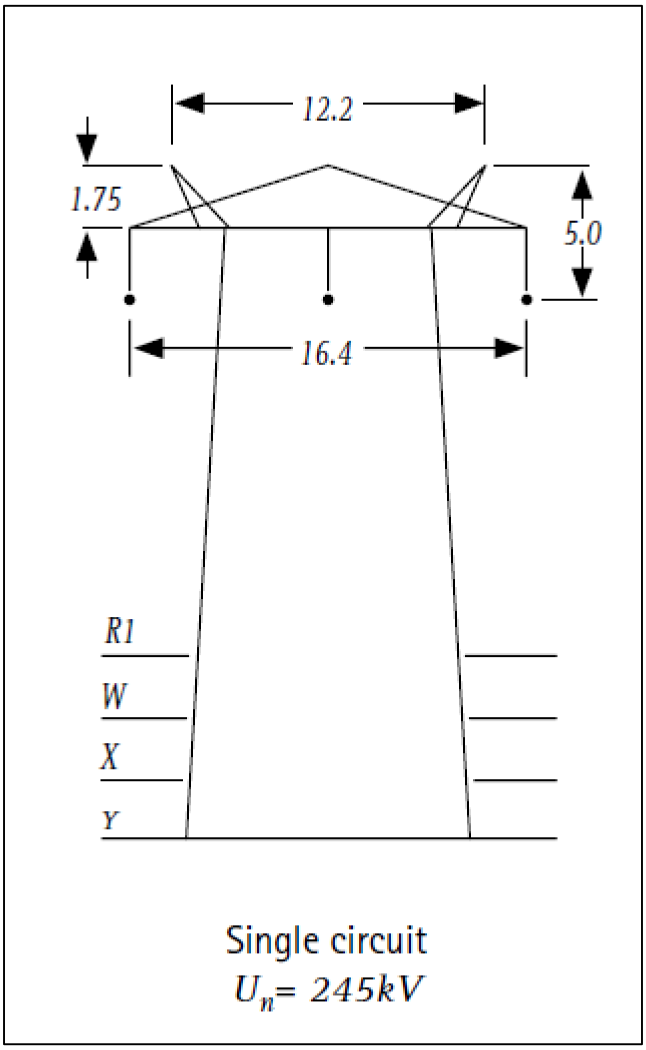
Validation of Transmission Line Model in Etap With CDEGS

Purpose and Description :

Modelling of transmission line in etap.



Reference Circuit

Procedure:

i) Open the OTI file “TransmissionLine.oti”.

ii) Double click on the transmission line “Line1”

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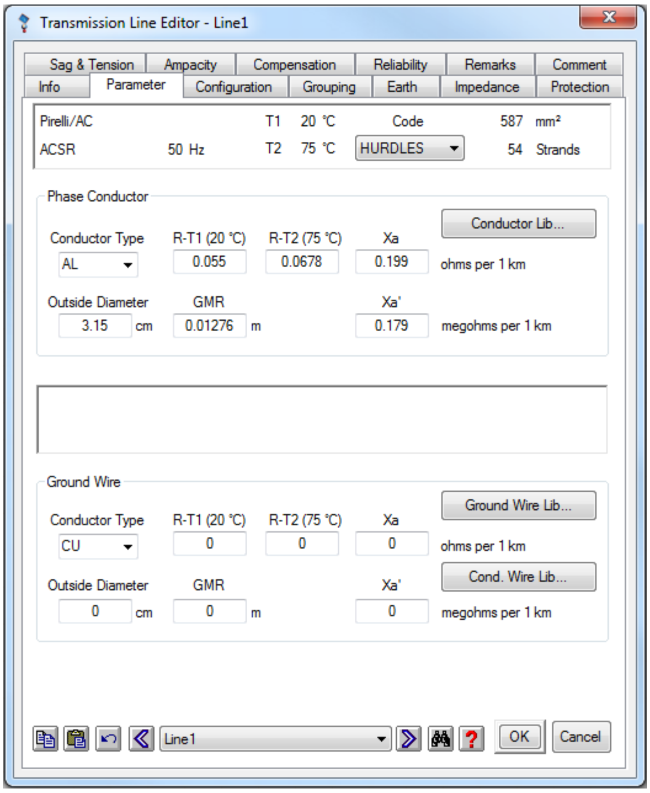
Properties of the selected conductor is as follows:

T1	20	deg-C				
T2	75	deg-C				
Code	**Size (sq.mm)**	**Ampacity (A)**	**Strands**	**Strand Dia (cm)**	**Steel Strands**	**Steel Strand Dia (cm)**
Hurdles	587	988	54	0.35	7	0.35
OD (cm)	**GMR (m)**	**Ra (at T1) (ohm/km**	**Ra (at T2) (ohm/km**	**Xa (Inductive reactance in ohms/conductor/ km at 1ft spacing)**	**Xa' (Capacitive shunt reactance in megaohms/conductor/ km at 1ft spacing)**	**Rdc (ohm/km)**
3.15	0.01276	0.055	0.0678	0.199	0.179	0.0533
		0.0533 (excel calc)	0.0651 (excel calc)	0.199 (excel calc)	0.169 (excel calc)	

iii) Select conductor code "Hurdles" from Source "Pirelli/AC" under the Phase Conductor Lib in the Parameter page.



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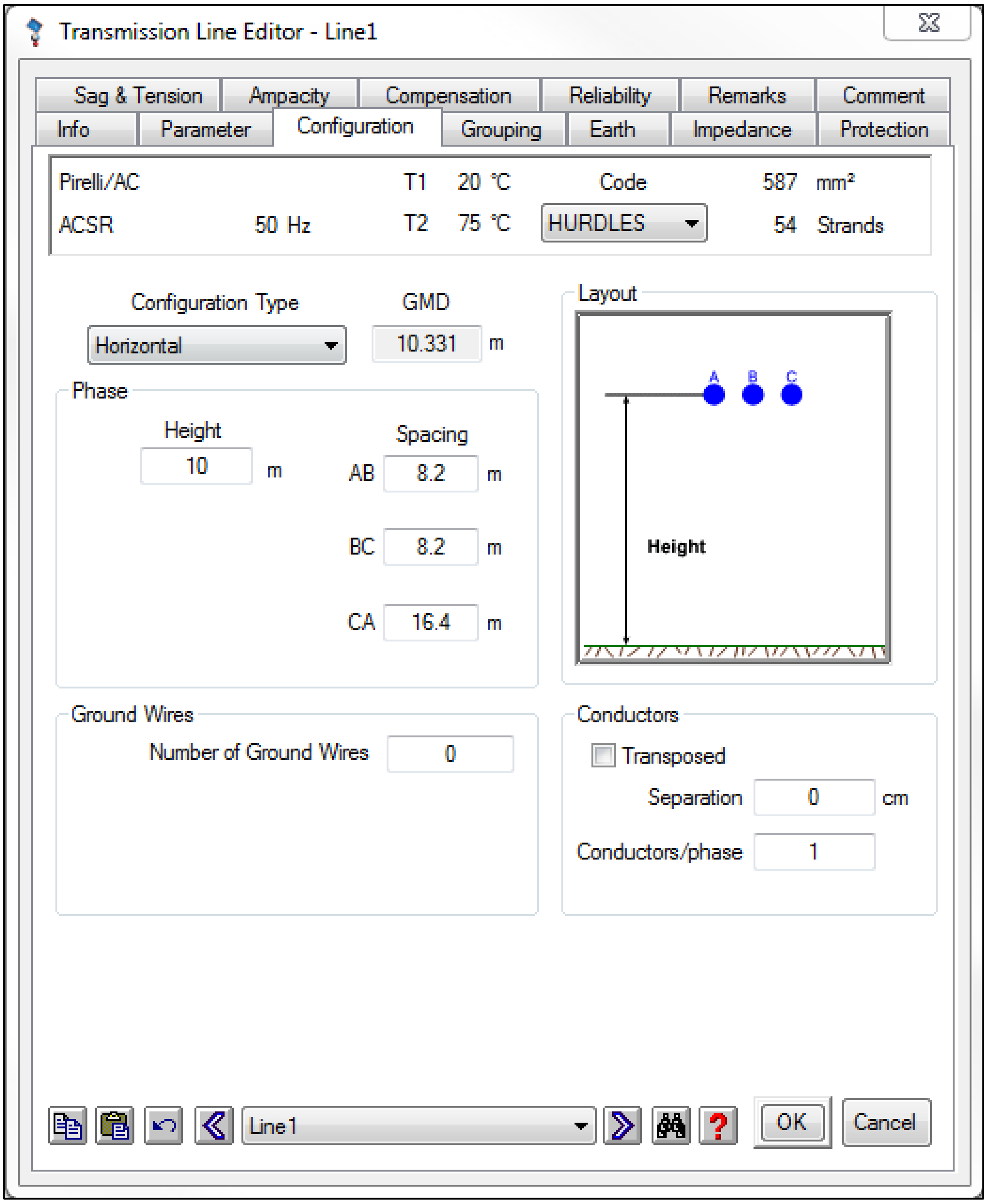
iv) In the configuration page enter the spacing as shown below in line with the "Reference Circuit"



v) Leave the Grouping and Earth pages untouched with the default parameters.

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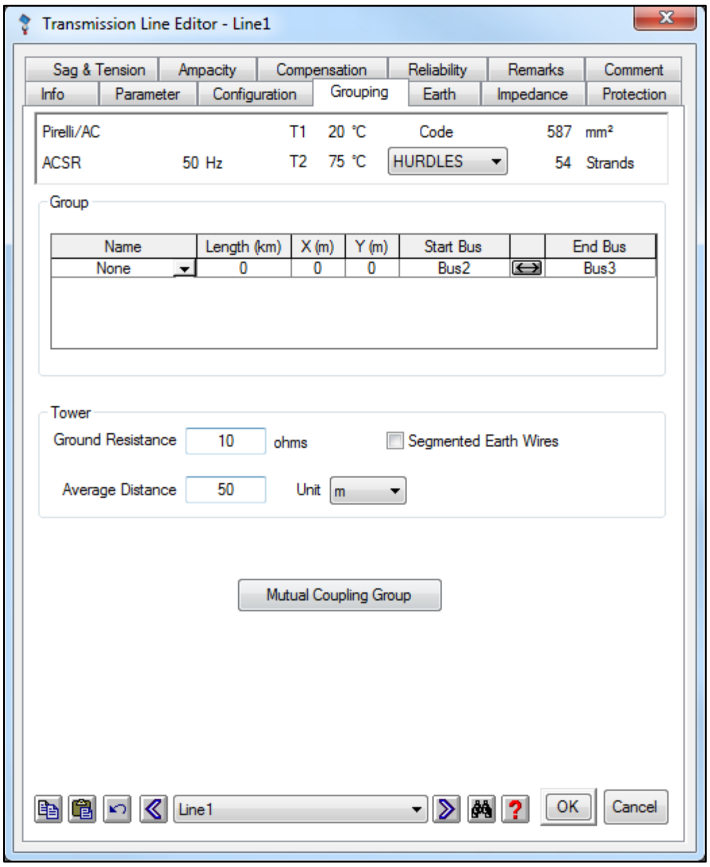

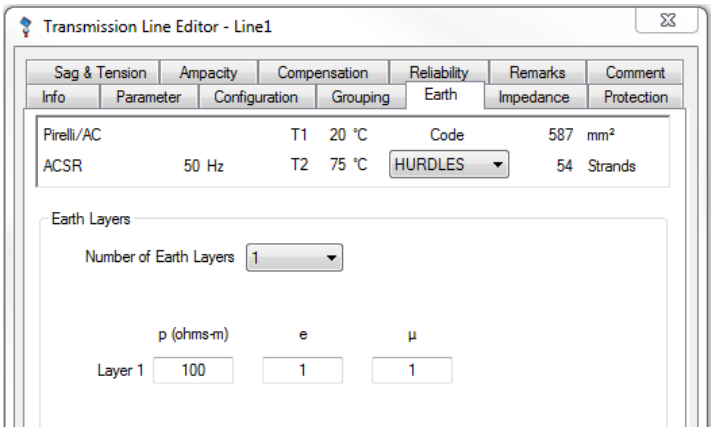

vi) Now in the impedance page, the computed impedance value is found as:

	R-T1 (ohm/phase/km)	X (ohms/phase/km)	Y (microsiemens/phase/km)
Zero	0.1997	1.27263	2.00042
Positive	0.05501	0.41969	2.76139
Negative	0.05501	0.41969	2.76139

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Also, under R,X,Y Matrices section, under Phase Domain it is seen that,

R - Matrix					**X - Matrix**			
	A	**B**	**C**			**A**	**B**	**C**
A	0.103	0.048	0.048		**A**	0.704	0.298	0.256
B	0.048	0.103	0.048		**B**	0.298	0.704	0.298
C	0.048	0.048	0.103		**C**	0.256	0.298	0.704
Note: represented in ohms (however, line length is taken as 1km in view of the ease of comparison with CDEGS where it is represented in ohm/km)					**Note:** represented in ohms (however, line length is taken as 1km in view of the ease of comparison with CDEGS where it is represented in ohm/km)			

Under R,X,Y Matrices section, under sequence domain it is seen that,

R - Matrix					**X - Matrix**			
	0	**1**	**2**			**0**	**1**	**2**
0	0.2	0.012	-0.012		**0**	1.273	-0.007	-0.007
1	-0.012	0.055	-0.024		**1**	-0.007	0.42	0.014
2	0.012	0.024	0.055		**2**	-0.007	0.014	0.42
Note: represented in ohms (however, line length is taken as 1km in view of the ease of comparison with CDEGS where it is represented in ohm/km)					**Note:** represented in ohms (however, line length is taken as 1km in view of the ease of comparison with CDEGS where it is represented in ohm/km)			

For calculation formulas refer **Annex. 1** attached at the end of this exercise.
For detailed calculation performed in excel, refer **Annex. 2**

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The relations ship between the self-mutual impedance matrix & sequence impedance matrix is as follows,

$$\mathbf{Z}_{012} = \mathbf{A}^{-1}\begin{bmatrix} Z_{AA} & Z_{AB} & Z_{AC} \\ Z_{BA} & Z_{BB} & Z_{BC} \\ Z_{CA} & Z_{CB} & Z_{CC} \end{bmatrix}\mathbf{A} = \begin{bmatrix} Z_{00} & Z_{01} & Z_{02} \\ Z_{10} & Z_{11} & Z_{12} \\ Z_{20} & Z_{21} & Z_{22} \end{bmatrix}$$

On solving the same, the sequence impedance matrix is reduced to the following:

Z0 = Zs + 2Zm

Z1 = Zs – Zm

Z2 = Zs – Zm

It can be seen that the diagonal elements in the sequence impedance matrix, holds true to the above relation with respect to the self-mutual impedance matrix.

Validation of Transmission Line Model in Etap With CDEGS
CDEGS

The above exercise has been conducted in CDEGS software to validate the calculated impedance value in ETAP. Attached below are the screenshot of the inputs and the results in CDEGS – SES TRALIN tool:

Input:

Location #	Name	Component Type	Y (m)	Z (m)	Associated Phase
1	R	[ACSR - AW Australian Standard] Hurdles	-8.2	10	1 - R
2	Y	[ACSR - AW Australian Standard] Hurdles	0	10	2 - Y
3	B	[ACSR - AW Australian Standard] Hurdles	8.2	10	3 - B
		None Selected			Select a Component Type

Output:
Self and Mutual Impedance Matrix (ohms/km)

```
Conductor Number:            1                       2                       3
=================

      1           0.1030     +j 0.7077

      2           0.4822E-01 +j 0.2986     0.1030     +j 0.7077

      3           0.4820E-01 +j 0.2550     0.4822E-01 +j 0.2986     0.1030     +j 0.7077
```

Sequence Impedance Matrix (ohm/km)

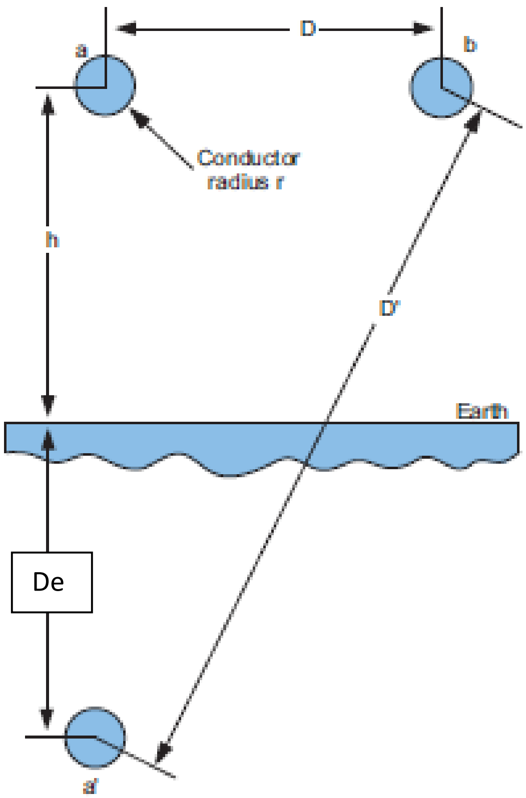
```
  Symmetrical
Sequence  Number:          0                      1                      2
=================

            0        0.1994     +j  1.276     -0.1257E-01 +j-0.7252E-02   0.1257E-01 +j-0.7263E-02

            1        0.1257E-01 +j-0.7263E-02   0.5474E-01 +j 0.4237      0.2515E-01 +j 0.1450E-01

            2       -0.1257E-01 +j-0.7252E-02  -0.2514E-01 +j 0.1453E-01   0.5474E-01 +j 0.4237
```

From the results, it can be seen that the results in Etap and CDEGS are matching.

Validation of Transmission Line Model in Etap With CDEGS

ANNEX. 1

Formulae used for calculation of transmission line self and mutual impedance:



Effective Depth, De= 659 $* \sqrt{\frac{\rho}{f}} m;$

$\rho = resistivity\ in\ ohm/m$

By Ampere's Circuital Law:

$I_x = 2\,\pi\,x\,H_x$

$I_x = \frac{\pi\,x^2}{\pi\,r^2} I$ A/m

$B_x = \frac{\mu\,x}{2\,\pi\,r^2} I\ Wb/m^2$

$d\emptyset = \frac{\mu\,x\,I}{2\,\pi\,r^2} dx\ Wb/m$

Flux linkage, $d\lambda$ per meter of length,

$$d\lambda = \frac{\pi\,x^2}{\pi\,r^2} d\emptyset = \frac{\mu\,x^3\,I}{2\,\pi\,r^4} dx\ Wb/m$$

Internal Inductance is:

$$\lambda_{int} = \int_0^r \frac{\mu\,x^3\,I}{2\,\pi\,r^4} dx = \frac{\mu\,I}{8\,\pi}\ Wb/m$$

μ_r=1 (air)

$\lambda_{int} = \frac{I}{2} * 10^{-7} Wb/m$

$L_{int} = 0.5 * 10^{-7} Wb/m$

By Ampere's Circuital Law:

Validation of Transmission Line Model in Etap With CDEGS

$$I = 2\,\pi\,x\,H_x$$

Solving for H_x and multiplying by µ yield the flux density B_x.

$$B_x = \frac{\mu\,I}{2\,\pi\,x}\;Wb/m^2$$

$$d\emptyset = \frac{\mu\,I}{2\,\pi\,x}dx\;Wb/m$$

The flux linkage $d\lambda$ per meter is:

$$\lambda_{ext} = \int_r^{De+h}\frac{\mu\,I}{2\,\pi\,x}dx = \frac{\mu\,I}{2\,\pi}ln\frac{De+h}{r}\;Wb/m$$

μ_r=1 (air)

$$\lambda_{ext} = 2*10^{-7}*I*ln\frac{De+h}{r}\;Wb/m$$

The external inductance is:

$$L_{ext} = 2*10^{-7}\;ln\frac{De+h}{r}\text{ H/m}$$

The total Inductance is:

$$L_a = \left(0.5 + 2\;ln\frac{De+h}{r}\right)*10^{-7}\text{ H/m}$$

$$L_a = 2*\left(\ln e^{1/4} + ln\frac{De+h}{r}\right)*10^{-7}\text{ H/m}$$

$$L_a = 2*10^{-7}\left(ln\frac{De+h}{r\,e^{-1/4}}\right)\text{ H/m}$$

Here, $r\;e\;-^{1/4}= GMR$

$$L_a = 2*10^{-7}\left(ln\frac{De+h}{GMR}\right)\text{ H/m}$$

Self-Reactance:

$$X_a = \omega\,L_a = 4\,\pi\,f\;10^{-7}\;ln\frac{De+h}{GMR}\frac{ohm}{m} = 0.001256637\;f\;ln\frac{De+h}{GMR}\frac{ohm}{km}$$

Mutual Reactance:

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For computing the Mutual Reactance, we consider the distance between the two conductors. Thus the GMR would be replaced by 'D-Distance between the conductor' in the equation:

$$X_{aa'} = 0.001256637\, f\, ln \frac{De+h}{D} \frac{ohm}{km}$$

(referred from 'POWER SYSTEM ANALYSIS- John J. Grainger & William D. Stevenson')

BY CARSON-CLEM'S FORMULA:

Self- Resistance:

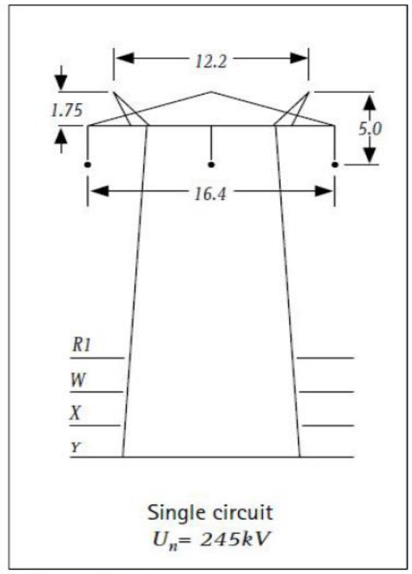
$$R_a = R_c + \frac{\pi\, \mu_0}{4}\, f \frac{ohm}{m} = R_c + 0.0009869604\, f\; ohm/km$$

Mutual- Resistance:

$$R_{aa'} = \frac{\pi\, \mu_0}{4}\, f \frac{ohm}{m} = 0.0009869604\, f\; ohm/km$$

ANNEX. 2
Calculation performed in excel

A	CONDUCTOR INPUT		(Value)	(Units)
1	Code	:	Hurdles	
2	Size	:	587	mm^2
3	No. of Strands	:	54	
4	T1	:	20	°C
5	T2	:	75	°C
6	Ampacity	:	988	A
7	Strand Diameter	:	0.35	cm
8	Steel Strand Diameter	:	0.35	cm
9	OD	:	3.15	cm
10	Rdc	:	0.0533	ohm/km
11	Frequency	:	50	Hz
12	Ks (skin effect Factor)	:	1	
13	Xs (Argument of a bessel function used to calculate skin effect)	:	0.002357668	
14	Ys(Skin effect factor)	:	1.60927E-13	
15	Rc (at T1)	:	0.0533	ohm/km
16	Rc (at T2)	:	0.065120565	ohm/km



Reference Circuit

$$Xs = \frac{8 * \pi * f * ks * 10^{-7}}{R_{dc}}$$

$$Ys = \frac{Xs^4}{192 + (0.8 + Xs^4)}$$

$$Rc\ (at\ T1) = R_{dc} * (1 + Ys)\ \frac{ohm}{unit\ length}$$

$$Rc\ (at\ T2) = \frac{Rc\ (at\ T1) * (228 + T2)}{(228 + T1)}\ \frac{ohm}{unit\ length}$$

Ref: Stevenson- Second Edition

B	Configuration		(Value)	(Units)
1	Distance between conductor (AB)	:	8.2	m
2	Distance between conductor (BC)	:	8.2	m
3	Distance between conductor (CA)	:	16.4	m
4	Height of conductor	:	10	m
5	Resistivity of soil	:	100	ohm/m

C	General Output		(Value)	(Units)
1	GMR	:	0.01276	m
2	Effective Depth (De)	:	931.9667376	m
3	Total depth (De+h)	:	941.9667376	m
4	Xa (Inductive Reactance)	:	0.199154555	ohms/conductor/km at 1 ft spacing)
5	Xa' (Capacitive Shunt Reactance)	:	0.169651751	Megaohms/conductor/km at 1 ft spacing

Effective Depth, De= $659 * \sqrt{\frac{\rho}{f}}\, m;$

$\rho = resistivity\ in\ ohm/m$

$$Xa = 2.022 * 10^{-3} * f * \ln\left(\frac{1}{Ds}\right) ohm/mile$$

$$Xa' = \frac{1.779}{f * \ln\left(\frac{1}{r}\right)} ohm/mile$$

Ref: IEC- 60287-1

D	Self Impedance		(Value)	(Units)
1	Self Resistance (Raa)	:	0.1026452	ohm/km
2	Self Resistance (Rbb)	:	0.1026452	ohm/km
3	Self Resistance (Rcc)	:	0.1026452	ohm/km
4	Self Reactance (Xaa)	:	0.704307965	ohm/km
5	Self Reactance (Xbb)	:	0.704307965	ohm/km
6	Self Reactance (Xcc)	:	0.704307965	ohm/km

E	Mutual Impedance		(Value)	(Units)
1	Mutual Resistance (Rab)	:	0.0493452	ohm/km
2	Mutual Resistance (Rbc)	:	0.0493452	ohm/km
3	Mutual Resistance (Rca)	:	0.0493452	ohm/km
4	Mutual Reactance (Xab)	:	0.29806398	ohm/km
5	Mutual Reactance (Xbc)	:	0.29806398	ohm/km
6	Mutual Reactance (Xca)	:	0.25451226	ohm/km

Legend

	:	Formula present in Annex. 1

Resistance Matrix (R)

	A	B	C
A	0.1026452	0.0493452	0.0493452
B	0.0493452	0.1026452	0.0493452
C	0.0493452	0.0493452	0.1026452

Reactance Matrix (X)

	A	B	C
A	0.704307965	0.29806398	0.25451226
B	0.29806398	0.704307965	0.29806398
C	0.25451226	0.29806398	0.704307965

Impedance Matrix (Zabc)

	A	B	C
A	0.102645200000009+0.704307965485455i	0.0493452+0.298063979993526i	0.0493452+0.25451226031666i
B	0.0493452+0.298063979993526i	0.102645200000009+0.704307965485455i	0.0493452+0.298063979993526i
C	0.0493452+0.25451226031666i	0.0493452+0.298063979993526i	0.102645200000009+0.704307965485455i

Transformation Matrix (A)

$$\alpha = \sin(120) + i\cos(120)$$

$$\alpha^2 = \sin(240) + i\cos(240)$$

$$\begin{matrix} \mathbf{1} & \mathbf{1} & \mathbf{1} \\ \mathbf{1} & \boldsymbol{\alpha^2} & \boldsymbol{\alpha} \\ \mathbf{1} & \boldsymbol{\alpha} & \boldsymbol{\alpha^2} \end{matrix}$$

=

1	1	1
1	-0.5-0.866025403784438i	-0.5+0.866025403784439i
1	-0.5+0.866025403784439i	-0.5-0.866025403784438i

Sequence Z Matrix (Z012)

$$Z_{012} = A^{-1} Z_{abc} A$$

	0	1	2
0	0.2030356+1.27140144569i	0.0125722985396-0.00725861994633i	-0.0125722985396-0.00725861994633i
1	-0.0125722985378-0.00725861994627i	0.0549999999999+0.420761225384i	-0.0251445970791+0.0145172398919i
2	0.0125722985374-0.00725861994627i	0.0251445970792+0.0145172398919i	0.055+0.420761225384i

Sequence Resistance Matrix (R012)

	0	1	2
0	0.2030356	0.012572299	-0.012572299
1	-0.012572299	0.055	-0.025144597
2	0.012572299	0.025144597	0.055

Sequence Reactance Matrix (X012)

	0	1	2
0	1.271401446	-0.00725862	-0.00725862
1	-0.00725862	0.420761225	0.01451724
2	-0.00725862	0.01451724	0.420761225