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Zero sequence behaviour of a double-circuit overhead line

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ABSTRACT

Positive, negative and zero sequence series impedances (in Ω/km units) are the first step for power flow and short circuit analyses and are also necessary for setting the distance relays. The paper is devoted to the computation of zero sequence series impedance (in Ω/km units) (self and mutual) in double-circuit overhead lines (OHLs) with one or more earth wires. A systematic comparison with matrix approaches demonstrates that IEC 60909-2 formula adds the zero sequence self and the zero sequence mutual impedance between the two circuits. This approximation of having a unique value of zero sequence impedance is misleading and gives great errors when phase-to-ground short circuit occurs along a circuit. It is worth noting that the zero sequence mutual impedance between parallel circuits installed on the same tower may be as high as 50% (or more) of the zero sequence self impedance of a circuit alone. Consequently, zero sequence mutual impedance between the two circuits cannot be neglected or mixed. MCA (Multiconductor Cell Analysis) shows that the simplified IEC approach underestimates heavily (more than 18%, depending upon the spacing between the circuits) the phase-to-ground fault current for a fault occurrence along one circuit of the double circuit.

1. Introduction

The selectivity of the protection system in a meshed network strictly depends upon the correct settings of the distance relays. As it is well known, their settings are based on positive (negative) and zero sequence series impedances [1,2]. Moreover, unless in-depth multiconductor short circuit computations are necessary (e.g. knowledge of the current sharing between phase conductors, earth wires and the ground [3]), short circuit current magnitudes are usually computed by means of the sequence theory. Consequently, suitable and accurate formulae of kilometric sequence impedances must be used. For EHV cable lines, previous papers have been published [4–6]. This paper is devoted to the zero sequence series impedance for a double-circuit OHL and to the short circuit (involving the earth) computations. In a double-circuit OHL, the influence of the zero sequence mutual impedance on the phase-to-ground short circuit current, occurring along the line, is different from the zero sequence self impedance. Therefore it is fundamental to consider them separately for the computations of all those short circuits involving the earth. The paper shows a comparison of zero sequence impedances computed by means of two approaches: the IEC 60909-2 [7] one and a matrix one which starts from Carson impedance matrix. The different zero sequence impedances are used to compute the effect on a phase-to-ground short circuit occurring in different location along one circuit of the double-circuit. In conclusion, the two aforementioned approaches are compared with the most accurate MCA procedures without simplifications or approximations.

2. Zero sequence behaviour of a double-circuit overhead lines

Let us consider a typical UK un-transposed double-circuit EHV overhead line shown in Fig. 1 [8]. The conductors and earth wire characteristics are reported in Table 1. This table also reports the positive sequence parameters of the double-circuit OHL. It is worth noting that the double-circuit OHL length is equal to 135.42 km which is the maximum 400 kV OHL length in UK (i.e. Cottam-Eaton Socon OHL). For the sake of completeness, in

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Nomenclature

$\underline{z}_{0\text{-}ca}$	series self impedance of one circuit (e.g. circuit *a*)
$\underline{z}_{0\text{-}a\text{-}b}$	series mutual impedance between circuit a and circuit b
OHL	overhead lines
MCA	Multiconductor Cell Analysis
HV	high voltage
EHV	extra high voltage
EW	earth wire
TSO	Transmission System Operator
ACSR	Aluminium Conductor Steel Reinforced
ST	sequence theory
ℓ	distance from sending end substation
ℓ'	distance from receiving end substation
d	line length
Sc	fault section

Subscripts

REC.	receiving
SEND.	sending
SUB SEND.	substation sending
SUB REC.	substation receiving

Table 1
Data assumed in the MCA of 400 kV double-circuit OHL in UK grid.

Line length *d*	km	135.42
Span length	km	0.366
Earth resistivity	Ω m	20
Substation earthing resistance	Ω	0.1
Tower earthing resistance	Ω	10
Bundled Conductor		4 sub-cond. ACSR Zebra Φ = 28.62 mm Spacing = 0.3 m
Earth wire (EW)		ACSR Zebra Φ = 28.62 mm
Positive sequence series resistance at 20 °C (50 Hz)	mΩ/km	8.25
Positive sequence series inductance	mH/km	0.422
Positive sequence shunt leakance (50 Hz)	nS/km	33.56
Positive sequence capacitance	μF/km	0.0267
Single circuit ampacity I_a referred to winter rating [8]	A	4 × 800 = 3200
Winter rating [8] of double-circuit OHL	MVA	2 × 2217

Table 1, the ampacity and winter rating are also reported but they are useless in short circuit computations since the network must be at no-load (shunt admittances can be neglected after IEC 60909).

The resistance of the bundle conductor and of the earth wire must be computed at 20 °C since, according to IEC 60909, the conductors must be "cold" for maximum short circuit computations i.e. $r_{ph\_20^\circ C} = \dfrac{r_{PC\_20^\circ C}}{n} = \dfrac{0.066}{4} = 0.0165\ \Omega/\text{km}$; $r_{ew\_20^\circ C} = 0.066\ \Omega/\text{km}$.

In the following, a matrix technique which starts from the kilometric impedance matrix of all the conductors (active and passive ones) is proposed. Fig. 2 shows the circuital scheme in order to model and to compute the zero sequence impedances (both self and mutual ones) of a double-circuit OHL with one earth wire. First the impedance matrix $\underline{\boldsymbol{Z}}_{tot}$ of all 7 conductors (phase conductors plus earth wire) can be obtained by means of the simplified Carson-Clem [9] or complete Carson theory [10]:

$$\overbrace{\left|\begin{matrix} \underline{z}_{ph11} & \underline{z}_{ph12} & \underline{z}_{ph13} & \underline{z}_{ph14} & \underline{z}_{ph15} & \underline{z}_{ph16} & \underline{z}_{pe17} \\ \underline{z}_{ph21} & \underline{z}_{ph22} & \underline{z}_{ph23} & \underline{z}_{ph24} & \underline{z}_{ph25} & \underline{z}_{ph26} & \underline{z}_{pe27} \\ \underline{z}_{ph31} & \underline{z}_{ph32} & \underline{z}_{ph33} & \underline{z}_{ph34} & \underline{z}_{ph35} & \underline{z}_{ph36} & \underline{z}_{pe37} \\ \underline{z}_{ph41} & \underline{z}_{ph42} & \underline{z}_{ph43} & \underline{z}_{ph44} & \underline{z}_{ph45} & \underline{z}_{ph46} & \underline{z}_{pe47} \\ \underline{z}_{ph51} & \underline{z}_{ph52} & \underline{z}_{ph53} & \underline{z}_{ph54} & \underline{z}_{ph55} & \underline{z}_{ph56} & \underline{z}_{pe57} \\ \underline{z}_{ph61} & \underline{z}_{ph62} & \underline{z}_{ph63} & \underline{z}_{ph64} & \underline{z}_{ph65} & \underline{z}_{ph66} & \underline{z}_{pe67} \\ \underline{z}_{ep71} & \underline{z}_{ep72} & \underline{z}_{ep73} & \underline{z}_{ep74} & \underline{z}_{ep75} & \underline{z}_{ep76} & \underline{z}_{ew77} \end{matrix}\right|}^{\underline{\boldsymbol{Z}}_{tot}} \quad (1)$$

In the hypothesis that earth wire voltage is constantly zero, the "elimination technique of the grounded conductors" [11] can be

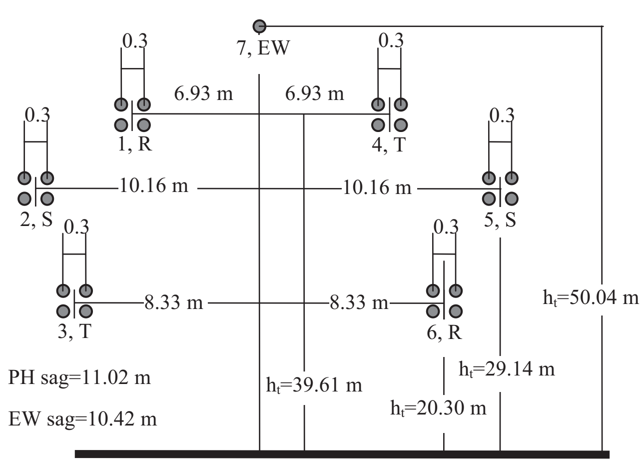

Fig. 1. National Grid UK typical double-circuit overhead line (not to scale) with asymmetric phasing (RST-TSR also called low-reactance phasing).

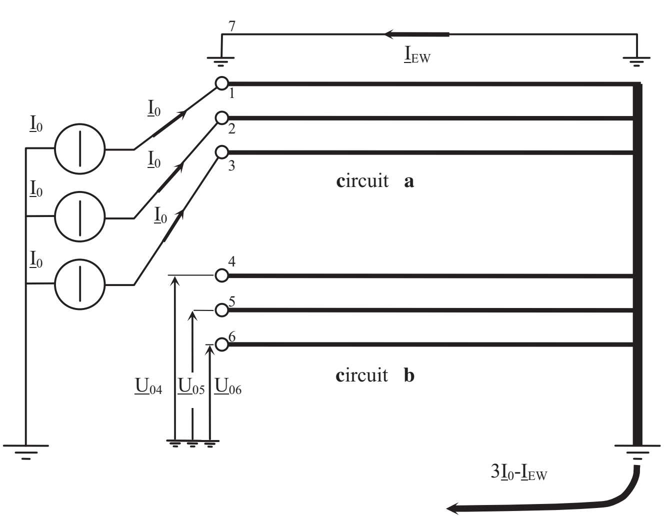

Fig. 2. Zero sequence scheme of a double circuit OHL with one earth wire.