MULTICONDUCTOR CELL ANALYSIS OF POWER CABLE STEADY STATE

Roberto BENATO, University of Padova, (Italy), roberto.benato@unipd.it

ABSTRACT

The paper deals with the multiconductor analysis of transmission lines namely AC underground cable lines (UGC). A multiconductor matrix procedure based on the use of admittance matrices, which account for the line cells (with earth return currents), different types of sheath bonding, possible multiple circuits, allows predicting the steady-state regime of any cable system. In particular, the method calculates the proportion and behaviour of the phase currents carried by each parallel conductor, the circulating current in the sheath of each cable and the stray current in the earth. A general outline of the multiconductor cell analysis has been thoroughly developed in [1]. Only a brief description of the theoretical procedure will be given in the paper making more room for some examples of application.

KEYWORDS

Underground cables, Multiconductor Matrix Analysis, Extra High Voltage, Short-circuit condition.

INTRODUCTION

The necessity of enforcing the electrical transmission network has become an unavoidable issue to any transmission system operator (TSO). On the other hand, many TSOs have experienced insurmountable difficulties in erecting new overhead lines. Therefore, "underground" technologies as UGC or Gas Insulated Lines (GIL) will play a leading role in the future transmission grids. The possibility of integrating power transmission and other services (i.e. railway and highway transport, bridges, galleries) in the same corridor or in the same "structure" is another fascinating technical challenge favouring underground technologies [2,3]. UGC and GIL are examples of multiconductor systems (phases and sheaths or enclosures) which cannot be studied in detail by means of a simplified single-phase equivalent circuit. The author has already presented a powerful procedure in order to evaluate the transmission operating characteristics of long AC cables [4] and mixed overhead-cable links [5]. The present method, which considers the transmission line in its real asymmetric structure, allows:

- Detecting the exact current sharing between single-core cables and the circulating currents in the sheaths of any number of circuits and with any bonding configuration (cross-bonding, single-point-and solid-bonding);
- Knowing the precise steady-state behaviour of any component of the cable line (e.g. cross-bonding boxes);
- Considering possible phase transpositions;
- Studying the short-circuit regime and the voltages in any line section (consequently the touch-voltages);
- Studying the power loss behaviour along the line;
- Including, for cables installed in a tunnel, the grounding conductors e.g. longitudinal wires or the steel reinforcement of the tunnel itself.

MULTICONDUCTOR MATRIX PROCEDURES: BRIEF DESCRIPTION OF THE METHOD

A single-circuit UGC composed of three single-pole cables is a multiconductor system of *n=6* conductors (*3* phases and 3 sheaths) parallel to themselves and to the ground. If a double-circuit UGC is considered, n=*12* etc. In fig. 1, the conductors can be identified as follows: *1, 2, 3* are the phase conductors and *4, 5, 6* are the metallic sheaths.

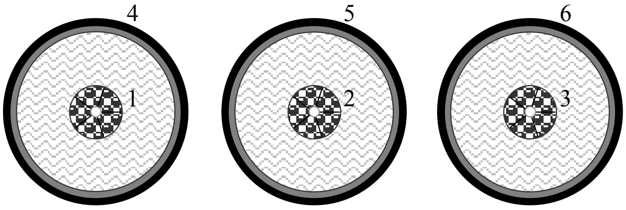

Figure 1: Basic single-pole EHV UGC (flat arrangement)

The line may be represented as a cascade connection of *m* elementary cells of length Δ_ℓ (suitably chosen i.e. ranging between *100* and *300* m), modelled by a lumped PI-circuit (see fig. 2) where the voltage column vectors $\underline{\mathbf{u}}_S$, $\underline{\mathbf{u}}_R$ and the current column vectors $\underline{\mathbf{i}}_S$, $\underline{\mathbf{i}}_{SL}$, $\underline{\mathbf{i}}_{ST}$, $\underline{\mathbf{i}}_R$, $\underline{\mathbf{i}}_{RL}$, $\underline{\mathbf{i}}_{RT}$ are shown. Being that Δ_ℓ is sufficiently small (neglecting the border effects), it is possible to lump the uniformly distributed shunt admittances at both ends of the cell (transverse blocks T_S and T_R) and to consider separately the longitudinal elements in the block *L* (where $\underline{\mathbf{i}}_{RL}\equiv-\underline{\mathbf{i}}_{SL}$). Self and mutual longitudinal impedances, which account for the earth return currents, can be obtained by applying the simplified or the complete Carson's theory [6, 7] or Wedepohl's theory [8]. The matrix $\underline{\mathbf{Z}}_L$ ($n\times n$) that characterises the longitudinal block *L* can be formed as in *Sect. A*. By considering that

$$\underline{\mathbf{u}}_S-\underline{\mathbf{u}}_R=\underline{\mathbf{Z}}_L\,\underline{\mathbf{i}}_{SL}\quad,\qquad \underline{\mathbf{i}}_{RL}\equiv-\underline{\mathbf{i}}_{SL} \qquad [1]$$

being $\underline{\mathbf{Z}}_L$ non-singular, the following matrix relation yields

$$\underbrace{\begin{bmatrix}\underline{\mathbf{i}}_{SL}\\ \underline{\mathbf{i}}_{RL}\end{bmatrix}}_{\underline{\mathbf{i}}_{L\Delta}}=\underbrace{\begin{bmatrix}\underline{\mathbf{Z}}_L^{-1} & -\underline{\mathbf{Z}}_L^{-1}\\ -\underline{\mathbf{Z}}_L^{-1} & \underline{\mathbf{Z}}_L^{-1}\end{bmatrix}}_{\underline{\mathbf{Y}}_{L\Delta}\ (2n\times 2n)}\underbrace{\begin{bmatrix}\underline{\mathbf{u}}_S\\ \underline{\mathbf{u}}_R\end{bmatrix}}_{\underline{\mathbf{u}}_{\Delta}}\ ; \qquad [2]$$

the vectors of the shunt currents at sending-end $\underline{\mathbf{i}}_{ST}$ and at receiving-end $\underline{\mathbf{i}}_{RT}$ are

$$\underbrace{\begin{bmatrix}\underline{\mathbf{i}}_{ST}\\ \underline{\mathbf{i}}_{RT}\end{bmatrix}}_{\underline{\mathbf{i}}_{T\Delta}}=\underbrace{\begin{bmatrix}\underline{\mathbf{Y}}_{TS} & \\ & \underline{\mathbf{Y}}_{TR}\end{bmatrix}}_{\underline{\mathbf{Y}}_{T\Delta}\ (2n\times 2n)}\underbrace{\begin{bmatrix}\underline{\mathbf{u}}_S\\ \underline{\mathbf{u}}_R\end{bmatrix}}_{\underline{\mathbf{u}}_{\Delta}}\ ; \qquad [3]$$

$\underline{\mathbf{Y}}_{TS}$ and $\underline{\mathbf{Y}}_{TR}$ ($n\times n$) are defined in *Sect. B*.