SELECTION OF THE OPTIMAL PHASE ARRANGEMENT FOR PARALLEL CABLES AND ANALYSIS OF END EFFECTS BY MEANS OF CIM

Heiner **BRAKELMANN**, BCC Cable Consulting in Rheinberg (Germany), brakelmann.heinrich@gmail.com
George J. **ANDERS,** Technical University of Lodz (Poland), george.anders@p.lodz.pl
Camilo **APRAEZ**, Eaton Corp., Camilo.apraez@eaton.com

ABSTRACT

In this paper, the analysis of some cable arrangements is described, where a wrong choice of the phase sequence or a disregard of end effects may cause a risk of overheating the cables or – at least – of their suboptimal utilization. The paper summarizes published approaches for the determination of conductor and sheaths currents using the Complex Impedance Matrix (CIM) approach. Different critical cases are discussed, followed by some practical examples.

KEYWORDS

Cable ampacity, phase arrangement, CIM calculations

INTRODUCTION

When sheaths of a single-conductor 3-phase system are bonded at two or more points along the route, circulating currents will flow in them. The thermal losses produced by these currents can, sometime, be larger than the conductor losses reducing considerably circuit ampacity. This phenomenon is well known and understood. What is less understood is the influence of the phase arrangements, especially for installations with multiple cables per phase, on the magnitude of these losses.

In this paper, the analysis of some cable arrangements is described, where a wrong choice of the phase sequence or a disregard of end effects may cause a risk of overheating the cables or – at least – of their suboptimal utilization. The paper summarizes published approaches for the determination of conductor and sheaths currents using the Complex Impedance Matrix (CIM) approach. Different critical cases are discussed, followed by some practical examples. Whereas such methods were developed and published in different papers some time ago [1]-[8], this presentation focusses on a possible compact formulation.

A numerical example will focus on a discussion concerning a proper phase arrangement for a circuit composed of three cables per phase as illustrated in Fig. 1. Each cable is a 110 kV XLPE insulated with lead sheath and PE jacket.

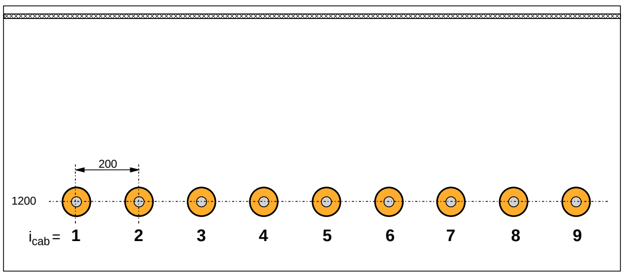

Fig. 1: Example of a circuit with 3 cables per phase

CURRENTS IN PARALLEL CABLE SYSTEMS

Given are n_{sys} HVAC-cable systems (number of cable cores: n_{cab}), which are working in parallel with the impressed phase currents of the conductors I_A, I_B, I_C.

The general equation for the currents (I) and voltages (U) in the conductors and sheaths of the parallel cables is:

$$\begin{bmatrix} \overrightarrow{U_{c,cab}} \\ \overrightarrow{U_{S,cab}} \end{bmatrix} = \begin{bmatrix} \overleftrightarrow{CC} & \overleftrightarrow{CS} \\ \overleftrightarrow{SC} & \overleftrightarrow{SS} \end{bmatrix} \begin{bmatrix} \overrightarrow{I_{c,cab}} \\ \overrightarrow{I_{S,cab}} \end{bmatrix} \qquad (1)$$

with

CC_{ij} n_{cab}*n_{cab}-matrix of coupling impedances between the conductors of cable i and cable j

CS_{ij} n_{cab}*n_{cab}-matrix of coupling impedances between the conductor of cable i and the sheath of cable j

SC_{ij} n_{cab}*n_{cab}-matrix of coupling impedances between the conductor of cable j and the sheath of cable i

SS_{ij} n_{cab}*n_{cab}-matrix of coupling impedances between the sheaths of cable i and cable j.

The algorithms for the determination of the impedances in (1) are described in [11].

The application of equation (1) for various sheath bonding schemes is discussed next.

Both sheath ends bonded („BEB")

BEB means: $\overrightarrow{U_{s,cab}} = 0$ (2)

From (1), we get:

$$\overrightarrow{I_{s,cab}} = -\overleftrightarrow{SS}^{-1}\,\overleftrightarrow{SC}\,\overrightarrow{I_{c,cab}} \qquad (3)$$

and

$$\overrightarrow{U_{c,cab}} = \left[\overleftrightarrow{CC} - \overleftrightarrow{SS}^{-1}\,\overleftrightarrow{SC}\,\overleftrightarrow{CS}\right]\overrightarrow{I_c} = \overleftrightarrow{Z_{cab}}\,\overrightarrow{I_{C,cab}} \qquad (4a)$$

Single point bonded of sheath ends („SPB")

SPB means:

$$\overrightarrow{I_{s,cab}} = 0 \qquad (5)$$

From (1), we get:

$$\overrightarrow{U_{C,cab}} = \overleftrightarrow{CC}\,\overrightarrow{I_{c,cab}} = \overleftrightarrow{Z_{cab}}\,\overrightarrow{I_{C,cab}} \qquad (4b)$$