SEQUENCE IMPEDANCE COMPUTATION BY MEANS OF MULTICONDUCTOR CELL ANALYSIS

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ABSTRACT

The computation of sequence impedances is a very important topic for insulated cable systems chiefly in HV and EHV levels. Both in planning and operating activities, power flow and short circuit studies are always based on the knowledge of sequence impedances. Furthermore, the correct behaviour of network protection (mainly distance relays) is strictly depending upon their correct settings which are based on positive-negative and zero sequence impedances. Moreover in the planning phase of a new cable link power flow and short circuit studies are always based on the knowledge of sequence impedances. This highlights the importance of using reliable procedures in order to compute these impedances since, up to now, their computations are based on simplified formulae. One of the authors has already presented some papers [1, 2, 3] which allow studying cable systems by means of the multiconductor cell analysis (MCA). This method considers the cable system in its real asymmetry without simplified and approximated hypotheses. One of the advantages of the MCA is the possibility to supply the cable system with three sequence voltage phasors and to compute the ratios between voltage and current phasors for each phase.

KEYWORDS

Insulated Cables, Multiconductor Cell Analysis MCA, Extra High Voltage, Sequence Impedances, Asymmetric Systems.

INTRODUCTION

The use of zero, positive-negative sequence impedances $\underline{Z}_0$, $\underline{Z}_1$, $\underline{Z}_2$, is only exact if the system is symmetric since the application of voltage phasors of a sequence causes the circulation of current phasors only of the same sequence so that it is possible to compute the ratios between voltage and current phasors. For cable lines, this assumption is only true if the insulated cables are cross-bonded with phase transpositions (PTs) or if they are cross-bonded in trefoil arrangement. In all the other cases, the use of sequence impedances $\underline{Z}_0$, $\underline{Z}_1$, $\underline{Z}_2$ would be theoretically mistaken. Even if the insulated cable is cross-bonded with PTs (or in trefoil arrangement) there could be causes of asymmetry:

- minor sections with different lengths, so that the induced currents in the screens are not zeroed;
- the presence of joint chambers and terminals which introduce a flat arrangement and a consequent asymmetry;
- crossings of possible interfering services or natural obstacles usually overcome by means of directional drillings which can introduce a great spacing between the cables;

If the line length is long enough, the presence of these installation differences can become less important but theoretically they would give always an asymmetric system. In this context, as already highlighted, it would not licitly possible to refer with precision to sequence impedances.

BRIEF RECALLS TO THE MCA

The whole exposition of the general procedure can be found in [1, 2] or, with a more didactical approach, in the book [3]. In the following only a brief synopsis is provided. Let us consider three single-core cables (*3 phases and 3 screens* for a total of 6 conductors parallel to themselves and to the ground surface where earth return current flows) with total length *d* (see Fig. 1) and a stretch of length Δ_ℓ between the two sections *S* and *R* composed of *6* conductors; if $d>>\Delta_\ell$, the border effects can be neglected. In such a case, the treatment (given by Carson [4], Pollaczek [5]), shows (if the transversal couplings due to the phase-to-screen and screen-to-earth conductive-capacitive susceptances are treated separately) how the longitudinal ohmic-inductive self impedances $\underline{z}_{i,i}$ and mutual impedances $\underline{z}_{i,j}$ of *n* conductors (*n=6* in the present case) can be computed, considering also the electromagnetic field inside the earth; once $\underline{z}_{i,i}$ and $\underline{z}_{i,j}$ have been computed, it is possible to form the matrix $\underline{Z}_L$ (6×6) and to characterize, by means of the relation (1), the steady state regime of longitudinal block *L* of Fig. 2 (where the voltage column vectors $\underline{\boldsymbol{u}}_S$, $\underline{\boldsymbol{u}}_R$ and the current column vectors $\underline{\boldsymbol{i}}_S$, $\underline{\boldsymbol{i}}_{SL}$, $\underline{\boldsymbol{i}}_{ST}$, $\underline{\boldsymbol{i}}_R$, $\underline{\boldsymbol{i}}_{RL}$, $\underline{\boldsymbol{i}}_{RT}$ are shown):

$$\underline{\boldsymbol{u}}_S - \underline{\boldsymbol{u}}_R = \underline{\boldsymbol{Z}}_L \, \underline{\boldsymbol{i}}_{SL} \quad , \tag{1}$$

and by considering the obvious relation (2)

$$\underline{\boldsymbol{i}}_{RL} \equiv - \underline{\boldsymbol{i}}_{SL} \tag{2}$$

it yields, (being $\underline{\boldsymbol{Z}}_L$ not singular)

$$\underline{\boldsymbol{Z}}_L^{-1}\boldsymbol{u}_S - \underline{\boldsymbol{Z}}_L^{-1}\boldsymbol{u}_R = \boldsymbol{i}_{SL} \tag{3}$$

$$-\underline{\boldsymbol{Z}}_L^{-1}\boldsymbol{u}_S + \underline{\boldsymbol{Z}}_L^{-1}\boldsymbol{u}_R = \boldsymbol{i}_{RL} \quad . \tag{4}$$

Hence the following matrix relation (5), where $\underline{\boldsymbol{Y}}_{L\Delta}$ (*12×12*) regards the block *L* circuit formed by the 6 longitudinal links, can be written:

$$\underbrace{\begin{bmatrix} \underline{\boldsymbol{i}}_{SL} \\ \underline{\boldsymbol{i}}_{RL} \end{bmatrix}}_{\substack{\underline{\boldsymbol{i}}_{L\Delta} \\ (12\times1)}} = \underbrace{\begin{bmatrix} \underline{\boldsymbol{Z}}_L^{-1} & -\underline{\boldsymbol{Z}}_L^{-1} \\ -\underline{\boldsymbol{Z}}_L^{-1} & \underline{\boldsymbol{Z}}_L^{-1} \end{bmatrix}}_{\substack{\underline{\boldsymbol{Y}}_{L\Delta} \\ (12\times12)}} \underbrace{\begin{bmatrix} \underline{\boldsymbol{u}}_S \\ \underline{\boldsymbol{u}}_R \end{bmatrix}}_{\substack{\underline{\boldsymbol{u}}_{\Delta} \\ (12\times1)}} \quad . \tag{5}$$

In particular, it is important to mark the directions of the currents in correspondence to *S* and *R* (both towards the circuital block) since the study will be developed by means of models identified by nodal admittance matrices.