Overload of multi-system cables due to coupling on cable shields

Daniel Goetz, InfraServ GmbH & Co. Knapsack KG; Moritz Pikisch / Florian Fink, OMICRON

Abstract

When a high power needs to be transported via a cable route, several cables are often used in parallel due to the current carrying capacity and to keep the voltage drop low. With today's standard single-core cable, inhomogeneous magnetic fields can cause currents to couple to the cable shields. This coupling can lead to increased thermal stress and can even damage these medium-voltage cables. In this article, we show how this coupling can be easily measured and how, after an evaluation, possible countermeasures can be taken.

Keywords

- Medium voltage cable
- Cable shield
- Cable laying
- CPC 100
- Commissioning test

1 Parallel single-core medium voltage cables

Whenever higher power in a medium-voltage (MV) system has to be transmitted via cable routes, parallel cable systems are used due to ampacity and voltage drop. When dimensioning the cable section, the planner has to consider a large number of criteria:

- Power / current to be transmitted
- Acceptable voltage drop
- Ampacity of MV cables
- Reduction factors:
    - Type of installation
    - Environment (temperature, soil, etc.)
    - Clustering/parallel cables
    - Simultaneity factors
- Tensile forces during laying
- Bending radii
- Short-circuit withstand, bundling if necessary

For a correctly dimensioned cable section, it is therefore necessary to comply with a number of basic conditions. The conductive cross-section of a cable cannot be increased arbitrarily, since the cables must still be manageable for production, transport, and installation. In the case of medium-voltage cables, the optimum is usually reached with a cross-section of 500mm².

In addition to the conductor and the insulating materials, single-phase medium-voltage cables (single-core cables) also consist of a cable shield (see Fig. 1). It has several tasks - for example, potential equalization (grounding) between the equipment that is connected by the cable. Furthermore, in the event of cable damage, it ensures that the best possible grounding is achieved at the fault location.

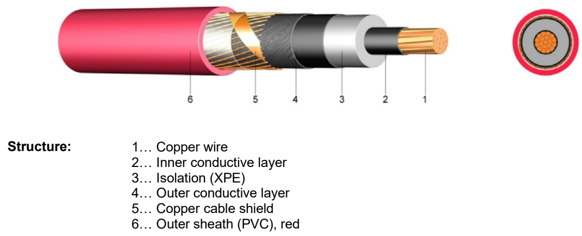

Figure 1 - Single cable for medium voltage N2XSY (Source: Meinhart Kabel)

2 Cable damage due to coupling onto the cable shields

Again and again, one hears in reports that damage has occurred to cable lines due to increased shield currents. Research into the cause of this is usually difficult. Often, optimal routing (as shown in Fig. 4) is not possible. Single-core cables are connected to switchgear and other equipment in phases (see Fig. 2).

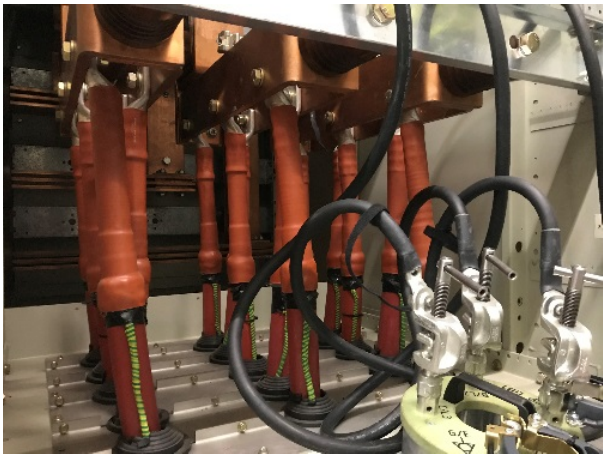

Figure 2 - Parallel connection of single-core medium-voltage cables to a switchgear system

This results in the problem that already on the first section up to the raised floor, the magnetic fields generated around the conductors can add up per phase and inductively couple into the respective cable shields.

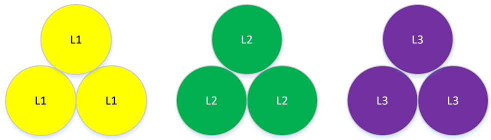

Figure 3 - Parallel single-core medium-voltage cables when connected to a switchgear or other equipment

The cable system is then crossed out in the raised floor as soon as possible. By laying the cable system by system, the resulting magnetic fields are to be eliminated so that they cannot be copied into neighboring cables, cable platforms or the cable shields. For this purpose, phases are also cyclically exchanged.

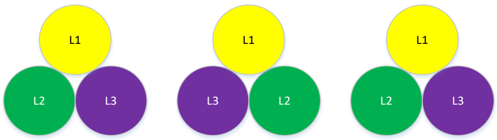

Figure 4 - Parallel single-core medium-voltage cables after crossing out

In order to make an exact statement about the load capacity of a cable section, one also needs the coupling into the cable shields. Determining this coupling by calculation is very time-consuming. To do this, one would have to create an exact, three-dimensional image of each section of the cable route and perform calculations with a computer program based on the finite element method. In this case, however, it is still assumed that the sections are laid as homogeneously as possible, which is not the case in reality.

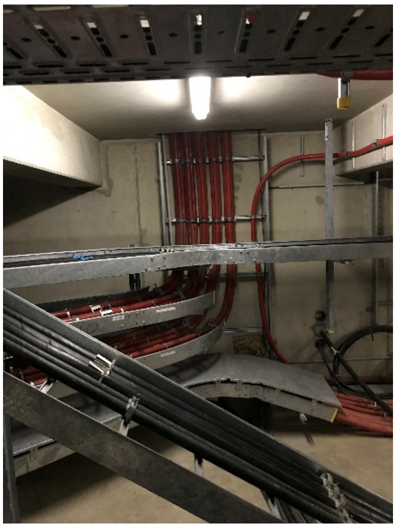

Figure 5 - Various medium-voltage cable routes in the cable basement

Thus, other methods for determining coupling are desirable.

3 Cable connection between two switchgears in the Chemical Park

At InfraServ Knapsack, too, damage has already occurred to cable lines due to coupling onto cable shields.

Figure 6 - Shield visible from the outside, the insulation has melted

Figure 7 - The sand has bonded with the insulation

In order to be able to avoid expensive repairs in the future, there was a wish to carry out an exemplary measurement on a cable section in order to test a new measurement method by means of which exact statements can be made about the shield currents actually arising.

The cable section is used as a coupling between two 6 kV main switchgears. In this way, when one of the feeder transformers is overhauled, the feed-in can be carried out via the other system. The following are the data on the cable section:

- Cable type: N2XSY 3 x 1 x 500 mm²
- Number of parallel systems: 5
- Length: 500 m
- Operating voltage: 6 kV
- Rated current: 2300 A
- Rated power: 23 MVA

Figure 8 - 500 m, 6-kV-Cable system with 2300 A rated current

The rated current of 2300 A is not utilized at the time being, since currently only electrical loads are in operation that generate a current flow of approx. 600 A between the plants. However, should there be new installations on the chemical park site in the future, the cable route could be subjected to significantly higher loads.

4 Measurement on the cable section

The shield currents are estimated with CPC 100, CP CU1 and CP GB1. The injection of the test currents is similar to a line impedance measurement. However, instead of the voltage, the currents in the shields are measured by means of a current clamp. Figure 9 shows the test setup with CPC 100, CP CU1, CP GB1 and a current clamp.

Furthermore, a corresponding template must be used to calculate the currents in the operating case.

In total, there are two different methods to estimate the coupling into cable shields with a single-phase test source consisting of CPC 100 and CP CU1:

- Feeding into all three phase-earth combinations: This can be used to estimate shield currents of any 3-phase load case.
- Feeding into two phase-phase combinations: Here, only shield currents of a load case can be estimated, where the operating current has no zero-sequence current component. In the case of the estimation of the symmetrical load case, this approach is recommended, since only 2 instead of 3 measurements are necessary. In addition, a more accurate measurement is obtained if the coupling between the phase conductors and the shields in the positive-sequence system is significantly smaller than the coupling in the zero-sequence system.

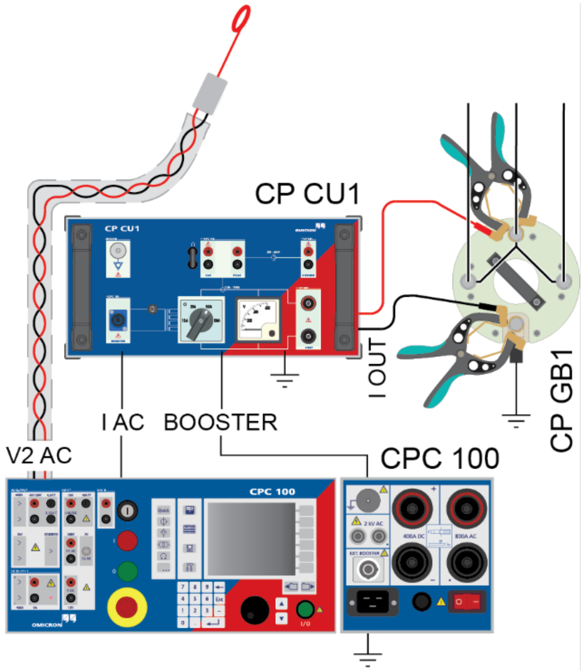

Figure 9 - Test setup with CPC 100, CP CU1, CP GB1 and a current clamp

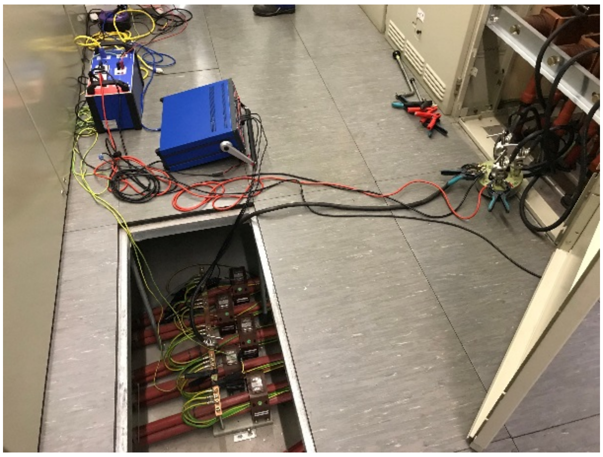

Figure 10 - Test setup in the switchgear

4.1 Current injection in all three phase-earth combinations

When injecting into all three phase-ground combinations, the following measurements are made:

- $I_{S1, L1\text{-}E}$, phase in relation to $I_{L1\text{-}E}$
- $I_{S1, L2\text{-}E}$, phase in relation to $I_{L2\text{-}E}$
- $I_{S1, L3\text{-}E}$, phase in relation to $I_{L3\text{-}E}$
- $I_{S2, L1\text{-}E}$, phase in relation to $I_{L1\text{-}E}$
- $I_{S2, L2\text{-}E}$, phase in relation to $I_{L2\text{-}E}$

- $I_{S2,\,L3\text{-}E}$, phase in relation to $I_{L3\text{-}E}$
- …
- $I_{Sn,\,L1\text{-}E}$, phase in relation to $I_{L1\text{-}E}$
- $I_{Sn,\,L2\text{-}E}$, phase in relation to $I_{L2\text{-}E}$
- $I_{Sn,\,L3\text{-}E}$, phase in relation to $I_{L3\text{-}E}$

Interpretation of the indices with an example: $I_{S1,L1\text{-}E}$ is the current in shield 1 measured for an injection into the loop L1-E. *n* is the number of shield whose current is measured.

Fig. 11 shows a cable with 2 systems, on which L1-E is fed and shield 6 (that of cable 2, L3) is measured.

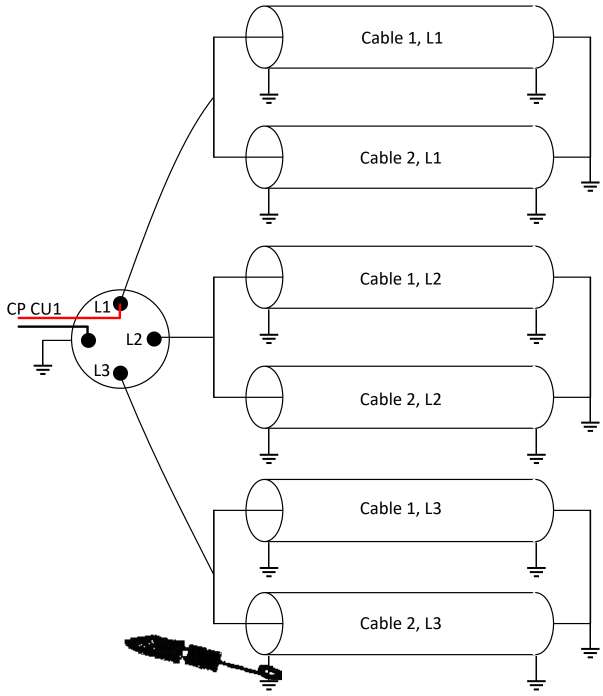

Figure 11 - Feed at L1-E and measurement at shield of cable 2, L3

The calculation of the current in shield *n* for any 3-phase operating case is then calculated according to:

$$\underline{I}_{Sn,ber} = \frac{\underline{I}_{Sn,L1-E}}{\underline{I}_{L1-E}} * \underline{I}_{L1,Operation} + \frac{\underline{I}_{Sn,L2-E}}{\underline{I}_{L2-E}} * \underline{I}_{L2,Operation} + \frac{\underline{I}_{Sn,L3-E}}{\underline{I}_{L3-E}} * \underline{I}_{L3,Operation} \qquad \text{Eq. 1}$$

The phase of $\underline{I}_{Sn,ber}$ refers to $\underline{I}_{L1,Operation}$.

4.2 Current injection in two phase-conductor combinations

When injection in two conductor-earth combinations, the following measurements are performed:

- $I_{S1,\,L1\text{-}L2}$, phase in relation to $I_{L1\text{-}L2}$
- $I_{S1,\,L2\text{-}L3}$, phase in relation to $I_{L2\text{-}L3}$
- $I_{S2,\,L1\text{-}L2}$, phase in relation to $I_{L1\text{-}L2}$
- $I_{S2,\,L2\text{-}L3}$, phase in relation to $I_{L2\text{-}L3}$
- …
- $I_{Sn,\,L1\text{-}L2}$, phase in relation to $I_{L1\text{-}L2}$
- $I_{Sn,\,L2\text{-}L3}$, phase in relation to $I_{L2\text{-}L3}$

Fig. 12 shows a cable with 2 systems, on which L1-L2 is fed and shield 6 is measured.

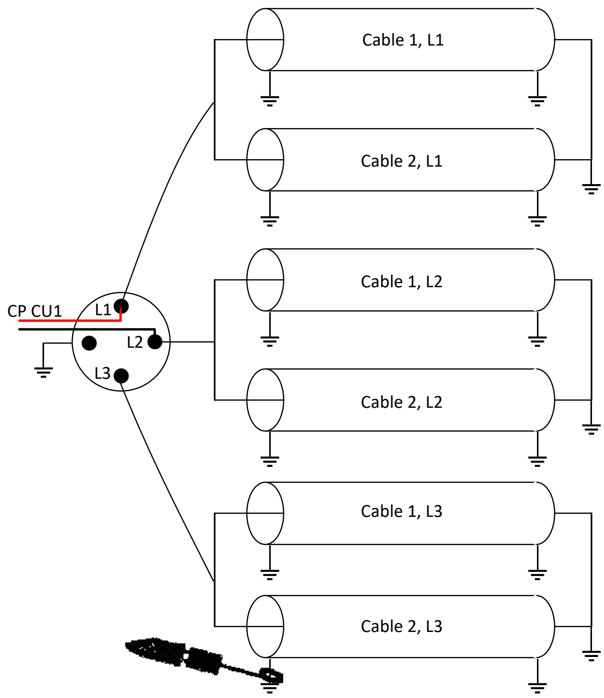

Figure 12 - Supply at L1-L2 and measurement at shield of cable 2, L3

The calculation of the current in shield *n* for a symmetrical 3-phase operating case is then calculated according to Eq. 2:

$$\left|\underline{I}_{Sn,ber}\right| = \frac{\left|\underline{I}_{Phase,Operation}\right|}{\sqrt{3}} * \left| \frac{\underline{I}_{Sn,L1-L2}}{\underline{I}_{L1-L2}} + \frac{\underline{I}_{Sn,L2-L3}}{\underline{I}_{L2-L3}} * e^{j120°} - \frac{\underline{I}_{Sn,L1-L3}}{\underline{I}_{L1-L3}} * e^{j240°} \right| \qquad \text{Eq. 2}$$

The ratio $\frac{\underline{I}_{Sn,L1-L3}}{\underline{I}_{L1-L3}}$ is calculated here from the two measured ratios for L1-L2 and L2-L3. This is possible because a 3-phase operating case without zero-sequence component is defined by 2 phase currents.

5 Practical measurement

The two measurements described in chapter 4 were carried out on the cable section described in chapter 3. Here, only the couplings at the 3 screens of system 1 were measured.

On top of that, a symmetrical 3-phase feed-in was performed with the CMC 356 to prove that the calculation based on the 1-phase feed-in gives the same results as a 3-phase feed-in.

The results of the three methods mentioned with respect to a symmetrical operating case with 32 A are as follows:

- Injection via L1-E, L2-E and L3-E:
  - I_S1 = 0,917 A
  - I_S2 = 0,976 A
  - I_S3 = 0,930 A
- Injection via L1-L2 and L2-L3:
  - I_S1 = 0,896 A
  - I_S2 = 0,989 A
  - I_S3 = 0,935 A
- Directly measured currents with symmetrical supply of 32 A with CMC 356:
  - I_S1 = 0,892 A
  - I_S2 = 0,980 A
  - I_S3 = 0,927 A

The deviations of both methods described in chapter 4 from direct injection with the CMC 356 are negligible. Thus, the 1-phase injection with CPC 100 and CP CU1 is a possibility to estimate very accurately currents in cable shields at any load cases.

Regarding the feeding with CMC 356 it should be noted that this is not an official OMICRON recommended application of this device. The injection with CMC 356 has been performed by OMICRON engineers with special safety precautions. The measurement of the coupling into cable shields must therefore be carried out with CPC 100, CP CU1 and CP GB1 to ensure a safe measurement.

6 Evaluation of the measurement results

The measurement results were surprising for all involved, as shield currents of approx. 70 A can occur with a load current of 2300 A, for which the cable section is designed. With a shield cross-section of 35 mm², these currents can contribute to significant heating of the cables and cause damage if cooling or ventilation is inadequate.

There are several options as countermeasures to eliminate the shield currents.

6.1.1 Single-sided grounding of the cable shields

In order to avoid different ground potential between switchgears, in case of one-sided grounding, either a good grounding system must be installed on both sides of the cable routes, or an additional equipotential bonding cable must be carried. However, in industrial plants, the grounding system is usually very good. Furthermore, the installation of surge arresters on the ungrounded side of the cable shields is recommended since medium-voltage systems in industry are usually operated isolated or with an inductive neutral grounding and very high voltages can occur in the event of a ground fault.

6.1.2 Cross-Bonding

By crossing out the shields on the course of the cable route, the shield currents can eliminate each other. However, this requires complex junction boxes or sleeves. These installations are usually only found in high voltage systems.

7 Summary

A number of design factors must be taken into account for cable routes. To avoid over-dimensioning and damage to the cable route, engineers want to know these factors as precisely as possible. A simple test procedure now provides certainty in the evaluation of a cable route. A measurement is much more informative than a calculation, since the exact installation scenario is considered. Medium-voltage cable routes with parallel cables can now be tested in a short time before faults occur during operation.

About the authors

Dipl.-Ing. (FH) **Daniel Goetz,** born in Cologne in 1982. After successfully completing his studies in electrical power engineering at the University of Applied Sciences in Cologne, he joined InfraServ GmbH & Co. Knapsack KG as a technical planner for electrical energy technology. From 2015 to 2016, he worked as an expert for protection and control technology at ABB in Ratingen. In 2016, he returned to InfraServ GmbH & Co. Knapsack KG as a team leader and has since been responsible for the further development of services and technical expertise in the field of electrical power engineering.

daniel.goetz@infraserv-knapsack.de

Moritz Pikisch studied electrical engineering at the University of Karlsruhe (TH). After working in the training department at OMICRON from 2010 to 2013, he moved to product management at the beginning of 2014. There, he was in charge of the CPC 100 and the CP CU1 with a focus on the applications of lead impedance measurement and testing of grounding systems. In March 2018, he joined OMICRON USA as an application engineer. In this role, he continues to be the company-wide contact for line impedance and grounding measurements.

moritz.pikisch@omicronenergy.com

Dipl.-Ing. (FH) **Florian Fink,** born in 1983 in Bergisch Gladbach. He studied electrical power engineering at the University of Applied Sciences in Cologne, where he received his diploma (Dipl.-Ing. FH) in 2009. From 2009 to 2012 he worked at Cegelec Germany as a project engineer and from 2012 to 2013 at InfraServ Knapsack as a planning engineer. Since 2013, he has been working in product management at OMICRON and is responsible for solutions for industrial and distribution networks.

florian.fink@omicronenergy.com