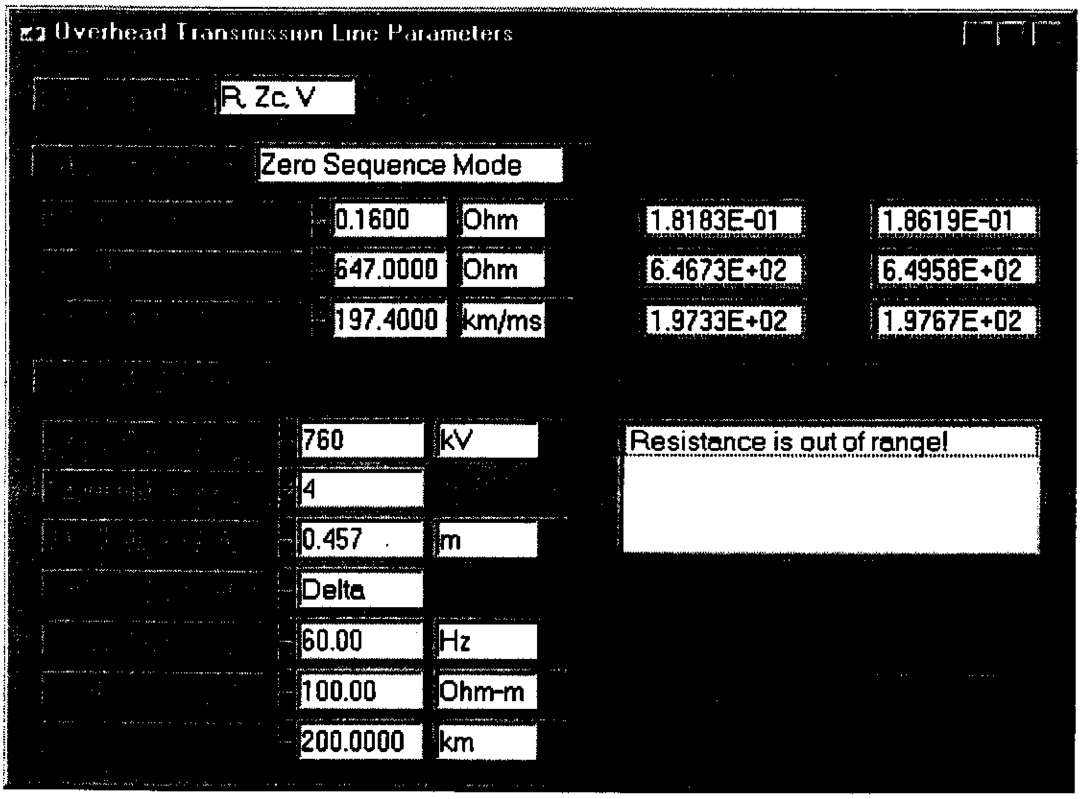
Positive Sequence Mode

0.0086	Ohm	5.8600E-03	2.5180E-02
238.0000	Ohm	2.3993E+02	2.4706E+02
0.3402	ms	3.4023E-01	3.4037E-01

500 kV
4
0.457 m
Horizontal
60.00 Hz
100.00 Ohm-m
100.0000 km

Surge impedance is out of range!
Travel time is out of range!

Fig. 1. User Interface for Data Validation for Positive Sequence Mode of OHL


Overhead Transmission Line Parameters

R, Zc, V

Zero Sequence Mode

0.1600	Ohm	1.8183E-01	1.8619E-01
647.0000	Ohm	6.4673E+02	6.4958E+02
197.4000	km/ms	1.9733E+02	1.9767E+02

760 kV
4
0.457 m
Delta
60.00 Hz
100.00 Ohm-m
200.0000 km

Resistance is out of range!

Fig. 2. User Interface for Data Validation of Zero Sequence Mode of OHL

Table 2.1. OHL positive and zero sequence resistances at 60 Hz, with ρ = 100 Ωm

Nominal Voltage(kV)	Line Type	Conductor Number	Bundle Spacing(m)	Rposmin (Ohm/km)	Rposmax (Ohm/km)	Romin (Ohm/km)	Romax (Ohm/km)
138	Hor.	1	0	0.1012	0.211	0.2754	0.385
230	Hor.	1	0	0.0587	0.2746	0.232	0.2746
345	Delta	1	0	0.0263	0.0318	0.2	0.2052
345	Hor.	2	0.457	0.013	0.0392	0.1865	0.2125
500	Hor.	4	0.457	0.00586	0.02518	0.1787	0.1981
500	Ver.	4	0.457	0.00586	0.02518	0.1787	0.1981
500	Delta	4	0.457	0.00586	0.02518	0.1787	0.1981
760	Hor.	2	0.457	0.01314	0.01777	0.1845	0.1892
760	Hor.	4	0.457	0.01044	0.0148	0.1818	0.1862
760	Delta	4	0.61	0.00657	0.00795	0.178	0.1793
1100	Hor.	8	1.01	0.00329	0.00398	0.1729	0.1736
1100	Delta	8	1.01	0.00329	0.00398	0.1729	0.1736

Table 3.1. OHL positive and zero sequence inductances at 60 Hz, with ρ = 100 Ωm

Nominal Voltage(kV)	Line Type	Conductor Number	Bundle Spacing(m)	Lposmin (mH/km)	Lposmax (mH/km)	Lomin (mH/km)	Lomax (mH/km)
138	Hor.	1	0	1.2754	1.3587	4.3813	4.4544
230	Hor.	1	0	1.3287	1.399	4.0865	4.1568
345	Delta	1	0	1.2546	1.2738	4.0093	4.0285
345	Hor.	2	0.457	0.9297	0.9854	3.6875	3.7432
500	Hor.	4	0.457	0.8166	0.8405	3.4032	3.4272
500	Ver.	4	0.457	0.8001	0.824	3.436	3.4603
500	Delta	4	0.457	0.8197	0.8437	3.396	3.4209
760	Hor.	2	0.457	1.054	1.0708	3.4444	3.4611
760	Hor.	4	0.457	0.8872	0.8956	3.2774	3.2862
760	Delta	4	0.61	0.8332	0.8364	3.2234	3.2266
1100	Hor.	8	1.01	0.6295	0.6311	2.8565	2.8581
1100	Delta	8	1.01	0.618	0.6197	2.8794	2.8811

Table 4.1. OHL positive and zero sequence surge impedances at 60 Hz, with ρ = 100 Ωm

Nominal Voltage(kV)	Line Type	Conductor Number	Bundle Spacing(m)	Zcposmin (Ohm)	Zcposmax (Ohm)	Zcomin (Ohm)	Zcomax (Ohm)
138	Hor.	1	0	376.3	398.4	896.5	920.3
230	Hor.	1	0	389.6	409.3	835.9	856.6
345	Delta	1	0	362.7	368.4	822.7	828.8
345	Hor.	2	0.457	272.6	289.2	710	728.2
500	Hor.	4	0.457	239.9	247	637.5	645.4
500	Ver.	4	0.457	232.2	240.3	654	662
500	Delta	4	0.457	238.7	245.8	642	650
760	Hor.	2	0.457	308.7	313.9	686.7	692.5
760	Hor.	4	0.457	260.6	263.2	635.1	638
760	Delta	4	0.61	240.1	241.5	628.5	630.2
1100	Hor.	8	1.01	183.9	184.6	532.8	533.7
1100	Delta	8	1.01	175.3	176	556	556.9

Table 2.2. OHL positive and zero sequence resistances at 10000 Hz, with ρ = 100 Ωm

Nominal Voltage(kV)	Line Type	Conductor Number	Bundle Spacing(m)	Rposmin (Ohm/km)	Rposmax (Ohm/km)	Romin (Ohm/km)	Romax (Ohm/km)
138	Hor.	1	0	0.1012	0.211	23.5174	23.6272
230	Hor.	1	0	0.0587	0.2746	22.2639	22.306
345	Delta	1	0	0.0263	0.0318	22.2347	22.237
345	Hor.	2	0.457	0.013	0.0392	22.2183	22.2443
500	Hor.	4	0.457	0.00586	0.02518	21.5362	21.5555
500	Ver.	4	0.457	0.00586	0.02518	21.5362	21.5555
500	Delta	4	0.457	0.00586	0.02518	21.5362	21.5555
760	Hor.	2	0.457	0.01314	0.01777	19.7231	19.7277
760	Hor.	4	0.457	0.01044	0.0148	19.7204	19.7247
760	Delta	4	0.61	0.00657	0.00795	19.7165	19.7179
1100	Hor.	8	1.01	0.00329	0.00398	17.8379	17.839
1100	Delta	8	1.01	0.00329	0.00398	17.8379	17.839

Table 3.2. OHL positive and zero sequence inductances at 10000 Hz, with ρ = 100 Ωm

Nominal Voltage(kV)	Line Type	Conductor Number	Bundle Spacing(m)	Lposmin (mH/km)	Lposmax (mH/km)	Lomin (mH/km)	Lomax (mH/km)
138	Hor.	1	0	1.2856	1.3587	2.9542	3.0272
230	Hor.	1	0	1.3287	1.399	2.6849	2.7552
345	Delta	1	0	1.2546	1.2738	2.6078	2.6269
345	Hor.	2	0.457	0.9297	0.9854	2.2859	2.3416
500	Hor.	4	0.457	0.8166	0.8459	2.0166	2.0406
500	Ver.	4	0.457	0.8001	0.8241	2.0497	2.0737
500	Delta	4	0.457	0.8197	0.8437	2.0103	2.0343
760	Hor.	2	0.457	1.054	1.0708	2.1011	2.1179
760	Hor.	4	0.457	0.8872	0.896	1.9343	1.9431
760	Delta	4	0.61	0.8332	0.836	1.8802	1.8835
1100	Hor.	8	1.01	0.6295	0.6311	1.5632	1.5649
1100	Delta	8	1.01	0.618	0.6197	1.586	1.5878

Table 4.2. OHL positive and zero sequence surge impedances at 10000 Hz, with ρ = 100 Ωm

Nominal Voltage(kV)	Line Type	Conductor Number	Bundle Spacing(m)	Zcposmin (Ohm)	Zcposmax (Ohm)	Zcomin (Ohm)	Zcomax (Ohm)
138	Hor.	1	0	376.3	398.4	736.2	758.6
230	Hor.	1	0	389.6	409.3	677.5	697.4
345	Delta	1	0	362.7	368.4	663.5	669.3
345	Hor.	2	0.457	272.6	289.2	559	575.9
500	Hor.	4	0.457	238.7	245.8	494	501.2
500	Ver.	4	0.457	233.2	240.3	505.2	512.4
500	Delta	4	0.457	240	247	490.7	498
760	Hor.	2	0.457	308.7	313.9	536.4	541.7
760	Hor.	4	0.457	260.6	263.2	487.9	490.6
760	Delta	4	0.61	240.1	241.5	480	481.5
1100	Hor.	8	1.01	183.9	184.6	394.2	394.9
1100	Delta	8	1.01	175.3	176	412.7	413.4

```
Rpmin  Rpmax  0.00586  0.02518
Romin  Romax  0.178743  0.198063
Lpmin  Lpmax  0.8166e-003  0.8406e-003
Lomin  Lomax  3.4032e-003  3.4272e-003
Cpmin  Cpmax  1.3771e-008  1.4186e-008
Comin  Comax  8.2279e-009  8.3743e-009
Zcpmin  Zcpmax  239.926  247.062
Zcomin  Zcomax  637.487  645.395
vpmin  vpmax  293.799  293.916
vomin  vomax  187.318  188.316
taupmin  taupmax  0.3402  0.3404
tauomin  tauomax  0.5310  0.5339
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Fig. 3. 500 kV OHL output data of the validation engine at frequency of 60 Hz, with $\rho = 100\ \Omega m$

```
Rpmin  Rpmax  0.00586  0.02518
Romin  Romax  25.460637  25.479957
Lpmin  Lpmax  0.8166e-003  0.8406e-003
Lomin  Lomax  2.4123e-003  2.4363e-003
Cpmin  Cpmax  1.37712e-008  1.41864e-008
Comin  Comax  8.22786e-009  8.37432e-009
Zcpmin  Zcpmax  239.926  247.062
Zcomin  Zcomax  536.716  544.154
vpmin  vpmax  293.799  293.916
vomin  vomax  222.488  223.353
taupmin  taupmax  0.3402  0.3404
tauomin  tauomax  0.4477  0.4495
```

Fig. 4. 500 kV OHL output data at frequency of 10000 Hz, with $\rho = 500\ \Omega m$

V. CONCLUSIONS

This paper describes a database implementation of typical power system parameters for data validation in EMTP studies. This database also supports the Real Time Power System Simulator being developed at the University of British Columbia. The complex database and formula-based validation processes that go on behind the scenes are shielded from the user, who only sees very simple data input forms with optional physical information on the line he is modelling. The extensive background checking procedures performed by the validation engines assure a high degree of confidence in that the correct data has been entered for the simulation.

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