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

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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 Stoen 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]:

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

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.

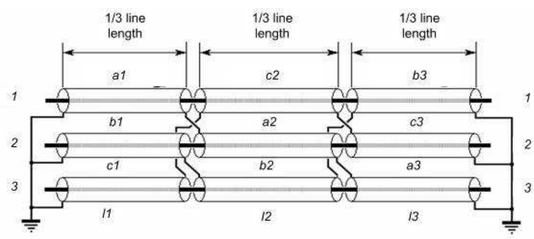


Figure 1 – return conductor crossing

Let us look at the return conductor a1 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 a2 of the phase 2 cable, which is jointed in the section 3 of the cable line with the return conductor a3 of the phase 3. If the lengths of the following sections are equal, then the induced current in the following sections a1, a2 and a3 are equal in relation to module but they are rotated to each other by 120^0. The vector sum of current induced in the following sections a1, a2 and a3 gives a resultant equal to zero. A similar situation is in the return conductors b1, b2 and b3 and c1, c2 and c3.

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 fallows [2]:

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

where
Rt_m – resistance of main conductor
Rt_r – resistance of return conductor
I – current in main conductor
20%I – return conductor current

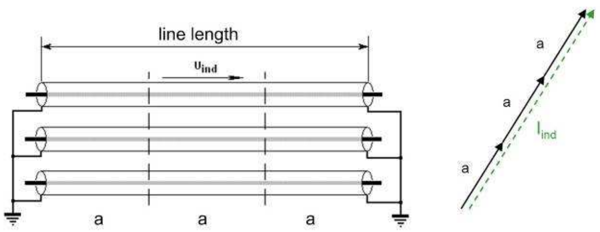


Figure 2 – line without cross-bonding

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..

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

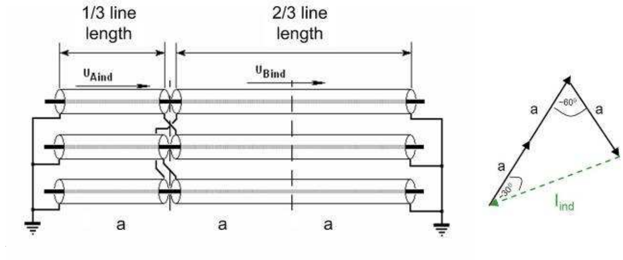


Figure 3- line with half cross-bonding

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 inducted by main conductor.

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

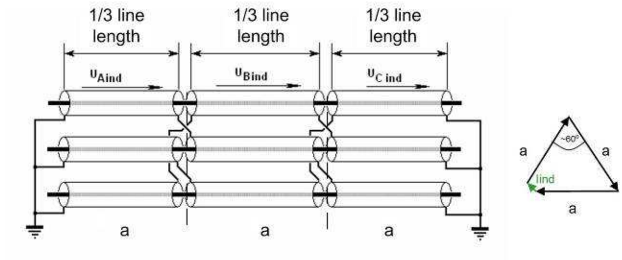


Figure 4 - line with full cross-bonding

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: $3x1x240mm^2$ 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.

Image 1 – MV cable prepared to cross-bonding joint installation (cooper return conductor being separated)

Image 2 – one phase return conductor pulled outside in order to connect it with other phase return conductor (crossing)

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 aproximetly week time for each of steps (regural line, line with one and with two jonits sets) Samples of results are schown in tables 1-3

Table 1 – currents in regular line

line without cross-bonding		
Return conductor current [A]	main conductor current [A]	return current / main current
21,18	115,75	18%
24,66	130,41	19%
30,01	160,97	19%

Table 2 - currents in line with half cross-bonding

half cross-bonding		
return conductor current [A]	main conductor current [A]	return current / main current
12,1	116,7	10%
14,2	130,41	11%
17,0	161,48	11%

Table 3 - currents in line with full cross-bonding

full cross-bonding		
return conductor current [A]	main conductor current [A]	return current / main current
1,6	116,5	1,4%
1,7	129,4	1,3%
2,0	160,4	1,3%

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.

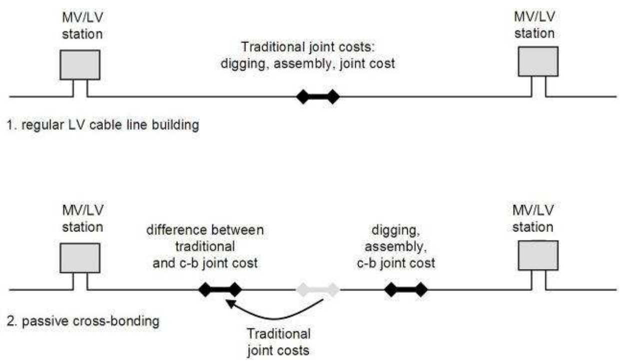


Figure 5 – passive cross-bondnig costs allocation

Active cross-bonding

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 needs to be incurred for two localizations. Expenditures comparing to losses reduction benefits are lower.

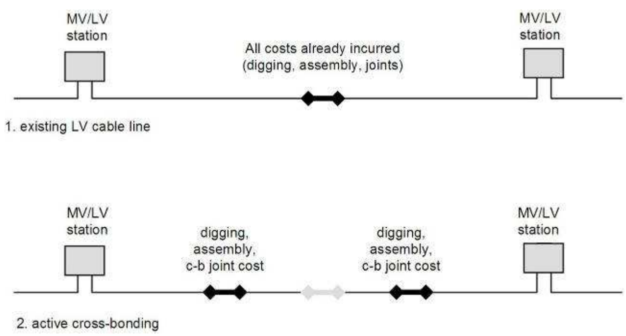
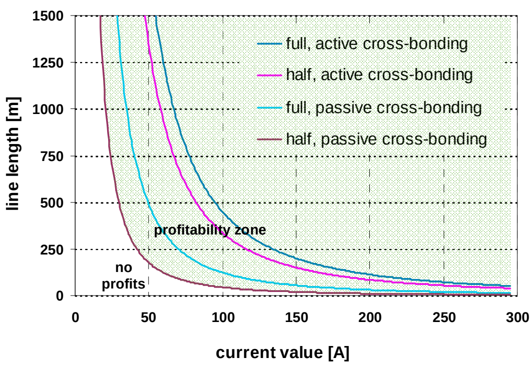


Figure 5 – active cross-bonding costs allocation

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 build 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

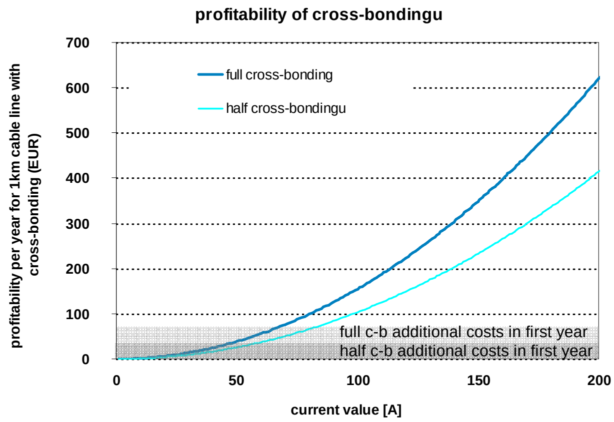


Graph 1 – technology profitability boundries for different cross-bonding implementation options

Graph 1 shows different types of cross-bonding profitability curves for typical 150mm^2 middle voltage cable. Profits depend on line length and current load. Long cable lines loaded heavily give most profits after installing cross-bonding joints.

Benefits of cross-bonding

After installing c-b joints, cable line has better capacity and its losses are lower. This profits can be calculated to real money value, which is obtained every year. If cable line meets technical conditions for specific cross-bonding type, investment additional costs are covered after year or two. Full investment costs return and final profit, depends on technical and economic environment such as energy prices and regulatory aspects. Generally, after calculating few different variants of implementing cross-bonding, most cases were NPV positive.



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

Table 4 – economic analysis of different c-b variants

Cross-bonging variant		full C-B	half C-B	full C-B	half C-B	full C-B	half C-B	full C-B	half C-B
Active	NPV	2 241	1 469	-590	-135	1 181	750	470	1 350
	IRR	8%	10%	-2%	-1%	5%	6%	1%	8%
Passive	NPV	2 075	1 385	290	305	1 015	667	583	1 023
	IRR	15%	18%	3%	5%	10%	13%	3%	12%
Regulatory incentive		X	X			X	X		
Energy price growth		X	X					X	X

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