Collation Studies of Sequence Impedances for Underground Cables with Different Layouts

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Abstract *- Sequence impedances are very important for short circuit studies and also in planning and operational activities of power system. The computation of the sequence impedances is a very important for insulated cable systems mainly in EHV and HV levels. The objective of this paper is to compute the sequence impedances for a chosen 400kV self contained single core underground cable with different layouts for Copper and Aluminium Core .The Phase impedance matrix (3X3) calculated by eliminating sheaths impedances of (6x6) and also its corresponding sequence impedance matrix (3X3).*

Keywords–*Underground Cable, Phase Impedance Matrix, Sequence Impedance Matrix*.

I. INTRODUCTION

The main use of underground cables for many years has been for distribution of electric power in congested urban areas at comparatively low or moderate voltages. Planning and operational activities, power flow and short circuit studies are always based on the knowledge of the sequence impedances, and also the correct behavior of network protection is strictly depending upon their correct settings which are based on the positive-negative and zero sequence impedances. Most in the planning phase of an underground cable link the evaluation of its impact on the grid needs to know the sequence impedances. The modeling of multi conductor overhead lines and cables both in the phase and sequence frames of reference. Calculations and measurement techniques of the electrical parameters, or constants, of lines and cables is described [1]. The measurement campaigns have been compared with both simplified IEC formulae and advanced matrix procedures based on Multi conductor Cell Analysis (MCA) of cables in HV and EHV levels [2].A mathematical model suitable for the analysis of travelling-wave phenomena in underground power-transmission systems [3]. The simplicity of the approach, the conciseness of the matrix algebra applied, and the close-to-reality procedure make this method extremely attractive for self-made software implementation on any commercially available math packages such as Matlab [4]. A multi conductor matrix procedure based on bus admittance matrix, which accounts for the earth return currents, allows predicting the high frequency behavior of distribution networks and hence the effectiveness of transmitted signals[5].

The objective of this paper is to compute the phase and sequence impedances for a chosen 400kV self contained single core underground cable with different layouts for Copper and Aluminium core.The unbalanced phase impedance matrix constructed by using the Physical data of the conductors and is transformed to sequence impedance matrix for single core and three core cables for different cable layouts.

II. SELF AND MUTUAL IMPEDANCES OF CABLES

The basic electrical parameters of cables are the self and mutual impedances between conductors, and conductor shunt admittances.

The self-impedance of a core conductor with earth return is given by

$$Z_{cc} = R_{c(ac)} + \pi^2 10^{-4} f + j4\pi 10^{-4} f\left(\frac{\mu_c}{4} * f(r_o, r_i) + \log_e\left(\frac{D_{erc}}{r_{oc}}\right)\right)\Omega/km \quad (1)$$

The self-impedance of a sheath with earth return is given by

$$Z_{ss} = R_{s(ac)} + \pi^2 10^{-4} f + j4\pi 10^{-4} f\left(\frac{\mu_s}{4} * f(r_o, r_i) + \log_e\left(\frac{D_{erc}}{r_{os}}\right)\right)\Omega/km \quad (2)$$

where

$$f(r_o, r_s) = 1 - \frac{2r_i^2}{(r_o^2 - r_i^2)} + \frac{4r_i^4}{(r_o^2 - r_s^2)^2}\log_e\left(\frac{r_o}{r_i}\right) \quad (3)$$

The mutual impedance between core or sheath or armour i, and core or sheath or armour j, with earth return, is given by

$$Z_{ij} = \pi^2 10^{-4} f + j4\pi 10^{-4} f \log_e\left(\frac{D_{erc}}{S_{ij}}\right)\Omega/km \quad (4)$$

where *S*ij is the distance between the centres of cables i and j if the conductors belong to different cables. If the conductors belong to the same cable, *S*ij is the geometric mean distance between the two conductors the Geometrical Mean Distance between the core and the sheath of cable j is given by $S_{ij}=(r_{os}+r_{is})/2$ which is sufficiently accurate for practical cable dimensions. *D*erc is the depth of equivalent earth return conductor given by

$$D_{erc} = 658.87 * \sqrt{\frac{\rho_e}{f}}$$
(5)

III. PHASE AND SEQUENCE IMPEDANCES

The series voltage drop per unit length across the cores and sheaths is calculated from the cable's full impedance matrix, core and sheath conductor currents and is given by

$$\begin{bmatrix} V_{C1} \\ V_{C2} \\ V_{C3} \\ V_{S1} \\ V_{S2} \\ V_{S3} \end{bmatrix} = \begin{array}{c} \\ \\ C1 \\ \text{Cores } C2 \\ C3 \\ S1 \\ \text{Sheaths } S2 \\ S3 \end{array} \begin{array}{cccccc} \multicolumn{3}{c}{\text{Cores}} & \multicolumn{3}{c}{\text{Sheaths}} \\ C1 & C2 & C3 & S1 & S2 & S3 \\ \end{array} \left[\begin{array}{ccc|ccc} Z_{C1C1} & Z_{C1C2} & Z_{C1C3} & Z_{C1S1} & Z_{C1S2} & Z_{C1S3} \\ Z_{C2C1} & Z_{C2C2} & Z_{C2C3} & Z_{C2S1} & Z_{C2S2} & Z_{C2S3} \\ Z_{C3C1} & Z_{C3C2} & Z_{C3C3} & Z_{C3S1} & Z_{C3S2} & Z_{C3S3} \\ \hline Z_{S1C1} & Z_{S1C2} & Z_{S1C3} & Z_{S1S1} & Z_{S1S2} & Z_{S1S3} \\ Z_{S2C1} & Z_{S2C2} & Z_{S2C3} & Z_{S2S1} & Z_{S2S2} & Z_{S2S3} \\ Z_{S3C1} & Z_{S3C2} & Z_{S3C3} & Z_{S3S1} & Z_{S3S2} & Z_{S3S3} \end{array}\right] \begin{bmatrix} I_{C1} \\ I_{C2} \\ I_{C3} \\ I_{S1} \\ I_{S2} \\ I_{S3} \end{bmatrix}$$
(6)

where $\mathbf{Z}_{CC}$ and $\mathbf{Z}_{SS}$ are the core and sheath self impedances with earth return, respectively, and $\mathbf{Z}_{CS}$ is the mutual impedance between core and sheath with earth return.

The phase impedance matrix involving the cores only can be calculated by setting $\mathbf{V}_S=0$ in Equation (6). The resultant core or phase impedance matrix is given by

$$Z_{Phase} = Z_{cc} - Z_{cs} Z_{ss}^{-1} Z_{cs}$$
(7)

Z_{Phase} is the phase impedance matrix. The corresponding sequence impedance matrix is obtained by transforming the phase impedance matrix by using equation (8).The Sequence impedance matrix is calculated by assuming phase rotation of RYB by using

$$Z^{PNZ}=H^{-1}Z_{Phase}H$$
(8)

where H is the sequence to phase transformation matrix.

IV. CASE STUDY OF 400KV UNDERGROUND CABLE

The physical geometrical data of 400kV underground cable is given in the table shown below [6].

TABLE I PHYSICAL DATA OF 400KV UNDERGROUND CABLE

Parameter	Conductor (Cu)	Sheath
Inner radius	11.9mm	47.9mm
Outer radius	26.9mm	50.9mm
Ac resistance	0.0317Ω/km	0.28865 Ω/km

For aluminium conductor the ac resistance is 0.0493Ω/km. Earth resistivity=20 Ωm, Nominal frequency f=50Hz.

By using the geometrical data the sequence impedances for underground cables with different layouts can be calculated as shown below.

A. *Single Core Cables in Flat Layout*

1) ***Copper Core:*** Consider the cable layout as shown in Fig .1.

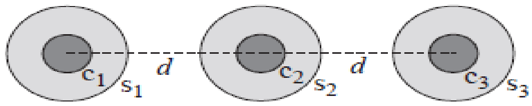

Fig.1 Single Core Cables in Flat Layout

The impedance matrix for the above layout is calculated by using the equations (1), (2) and (4), and is given by

$$Z = \left[\begin{array}{ccc|ccc} 0.0810+j0.6174 & 0.0493+j0.5087 & 0.0493+j0.4651 & 0.0493+j0.5680 & 0.0493+j0.5087 & 0.0493+j0.4651 \\ 0.0493+j0.5087 & 0.0810+j0.6174 & 0.0493+j0.5087 & 0.0493+j0.5087 & 0.0493+j0.5680 & 0.0493+j0.5087 \\ 0.0493+j0.4651 & 0.0493+j0.5087 & 0.0810+j0.6174 & 0.0493+j0.4651 & 0.0493+j0.5087 & 0.0493+j0.5680 \\ \hline 0.0493+j0.5680 & 0.0493+j0.5087 & 0.0493+j0.4651 & 0.3379+j0.5674 & 0.0493+j0.5087 & 0.0493+j0.4651 \\ 0.0493+j0.5087 & 0.0493+j0.5680 & 0.0493+j0.5087 & 0.0493+j0.5087 & 0.3379+j0.5674 & 0.0493+j0.5087 \\ 0.0493+j0.4651 & 0.0493+j0.5087 & 0.0493+j0.5680 & 0.0493+j0.4651 & 0.0493+j0.5087 & 0.3379+j0.5674 \end{array}\right]$$

From the impedance matrix core or phase impedance matrix by eliminating the sheath can be calculated using equation (7) and is given by

$$Z_{Phase} = \begin{bmatrix} 0.1391+j0.1184 & 0.0902+j0.0019 & 0.0748-j0.0223 \\ 0.0902+j0.0019 & 0.1313+j0.0951 & 0.0902+j0.0019 \\ 0.0748-j0.0223 & 0.0902+j0.0019 & 0.1391+j0.1184 \end{bmatrix}$$

Z_{Phase} is the Phase impedance matrix. The impedance matrix in the sequence frame of reference obtained by transforming the phase impedance matrix by using equation (8).The Sequence impedance matrix is given by

$$Z^{PNZ} = \begin{bmatrix} 0.0514+j0.1168 & 0 & 0 \\ 0 & 0.0514+j0.1168 & 0 \\ 0 & 0 & 0.3066+j0.0984 \end{bmatrix}$$

2) ***Aluminium Core:*** The similar calculations are done for the aluminium core; the full impedance matrix is given by

$$Z=\left[\begin{array}{ccc|ccc} 0.0986+j0.6174 & 0.0493+j0.5087 & 0.0493+j0.4651 & 0.0493+j0.5680 & 0.0493+j0.5087 & 0.0493+j0.4651 \\ 0.0493+j0.5087 & 0.0986+j0.6174 & 0.0493+j0.5087 & 0.0493+j0.5087 & 0.0493+j0.5680 & 0.0493+j0.5087 \\ 0.0493+j0.4651 & 0.0493+j0.5087 & 0.0986+j0.6174 & 0.0493+j0.4651 & 0.0493+j0.5087 & 0.0493+j0.5680 \\ \hline 0.0493+j0.5680 & 0.0493+j0.5087 & 0.0493+j0.4651 & 0.3379+j0.5674 & 0.0493+j0.5087 & 0.0493+j0.4651 \\ 0.0493+j0.5087 & 0.0493+j0.5680 & 0.0493+j0.5087 & 0.0493+j0.5087 & 0.3379+j0.5674 & 0.0493+j0.5087 \\ 0.0493+j0.4651 & 0.0493+j0.5087 & 0.0493+j0.5680 & 0.0493+j0.4651 & 0.0493+j0.5087 & 0.3379+j0.5674 \end{array}\right]$$

The phase impedance matrix is given by

$$Z_{Phase}=\begin{bmatrix} 0.1567+j0.1184 & 0.0902+j0.0019 & 0.0748-j0.0223 \\ 0.0902+j0.0019 & 0.1489+j0.0951 & 0.0902+j0.0019 \\ 0.0748-j0.0223 & 0.0902+j0.0019 & 0.1567+j0.1184 \end{bmatrix}$$

And the corresponding sequence impedance matrix is given by

$$Z^{PNZ}=\begin{bmatrix} 0.0690+j0.1168 & 0 & 0 \\ 0 & 0.0690+j0.1168 & 0 \\ 0 & 0 & 0.3242+j0.0984 \end{bmatrix}$$

B. *Single Core Cables in Touching Trefoil Layout*

1) Copper Core: Consider the single core cables as shown in Fig.2.

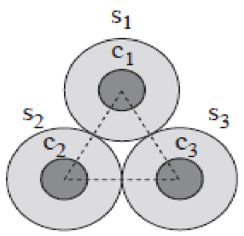

Fig.2 Single Core Cables in Touching Trefoil Layout

The full impedance matrix is given by

$$Z=\left[\begin{array}{ccc|ccc} 0.0810+j0.6174 & 0.0493+j0.5087 & 0.0493+j0.5087 & 0.0493+j0.5680 & 0.0493+j0.5087 & 0.0493+j0.5087 \\ 0.0493+j0.5087 & 0.0810+j0.6174 & 0.0493+j0.5087 & 0.0493+j0.5087 & 0.0493+j0.5680 & 0.0493+j0.5087 \\ 0.0493+j0.5087 & 0.0493+j0.5087 & 0.0810+j0.6174 & 0.0493+j0.5087 & 0.0493+j0.5087 & 0.0493+j0.5680 \\ \hline 0.0493+j0.5680 & 0.0493+j0.5087 & 0.0493+j0.5087 & 0.3379+j0.5674 & 0.0493+j0.5087 & 0.0493+j0.5087 \\ 0.0493+j0.5087 & 0.0493+j0.5680 & 0.0493+j0.5087 & 0.0493+j0.5087 & 0.3379+j0.5674 & 0.0493+j0.5087 \\ 0.0493+j0.5087 & 0.0493+j0.5087 & 0.0493+j0.5680 & 0.0493+j0.5087 & 0.0493+j0.5087 & 0.3379+j0.5674 \end{array}\right]$$

The phase impedance matrix is given by

$$Z_{Phase}=\begin{bmatrix} 0.1313+j0.1034 & 0.0879-j0.0029 & 0.0879-j0.0029 \\ 0.0879-j0.0029 & 0.1313+j0.1034 & 0.0879-j0.0029 \\ 0.0879-j0.0029 & 0.0879-j0.0029 & 0.1313+j0.1034 \end{bmatrix}$$

And the corresponding sequence impedance matrix is given by

$$Z^{PNZ}=\begin{bmatrix} 0.0434+j0.1063 & 0 & 0 \\ 0 & 0.0434+j0.1063 & 0 \\ 0 & 0 & 0.3071+j0.0976 \end{bmatrix}$$

2) ***Aluminium Core:*** The full impedance matrix is given by

$$Z=\left[\begin{array}{ccc|ccc} 0.0986+j0.6174 & 0.0493+j0.5087 & 0.0493+j0.5087 & 0.0493+j0.5680 & 0.0493+j0.5087 & 0.0493+j0.5087 \\ 0.0493+j0.5087 & 0.0986+j0.6174 & 0.0493+j0.5087 & 0.0493+j0.5087 & 0.0493+j0.5680 & 0.0493+j0.5087 \\ 0.0493+j0.5087 & 0.0493+j0.5087 & 0.0986+j0.6174 & 0.0493+j0.5087 & 0.0493+j0.5087 & 0.0493+j0.5680 \\ \hline 0.0493+j0.5680 & 0.0493+j0.5087 & 0.0493+j0.5087 & 0.3379+j0.5674 & 0.0493+j0.5087 & 0.0493+j0.5087 \\ 0.0493+j0.5087 & 0.0493+j0.5680 & 0.0493+j0.5087 & 0.0493+j0.5087 & 0.3379+j0.5674 & 0.0493+j0.5087 \\ 0.0493+j0.5087 & 0.0493+j0.5087 & 0.0493+j0.5680 & 0.0493+j0.5087 & 0.0493+j0.5087 & 0.3379+j0.5674 \end{array}\right]$$

The phase impedance matrix is given by

$$Z_{Phase}=\begin{bmatrix} 0.1489+j0.1034 & 0.0879-j0.0029 & 0.0879-j0.0029 \\ 0.0879-j0.0029 & 0.1489+j0.1034 & 0.0879-j0.0029 \\ 0.0879-j0.0029 & 0.0879-j0.0029 & 0.1489+j0.1034 \end{bmatrix}$$

And the corresponding sequence impedance matrix is given by

$$Z^{PNZ}=\begin{bmatrix} 0.0610+j0.1063 & 0 & 0 \\ 0 & 0.0610+j0.1063 & 0 \\ 0 & 0 & 0.3247+j0.0976 \end{bmatrix}$$

C. *Single Core Cables in Trefoil Layout*

1) ***Copper Core:*** Consider the single core cables as shown in Fig. 3.

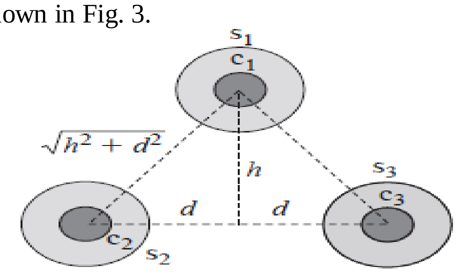

Fig.3 Single Core Cables in Trefoil Layout

The full impedance matrix is equal to

$$Z=\left[\begin{array}{ccc|ccc} 0.0810+j0.6174 & 0.0493+j0.4899 & 0.0493+j0.4899 & 0.0493+j0.5680 & 0.0493+j0.4899 & 0.0493+j0.4899 \\ 0.0493+j0.4899 & 0.0810+j0.6174 & 0.0493+j0.4651 & 0.0493+j0.4899 & 0.0493+j0.5680 & 0.0493+j0.4651 \\ 0.0493+j0.4899 & 0.0493+j0.4651 & 0.0810+j0.6174 & 0.0493+j0.4899 & 0.0493+j0.4651 & 0.0493+j0.5680 \\ \hline 0.0493+j0.5680 & 0.0493+j0.4899 & 0.0493+j0.4899 & 0.3379+j0.5674 & 0.0493+j0.4899 & 0.0493+j0.4899 \\ 0.0493+j0.4899 & 0.0493+j0.5680 & 0.0493+j0.4651 & 0.0493+j0.4899 & 0.3379+j0.5674 & 0.0493+j0.4651 \\ 0.0493+j0.4899 & 0.0493+j0.4651 & 0.0493+j0.5680 & 0.0493+j0.4899 & 0.0493+j0.4651 & 0.3379+j0.5674 \end{array}\right]$$

The phase impedance matrix is given by

$$Z_{Phase}=\begin{bmatrix} 0.1358+j0.1100 & 0.0867-j0.0054 & 0.0867-j0.0054 \\ 0.0867-j0.0054 & 0.1412+j0.1226 & 0.0769-j0.0181 \\ 0.0867-j0.0054 & 0.0769-j0.0181 & 0.1412+j0.1226 \end{bmatrix}$$

And the corresponding sequence impedance matrix is given by

$$Z^{PNZ}=\begin{bmatrix} 0.0560+j0.1280 & 0 & 0 \\ 0 & 0.0560+j0.1280 & 0 \\ 0 & 0 & 0.3062+j0.0991 \end{bmatrix}$$

*2) **Aluminium Core:*** The full impedance matrix is given by

$$Z=\left[\begin{array}{ccc|ccc} 0.0986+j0.6174 & 0.0493+j0.4899 & 0.0493+j0.4899 & 0.0493+j0.5680 & 0.0493+j0.4899 & 0.0493+j0.4899 \\ 0.0493+j0.4899 & 0.0986+j0.6174 & 0.0493+j0.4651 & 0.0493+j0.4899 & 0.0493+j0.5680 & 0.0493+j0.4651 \\ 0.0493+j0.4899 & 0.0493+j0.4651 & 0.0986+j0.6174 & 0.0493+j0.4899 & 0.0493+j0.4651 & 0.0493+j0.5680 \\ \hline 0.0493+j0.5680 & 0.0493+j0.4899 & 0.0493+j0.4899 & 0.3379+j0.5674 & 0.0493+j0.4899 & 0.0493+j0.4899 \\ 0.0493+j0.4899 & 0.0493+j0.5680 & 0.0493+j0.4651 & 0.0493+j0.4899 & 0.3379+j0.5674 & 0.0493+j0.4651 \\ 0.0493+j0.4899 & 0.0493+j0.4651 & 0.0493+j0.5680 & 0.0493+j0.4899 & 0.0493+j0.4651 & 0.3379+j0.5674 \end{array}\right]$$

The phase impedance matrix is given by

$$Z_{Phase}=\begin{bmatrix} 0.1534+j0.11 & 0.0867-j0.0054 & 0.0867-j0.0054 \\ 0.0867-j0.0054 & 0.1588+j0.1226 & 0.0769-j0.0181 \\ 0.0867-j0.0054 & 0.0769-j0.0181 & 0.1588+j0.1226 \end{bmatrix}$$

And the corresponding sequence impedance matrix is given by

$$Z^{PNZ}=\begin{bmatrix} 0.0736+j0.128 & 0 & 0 \\ 0 & 0.0736+j0.128 & 0 \\ 0 & 0 & 0.3238+j0.0991 \end{bmatrix}$$

D. Transposition of Single Core Cables

1) ***Copper Core:*** Consider the core transposition of single core cables as shown in Fig. 4.

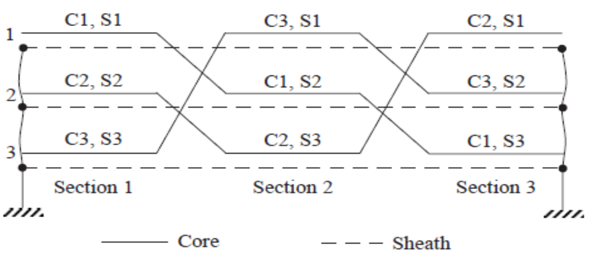

Fig.4 Core Transpositions of Cables

The full impedance matrix of cable with transposed cores in each major section is given by

$$Z=\frac{1}{3}\sum_{i=1}^{3} Z_{section-i}$$

$$Z=\left[\begin{array}{ccc|ccc} 0.0810+j0.6174 & 0.0493+j0.4942 & 0.0493+j0.4942 & 0.0493+j0.5139 & 0.0493+j0.5285 & 0.0493+j0.5139 \\ 0.0493+j0.4942 & 0.0810+j0.6174 & 0.0493+j0.4942 & 0.0493+j0.5139 & 0.0493+j0.5285 & 0.0493+j0.5139 \\ 0.0493+j0.4942 & 0.0493+j0.4942 & 0.0810+j0.6174 & 0.0493+j0.5139 & 0.0493+j0.5285 & 0.0493+j0.5139 \\ \hline 0.0493+j0.5139 & 0.0493+j0.5139 & 0.0493+j0.5139 & 0.3379+j0.5674 & 0.0493+j0.5087 & 0.0493+j0.4651 \\ 0.0493+j0.5285 & 0.0493+j0.5285 & 0.0493+j0.5285 & 0.0493+j0.5087 & 0.3379+j0.5674 & 0.0493+j0.5087 \\ 0.0493+j0.5139 & 0.0493+j0.5139 & 0.0493+j0.5139 & 0.0493+j0.4651 & 0.0493+j0.5087 & 0.3379+j0.5674 \end{array}\right]$$

The phase impedance matrix is given by

$$Z_{Phase}=\begin{bmatrix} 0.1233+j0.1149 & 0.0916-j0.0083 & 0.0916-j0.0083 \\ 0.0916-j0.0083 & 0.1233+j0.1149 & 0.0916-j0.0083 \\ 0.0916-j0.0083 & 0.0916-j0.0083 & 0.1233+j0.1149 \end{bmatrix}$$

And the corresponding sequence impedance matrix is given by

$$Z^{PNZ}=\begin{bmatrix} 0.0317+j0.1232 & 0 & 0 \\ 0 & 0.0317+j0.1232 & 0 \\ 0 & 0 & 0.3066+j0.0984 \end{bmatrix}$$

2) ***Aluminium Core:*** The full impedance matrix is given by

$$Z=\left[\begin{array}{ccc|ccc} 0.0986+j0.6174 & 0.0493+j0.4942 & 0.0493+j0.4942 & 0.0493+j0.5139 & 0.0493+j0.5285 & 0.0493+j0.5139 \\ 0.0493+j0.4942 & 0.0986+j0.6174 & 0.0493+j0.4942 & 0.0493+j0.5139 & 0.0493+j0.5285 & 0.0493+j0.5139 \\ 0.0493+j0.4942 & 0.0493+j0.4942 & 0.0986+j0.6174 & 0.0493+j0.5139 & 0.0493+j0.5285 & 0.0493+j0.5139 \\ \hline 0.0493+j0.5139 & 0.0493+j0.5139 & 0.0493+j0.5139 & 0.3379+j0.5674 & 0.0493+j0.5087 & 0.0493+j0.4651 \\ 0.0493+j0.5285 & 0.0493+j0.5285 & 0.0493+j0.5285 & 0.0493+j0.5087 & 0.3379+j0.5674 & 0.0493+j0.5087 \\ 0.0493+j0.5139 & 0.0493+j0.5139 & 0.0493+j0.5139 & 0.0493+j0.4651 & 0.0493+j0.5087 & 0.3379+j0.5674 \end{array}\right]$$

The phase impedance matrix is given by

$$Z_{Phase}=\begin{bmatrix} 0.1409+j0.1149 & 0.0916-j0.0083 & 0.0916-j0.0083 \\ 0.0916-j0.0083 & 0.1409+j0.1149 & 0.0916-j0.0083 \\ 0.0916-j0.0083 & 0.0916-j0.0083 & 0.1409+j0.1149 \end{bmatrix}$$

And the corresponding sequence impedance matrix is given by

$$Z^{PNZ} = \begin{bmatrix} 0.0493 + j0.1232 & 0 & 0 \\ 0 & 0.0493 + j0.1232 & 0 \\ 0 & 0 & 0.3242 + j0.0984 \end{bmatrix}$$

V. SUMMARY OF THE PROGRAM

i. Read the input data. These include physical geometry of the cable, earth resistivity and frequency.
ii. Calculate the distances between the conductors and substitute the values in self and mutual impedances.
iii. The Z matrix of size 6x6 is formed and by eliminating sheaths get reduced to 3x3 by using the equation(7).
iv. Sequence impedance matrix is formed by using equation (8).

VI. RESULTS AND DISCUSSIONS

To overcome the complexity of manual iterative calculations, a program is written to generate phase and sequence impedance matrices of 400 kV underground cables. The phase and sequence impedance matrices for the different cable layouts for Copper and Aluminium Core are shown in below figures.

A. Copper Core

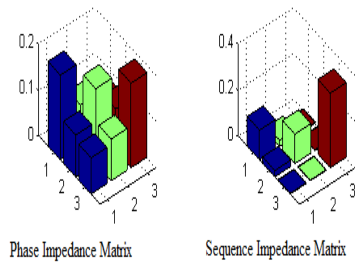

Fig.5 MATLAB plot for 400kV Underground Cable Cu Core with Flat Layout

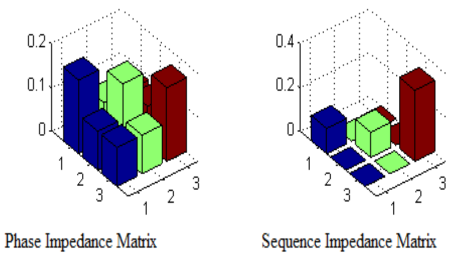

Fig.6 MATLAB plot for 400kV Underground Cable with Cu Core Touching Trefoil Layout

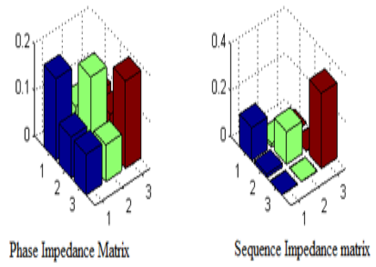

Fig.7 MATLAB plot for 400kV Underground Cable with Cu Core Trefoil Layout

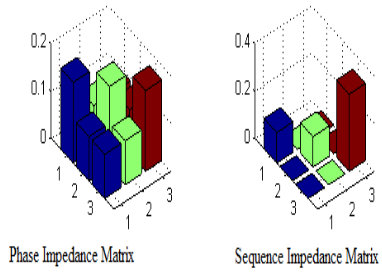

Fig.8 MATLAB plot for 400kV Underground Cable with Cu Core Transposition

B. Aluminium core

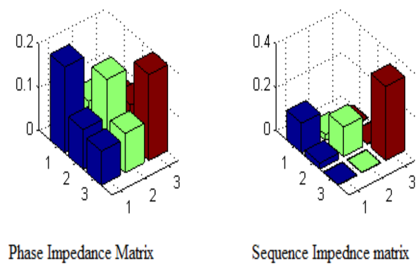

Fig.9 MATLAB plot for 400kV Underground Cable Al Core with Flat Layout

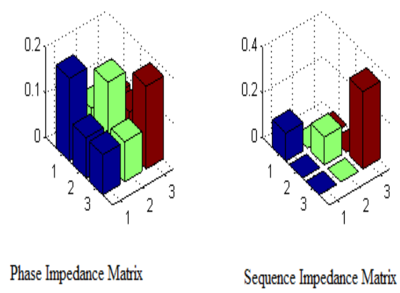

Fig.10 MATLAB plot for 400kV Underground cable with Al Core Touching Trefoil Layout

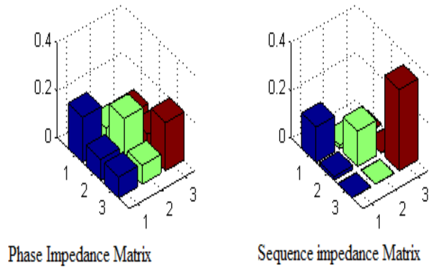

Fig.11 MATLAB plot for 400kVUnderground Cable with Al Core Trefoil Layout

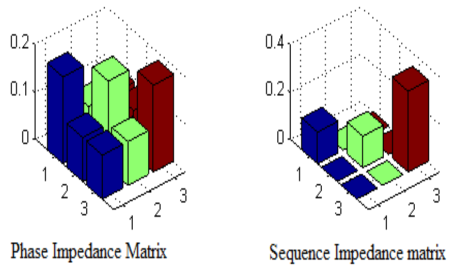

Fig.12 MATLAB plot for 400kV Underground Cable with Al Core Transposition

The comparison of Sequence impedances of 400kV Underground Cable with Copper and Aluminium Core is shown below.

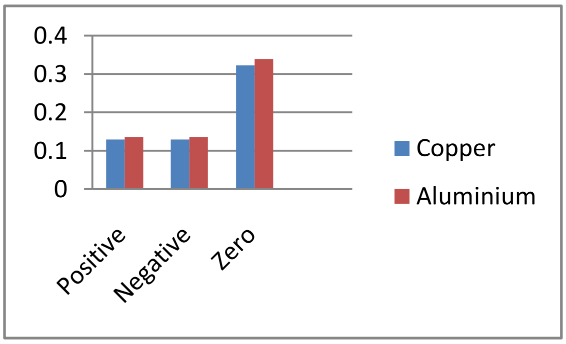

Fig.13 Comparison of Sequence Impedances of 400kV Underground Cable with Flat Layout

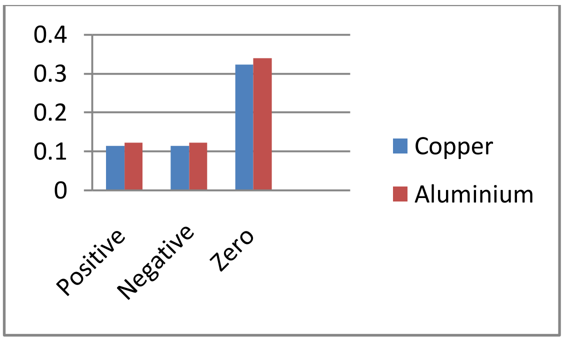

Fig.14 Comparison of Sequence Impedances of 400kV Underground Cable with Touching Trefoil Layout

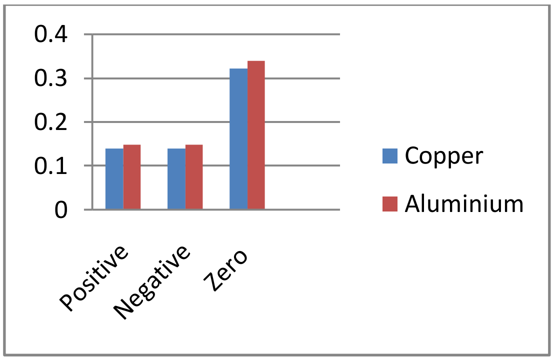

Fig.15 Comparison of Sequence Impedances of 400kV Underground Cable with Trefoil Layout

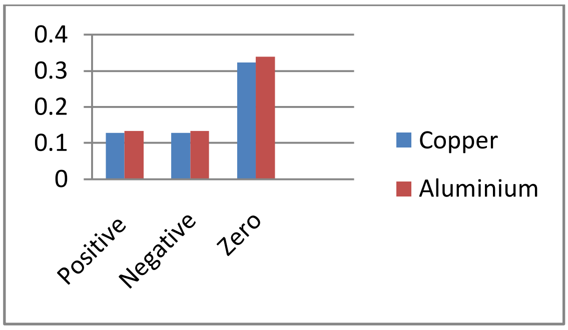

Fig.16 Comparison of Sequence Impedances of 400kV Underground Cable with Transposition

VII. CONCLUSION

The transposed phase and sequence impedance matrices for single core cable with copper and aluminium core for different layouts are obtained. An algorithm is developed to compute phase and sequence impedance matrices for different cable layouts hence shows an excellent resemblance in similarity by which it is proved that the calculation in computing impedance has been reduced the complexity by using programming technique. The results are obtained for 400kV single core underground cable with copper and aluminium core.

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