CROSS-BONDING IN MIDDLE VOLTAGE DISTRIBUTION GRIDS, AS A METHOD OF ENERGY EFFICIENCY IMPROVEMENT

Dr Janusz JAKUBOWSKI
RWE Stoan Operator – Poland
janusz.jakubowski@rwe.pl

Maciej PAŞNIEWSKI
RWE Stoan Operator – Poland
maciej.pasniewski@rwe.pl

Marek KIBLER
RWE Stoan Operator - Poland
marek.kibler@rwe.pl

ABSTRACT

The subject addressed is Cross-bonding in middle voltage distribution grids. Cross-bonding is a method of connecting cable conductors. Special joints allow to cross return conductors between phases in order to minimize losses. After preliminary calculations, cross-bonding pilot project have been run in RWE Stoan Operator’s middle voltage cable grid. Based on pilot project results, which have confirmed theoretical assumptions, calculation have been made

Cross-bonding is common in high voltage cable lines but not in middle voltage grid. Analysis show, that taking middle voltage grid scale into account, middle voltage cable lines cross-bonding leads to reduction of energy losses.

INTRODUCTION

A natural endeavour of every Distribution System Operator is to attain the highest possible capacity relative to the building costs. A higher capacity of power lines offers a possibility to supply more customers with electrical energy, and a possibility to use the financial resources for the grid investments more rationally.

The parameter which limits the capacity of the lines is the maximum temperature of the main conductor. When the temperature exceeds long lastingly, it damages the insulation (in case of cable lines) or the conductor itself (in case of overhead lines). It is especially important for cable lines where the material degradation makes it necessary to rebuild the whole line.

It is possible to lower the temperature of the main conductors through the improvement of heat removal from the line or through the decrease of losses in the cables.

One of the methods to decrease the losses in cables is the reduction of losses in the metal coats (return conductors) of single conductor cables.

In the return conductor of a single conductor cable which is one of three phases of a three-phase line with cables put in the shape of a triangle, there will be voltage induced, figure of which per length unit can be calculated in accordance with the following equation [1]:

\[ E = 2 \cdot \pi \cdot f \cdot I \cdot 2 \cdot 10^{-7} \ln (2 \cdot m/d) \]  \[ [1] \]  

where:

- \( E \) - voltage induced per length unit of the line [V/m]
- \( f \) – system frequency [Hz]
- \( m \) – distance between the cables’ axes [m]
- \( d \) – average diameter of the return conductor [m]
- \( I \) – current intensity in the main conductors [A]

In case of both-side earthing of the return conductors in cables which is a very often used solution, the voltage induced in the in the return conductors causes in them an electric current flow. The current enforced by the induced voltage, flowing in the return conductors, will cause a voltage decrease on the impedance of those conductors which will compensate the induced voltage. This current will also cause the growing warm of the return conductors and power losses. The warm emitted in the return conductor rises its temperature and hamper the heat emission from the main conductor which in consequence reduces the capacity of a cable line.

A method to lower the losses in the return conductor and thus to increase the line’s capacity is to decrease the current intensity in the return conductor. It is possible to achieve this through: one-side earthing of return conductors, application of a break in the return conductor or crossing of conductors i.e. cross bonding.

In cable lines which are longer than typically fabricated cable sections, and the application of sleeves is necessary, the crossing of return conductors is a very popular solution.

The working principle of conductors’ crossing is described below.

During the project planning of the junctures for a cable line, we try to build a line of three fabricated cable sections of possibly the same length. The cable sections are to be jointed together with sleeves which allow taking out the return conductors. The taken out return conductors are to be jointed together in accordance with the figure 1.

![Figure 1 – return conductor crossing](image-url)
Let us look at the return conductor $a_1$ of the phase 1 cable in the section 1 of the cable line. It is jointed in the section 2 of the cable line with the return conductor $a_2$ of the phase 2 cable, which is jointed in the section 3 of the cable line with the return conductor $a_3$ of the phase 3. If the lengths of the following sections are equal, then the induced current in the following sections $a_1$, $a_2$ and $a_3$ are equal in relation to module but they are rotated to each other by 120°. The vector sum of current induced in the following sections $a_1$, $a_2$ and $a_3$ gives a resultant equal to zero. A similar situation is in the return conductors $b_1$, $b_2$ and $b_3$ and $c_1$, $c_2$ and $c_3$.

The neutralizing of current induced to zero means that in the return conductors there is no current enforced by the induced voltage, although the conductors are earthed by both sides. No current flow in the return conductors means a reduction of losses, no warm source which would hamper the cooling of main conductors, and resultantly an increase of capacity of power lines.

**THEORETICAL ASSUMPTIONS**

**Cross-bonding leads to return conductor current reduction**

**Cable line losses without cross-bonding**

In normal conditions, current in return conductors is about 20% of current in the main conductor. Technical losses in cable line without cross-bonding are as follows [2]:

$$3 \cdot [(I^2 \cdot Rt_m) + ((20\%I)^2 \cdot Rt_r)]$$  \[2\]

where

- $Rt_m$ – resistance of main conductor
- $Rt_r$ – resistance of return conductor
- $I$ – current in main conductor
- $20\%I$ – return conductor current

**Cable line losses with half cross-bonding**

In ideal environmental conditions, after adding one cross-bonding joint (half cross-bonding), current in each return conductor is reduced to about 57% of primary current.

$$3 \cdot [(I^2 \cdot Rt_m) + ((0,57 \cdot 20\%I)^2 \cdot Rt_r)]$$  \[3\]

**Cable line losses with full cross-bonding**

When two set of cross-bonding joints are installed in every one third of the line length, current in return conductor in each phase is reduced almost to zero. Taking asymmetry into account, we can assume that 5% of return conductor current is still being induced by main conductor.

$$3 \cdot [(I^2 \cdot Rt_m) + ((0,05 \cdot 20\%I)^2 \cdot Rt_r)]$$  \[4\]

**PILOT PROJECT DESCRIPTION**

The object of analysis was a middle voltage (15kV) cable line which connects two substations (HV/MV RPZ Stegny and MV/MV RSM Orezna). Cable type: 3x1x240mm² XUHAKXS, length 2 km.

At first stage of the project, return conductor current was measured. Results confirmed theoretical assumptions of 20% main current value. Next step was installing one cross-bonding joint in one third of a line and measurements. After month of one joint operating (half cross-bonding), second set of joints in two thirds was installed in order to obtain full cross-bonding. Results corresponded with theoretical assumptions. Current in return conductors was reduced on average to the level of 11% (after half cross-bonding) and 1,3% (after full cross-bonding) of main conductor level.
PILOT PROJECT RESULTS

Measurements
Results of measurements at all stages of pilot project are in line with expectations and they correspond with theoretical assumptions. Measures were taken every 15 minutes for approximately week time for each of steps (regular line, line with one and with two jonits sets) Samples of results are shown in tables 1-3

<table>
<thead>
<tr>
<th>line without cross-bonding</th>
<th>return conductor current [A]</th>
<th>main conductor current [A]</th>
<th>return current / main current</th>
</tr>
</thead>
<tbody>
<tr>
<td>21,18</td>
<td>115,75</td>
<td>18%</td>
<td></td>
</tr>
<tr>
<td>24,66</td>
<td>130,41</td>
<td>19%</td>
<td></td>
</tr>
<tr>
<td>30,01</td>
<td>160,97</td>
<td>19%</td>
<td></td>
</tr>
</tbody>
</table>

Table 2 - currents in line with half cross-bonding

<table>
<thead>
<tr>
<th>half cross-bonding</th>
<th>return conductor current [A]</th>
<th>main conductor current [A]</th>
<th>return current / main current</th>
</tr>
</thead>
<tbody>
<tr>
<td>12,1</td>
<td>116,7</td>
<td>10%</td>
<td></td>
</tr>
<tr>
<td>14,2</td>
<td>130,41</td>
<td>11%</td>
<td></td>
</tr>
<tr>
<td>17,0</td>
<td>161,48</td>
<td>11%</td>
<td></td>
</tr>
</tbody>
</table>

Table 3 - currents in line with full cross-bonding

<table>
<thead>
<tr>
<th>full cross-bonding</th>
<th>return conductor current [A]</th>
<th>main conductor current [A]</th>
<th>return current / main current</th>
</tr>
</thead>
<tbody>
<tr>
<td>1,6</td>
<td>116,5</td>
<td>1,4%</td>
<td></td>
</tr>
<tr>
<td>1,7</td>
<td>129,4</td>
<td>1,3%</td>
<td></td>
</tr>
<tr>
<td>2,0</td>
<td>160,4</td>
<td>1,3%</td>
<td></td>
</tr>
</tbody>
</table>

Analysis
Further calculation of losses an economical analysis of cross-bonding implementation were based on pilot project results and theoretical assumptions confirmations. Few variants were calculated for RWE Stoen Operator’s MV grid. Energy prices prognosis for future years, infrastructure development in Warsaw and National Regulatory aspects were also taken into account.

CROSS-BONDING COSTS AND BENEFITS

Additional costs of cross-bonding
Costs of installing cross-bonding joints varies, depending on realisation technique. Generally there are two paths: passive and active joint installation. Additionally costs depend on number of joints installed, weather one or two is being installed. For this paper needs, only full cross-bonding (two joints) will be discussed

Passive cross-bonding
When new cable line over 1 km length is being build, a joint is needed to connect two cable sections, about 500m each (for technical reasons cable is delivered in two sections). Instead of one traditional joint, two cross bonding joints can be used in one third and two thirds of the line length. In this case, traditional joint versus cross-bonding joint cost and second cross-bonding joint with digging and assembly costs is the additional expenditure.
Another way of implementing cross-bonding requires higher additional costs. When installing cross-bonding joints on existing cable line, additional digging, assembling and material costs need to be incurred for two localizations. Expenditures comparing to losses reduction benefits are lower.

Figure 5 – active cross-bonding costs allocation

Conclusions – passive or active cross-bonding
Passive way of implementing cross-bonding is more cost efficient but not always possible. Most MV grids, especially in developed cities with small growth, are already built and only active cross-bonding on existing cable lines can be implemented. However level of benefits depends on technical aspects of the grid such as load level and length of lines.

Graph 1 – technology profitability boundries for different cross-bonding implementation options

Graph 2 – profitability of cross-bonding for typical 150mm² MV cable line, 1 km long

Table 4 – economic analysis of different c-b variants

<table>
<thead>
<tr>
<th>Cross-bonding variant</th>
<th>full C-B</th>
<th>half C-B</th>
<th>full C-B</th>
<th>half C-B</th>
<th>full C-B</th>
<th>half C-B</th>
<th>full C-B</th>
<th>half C-B</th>
<th>full C-B</th>
<th>half C-B</th>
</tr>
</thead>
<tbody>
<tr>
<td>Active NPV</td>
<td>2 241</td>
<td>1 468</td>
<td>590</td>
<td>150</td>
<td>1 181</td>
<td>750</td>
<td>470</td>
<td>1 350</td>
<td>2 341</td>
<td>1 568</td>
</tr>
<tr>
<td>IRR</td>
<td>8%</td>
<td>10%</td>
<td>2%</td>
<td>1%</td>
<td>5%</td>
<td>6%</td>
<td>1%</td>
<td>8%</td>
<td>5%</td>
<td>7%</td>
</tr>
<tr>
<td>Passive NPV</td>
<td>2 075</td>
<td>1 380</td>
<td>590</td>
<td>150</td>
<td>1 015</td>
<td>667</td>
<td>583</td>
<td>1 023</td>
<td>2 003</td>
<td>1 323</td>
</tr>
<tr>
<td>IRR</td>
<td>15%</td>
<td>18%</td>
<td>2%</td>
<td>5%</td>
<td>10%</td>
<td>12%</td>
<td>3%</td>
<td>12%</td>
<td>15%</td>
<td>18%</td>
</tr>
<tr>
<td>Regulatory incentive</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
</tr>
<tr>
<td>Energy price growth</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
</tr>
</tbody>
</table>

SUMMARY
The outcome of middle voltage cross-bonding is:
- Cable lines losses reduction results in money savings
- Increase of cables capacity allows to distribute higher energy volumes
- Analysis results can encourage DSO’s to adapt MV cross-bonding in their grids