Distance Protection of Cross-Bonded Transmission Cable-Systems

by

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Outline of the presentation

• Introduction
• Fault loop impedance on cross-bonded cable systems
  – Double-sided infeed
  – Long cables
  – Trefoil formation
  – Field- and substation grounding resistances and ground resistivity
  – Fault resistance between core and sheath
  – Core to sheath to ground faults
  – Hybrid lines
• Discussions
The cable act plan as decided by Danish government undergounds most of the transmission network in the years to come.

Distance protection is widely used in Denmark and will play a role as back-up protection in a cable based transmission network. Hybrid lines also uses distance protection.
Horns Reef 2 165 kV 12 km two major section cable system with minor sections of 2 km is implemented in DigSILENT Power Factory. Laid in flat formation.
Distance protection relies on a linear relation between measured impedance and distance to fault. We would not expect this from a crossbonded cable system due to the shifting of the sheath current.
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Fault loop impedance on cross-bonded cable systems

Single-ended infeed
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Fault loop impedance on cross-bonded cable systems

Two cases: Shifting of applied fault either at the end of minor section 1 or at the beginning of minor section 2.

The different flow of return currents for a fault at almost the same location gives rise to a discontinuity in the fault loop impedance at the cross-bondings. Impedance becomes more inductive as the fault location is moved to the second minor section because the current loop made up by the conductor and combined return path changes physical size as the sheath from another cable must carry the major part of the return current. It is also noticed that the impedance of one phase is different compared to the impedance of the other two phases.
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Fault loop impedance on cross-bonded cable systems

Double-ended infeed

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[Graphs showing fault loop impedance for different phases and a linear sequence based approximation.]
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Fault loop impedance on cross-bonded cable systems

30 km cable instead of 12 km cable – single-ended infeed

Absolute error remains the same.
Relative error is reduced!!
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Fault loop impedance on cross-bonded cable systems

12 km cable laid in trefoil formation – single ended infeed

Trefoil formation makes impedance equal in all phases.
Impedance jumps still present, but less pronounced.
Will single-phase to sheath fault current, which escapes the sheath and enters into ground through a damaged outer jacket, cause any noticeable change in measured impedance?
Variations of field grounding resistance and station grounding resistance shows that the measured fault loop impedance is almost independent of these.
Variations of the soil resistivity in the range 5 – 280 Ωm gives rise to a 2 % variation of the measured impedance.
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Fault loop impedance on cross-bonded cable systems

Core to sheath to ground faults

Fault current escaping to ground through a damaged outer jacket has no practical importance for fault loop measured impedance!

This is due to the fact that the screen current path has overall lower impedance than ground return.
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Fault loop impedance on cross-bonded cable systems

The fault resistance is time varying and can vary from close to zero to some ohms on cable systems. For single-ended infeed the reactance is not affected.

For double-ended infeed (figure above) a reactance effect is seen.
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Fault loop impedance on cross-bonded cable systems

Hybrid lines (OHL and cables in series)

When replacing the OHL’s over a longer period, cables and OHL’s exists at the same time. In other words; when replacing one OHL between any two substations with a cable, remaining OHL’s can still be connected to the two substations connecting to the new cable. Distance relays installed in the ends of the new cable will see the combined impedance of OHL and cable when using higher zones for back-up.

When crossing locations of natural beauty with OHL’s, cables can be used as part of the entire line. In other words; OHL series impedance gets in series with cross-bonded cable impedance along the line.

Cables are also put in series when an OHL is approaching urban areas or an offshore wind park is being connected.
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Fault loop impedance on cross-bonded cable systems

The Århus – Aalborg 420 kV line

The Mariager Fjord and the Gudenå are locations of natural beauty 😊
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Fault loop impedance on cross-bonded cable systems

Fault current distribution having fault in a) cable section or b) OHL section

In hybrid lines ground return (in the soil) plays a larger role than in a 100% cable system. This is due to the fact that cable’s sheath can only carry fault current part of the way.
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Fault loop impedance on cross-bonded cable systems

Hybrid line example: 6 km 165 kV Horns Reef cable (2 major sections, 1 km minor sections each) connected to 6 km typical 165 kV OHL

OHL relative large impedance compared to cable makes the cable impedance jumps less pronounced.

Reactance piecewise linear.

Distance protection can be applied.
The main findings are that distance protection can be applied for most cross-bonded transmission cable systems having a realistic line length, but proper short circuit simulation studies using cable models able to describe a cross-bonded cable systems impedance variations, must be used in the design phase of the protection settings.

References:
Distance protection of cross-bonded transmission cable-systems, Claus Leth Bak and Christian F. Jensen, DPSP 2014
Online location of faults on AC cables in underground transmission systems, Christian F. Jensen, Springer Theses, ISBN 978-3-319-05397-4