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Current-carrying capacity parallel single-core LV cable

Abstract. *The paper presents the problems related to the selection of parallel single-core low voltage cables in terms of their current carrying capacity and accordance with PN-IEC 60364-5-523 national standard, exemplified by electric power transmission from transformer MV/LV 1600kVA, with proximity effects also taken into consideration.*

Streszczenie. *Przedstawiony poniżej tekst opisuje problemy związane z doborem wielowiązkowych linii kablowych niskiego napięcia pod względem obciążalności długotrwałej zgodnie z normą* PN-IEC 60364-5-523 *na przykładzie wyprowadzenia mocy z transformatora SN/nN 1600kVA z uwzględnieniem wpływu zjawiska zbliżenia.* ***(Obciążalność długotrwała wielowiązkowych linii kablowych nN).***

Keywords: Multi-conductor parallel cables, current carrying capacity, proximity effects.
Słowa kluczowe: wielowiązkowe linie kablowe, obciążalność długotrwała, zjawisko zbliżenia.

Introduction

While designing networks and electrical installation, a problem that often appears in the practice is how to select properly low voltage cables, taking into account their current-carrying capacity. The main document that is used by the designers is the Polish national standard "Low-voltage electrical installations – Current-carrying capacity" PN-IEC 60364-5-523:2001 [1] (translation from IEC 60364-5 part 52 International Standard). The above-given standard along with other publications [2],[3] refer in detail to the configurations of cables, distances between them and their surroundings. The standard introduces various reduction factors as well as other calculative tools that allow for the optimal selection of wires and cables and protection. It seems, however, that the authors of the above mentioned standard and relative studies, in their calculation or research into the mutual influence of parallel cables have focused principally on thermal phenomena. Thus they have neglected the electromagnetic field generated by the flow of currents, which are significant in particular for parallel core which forms one circuit. This situation requires an attempt to study the effects of uneven load in the parallel line and its effect on current-carrying capacity of the cable. In the present paper the authors focus on the description of the problem on a real-life example of selecting multi-core low voltage cable which is the power lead from 1600kVA transformer. The tests have been conducted in accordance with PN-IEC 60364-5-523:2001 Polish National Standard

In the example analyzed here, it was necessary to select a low-voltage cable which was connecting a 1600kVA transformer to the main low-voltage switchboard. Due to the location of the transformer station and the building specifications, it was impossible to make bus-ducts connections. Financial limitation made it impossible to build insulated bus-ducts.

A cable line made from single core cables of the YAKXS 1X240 type, laid out on cable tracks, with the temperature kept below 20^0C has been selected. The distance between the cores of one phase was equal to the diameter of the line, whereas the subsequent phases were laid out analogically at distances considerably exceeding twice of the diameter of a single line.

The nominal transformer current on the low-voltage side, with the power factor *cos* φ =0,9 (system working with reactive power compensation) for a single phase, under the symmetrical load equals 2576A.

According to the Standard [1], the cables were laid out in accordance with the 52-C12 Table (reference method of installation - G horizontal) . While calculating the current-carrying capacity, the correction factor were taken into consideration – according to 52-D1 Table of coefficients and exponents, taking into account the ambient temperature different from 30^0C (coefficient 1,08) – the increasing coefficient has been skipped, and in accordance with 52-E1 Table (reduction factor 0,79 for a group of more than one circuit). After meeting all the conditions, included in the 523.6 Chapter of Standard [1], the following electrical system has been designed.

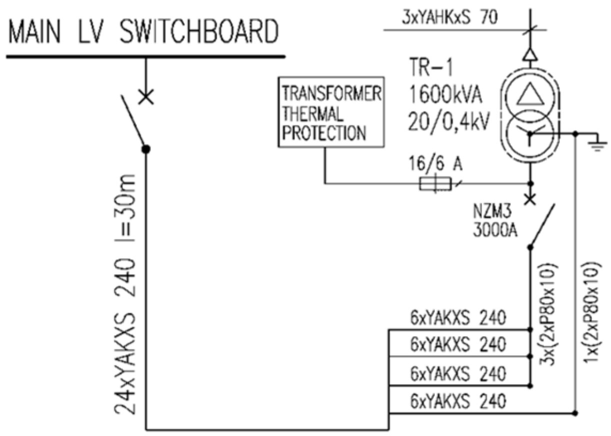

Fig.1. Diagram of connecting low-voltage switchboard

For each phase, 6 parallel lines were selected, made from XPLE insulated aluminum cable with the cross-section of 240 mm^2 of the YAKXS type. The current-carrying capacity of each core, according to 52-C12 Table of norm [1] was 521A. However, if one accepts the values provided by the manufacturer i.e. those from Telefonika Kable catalogue [4], the current-carrying capacity will be 480A. The calculated current value of a single core for the nominal transformer load was 429A. It can be assumed then, that the cables have been selected correctly, with a substantial safety margin up to 10%. The designed system was made in accordance with the specification and put into operation. After a few days of operation, the system suffered a fault, which resulted in a total destruction of the cable line.

Measurements and registration of currents in the cable line

After rebuilding the power system, current measurements of each phase in the cable line were made in order to exclude possible asymmetries of the load and system over-current. We have also made check-up measurements of the circuit breaker, equipped with integrated protection system. The check-up of the circuit breaker excluded the possibility of its malfunction while the measurements confirmed that the system load was symmetrical.

Fot.1 Cables after fault

The maximum recorded effective value of the current did not exceed the current-carrying capacity in amperes. However, we have noticed a considerable discrepancy between the effective values of current in particular lines being a part of one phase. The courses of effective current values in extremely loaded lines for a selected period of time are presented below.

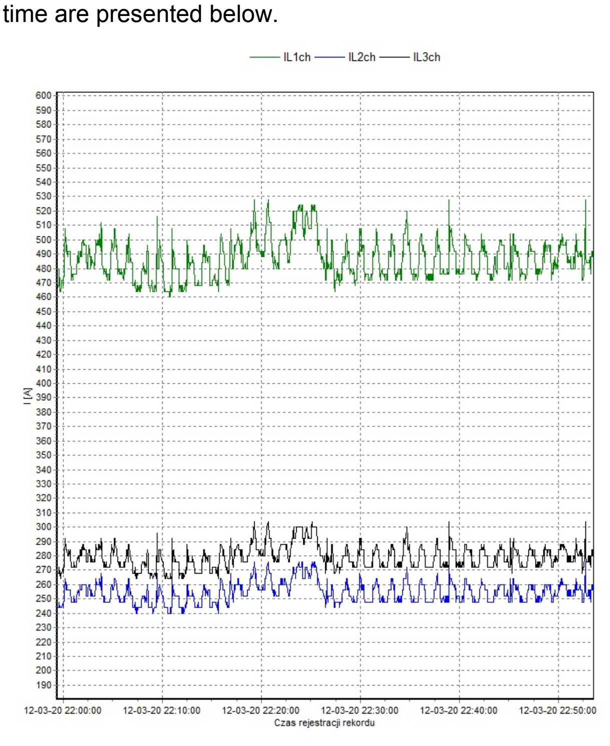

Fig.2. RMS current extremely loaded core of line

The difference in the load of extremely loaded lines is nearly double. For line L1, the effective current value of a maximum of 528A was recorded, while this value was 280A for line L3 – the proportion of load for extremely loaded lines was 1.9. It is worth recalling that the lines were made from the same material and had the same length whereas differences in the resistance of cable clamps were excluded from the analyses. Due to the significant differences in the load of particular lines as well as the possibility of another fault, we have investigated the causes of the uneven load of the lines. For his purpose, a computational model of the system was developed.

The computational model of the system

The simulations were made in FEMM program which is a suite of programs for solving low frequency electromagnetic problems on two-dimensional planar and axi-symmetric domains. The program currently addresses linear/nonlinear magnetostatic problems, linear/nonlinear time harmonic magnetic problems, linear electrostatic problems.

Six cores with the cross-section of 240mm^2 and total length of 30m were entered into the model. Then, a sinusoidal current flow (amplitude 3632 A, frequency 50 Hz) was forced as the excitation source, with The cores were assumed to be made of AL 1100 aluminum, with electric conductivity γ = 34,45 MS/m. The cable insulation was not considered in the simulation.

The calculations were made for various types of line configuration – vertically (two variants), spherical layout, parallel layout.

For each case, two coefficients k_{AS} –unbalance and k_{PZ} – overload were defined

(1) $k_{AS}=I_{max}/I_{min}$,

(2) $k_{PZ}=6*I_{max}/I_C$,

I_{max} – current amplitude of the highest load core,

I_{min} – current amplitude of the lowest load core,

I_C - current amplitude of the circuit (one phase).

Parallel single core in the flat layout

In the first variant, the core of the circuit being one phase were laid out as flat - vertically laid, with a distance of 17.5 mm between each one, which means that the gap between each line was equal to the line diameter. The simulation is a model of a real system. The mesh being used for calculations consisted of 44736 nodes and 88748 triangle elements. Table 1 presents the results of the total current calculations for each core, whereas Figure 3 presents the real component of magnetic vector potential $\underline{\boldsymbol{A}}$, $\boldsymbol{B}$ = rot $\underline{\boldsymbol{A}}$, rot $\underline{\boldsymbol{A}}$=0 for this section and the distribution of current density of each core. Fig. 4 presents the eddy and source current density – cross-section of cores (X-Y Plot).

Table 1 Total current of each core

nr of core	current amplitude (A)
L1	794.104+j157.279
L2	554.748-j68.193
L3	455.341-j93.6995
L4	457.639-j93.55
L5	562.36-j66.7541
L6	807.808+j164.918

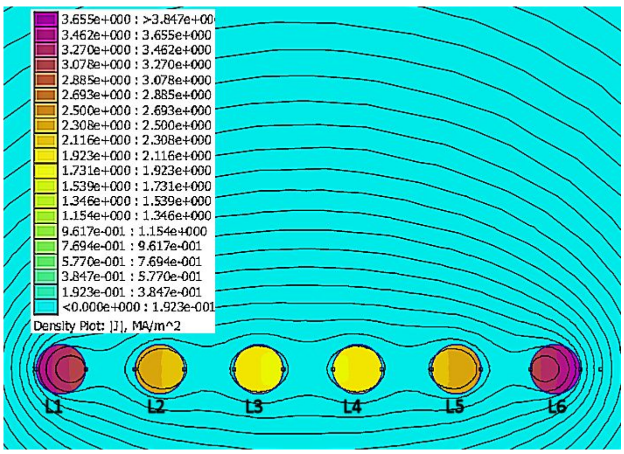

Fig.3 Real component of magnetic vector potential $\underline{\boldsymbol{A}}$, distribution of current density

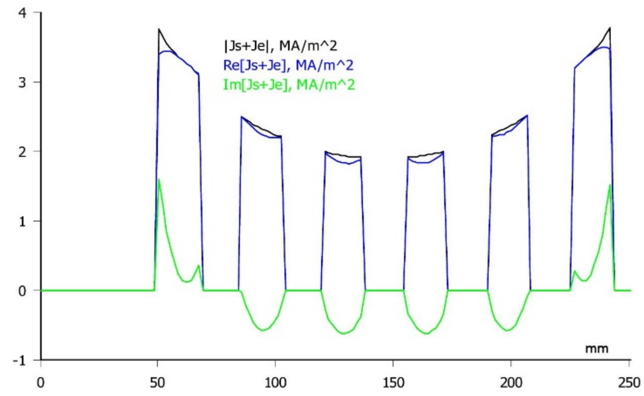

Fig.4 Eddy and source current density – cross-section of cores

The values of the asymmetry and overload coefficients are as follows: k_{AS}=1.78, k_{PZ}=1.32

The next variant features the lines of cores that were laid out flatly, with a distance of 35 mm between each one, which is equal to the double diameter of the line. The mesh being used for calculating had 44865 nodes and 89006 triangle elements. Table 2 presents the results of the total current calculations for each core, Fig. 5 presents the real component of magnetic vector potential ***A*** for this section and the distribution of current density of the each core.
The values of the asymmetry and overload coefficients are as follows: k_{AS}=1.73, k_{PZ}=1.33.

Table 2 Total current of each core

nr of core	current amplitude (A)
L1	784.783+j129.265
L2	550.948-j56.8479
L3	464.041-j78.238
L4	466.932-j78.024
L5	561.018-j54.816
L6	804.276+j138.663

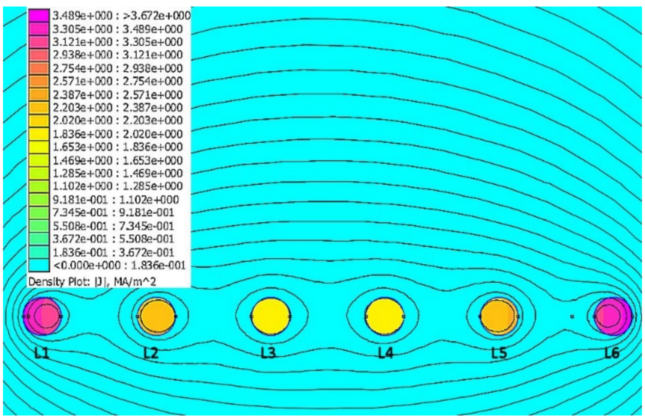

Fig.5 Real component of magnetic vector potential ***A,*** distribution of current density

Parallel single core in the spherical configuration

The cores were laid out spherically – around a circle. The lines did not come in contact with each other. The mesh being used for calculations had 42953 nodes and 85182 triangle elements. Table 3 presents the results of the total current calculations for each core, Fig. 6 presents the real component of magnetic vector potential ***A*** for this section and the distribution of current density of the each core. The values of the asymmetry and overload coefficients are as follows: k_{AS}=1.03, k_{PZ}=1.1

Table 3 Total current of each core

nr of core	current amplitude (A)
L1	598.269-j13.34
L2	608.951+j6.81
L3	606.94+j5.10
L4	594.214-j16.61
L5	610.733+j8.05
L6	612.893+j9.97

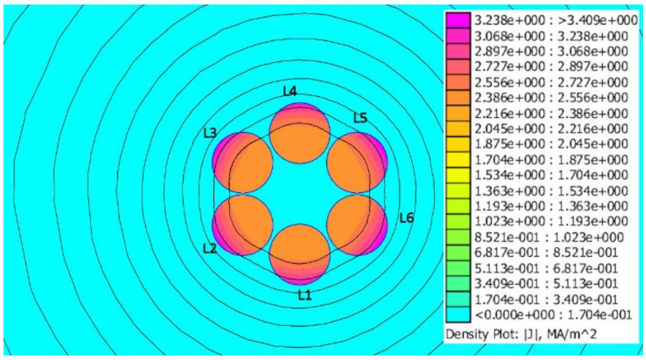

Fig.6 Real component of magnetic vector potential ***A***, distribution of current density

Current bus bar in a parallel layout

The lines were laid out parallely in two layers, with a distance of 17.5 mm between each line and each layer. The mesh being used for calculating had 44701 nodes and 888678 triangle elements. Table 4 presents the results of the total current calculations for each core, Fig. 7 presents the real component of magnetic vector potential ***A*** for this section and the distribution of current density of the each core. The values of the asymmetry and overload coefficients are as follows: k_{AS}=1.39, k_{PZ}=1.1

Table 4 Total current of each core

nr of core	current amplitude (A)
L1	670.656+j72.138
L2	485.061-j136.715
L3	664.842+j68.587
L4	661.654+j65.611
L5	482.294-j138.784
L6	667.494+j69.162

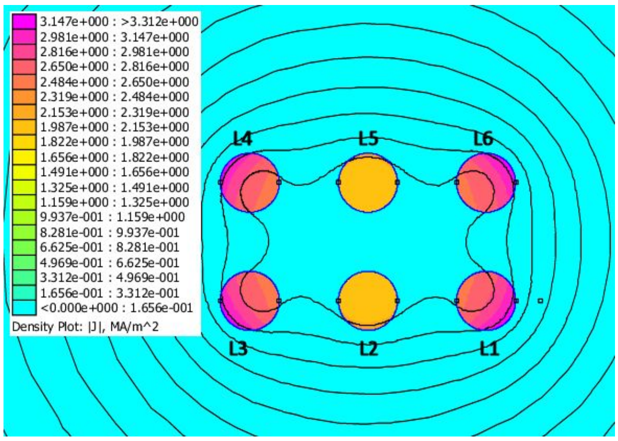

Fig.7 Real component of magnetic vector potential ***A***, distribution of current density

Summary and final conclusions

The simulations conducted on the prepared model proved to be compatible with the measurements recorded in the real system. The calculated asymmetry coefficients are, respectively, k_{AS}=1.9 for the real system, and k_{AS}=1.73 for the model. The analysis of mutual interaction between parallel lines that formed one circuit showed a significant influence of the proximity effect on the load layout which is also reported in publications [5],[6]. The configuration of core layout shown in PN-IEC 60364-5-523:2001 National Standard as an optimal one (horizontal layout, with the double diameter distance between the lines), seems to be the worst solution if field phenomena are to be taken into consideration. An asymmetry coefficient above 1.7 and overload coefficient above 1.3 practically render it impossible to construct multi-conductor low-voltage parallel cables. An optimal solution from the simulations conducted proved the spherical layout with the coefficient values of k_{AS}=1.03, k_{PZ}=1.1. It seems advisable to conduct further studies into the current carrying capacity of multi-conductor low-voltage parallel cables, including three-phase systems, harmonics and thermal phenomena in order to work out an optimal way of constructing multi-conductor cables and make corrections to norm [1]. The authors are planning to make a simulation using another tool (Maxwell from Ansoft), construction of a real-life model and taking measurements in real objects with transformer rated power over 1000KVA that include multi-conductor cable lines. Currently, designing multi-conductor cable lines in accordance with the Standard [1], without considering the proximity effect and performing additional calculations is both erroneous and hazardous.

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