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Guidance Note

Electrical Parameters and Impedance Characteristics of Plant, Lines and Cables

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ELECTRICAL PARAMETERS AND IMPEDANCE CHARACTERISTICS OF PLANT, LINES AND CABLES

FOREWORD

The second issue of This Technical Guidance Note (TGN) supersedes Planning Memorandum PLM-ST-3 Issue 2, dated February 1987, and also the first issue, dated April 2000.

As in the previous document, information is given on the effects on the electrical parameters of deviations from 'standard' line constructions. De-spacing and re-alignment of the sub-conductors of phase-conductor bundles is now being used to reduce wind-induced conductor-galloping, resulting in larger than 'standard' sub-conductor spacings being used. This de-spacing also allows the sub-conductors to electro-magnetically attract and approach each other more easily with the passage of load and fault current, so variations of electrical impedances with phase sub-conductor spacing are included. Since National Grid lines are normally untransposed, examples are given of the sequence parameters for an untransposed line for comparison with the parameters normally used which assume a fully transposed line.

For investigations where high accuracy is required and where there are known to be significant deviations from 'standard' conditions, line impedance parameter calculations should be made taking account of the specific conditions concerned. If sequence parameters are required for an untransposed line, the Head of Circuit Strategy, Network Engineering, Leatherhead, should be consulted.

The previous version of this TGN, PLM-ST-3, included some data on ratings for overhead lines; this has not been included since they are now available from TGN(T)26².

This second issue includes parameters for double-circuit overhead lines possessing two circuits with dissimilar constructions.

All parameters for overhead lines are given on a per kilometre basis.

1 SCOPE

This Technical Guidance Note gives the computed 50 Hz electrical parameters for double-circuit overhead lines, for use in electrical network studies. It is intended that future issues of this document will also include cables, transformers and other plant.

The factors of line construction which influence the electrical parameters are detailed and an indication of the sensitivity of some of the electrical parameters to changes in these factors is given in Appendix B. Since, in practice, National Grid overhead lines are normally untransposed (except where one line is teed into another, where phasing changes sometimes occur), and may not have a 'Standard' phasing of the six phases on the tower (see Section 1.2 below), examples of the sequence parameters (both sequence self- and mutual-parameters) are given in Appendix C, for an L6 standard tower construction, as a comparison with the fully-transposed parameters given in Section 5.11. It should be noted that, for most electrical network studies (which assume no interaction between the phase sequence networks), the use of fully-transposed line parameters is perfectly acceptable, introducing errors of less than 0.2% in the magnitudes of the positive-phase-sequence impedances and no errors in the zero-phase sequence impedances for the circuit phasings given in Section 1.2(i) below.

1.1 Parameters

The parameters of interest may be divided into two categories:

- (a) electrical parameters (positive and zero-sequence series impedance's and shunt susceptances),
- (b) subsidiary parameters calculated from those above such as X/R ratios, charging currents, natural loadings and residual compensation factors.

1.2 Calculation Assumptions

The sequence parameters tabulated in Sections 5 & 6 have been calculated using the old CEGB Program BESS05¹ and its replacements ATP and PSCAD (MATRAP). In each case, the following have been assumed:

- (a) perfect phase transposition within each circuit on the tower,
- (b) uniform earth resistivity,
- (c) zero tower footing impedance (the earthwire is at zero potential throughout its length)
- (d) standard line construction (suspension tower type)

In practice, none of these assumptions is completely justified but the errors introduced by using them will not be significant in the majority of applications. In particular, values given in the tables for Z_{1m} , Z_{1dc} , B , and B_{1dc} (see Section 4.3 for parameter definitions) assume that one of three standard phasing arrangements given below:

R	B	Y	R	B	Y
Y	Y	B	B	R	R
B	R	R	Y	Y	B
(i)		(ii)		(iii)	

are being used for the phases on the tower. Also the values of B_{1dc} and B_{0dc} assume equal positive-phase-sequence (PPS) and zero-phase-sequence (ZPS) voltages respectively on the two circuits, and the values of Z_{1dc} and Z_{0dc} assume that equal PPS and ZPS currents respectively are flowing in the two circuits and that the flows are in the same direction.

A proportion of National Grid circuits has sections with non-standard phasing arrangements. However, an approximate balance of all the possible phasing arrangements is aimed for across the whole network and the overall effect of these non-standard arrangements may be ignored. (See Section 2 below for special studies).

It should be noted that parameters for lines operating at reduced voltages are based on conductor heights appropriate to the design voltages and not on heights based on the insulator lengths appropriate to the reduced operating voltages. For instance, the parameters of an L2 line insulated to 400 kV, but operating at 275 kV, are calculated assuming the line dimensions appropriate with 400 kV insulators fitted.

The sensitivity of the line parameters, to variations in the standard arrangements of line constructions and running, are described in Appendix B. The variations considered are those with tower height, horizontal spacing between circuits, earth resistivity, system frequency, phase-bundle sub-conductor spacing, phase-conductor temperature (which alters both conductor resistance and sag) and with phase-conductor resistance.

Dimensions of standard 'D' type suspension towers (without extensions) have been used as a basis of the calculations. For tower dimensions see the relevant part of Section 5. An average earth-resistivity of 20 Ωm has been used throughout. A phase conductor temperature of 20 °C and an earth conductor temperature of 5 °C have been assumed, these conditions being taken to represent averagely loaded lines. With the ACSR conductors, it has been assumed that the steel cores carry no current and, since the changes are small, no account has been taken of conductor resistance variation due to load-current magnetic hysteresis loss effects in the steel. Proximity effects have been neglected as being small, and skin effects have also been neglected for uniformity between conductor types.

Perfect phase transposition within each circuit has been assumed, by which is implied that each phase conductor occupies each possible position for an equal total distance along the route.

The electrical parameters all refer to the phase-conductors only, but embody the presence of the earthwire (at zero potential) at the peak of the towers as noted in Section 1.2 (i) and Section 2 above.

The percentage impedances assume nominal voltage and are on a 100 MVA base.

1.3 Current Ratings

Information on current ratings and thermal losses should be taken from TGN(T)26 Issue 2 (Reference 2). More information on specific conductors is specified in NGTS 3.4.2³ and 3.4.13⁴

In the last few years rated temperatures of conductors systems have been increased, in some cases to 90°C. However it should be noted that the conductor temperature assumed for these calculations remains 20°C (earthwire at 5°C). If parameters are required for conductors at a specific temperature then the Circuit Strategy Group, Leatherhead should be consulted.

Note that overall circuit ratings may be restricted below the ratings of the overhead lines which form all or part of those circuits, due to the current-carrying capabilities of associated equipment such as cables, circuit-breakers, disconnectors, busbars, line traps, CTs and protection.

1.4 Subsidiary Parameters

The subsidiary parameters are all based on nominal system voltage, and the line losses are also based on the current ratings described in (Section 1.3) above.

2 SPECIAL STUDIES

In some specific circumstances, the parameters given in the tables in Section 5 may not be sufficiently accurate for the analysis to be undertaken.

Tension towers normally have different dimensions from suspension towers and if a line has a significant proportion of tension towers it may be necessary to recalculate the line parameters for these dimensions. Similarly, for a line which has had the sub-conductor spacers removed and the sub-conductors re-aligned, the sub-conductor spacing can be significantly larger than is normally used. In all these cases, and where an accurate representation is required of conductors when running at a temperature significantly different to the standard figure used (20°C) (a temperature change alters both conductor resistance and sag), line-specific electrical parameters may be obtained from the Circuit Strategy Group, Leatherhead.

Where the behaviour of one phase of a line is required to be studied in detail, it should be borne in mind in particular that the single conductor impedances Z_p and Z_{pp} tabulated in Section 5 include the effect of the earthwire, at zero potential throughout its length, and are averaged over the three phase-conductors of each circuit to represent a fully transposed line. If the performance of a specific phase-conductor is required, without the influence of the earthwire, use should be made of the seven-conductor series resistance and inductance matrices and shunt capacitance matrix which are calculated in PSCAD.

In particular areas of the network where certain of the possible phasings may predominate, the untransposed nature of National Grid lines, with associated unbalanced mutual couplings between sequence currents, can cause negative and zero-phase-sequence (NPS & ZPS) currents to flow due to the passage of PPS currents, particularly under outage conditions. The advice of Circuit Strategy Group, Leatherhead, should be sought as to the levels of these currents if they could cause operational difficulties.

3 RECOMMENDATIONS

It is recommended that the appropriate parameters given in Sections 5 and 6 should be used for power system analysis purposes and that these should supersede all previous data.

4 COMPUTATION OF ELECTRICAL PARAMETERS

4.1 Introduction

The tables in Sections 5 & 6 give the overhead line parameters required for most power system analysis for nominal system voltages of 132 kV, 275 kV and 400 kV.

The line constructions given here are those in use on the National Grid network, and include new tower and conductor configurations which have been introduced on the system since PLM-ST-3 was last issued. Some lower voltage (132 kV) configurations have been included as these are sometimes useful for detailed connection studies.

The impedance and susceptance parameters given in this TGN which were also previously found in PLM-ST-3 were computed using the CEGB Program BESS05¹ overhead line parameter program and have simply been transcribed from PLM-ST-3 rather than recalculated. The new parameters, not previously found in PLM-ST-3, have been calculated from PSCAD v2/v3/MATRAP. The current ratings, previously given in PLM-ST-3, are now to be found in TGN(T)26 Issue 2². TGN(T)26 should be consulted for the details of the basis on which these ratings have been calculated.

Appendix A contains the line/conductor dimensions assumed in the calculations, and the conductor data used.

Appendix B should be consulted for brief details of the ACSR conductor resistance variation with load current and of conductor resistance increase due to skin effect. Appendix B also describes the variations of the more important electrical parameters with conductor temperature etc.

Appendix C gives examples of the sequence parameter matrices for an L6 (4×400 mm²) tower construction, for a fully transposed line (for comparison with Section 5.10), and for untransposed phasings RYB/BYR and RYB/RYB.

4.2 Subsidiary Parameters

(a) Percentage Values

$$Z(\%) = Z(\Omega) \times \frac{\text{Base MVA}}{V_L^2} \times 100$$

$$B(\%) = \frac{B(\mu S)}{10^6} \times \frac{V_L^2}{\text{Base MVA}} \times 100$$

Where V_L^2 = Nominal Line Voltage (kV)

(b) Line Losses

$$\text{3-phase loss at full load} = 3I_{FL}^2 \times R_1 \times 10^{-3} \text{ kW/km}$$

where I_{FL} = Rated current (A/phase), and R_1 = Positive sequence resistance (Ω /km/phase). Alternatively R_{1dc} may be used in place of R_1 , although in practice there will be little difference.

(c) Charging current

$$= \frac{V_L}{\sqrt{3}} \times \frac{B_{1dc}}{10^3}$$

with V_L in kV, and B_{1dc} in μ S/km/phase.

(d) Natural Load

$$= \frac{V_L}{10^3} \times \sqrt{\frac{B_{1dc}}{X_{1dc}}} \quad \text{MW}$$

with V_L in kV

X_{1dc} in Ω /km/phase

B_{1dc} in μ S/km/phase.

For lines operating at reduced voltages, but having insulation appropriate to their construction voltages, the percentage parameters, charging current and natural load can also be obtained using the above formulae. The construction voltage ohmic parameters in the tables for Z or X_{1dc} (Ω /km) and for B or B_{1dc} (μ S/km), together with the operating voltage (kV) should be used.

(e) Residual Compensation Factor

$$Q = \frac{(Z_0 - Z_1)}{3Z_1}$$

Protection Engineers have conventionally used a scalar approximation to this complex quantity derived by using the scalar magnitudes of the two complex impedances Z_0 and Z_1 , namely: $|Z_0|$ and $|Z_1|$, where for

$$Z = a + jb, \quad |Z| = \sqrt{a^2 + b^2}$$

A scalar approximation is then obtained from

$$Q_{\text{approx}} = \frac{(|Z_0| + |Z_1|)}{3|Z_1|}$$

Two values are given in the tables for Q , the scalar approximation conventionally used and the true complex value in r, θ notation.

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4.3 Key To Symbols

The following symbols have been used in the tables in Sections 5 and 6:

Z_p	Self impedance of one phase with earth return.
Z_{pp}	Mutual impedance between two phases with earth return.
Z_1	Positive sequence impedance of a DC1 line.
Z_{1m}	Positive sequence mutual impedance between adjacent circuits.
$* Z_{1dc}$	Positive sequence impedance of a DC line per circuit with equal PPS currents in each circuit flowing in the same direction.
$\dagger Z_0$	Zero sequence impedance of a DC1 line.
$\dagger Z_{0m}$	Zero sequence mutual impedance between adjacent circuits.
Z_{0dc} in	Zero sequence impedance of a DC line per circuit with equal ZPS currents in each circuit flowing the same direction.
B_1	Positive sequence susceptance of a DC1 line.
B_{1m}	Positive sequence mutual susceptance between adjacent circuits.
$* B_{1dc}$	Positive sequence susceptance of a DC line per circuit with equal PPS voltages on each circuit.
B_{1E}	Positive sequence susceptance of a circuit with the other circuit solidly earthed (this parameter is not quoted but can be evaluated from the formula given in Section 4.4 below).
B_0	Zero sequence susceptance of a DC1 line.
$\dagger B_{0m}$	Zero sequence mutual susceptance between adjacent circuits.
$\dagger B_{0dc}$	Zero sequence susceptance of a DC line per circuit with equal ZPS voltages on each circuit.
B_{0E}	Zero sequence susceptance of a circuit with the other circuit solidly earthed (this parameter is not quoted but can be evaluated from the formula given in Section 4.4 below).

All parameters include the effect of the earthwire, and are averaged over the three phase conductors of each circuit.

A DC1 line refers to one circuit of a double-circuit line in which the other circuit is open-circuited at each end.

For the National Grid network analysis programs:

PPS parameters normally used are those marked * above.

ZPS parameters normally used are those marked † above.

4.4 Equations Relating To Impedance Parameters

The impedance parameters are related by the following equations:

$$Z_1 = Z_p - Z_{pp}$$

$$Z_{1dc} = Z_1 - Z_{1m}$$

$$Z_0 = Z_p + 2Z_{pp}$$

$$Z_{0dc} = Z_0 + Z_{0m}$$

$$B_{1dc} = B_{1E} + B_{1m}$$

$$B_1 = \frac{B_{1dc}^2 - 2 B_{1dc} B_{1m}}{B_{1dc} - B_{1m}}$$

$$B_{0dc} = B_{0E} + B_{0m}$$

$$B_0 = \frac{B_{0dc}^2 - 2 B_{0dc} B_{0m}}{B_{0dc} - B_{0m}}$$

5 OVERHEAD LINES

The electrical parameters are tabulated below for standard National Grid overhead line constructions; some constructions used by distribution network operators are also included. The following key table identifies the appropriate page number for each line construction.

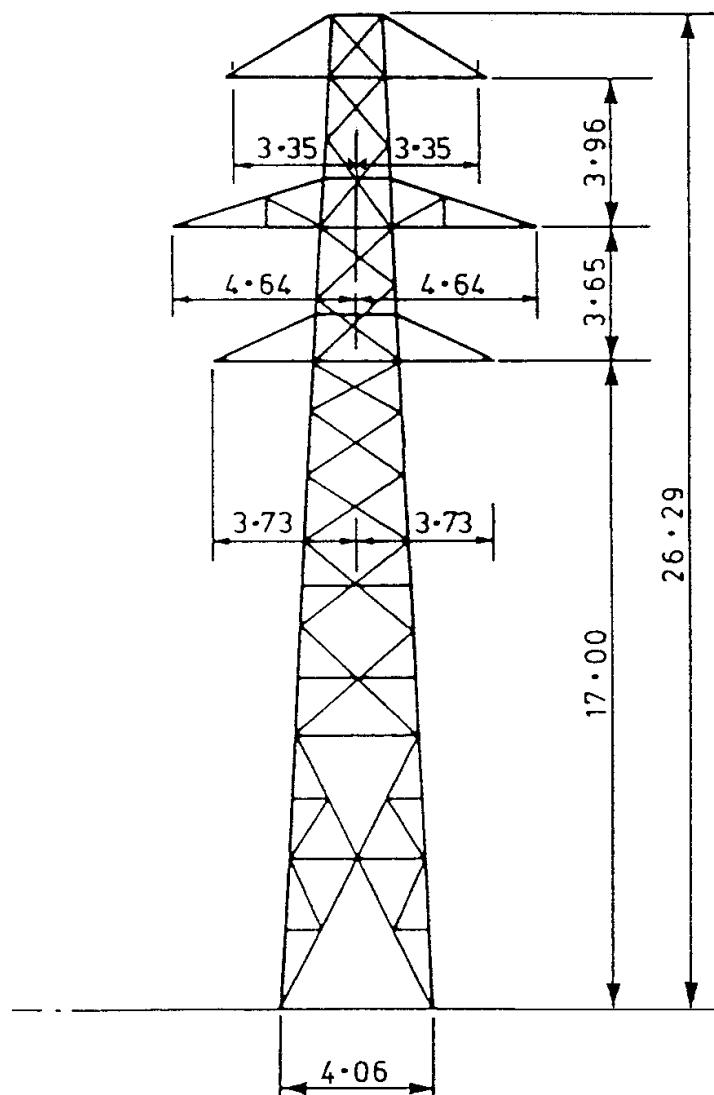
Line configuration	132 kV	275 kV	400 kV
L132	10		
L4	12		
L4M (sag of 1×175 ACSR)	13		
L4M (sag of 1×400 ACSR)	14		
L4/1	15		
L7	17		
L7/1	18		
L7/1 (strung with Finch)	19		
L7/2	20		
L3	22	23	
L3/1		24	
L3/2		25	
L2	27	28	35
L2/1		29	36
L2/1R		30	37
L2/2		31	38
L2/2R		32	39
L2/3		33	40
L2/4		34	41
L2/Compact (withdrawn)			42
L2/6			43
L6	45	47	50
L6/1	46	48	53
L6/2		49	54

L6/2R			55
L6/3R			56
L6/4			57
L6/5			58
L6H			51
L6M			52
L8	60	61	67
L8/1		62	68
L8/1R			69
L8/2		63	70
L8(C)R		64	
L8/3		65	
L8/4		66	71
L9			73
L12			77
L12A			78
L12A/1			79
L34		75	
L66		81	
L66/1		82	
L66/2		83	
L66/2R		84	
L6 and L6/2			85
L6/1 and L6/2			86
L6/1 and L6/4			87
L6/4 and L6/5			88
L8 and L8/6			89
L2 and L2/1			90
L2 and L2/2			91
L2 and L2/4			92
L2 and L2/6			93
L2/1 and L2/2			94
L2/2 and L2/6			95
L3 and L3/1		96	

The first row of each of the following tables in Sections 5 & 6 is colour coded for the appropriate operating voltage, where 132 kV lines are coded black (grey), 275 kV lines red and 400 kV lines blue.

5.1 L132 Lines – 132 kV

L132



CONDUCTOR TYPES

1 × 400 ACSR (L132). EW 1 × 175 ACSR

L132
Ω and μS (/km)

132 kV - Conductors 1 × 175 mm ² ACSR		
Z _p	0.2179 + j 0.6123 Ω	1.949 mH
Z _{pp}	0.0598 + j 0.2099 Ω	0.668 mH
Z ₁	0.1580 + j 0.4023 Ω	1.281 mH
Z _{1m}	-0.0004 - j 0.0110 Ω	-0.035 mH
Z _{1dc}	0.1576 + j 0.3914 Ω	1.246 mH
Z ₀	0.3376 + j 1.0322 Ω	3.286 mH
Z _{0m}	0.1799 + j 0.5183 Ω	1.650 mH
Z _{0dc}	0.5175 + j 1.5505 Ω	4.935 mH
B ₁	2.8449 μS	9.056 nF
B _{1m}	0.0555 μS	0.177 nF
B _{1dc}	2.9039 μS	9.243 nF
B ₀	1.6275 μS	5.180 nF
B _{0m}	-0.4728 μS	-1.505 nF
B _{0dc}	1.2827 μS	4.083 nF

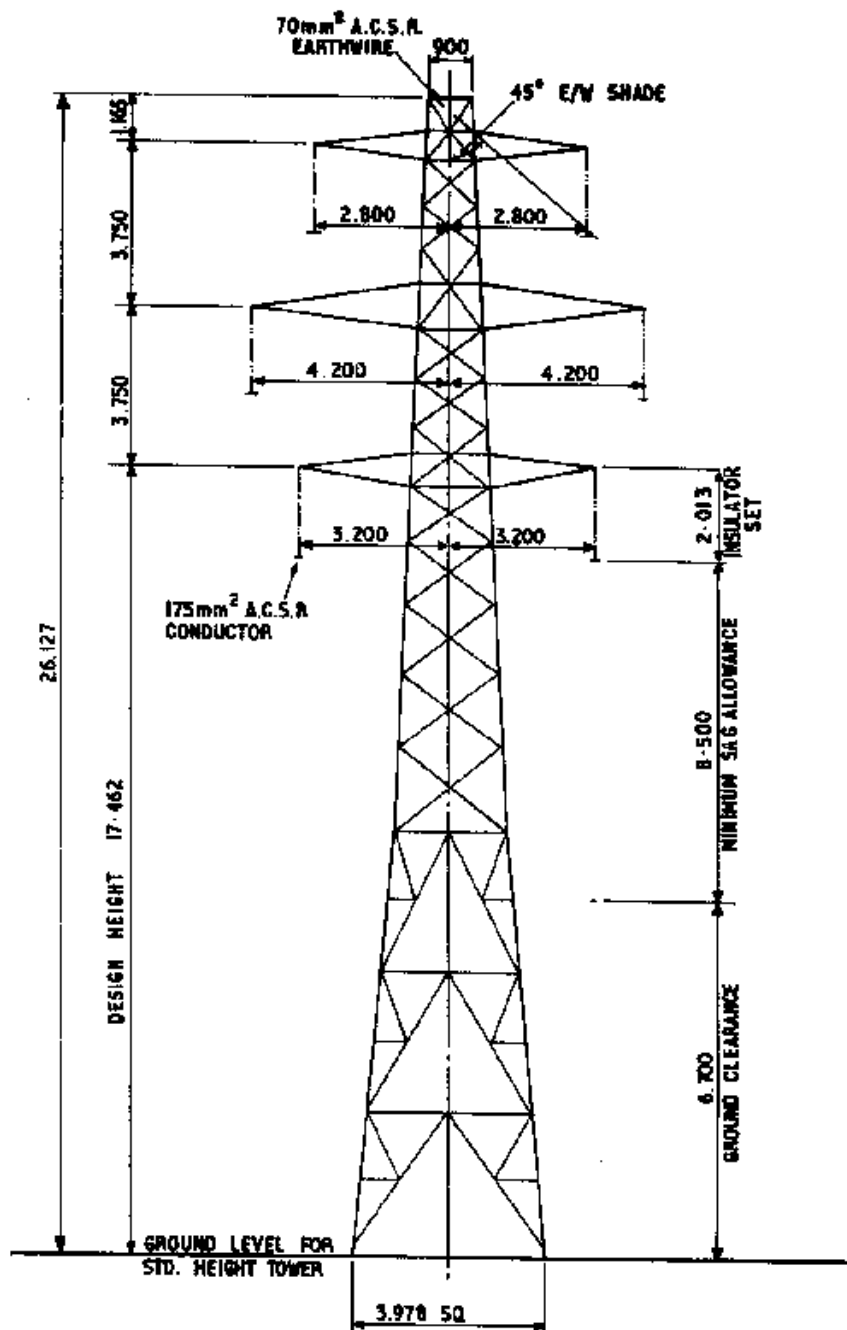
% on 100 MVA (/km)

Z _p	0.1251 + j 0.3514 %
Z _{pp}	0.0343 + j 0.1205 %
Z ₁	0.0907 + j 0.2309 %
Z _{1m}	-0.0002 - j 0.0063 %
Z _{1dc}	0.0905 + j 0.2246 %
Z ₀	0.1937 + j 0.5924 %
Z _{0m}	0.1033 + j 0.2975 %
Z _{0dc}	0.2970 + j 0.8899 %
B ₁	0.0496 %
B _{1m}	0.0010 %
B _{1dc}	0.0506 %
B ₀	0.0284 %
B _{0m}	-0.0082 %
B _{0dc}	0.0224 %

Charging Current	0.217 A/km/φ
Natural Load	47 MW
PPS X/R Ratio	2.483
Residual Compensation Factor (approx) RCF (actual, r,θ (deg))	0.504 0.505∠5.53°

5.2 L4 Lines – 132 kV

L4



CONDUCTOR TYPES

- 1 × 175 ACSR (L4). EW 1 × 70 ACSR
- 1 × 400 ACSR (L4/1). EW 1 × 175 ACSR
- 1 × 300 AAAC (L4M). EW 1 × 160 AAAC

L4
 Ω and μS (/km)

132 kV - Conductors $1 \times 175 \text{ mm}^2$ ACSR		
Z_p	$0.2192 + j 0.6090 \Omega$	1.939 mH
Z_{pp}	$0.0610 + j 0.2073 \Omega$	0.660 mH
Z_1	$0.1581 + j 0.4017 \Omega$	1.279.mH
Z_{1m}	$-0.0005 - j 0.0134 \Omega$	-0.043.mH
Z_{1dc}	$0.1576 + j 0.3883 \Omega$	1.236.mH
Z_0	$0.3412 + j 1.0235 \Omega$	3.258.mH
Z_{0m}	$0.1836 + j 0.5303 \Omega$	1.688.mH
Z_{0dc}	$0.5248 + j 1.5539 \Omega$	4.946.mH
B_1	$2.8489 \mu S$	9.068 nF
B_{1m}	$0.0705 \mu S$	0.224 nF
B_{1dc}	$2.9247 \mu S$	9.310 nF
B_0	$1.6251 \mu S$	5.173 nF
B_{0m}	$-0.5316 \mu S$	-1.692 nF
B_{0dc}	$1.2525 \mu S$	3.987 nF

% on 100 MVA (/km)

Z_p	$0.1258 + j 0.3495 \%$
Z_{pp}	$0.0350 + j 0.1190 \%$
Z_1	$0.0908 + j 0.2306 \%$
Z_{1m}	$-0.0003 - j 0.0077\%$
Z_{1dc}	$0.0905 + j 0.2229 \%$
Z_0	$0.1958 + j 0.5874 \%$
Z_{0m}	$0.1054 + j 0.3044 \%$
Z_{0dc}	$0.3012 + j 0.8918 \%$
B_1	0.0496%
B_{1m}	0.0012%
B_{1dc}	0.0510%
B_0	0.0283%
B_{0m}	-0.0093%
B_{0dc}	0.0218%

Charging Current	$0.217 \text{ A/km}/\phi$
Natural Load	47 MW
PPS X/R Ratio	2.464
Residual Compensation Factor (approx)	0.500
RCF (actual, r, θ (deg))	$0.501 \angle 5.08^\circ$

**L4M (to match sag of 1 × 175mm² ACSR)
Ω and μS (/km)**

132 kV - Conductors 1 × 300 mm ² AAAC		
Z _p	0.1544 + j 0.6009 Ω	1.913 mH
Z _{pp}	0.0615 + j 0.2097 Ω	0.667 mH
Z ₁	0.0929 + j 0.3912 Ω	1.245 mH
Z _{1m}	-0.0005 - j 0.0134 Ω	-0.043 mH
Z _{1dc}	0.09242 + j 0.3778 Ω	1.203 mH
Z ₀	0.2774 + j 1.0203 Ω	3.248 mH
Z _{0m}	0.1850 + j 0.5376 Ω	1.711 mH
Z _{0dc}	0.4625 + j 1.5579 Ω	4.959 mH
B ₁	2.9629 μS	9.431 nF
B _{1m}	0.0757 μS	0.241 nF
B _{1dc}	3.0445 μS	9.691 nF
B ₀	1.6616 μS	5.289 nF
B _{0m}	-0.5582 μS	-1.777 nF
B _{0dc}	1.2740 μS	4.055 nF

% on 100 MVA (/km)

Z _p	0.0886 + j 0.3449 %
Z _{pp}	0.0353 + j 0.1203 %
Z ₁	0.0533 + j 0.2245 %
Z _{1m}	-0.00027 - j 0.0077 %
Z _{1dc}	0.05304 + j 0.2168 %
Z ₀	0.1592 + j 0.5856 %
Z _{0m}	0.1062 + j 0.3086 %
Z _{0dc}	0.2654 + j 0.8941 %
B ₁	0.0516 %
B _{1m}	0.0013 %
B _{1dc}	0.0530 %
B ₀	0.0290 %
B _{0m}	-0.0097 %
B _{0dc}	0.0222 %

Charging Current	0.232 A/km/φ
Natural Load	49.5 MW
PPS X/R Ratio	4.088
Residual Compensation Factor (approx) RCF (actual, r, θ (deg))	0.543 0.544 ∠ -2.99°

**L4M (to match sag of $1 \times 400\text{mm}^2$ ACSR)
 Ω and μS (/km)**

132 kV - Conductors $1 \times 300\text{mm}^2$ AAAC		
Z_p	$0.1571 + j 0.5941 \Omega$	1.891 mH
Z_{pp}	$0.0640 + j 0.2031 \Omega$	0.646 mH
Z_1	$0.0931 + j 0.3909 \Omega$	1.244 mH
Z_{1m}	$-0.0006 - j 0.0132 \Omega$	-0.042 mH
Z_{1dc}	$0.09244 + j 0.3777 \Omega$	1.202 mH
Z_0	$0.2851 + j 1.0000 \Omega$	3.183 mH
Z_{0m}	$0.1927 + j 0.5177 \Omega$	1.648 mH
Z_{0dc}	$0.4777 + j 1.5181 \Omega$	4.832 mH
B_1	$2.9653 \mu\text{S}$	9.439 nF
B_{1m}	$0.0740 \mu\text{S}$	0.236 nF
B_{1dc}	$3.0447 \mu\text{S}$	9.692 nF
B_0	$1.6515 \mu\text{S}$	5.257 nF
B_{0m}	$-0.5610 \mu\text{S}$	-1.786 nF
B_{0dc}	$1.2632 \mu\text{S}$	4.021 nF

% on 100 MVA (/km)

Z_p	$0.0901 + j 0.3410 \%$
Z_{pp}	$0.0367 + j 0.1166 \%$
Z_1	$0.0534 + j 0.2244 \%$
Z_{1m}	$-0.00036 - j 0.0076\%$
Z_{1dc}	$0.05305 + j 0.2168 \%$
Z_0	$0.1636 + j 0.5741 \%$
Z_{0m}	$0.1106 + j 0.2971 \%$
Z_{0dc}	$0.2742 + j 0.8713 \%$
B_1	0.0517%
B_{1m}	0.0013%
B_{1dc}	0.0531%
B_0	0.0288%
B_{0m}	-0.0097%
B_{0dc}	0.0220%

Charging Current	$0.232 \text{ A/km}/\phi$
Natural Load	49.5 MW
PPS X/R Ratio	4.086
Residual Compensation Factor (approx)	0.529
RCF (actual, r, θ (deg))	$0.530 \angle -4.10^\circ$

L4/1
 Ω and μS (/km)

132 kV - Conductors $1 \times 400 \text{ mm}^2$ ACSR		
Z_p	$0.1071 + j 0.5696 \Omega$	1.813 mH
Z_{pp}	$0.0383 + j 0.1910 \Omega$	0.608 mH
Z_1	$0.0688 + j 0.3786 \Omega$	1.205 mH
Z_{1m}	$-0.0003 - j 0.0131 \Omega$	-0.042 mH
Z_{1dc}	$0.0684 + j 0.3656 \Omega$	1.164 mH
Z_0	$0.1838 + j 0.9517 \Omega$	3.029 mH
Z_{0m}	$0.1153 + j 0.4812 \Omega$	1.532 mH
Z_{0dc}	$0.2991 + j 1.4329 \Omega$	4.561 mH
B_1	$3.0389 \mu S$	9.673 nF
B_{1m}	$0.0794 \mu S$	0.253 nF
B_{1dc}	$3.1245 \mu S$	9.946 nF
B_0	$1.6612 \mu S$	5.288 nF
B_{0m}	$-0.5866 \mu S$	-1.867 nF
B_{0dc}	$1.2611 \mu S$	4.014 nF

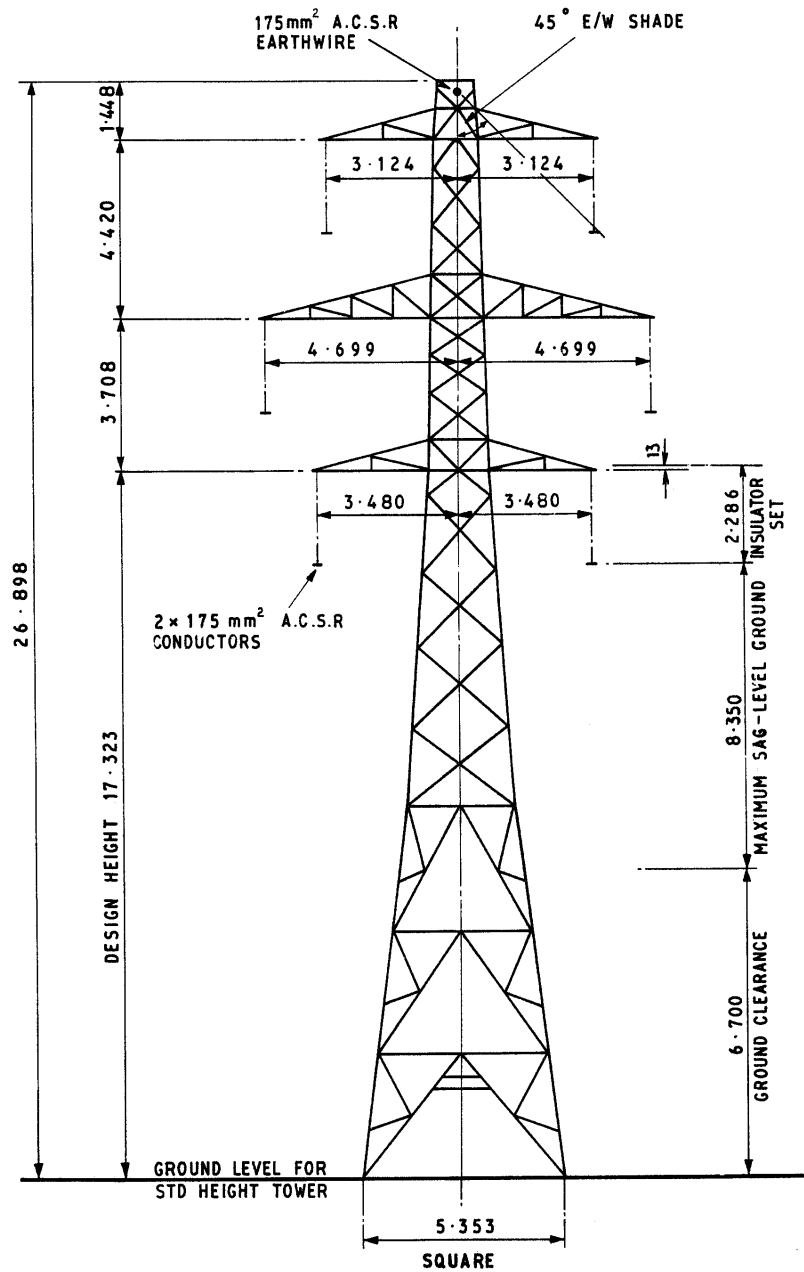
% on 100 MVA (/km)

Z_p	$0.0615 + j 0.3269 \%$
Z_{pp}	$0.0220 + j 0.1096 \%$
Z_1	$0.0395 + j 0.2173 \%$
Z_{1m}	$-0.0002 - j 0.0075 \%$
Z_{1dc}	$0.0393 + j 0.2098 \%$
Z_0	$0.1055 + j 0.5462 \%$
Z_{0m}	$0.0662 + j 0.2762 \%$
Z_{0dc}	$0.1716 + j 0.8224 \%$
B_1	0.0530%
B_{1m}	0.0014%
B_{1dc}	0.0544%
B_0	0.0289%
B_{0m}	-0.0102%
B_{0dc}	0.0220%

Charging Current	$0.232 \text{ A/km}/\phi$
Natural Load	50 MW
PPS X/R Ratio	5.343
Residual Compensation Factor (approx)	0.506
RCF (actual, r, θ (deg))	$0.506 \angle -1.05^\circ$

5.3 L7 Lines – 132 kV

L7



CONDUCTOR TYPES

2 x 175 ACSR (L7). EW 1 x 175 ACSR
1 x 400 ACSR (L7/1). EW 1 x 175 ACSR
2 x 400 ACSR (L7/2). EW 1 x 175 ACSR

L7
Ω and μS (/km)

132 kV - Conductors 2 × 175 mm ² ACSR		
Z _p	0.1173 + j 0.4822 Ω	1.535 mH
Z _{pp}	0.0382 + j 0.1893 Ω	0.603 mH
Z ₁	0.0792 + j 0.2929 Ω	0.932 mH
Z _{1m}	-0.0003 - j 0.0128 Ω	-0.041 mH
Z _{1dc}	0.0788 + j 0.2801 Ω	0.892 mH
Z ₀	0.1936 + j 0.8608 Ω	2.740 mH
Z _{0m}	0.1148 + j 0.4731 Ω	1.506 mH
Z _{0dc}	0.3084 + j 1.3339 Ω	4.246 mH
B ₁	3.8977 μS	12.407 nF
B _{1m}	0.1159 μS	0.369 nF
B _{1dc}	4.0253 μS	12.813 nF
B ₀	1.9823 μS	6.310 nF
B _{0m}	-0.7266 μS	-2.313 nF
B _{0dc}	1.4943 μS	4.757 nF

% on 100 MVA (/km)

Z _p	0.0673 + j 0.2768 %
Z _{pp}	0.0219 + j 0.1087 %
Z ₁	0.0454 + j 0.1681 %
Z _{1m}	-0.0002 - j 0.0074 %
Z _{1dc}	0.0452 + j 0.1608 %
Z ₀	0.1111 + j 0.4941 %
Z _{0m}	0.0659 + j 0.2715 %
Z _{0dc}	0.1770 + j 0.7655 %
B ₁	0.0679 %
B _{1m}	0.0020 %
B _{1dc}	0.0701 %
B ₀	0.0345 %
B _{0m}	-0.0127 %
B _{0dc}	0.0260 %

Charging Current	0.297 A/km/φ
Natural Load	65 MW
PPS X/R Ratio	3.553
Residual Compensation Factor (approx)	0.636
RCF (actual, r,θ (deg))	0.636∠3.74°

L7/1
 Ω and μS (/km)

132 kV - Conductors $1 \times 400 \text{ mm}^2$ ACSR		
Z_p	$0.1084 + j 0.5804 \Omega$	1.847 mH
Z_{pp}	$0.0385 + j 0.1936 \Omega$	0.616 mH
Z_1	$0.0699 + j 0.3867 \Omega$	1.231 mH
Z_{1m}	$-0.0003 - j 0.0129 \Omega$	-0.041 mH
Z_{1dc}	$0.0696 + j 0.3738 \Omega$	1.190 mH
Z_0	$0.1853 + j 0.9677 \Omega$	3.080 mH
Z_{0m}	$0.1157 + j 0.4861 \Omega$	1.547 mH
Z_{0dc}	$0.3010 + j 1.4538 \Omega$	4.628 mH
B_1	$3.0011 \mu S$	9.553 nF
B_{1m}	$0.0729 \mu S$	0.232 nF
B_{1dc}	$3.080 \mu S$	9.804 nF
B_0	$1.728 \mu S$	5.500 nF
B_{0m}	$-0.5292 \mu S$	-1.684 nF
B_{0dc}	$1.3486 \mu S$	4.293 nF

% on 100 MVA (/km)

Z_p	$0.0622 + j 0.3331 \%$
Z_{pp}	$0.0221 + j 0.1111 \%$
Z_1	$0.0401 + j 0.2220 \%$
Z_{1m}	$-0.0002 - j 0.0074 \%$
Z_{1dc}	$0.0400 + j 0.2146 \%$
Z_0	$0.1064 + j 0.5554 \%$
Z_{0m}	$0.0664 + j 0.2790 \%$
Z_{0dc}	$0.1728 + j 0.8344 \%$
B_1	0.0523 %
B_{1m}	0.0013 %
B_{1dc}	0.0537 %
B_0	0.0301 %
B_{0m}	-0.0092 %
B_{0dc}	0.0235 %

Charging Current	0.235 A/km/ ϕ
Natural Load	50.0 MW
PPS X/R Ratio	5.37
Residual Compensation Factor (approx)	0.502
RCF (actual, r, θ (deg))	$0.502 \angle -1.0^\circ$

L7/1 Finch (550 mm² ACSR)
Ω and μS (/km)

132 kV - Conductors 1 × 550 mm ² ACSR (Finch)		
Z _p	0.0849 + j 0.5716 Ω	1.819 mH
Z _{pp}	0.0385 + j 0.1936 Ω	0.616 mH
Z ₁	0.0464 + j 0.3779 Ω	1.203 mH
Z _{1m}	-0.0003 - j 0.0129 Ω	-0.041 mH
Z _{1dc}	0.0461 + j 0.3650 Ω	1.162 mH
Z ₀	0.1618 + j 0.9589 Ω	3.052 mH
Z _{0m}	0.1157 + j 0.4861 Ω	1.547 mH
Z _{0dc}	0.2776 + j 1.4450 Ω	4.600 mH
B ₁	3.074 μS	9.785 nF
B _{1m}	0.0761 μS	0.242 nF
B _{1dc}	3.156 μS	10.059 nF
B ₀	1.752 μS	5.577 nF
B _{0m}	-0.5452 μS	-1.735 nF
B _{0dc}	1.3631 μS	4.339 nF

% on 100 MVA (/km)

Z _p	0.0487 + j 0.3280 %
Z _{pp}	0.0221 + j 0.1111 %
Z ₁	0.0267 + j 0.2169 %
Z _{1m}	-0.0002 - j 0.0074 %
Z _{1dc}	0.0264 + j 0.2095 %
Z ₀	0.0929 + j 0.5503 %
Z _{0m}	0.0664 + j 0.2790 %
Z _{0dc}	0.1593 + j 0.8293 %
B ₁	0.05356 %
B _{1m}	0.00133 %
B _{1dc}	0.0550 %
B ₀	0.03052 %
B _{0m}	-0.0095 %
B _{0dc}	0.0238 %

Charging Current	0.241 A/km/φ
Natural Load	51.2 MW
PPS X/R Ratio	7.91
Residual Compensation Factor (approx.)	0.518
RCF (actual, r,θ (deg))	0.519∠-4.2°

L7/2
 Ω and μS (/km)

132 kV - Conductors $2 \times 400 \text{ mm}^2$ ACSR		
Z_p	$0.0726 + j 0.4715 \Omega$	1.501 mH
Z_{pp}	$0.0380 + j 0.1900 \Omega$	0.605 mH
Z_1	$0.0346 + j 0.2815 \Omega$	0.896 mH
Z_{1m}	$-0.0003 - j 0.0128 \Omega$	-0.069 mH
Z_{1dc}	$0.0342 + j 0.2687 \Omega$	0.855 mH
Z_0	$0.1485 + j 0.8514 \Omega$	2.710 mH
Z_{0m}	$0.1143 + j 0.4750 \Omega$	1.512 mH
Z_{0dc}	$0.2628 + j 1.3264 \Omega$	4.222 mH
B_1	$4.0674 \mu S$	12.947 nF
B_{1m}	$0.1283 \mu S$	0.408 nF
B_{1dc}	$4.2093 \mu S$	13.399 nF
B_0	$1.9691 \mu S$	6.268 nF
B_{0m}	$-0.7889 \mu S$	-2.511 nF
B_{0dc}	$1.4578 \mu S$	4.640 nF

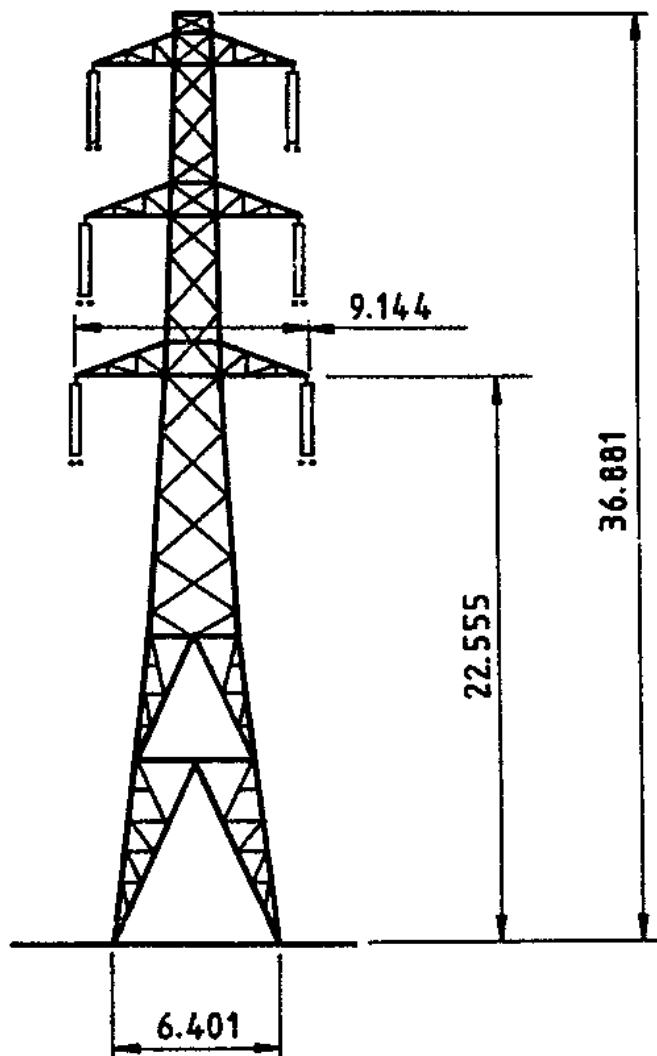
% on 100 MVA (/km)

Z_p	$0.0416 + j 0.2706 \%$
Z_{pp}	$0.0218 + j 0.1090 \%$
Z_1	$0.0198 + j 0.1616 \%$
Z_{1m}	$-0.0002 - j 0.0074 \%$
Z_{1dc}	$0.0197 + j 0.1542 \%$
Z_0	$0.0852 + j 0.4886 \%$
Z_{0m}	$0.0656 + j 0.2726 \%$
Z_{0dc}	$0.1508 + j 0.7612 \%$
B_1	0.0709%
B_{1m}	0.0022%
B_{1dc}	0.0733%
B_0	0.0343%
B_{0m}	-0.0138%
B_{0dc}	0.0254%

Charging Current	0.31 A/km/ ϕ
Natural Load	68 MW
PPS X/R Ratio	7.850
Residual Compensation Factor (approx)	1.85
RCF (actual, r, θ (deg))	$1.85 \angle 2.86^\circ$

5.4 L3 Lines – 132 kV

L3



CONDUCTOR TYPES

2 × 175 ACSR (L3). EW 1 × 175 ACSR

1 × 700 AAAC (L3/1). EW 1 × 160 AACSR

2 × 300 AAAC (L3/2). EW 1 × 160 AACSR

L3
 Ω and μS (/km)

132 kV - Conductors $2 \times 175 \text{ mm}^2$ ACSR		
Z_p	$0.1166 + j 0.4961 \Omega$	1.579 mH
Z_{pp}	$0.0369 + j 0.1801 \Omega$	0.573 mH
Z_1	$0.0797 + j 0.3160 \Omega$	1.006 mH
Z_{1m}	$-0.0004 - j 0.0133 \Omega$	-0.042 mH
Z_{1dc}	$0.0793 + j 0.3028 \Omega$	0.964 mH
Z_0	$0.1904 + j 0.8562 \Omega$	2.725 mH
Z_{0m}	$0.1110 + j 0.4780 \Omega$	1.522 mH
Z_{0dc}	$0.3013 + j 1.3342 \Omega$	4.247 mH
B_1	$3.6103 \mu S$	11.492 nF
B_{1m}	$0.0977 \mu S$	0.311 nF
B_{1dc}	$3.7203 \mu S$	11.842 nF
B_0	$1.9721 \mu S$	6.277 nF
B_{0m}	$-0.7639 \mu S$	-0.243 nF
B_{0dc}	$1.4728 \mu S$	4.688 nF

% on 100 MVA (/km)

Z_p	$0.0669 + j 0.2847 \%$
Z_{pp}	$0.0212 + j 0.1033 \%$
Z_1	$0.0458 + j 0.1814 \%$
Z_{1m}	$-0.0002 - j 0.0076 \%$
Z_{1dc}	$0.0455 + j 0.1738 \%$
Z_0	$0.1093 + j 0.4914 \%$
Z_{0m}	$0.0637 + j 0.2743 \%$
Z_{0dc}	$0.1730 + j 0.7657 \%$
B_1	0.0629%
B_{1m}	0.0017%
B_{1dc}	0.0648%
B_0	0.0344%
B_{0m}	-0.0133%
B_{0dc}	0.0257%

Charging Current	$0.275 \text{ A/km}/\phi$
Natural Load	60 MW
PPS X/R Ratio	3.818
Residual Compensation Factor (approx)	0.564
RCF (actual, r, θ (deg))	$0.564 \angle 2.58^\circ$

5.5 L3 Lines – 275 kV

L3 Ω and μS (/km)

275 kV - Conductors 2 × 175 mm ² ACSR		
Z _p	0.1166 + j 0.4961 Ω	1.579 mH
Z _{pp}	0.0369 + j 0.1801 Ω	0.573 mH
Z ₁	0.0797 + j 0.3160 Ω	1.006 mH
Z _{1m}	-0.0004 - j 0.0133 Ω	-0.042 mH
Z _{1dc}	0.0793 + j 0.3028 Ω	0.964 mH
Z ₀	0.1904 + j 0.8562 Ω	2.725 mH
Z _{0m}	0.1110 + j 0.4780 Ω	1.522 mH
Z _{0dc}	0.3013 + j 1.3342 Ω	4.247 mH
B ₁	3.6103 μS	11.492 nF
B _{1m}	0.0977 μS	0.311 nF
B _{1dc}	3.7203 μS	11.842 nF
B ₀	1.9721 μS	6.277 nF
B _{0m}	-0.7639 μS	-0.243 nF
B _{0dc}	1.4728 μS	4.688 nF

% on 100 MVA (/km)

Z _p	0.0154 + j 0.0656 %
Z _{pp}	0.0049 + j 0.0238 %
Z ₁	0.0105 + j 0.0418 %
Z _{1m}	-0.0001 - j 0.0018 %
Z _{1dc}	0.0105 + j 0.0400 %
Z ₀	0.0252 + j 0.1132 %
Z _{0m}	0.0147 + j 0.0632 %
Z _{0dc}	0.0399 + j 0.1764 %
B ₁	0.2730 %
B _{1m}	0.0074 %
B _{1dc}	0.2814 %
B ₀	0.1491 %
B _{0m}	-0.0578 %
B _{0dc}	0.1114 %

Charging Current	0.573 A/km/φ
Natural Load	261 MW
PPS X/R Ratio	3.818
Residual Compensation Factor (approx) RCF (actual, r, θ (deg))	0.564 0.564 ∠ 2.58°

L3/1
 Ω and μS (/km)

275 kV - Conductors $1 \times 700 \text{ mm}^2$ AAAC		
Z_p	$0.0797 + j 0.5759 \Omega$	1.833 mH
Z_{pp}	$0.0384 + j 0.1825 \Omega$	0.581 mH
Z_1	$0.0413 + j 0.3934 \Omega$	1.252 mH
Z_{1m}	$-0.0004 - j 0.0134 \Omega$	-0.043 mH
Z_{1dc}	$0.0409 + j 0.3801 \Omega$	1.210 mH
Z_0	$0.1565 + j 0.9409 \Omega$	2.995 mH
Z_{0m}	$0.1156 + j 0.4855 \Omega$	1.545 mH
Z_{0dc}	$0.2721 + j 1.4264 \Omega$	4.540 mH
B_1	$2.9537 \mu S$	9.402 nF
B_{1m}	$0.0696 \mu S$	0.222 nF
B_{1dc}	$3.0307 \mu S$	9.647 nF
B_0	$1.7528 \mu S$	5.579 nF
B_{0m}	$-0.5968 \mu S$	-1.900 nF
B_{0dc}	$1.3423 \mu S$	4.273 nF

% on 100 MVA (/km)

Z_p	$0.0105 + j 0.0762 \%$
Z_{pp}	$0.0051 + j 0.0241 \%$
Z_1	$0.0055 + j 0.0520 \%$
Z_{1m}	$-0.0001 - j 0.0018 \%$
Z_{1dc}	$0.0054 + j 0.0503 \%$
Z_0	$0.0207 + j 0.1244 \%$
Z_{0m}	$0.0153 + j 0.0642 \%$
Z_{0dc}	$0.0360 + j 0.1886 \%$
B_1	0.2234 %
B_{1m}	0.0053 %
B_{1dc}	0.2292 %
B_0	0.1326 %
B_{0m}	-0.0451 %
B_{0dc}	0.1015 %

Charging Current	0.469 A/km/ ϕ
Natural Load	211 MW
PPS X/R Ratio	9.290
Residual Compensation Factor (approx)	0.470
RCF (actual, r, θ (deg))	$0.470 \angle -5.89^\circ$

L3/2 *
 Ω and μS (/km)

275 kV - Conductors $2 \times 300 \text{ mm}^2$ AAAC		
Z_p	$0.0672 + j 0.4687 \Omega$	1.492 mH
Z_{pp}	$0.0226 + j 0.1583 \Omega$	0.504 mH
Z_1	$0.0446 + j 0.3104 \Omega$	0.988 mH
Z_{1m}	$-0.0002 - j 0.0129 \Omega$	-0.041 mH
Z_{1dc}	$0.04437 + j 0.2975 \Omega$	0.947 mH
Z_0	$0.1124 + j 0.7852 \Omega$	2.499 mH
Z_{0m}	$0.0680 + j 0.4123 \Omega$	1.312 mH
Z_{0dc}	$0.1803 + j 1.1975 \Omega$	3.812 mH
B_1	$3.7037 \mu\text{S}$	11.789 nF
B_{1m}	$0.0966 \mu\text{S}$	0.307 nF
B_{1dc}	$3.812 \mu\text{S}$	12.134 nF
B_0	$2.0822 \mu\text{S}$	6.628 nF
B_{0m}	$-0.7386 \mu\text{S}$	-2.351 nF
B_{0dc}	$1.5805 \mu\text{S}$	5.031 nF

% on 100 MVA (/km)

Z_p	$0.00889 + j 0.0620 \%$
Z_{pp}	$0.00299 + j 0.0209 \%$
Z_1	$0.00590 + j 0.0410 \%$
Z_{1m}	$-0.00003 - j 0.0017 \%$
Z_{1dc}	$0.00587 + j 0.0393 \%$
Z_0	$0.0149 + j 0.1038 \%$
Z_{0m}	$0.00899 + j 0.0545 \%$
Z_{0dc}	$0.0238 + j 0.1583 \%$
B_1	0.2801 %
B_{1m}	0.0073 %
B_{1dc}	0.2883 %
B_0	0.1575 %
B_{0m}	-0.0559 %
B_{0dc}	0.1195 %

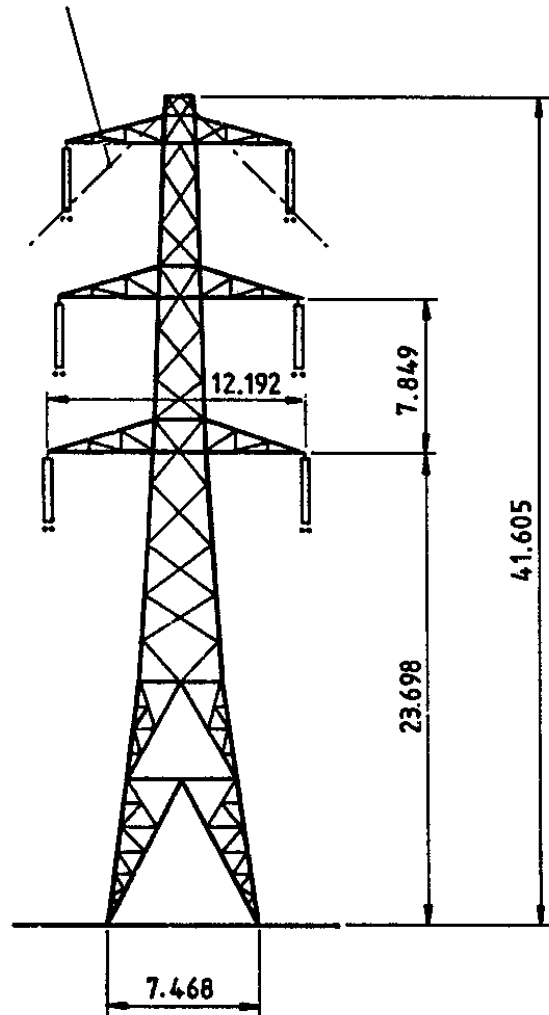
Charging Current	0.605 A/km/ ϕ
Natural Load	271 MW
PPS X/R Ratio	6.71
Residual Compensation Factor (approx)	0.510
RCF (actual, r, θ (deg))	$0.510 \angle 0.06^\circ$

* in limited use on some specific spans, see TPS 2.4.2

5.6 L2 Lines – 132 kV

L2

EARTH WIRE SHIELDING
ANGLE 45°



CONDUCTOR TYPES

- 2 × 400 ACSR (L2). EW 1 × 175 ACSR
- 2 × 500 ACAR (L2/1). EW 1 × 175 ACSR
- 2 × 500 AAAC (L2/2). EW 1 × 160 AACSR
- 2 × 425 AAAC (L2/3) . EW 1 × 160 AACSR
- 2 × 570 AAAC (L2/4) . EW 1 × 160 AACSR
- 2 × 635 AAAC (L2/5) . EW 1 × 160 AACSR
- 2 × 620 AACSR (L2/6) . EW 1 × 160 AACSR

L2
 Ω and μS (/km)

132 kV - Conductors $2 \times 400 \text{ mm}^2$ ACSR		
Z_p	$0.0708 + j 0.4953 \Omega$	1.577 mH
Z_{pp}	$0.0361 + j 0.1751 \Omega$	0.557 mH
Z_1	$0.0346 + j 0.3203 \Omega$	1.020 mH
Z_{1m}	$-0.0004 - j 0.0126 \Omega$	-0.040 mH
Z_{1dc}	$0.0342 + j 0.3077 \Omega$	0.979 mH
Z_0	$0.1430 + j 0.8454 \Omega$	2.691 mH
Z_{0m}	$0.1087 + j 0.4567 \Omega$	1.454 mH
Z_{0dc}	$0.2517 + j 1.3022 \Omega$	4.145 mH
B_1	$3.5803 \mu S$	11.396 nF
B_{1m}	$0.0843 \mu S$	0.268 nF
B_{1dc}	$3.6750 \mu S$	11.698 nF
B_0	$2.0633 \mu S$	6.568 nF
B_{0m}	$-0.6790 \mu S$	-2.161 nF
B_{0dc}	$1.5930 \mu S$	5.071 nF

% on 100 MVA (/km)

Z_p	$0.0406 + j 0.2843 \%$
Z_{pp}	$0.0207 + j 0.1005 \%$
Z_1	$0.0199 + j 0.1838 \%$
Z_{1m}	$-0.0003 - j 0.0072 \%$
Z_{1dc}	$0.0196 + j 0.1766 \%$
Z_0	$0.0821 + j 0.4852 \%$
Z_{0m}	$0.0624 + j 0.2621 \%$
Z_{0dc}	$0.1445 + j 0.7473 \%$
B_1	0.0624%
B_{1m}	0.0015%
B_{1dc}	0.0640%
B_0	0.0360%
B_{0m}	-0.0118%
B_{0dc}	0.0278%

Charging Current	0.273 A/km/ ϕ
Natural Load	59 MW
PPS X/R Ratio	8.995
Residual Compensation Factor (approx)	0.554
RCF (actual, r, θ (deg))	$0.554 \angle -5.50^\circ$

5.7 L2 Lines – 275 kV

L2

Ω and μS (/km)

275 kV - Conductors $2 \times 400 \text{ mm}^2$ ACSR		
Z_p	$0.0708 + j 0.4922 \Omega$	1.567 mH
Z_{pp}	$0.0362 + j 0.1721 \Omega$	0.548 mH
Z_1	$0.0347 + j 0.3201 \Omega$	1.019 mH
Z_{1m}	$-0.0005 - j 0.0124 \Omega$	-0.039 mH
Z_{1dc}	$0.0342 + j 0.3077 \Omega$	0.979 mH
Z_0	$0.1432 + j 0.8365 \Omega$	2.663 mH
Z_{0m}	$0.1088 + j 0.4478 \Omega$	1.425 mH
Z_{0dc}	$0.2520 + j 1.2842 \Omega$	4.088 mH
B_1	$3.5774 \mu S$	11.387 nF
B_{1m}	$0.0849 \mu S$	0.270 nF
B_{1dc}	$3.6723 \mu S$	11.689 nF
B_0	$2.0341 \mu S$	6.475 nF
B_{0m}	$-0.6902 \mu S$	-2.197 nF
B_{0dc}	$1.5601 \mu S$	4.966 nF

% on 100 MVA (/km)

Z_p	$0.0094 + j 0.0651 \%$
Z_{pp}	$0.0048 + j 0.0228 \%$
Z_1	$0.0046 + j 0.0423 \%$
Z_{1m}	$-0.0001 - j 0.0016 \%$
Z_{1dc}	$0.0045 + j 0.0407 \%$
Z_0	$0.0189 + j 0.1106 \%$
Z_{0m}	$0.0144 + j 0.0592 \%$
Z_{0dc}	$0.0333 + j 0.1698 \%$
B_1	0.2705 %
B_{1m}	0.0064 %
B_{1dc}	0.2777 %
B_0	0.1538 %
B_{0m}	-0.0522 %
B_{0dc}	0.1180 %

Charging Current	0.568 A/km/ ϕ
Natural Load	258 MW
PPS X/R Ratio	8.994
Residual Compensation Factor (approx)	0.545
RCF (actual, r, θ (deg))	$0.546 \angle -5.68^\circ$

L2/1
Ω and μS (/km)

275 kV - Conductors 2 × 500 mm ² ACAR		
Z _p	0.0660 + j 0.4920 Ω	1.566 mH
Z _{pp}	0.0361 + j 0.1727 Ω	0.550 mH
Z ₁	0.0299 + j 0.3194 Ω	1.017 mH
Z _{1m}	-0.0005 - j 0.0125 Ω	-0.040 mH
Z _{1dc}	0.0295 + j 0.3069 Ω	0.977 mH
Z ₀	0.1382 + j 0.8374 Ω	2.666 mH
Z _{0m}	0.1086 + j 0.4495 Ω	1.431 mH
Z _{0dc}	0.2468 + j 1.2869 Ω	4.096 mH
B ₁	3.5967 μS	11.449 nF
B _{1m}	0.0870 μS	0.277 nF
B _{1dc}	3.6938 μS	11.758 nF
B ₀	2.0258 μS	6.448 nF
B _{0m}	-0.7023 μS	-2.235 nF
B _{0dc}	1.5471 μS	4.925 nF

% on 100 MVA (/km)

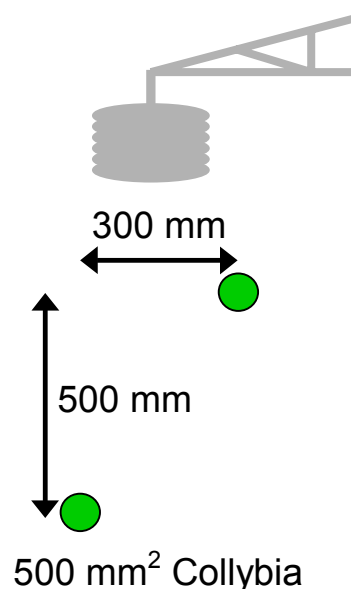
Z _p	0.0087 + j 0.0651 %
Z _{pp}	0.0048 + j 0.0228 %
Z ₁	0.0040 + j 0.0422 %
Z _{1m}	-0.0001 - j 0.0017 %
Z _{1dc}	0.0039 + j 0.0406 %
Z ₀	0.0183 + j 0.1107 %
Z _{0m}	0.0144 + j 0.0594 %
Z _{0dc}	0.0326 + j 0.1702 %
B ₁	0.2720 %
B _{1m}	0.0066 %
B _{1dc}	0.2793 %
B ₀	0.1532 %
B _{0m}	-0.0531 %
B _{0dc}	0.1170 %

Charging Current	0.571 A/km/φ
Natural Load	259 MW
PPS X/R Ratio	10.418
Residual Compensation Factor (approx)	0.549
RCF (actual, r,θ (deg))	0.550∠-6.46°

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**L2/1R (insulated to 400 kV, rotated bundle)
 Ω and μS (/km)**

275 kV - Conductors $2 \times 500 \text{ mm}^2$ ACAR		
Z_p	$0.0660 + j 0.4712 \Omega$	1.500 mH
Z_{pp}	$0.0361 + j 0.1727 \Omega$	0.550 mH
Z_1	$0.0299 + j 0.2985 \Omega$	0.950 mH
Z_{1m}	$-0.0005 - j 0.0125 \Omega$	-0.040 mH
Z_{1dc}	$0.0295 + j 0.2860 \Omega$	0.910 mH
Z_0	$0.1382 + j 0.8165 \Omega$	2.599 mH
Z_{0m}	$0.1086 + j 0.4495 \Omega$	1.431 mH
Z_{0dc}	$0.2468 + j 1.2660 \Omega$	4.030 mH
B_1	$3.8630 \mu S$	12.296 nF
B_{1m}	$0.0984 \mu S$	0.218 nF
B_{1dc}	$3.9736 \mu S$	12.648 nF
B_0	$2.1078 \mu S$	6.709 nF
B_{0m}	$-0.7662 \mu S$	-2.439 nF
B_{0dc}	$1.5952 \mu S$	5.078 nF



% on 100 MVA (/km)

Z_p	$0.0087 + j 0.0623 \%$
Z_{pp}	$0.0048 + j 0.0228 \%$
Z_1	$0.0040 + j 0.0395 \%$
Z_{1m}	$-0.0001 - j 0.0017 \%$
Z_{1dc}	$0.0039 + j 0.0378 \%$
Z_0	$0.0183 + j 0.1080 \%$
Z_{0m}	$0.0144 + j 0.0594 \%$
Z_{0dc}	$0.0326 + j 0.1674 \%$
B_1	0.2921 %
B_{1m}	0.0074 %
B_{1dc}	0.3005 %
B_0	0.1594 %
B_{0m}	-0.0579 %
B_{0dc}	0.1206 %

Charging Current	0.613 A/km/ ϕ
Natural Load	278 MW
PPS X/R Ratio	9.709
Residual Compensation Factor (approx)	0.587
RCF (actual, r, θ (deg))	$0.588 \angle -6.09^\circ$

L2/2

Ω and μS (/km)

275 kV - Conductors $2 \times 500 \text{ mm}^2$ AAAC		
Z_p	$0.0660 + j 0.4837 \Omega$	1.540 mH
Z_{pp}	$0.0376 + j 0.1740 \Omega$	0.554 mH
Z_1	$0.0284 + j 0.3097 \Omega$	0.986 mH
Z_{1m}	$-0.0005 - j 0.0125 \Omega$	-0.040 mH
Z_{1dc}	$0.0279 + j 0.2972 \Omega$	0.946 mH
Z_0	$0.1412 + j 0.8317 \Omega$	2.647 mH
Z_{0m}	$0.1132 + j 0.4535 \Omega$	1.444 mH
Z_{0dc}	$0.2543 + j 1.2852 \Omega$	4.091 mH
B_1	$3.7233 \mu S$	11.852 nF
B_{1m}	$0.0922 \mu S$	0.293 nF
B_{1dc}	$3.8267 \mu S$	12.181 nF
B_0	$2.0748 \mu S$	6.604 nF
B_{0m}	$-0.7290 \mu S$	-2.320 nF
B_{0dc}	$1.5809 \mu S$	5.032 nF

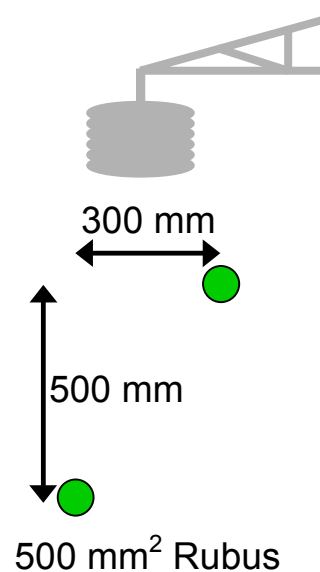
% on 100 MVA (/km)

Z_p	$0.0087 + j 0.0640 \%$
Z_{pp}	$0.0050 + j 0.0230 \%$
Z_1	$0.0038 + j 0.0410 \%$
Z_{1m}	$-0.0001 - j 0.0017 \%$
Z_{1dc}	$0.0037 + j 0.0393 \%$
Z_0	$0.0187 + j 0.1100 \%$
Z_{0m}	$0.0150 + j 0.0600 \%$
Z_{0dc}	$0.0336 + j 0.1699 \%$
B_1	0.2816 %
B_{1m}	0.0070 %
B_{1dc}	0.2894 %
B_0	0.1569 %
B_{0m}	-0.0551 %
B_{0dc}	0.1196 %

Charging Current	0.591 A/km/ ϕ
Natural Load	268 MW
PPS X/R Ratio	10.647
Residual Compensation Factor (approx)	0.571
RCF (actual, r, θ (deg))	$0.572 \angle -6.95^\circ$

**L2/2R (insulated to 400 kV, rotated bundle)
 Ω and μS (/km)**

275 kV - Conductors $2 \times 500 \text{ mm}^2$ AAAC		
Z_p	$0.0662 + j 0.4687 \Omega$	1.492 mH
Z_{pp}	$0.0377 + j 0.1710 \Omega$	0.544 mH
Z_1	$0.0284 + j 0.2977 \Omega$	0.948 mH
Z_{1m}	$-0.0005 - j 0.0124 \Omega$	-0.039 mH
Z_{1dc}	$0.0279 + j 0.2853 \Omega$	0.908 mH
Z_0	$0.1416 + j 0.8107 \Omega$	2.581 mH
Z_{0m}	$0.1136 + j 0.4444 \Omega$	1.415 mH
Z_{0dc}	$0.2552 + j 1.2550 \Omega$	3.995 mH
B_1	$3.8784 \mu S$	12.345 nF
B_{1m}	$0.0992 \mu S$	0.316 nF
B_{1dc}	$3.9897 \mu S$	12.700 nF
B_0	$2.0975 \mu S$	6.677 nF
B_{0m}	$-0.7755 \mu S$	-2.468 nF
B_{0dc}	$1.5814 \mu S$	5.034 nF



% on 100 MVA (/km)

Z_p	$0.0088 + j 0.0620 \%$
Z_{pp}	$0.0050 + j 0.0226 \%$
Z_1	$0.0038 + j 0.0394 \%$
Z_{1m}	$-0.0001 - j 0.0016 \%$
Z_{1dc}	$0.0037 + j 0.0377 \%$
Z_0	$0.0187 + j 0.1072 \%$
Z_{0m}	$0.0150 + j 0.0588 \%$
Z_{0dc}	$0.0337 + j 0.1660 \%$
B_1	0.2933%
B_{1m}	0.0075%
B_{1dc}	0.3017%
B_0	0.1586%
B_{0m}	-0.0587%
B_{0dc}	0.1196%

Charging Current	$0.616 \text{ A/km}/\phi$
Natural Load	279 MW
PPS X/R Ratio	10.223
Residual Compensation Factor (approx)	0.584
RCF (actual, r, θ (deg))	$0.586 \angle -6.99^\circ$

L2/3
 Ω and μS (/km)

275 kV - Conductors $2 \times 425 \text{ mm}^2$ AAAC		
Z_p	$0.0709 + j 0.4920 \Omega$	1.566 mH
Z_{pp}	$0.0377 + j 0.1707 \Omega$	0.543 mH
Z_1	$0.0331 + j 0.3213 \Omega$	1.023 mH
Z_{1m}	$-0.0005 - j 0.0124 \Omega$	-0.039 mH
Z_{1dc}	$0.0326 + j 0.3090 \Omega$	0.984 mH
Z_0	$0.1464 + j 0.8334 \Omega$	2.653 mH
Z_{0m}	$0.1137 + j 0.4433 \Omega$	1.411 mH
Z_{0dc}	$0.2600 + j 1.2767 \Omega$	4.064 mH
B_1	$3.5789 \mu S$	11.392 nF
B_{1m}	$0.0863 \mu S$	0.275 nF
B_{1dc}	$3.6749 \mu S$	11.698 nF
B_0	$2.0046 \mu S$	6.381 nF
B_{0m}	$-0.7042 \mu S$	-2.242 nF
B_{0dc}	$1.5263 \mu S$	4.858 nF

% on 100 MVA (/km)

Z_p	$0.0094 + j 0.0651 \%$
Z_{pp}	$0.0050 + j 0.0226 \%$
Z_1	$0.0044 + j 0.0425 \%$
Z_{1m}	$-0.0001 - j 0.0016 \%$
Z_{1dc}	$0.0043 + j 0.0409 \%$
Z_0	$0.0194 + j 0.1102 \%$
Z_{0m}	$0.0150 + j 0.0586 \%$
Z_{0dc}	$0.0344 + j 0.1688 \%$
B_1	0.2707 %
B_{1m}	0.0065 %
B_{1dc}	0.2779 %
B_0	0.1516 %
B_{0m}	-0.0533 %
B_{0dc}	0.1154 %

Charging Current	0.568 A/km/ ϕ
Natural Load	257 MW
PPS X/R Ratio	9.475
Residual Compensation Factor (approx)	0.540
RCF (actual, r, θ (deg))	$0.541 \angle -6.59^\circ$

L2/4
 Ω and μS (/km)

275 kV - Conductors $2 \times 570 \text{ mm}^2$ AAAC		
Z_p	$0.0633 + j 0.4788 \Omega$	1.524 mH
Z_{pp}	$0.0377 + j 0.1711 \Omega$	0.545 mH
Z_1	$0.0255 + j 0.3077 \Omega$	0.979 mH
Z_{1m}	$-0.0005 - j 0.0124 \Omega$	-0.039 mH
Z_{1dc}	$0.0250 + j 0.2953 \Omega$	0.940 mH
Z_0	$0.1387 + j 0.8210 \Omega$	2.613 mH
Z_{0m}	$0.1136 + j 0.4446 \Omega$	1.415 mH
Z_{0dc}	$0.2523 + j 1.2656 \Omega$	4.029 mH
B_1	$3.7450 \mu S$	11.921 nF
B_{1m}	$0.0934 \mu S$	0.297 nF
B_{1dc}	$3.8493 \mu S$	12.253 nF
B_0	$2.0584 \mu S$	6.552 nF
B_{0m}	$-0.7432 \mu S$	-2.366 nF
B_{0dc}	$1.5591 \mu S$	4.963 nF

% on 100 MVA (/km)

Z_p	$0.0084 + j 0.0633 \%$
Z_{pp}	$0.0050 + j 0.0226 \%$
Z_1	$0.0034 + j 0.0407 \%$
Z_{1m}	$-0.0001 - j 0.0016 \%$
Z_{1dc}	$0.0033 + j 0.0391 \%$
Z_0	$0.0183 + j 0.1086 \%$
Z_{0m}	$0.0150 + j 0.0588 \%$
Z_{0dc}	$0.0334 + j 0.1674 \%$
B_1	0.2832 %
B_{1m}	0.0071 %
B_{1dc}	0.2911 %
B_0	0.1557 %
B_{0m}	-0.0562 %
B_{0dc}	0.1179 %

Charging Current	0.595 A/km/ ϕ
Natural Load	269 MW
PPS X/R Ratio	11.808
Residual Compensation Factor (approx)	0.566
RCF (actual, r, θ (deg))	$0.567 \angle -7.70^\circ$