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Computation of Sequence Impedances for 220kv Underground Cable with Different Short Circuit Capacities

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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 HV and EHV levels. The objective of this paper is to compute the sequence impedances for a chosen 220kV self contained single core underground cable by representing with a digital computer program using MATLAB. The Phase impedance matrix (3X3) calculated by eliminating sheaths unbalanced impedances of (6x6) and also its corresponding sequence impedance matrix (3X3) . The comparison shows the closer agreement between calculated values and those obtained by the digital program. The same technique is valid for different types of cable layouts.

KEYWORDS: *Underground cable, Phase Impedance Matrix, Sequence Impedance Matrix, MATLAB*

I. Introduction

Electric power can be transmitted or distributed either by overhead system or by underground cables. The underground cables have several advantages such as less liable to damage through storms or lightning, low maintenance cost, less chance of faults, smaller voltage drop and better general appearance. However, their major drawback is that they have greater installation cost and introduce insulation problems at high voltages compared with the equivalent overhead system. For this reason, underground cables are employed where it is impracticable to use overhead lines. Such locations may be thickly populated areas where municipal authorities prohibit overhead lines for reasons of safety, or around plants and substations or where maintenance conditions do not permit the use of overhead construction.

The chief use of underground cables for many years has been for distribution of electric power in congested urban areas at comparatively low or moderate voltages. However, recent improvements in the design and manufacture have led to the development of cables suitable for use at high voltages.

Both in planning and operating activities, power flow and short circuit studies are always based on the knowledge of the sequence impedances. Furthermore, the correct behavior of network protection (mainly distance relays) is strictly depending upon their correct settings which are based on the positive-negative and zero sequence

impedances. Moreover in the planning phase of a new underground cable (UGC) link the evaluation of its impact on the grid needs to know the sequence impedances.[2]

The objective of this paper is to compute the phase and sequence impedance matrices for cables.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 short circuit capacities.

II. SERIES SELF AND MUTUAL IMPEDANCES OF CABLES

Figure below is across-section of a general cable showing a hollow core conductor, core insulation, sheath/screen conductor, sheath insulation, armour conductor and a further insulation layer such as a plastic sheath.

Figure. 1 Cross section of one phase of a self-contained armour cable

Similar to an overhead line, 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, e.g. the GMD between the core and the sheath of cable j is given by $S_{jj} = (r_{os} + r_{is})/2$ which is sufficiently accurate for practical cable dimensions. D_{erc} is the depth of equivalent earth return conductor given by

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

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

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

where **Z**CC and **Z**SS are the core and sheath self-impedances with earth return, respectively, and **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 **V**S =0 in Equation (6). The resultant core or phase impedance matrix is given by

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

ZPhase is the phase impedance matrix of the unbalanced three phase mutually coupled line. The matrix is symmetric but the self or diagonal terms are unequal to each other, and the mutual or off-diagonal terms on a given row or column are unequal to each other. 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 calculated by assuming phase rotation of RYB by using

$$\mathbf{Z}^{PNZ} = \mathbf{H}^{-1}\mathbf{Z}_{Phase}\mathbf{H} \quad (8)$$

Where H is the sequence to phase transformation matrix.

The sequence impedance matrix is full, non-diagonal and non-symmetric. A non diagonal matrix means that mutual coupling in the sequence circuits exist.

The conversion to sequence reference frame still produces a full and even asymmetric sequence impedance matrix that includes intersequence mutual couplings. Where this intersequence mutual coupling is to be eliminated, the circuit has to be perfectly transposed.

IV. CASE STUDY OF 220KV UNDERGROUND CABLE

The physical geometrical data of 220kv underground cable is given in the table shown below [6].

Table 1 physical data of 220kV underground cable

Parameter	Conductor	Sheath
Inner radius	6.8mm	37.9mm
Outer radius	21.9mm	40.9mm
Ac resistance	0.01665Ω/km	0.28865 Ω/km

Consider the layout of the cable as single core with touching trefoil layout as shown in figure 2.

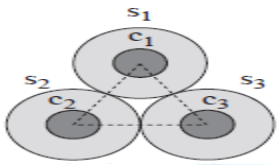

Figure 2. Single core cable with touching trefoil layout

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

$$Z=\begin{bmatrix} 0.0660+0.6323i & 0.0493+0.5087i & 0.0493+0.5087i & 0.0493+0.5822i & 0.0493+0.5087i & 0.0493+0.5087i \\ 0.0493+0.5087i & 0.0660+0.6323i & 0.0493+0.5087i & 0.0493+0.5087i & 0.0493+0.5822i & 0.0493+0.5087i \\ 0.0493+0.5087i & 0.0493+0.5087i & 0.0660+0.6323i & 0.0493+0.5087i & 0.0493+0.5087i & 0.0493+0.5822i \\ 0.0493+0.5822i & 0.0493+0.5087i & 0.0493+0.5087i & 0.3380+0.5814i & 0.0493+0.5087i & 0.0493+0.5087i \\ 0.0493+0.5087i & 0.0493+0.5822i & 0.0493+0.5087i & 0.0493+0.5087i & 0.3380+0.5814i & 0.0493+0.5087i \\ 0.0493+0.5087i & 0.0493+0.5087i & 0.0493+0.5822i & 0.0493+0.5087i & 0.0493+0.5087i & 0.3380+0.5814i \end{bmatrix}$$

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

$$Z_{Phase}=\begin{bmatrix} 0.1204+0.1121i & 0.0860-0.0071i & 0.0860-0.0071i \\ 0.0860-0.0071i & 0.1204+0.1121i & 0.0860-0.0071i \\ 0.0860-0.0071i & 0.0860-0.0071i & 0.1204+0.1121i \end{bmatrix}$$

Z_{Phase} is the phase impedance matrix of the unbalanced three phase mutually coupled line. 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 calculated by assuming phase rotation of RYB is given by

$$Z^{PNZ}=\begin{bmatrix} 0.0343+0.1192i & 0 & 0 \\ 0 & 0.0343+0.1192i & 0 \\ 0 & 0 & 0.2924+0.0979i \end{bmatrix}$$

In this sequence impedance matrix, mutual sequence coupling is eliminated completely.

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 220 kV, underground cable.

Figure.3 shows the perfectly transposed or balanced phase impedance matrix, showing the bars of equal length in the self and off diagonal positions.

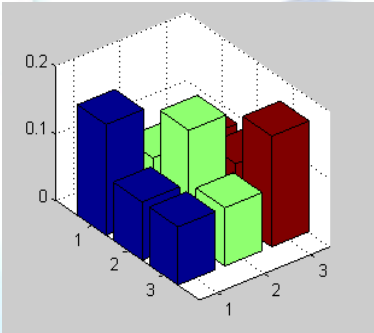

Figure3.Phase impedance matrix

And figure 4 contains only diagonal elements i.e.Positive, negative and zero sequence components only which shows that the mutual coupling is eliminated completely.

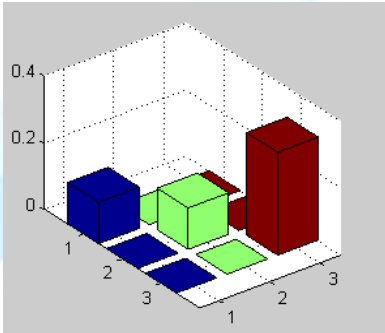

Figure 4. Sequence impedance matrix

VII. CONCLUSION

The transposed phase and sequence impedance matrices for single core cable with touching trefoil layout are obtained.

An algorithm is developed to compute phase and sequence impedance matrices for different cable layouts and the output and mathematical calculation 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 single core touching trefoil layout. This work can be extended for other cable layouts.

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