CEATI 11th Annual Grounding & Lightning Conference
Houston, TX, USA October 7-9, 2019

Accurate Calculation of the Split Factor A Numerical Study

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Introduction

The simulation of a grounding system requires the knowledge of grid layout, soil model and current to earth. This presentation is related to the evaluation of the **current to earth**.

Because alternative return paths as overhead earth wires and cable screens or armors, the current to earth can be substantially **different to the fault current**.

Introduction

The **split factor** is the ratio:

Current to earth / Fault current

The fault current (the single phase to earth fault current) can be calculated with traditional methods or is often a data provided by the distributor or the network owner.

Introduction

The calculation of the current to earth on the opposite **requires a specific tool**.

An accurate calculation of the current to earth can lead to a substantial economy in the grounding system sizing. On the other side, a wrong current to earth can lead to oversized or unsafe systems.

Introduction

The problem is obviously not new.

The relevance of the topic is increasing with the short circuit fault current values and so with the power systems expansion.

Introduction

The evaluation of the split factor has been widely treated in literature and in the past some analytical methods based on simplified assumption have been proposed (fault current independent on grounding impedance, uniform characteristics along lines, ungrounded ground wires, infinite line length …).

Unfortunately, these assumptions are not always realistic.

Introduction

The issue today can be easily solved with a rigorous numerical simulation.

Modern tools can consider complex scenarios without particular assumptions or constraints.

The true limit in simulation is the knowledge of the network parameters and the data entry process.
But some tools can do that quite easy.

Introduction

It's possible to consider in a very accurate way:

- Radial or meshed power networks
- Terminals and substations grounding systems
- Overhead lines with their ground wires and tower footings
- Cables with their screens or armors and junction chambers grounding
- Heterogeneous line and cable sections
- Transposition effects
- …

Introduction

All this is made possible by tools based on the **PCM** (Phase Components Method).

This method is general and versatile and can be applied with unbalanced and unsymmetrical multi-phase and multi-conductor systems and of course with systems that involve currents to earth.

Introduction

The module NETS™ of the program XGSLab™ is based on the PCM and is able to perform an accurate evaluation of the fault current distribution and then of the split factor.

In the following:

- A short comparison **symmetrical Vs phase components methods**
- A numerical study for the calculation of the split factor in a typical case

XGSLab

XGSLab^{TM} includes the following modules:

GSA, GSA_FD, XGSA_FD, XGSA_TD and **NETS**

The first 4 module are based on the electromagnetic field theory and on the so-called PEEC (Partial Element Equivalent Circuit) method and are used mainly for grounding, electromagnetic interferences, cathodic protections and lightning.

The module NETS is based on the circuit theory and in particular on the PCM.

Network Analysis

The analysis of electrical networks can be done essentially using the following two methods:

- Symmetrical Components Method (based on the Kirkhhoff laws and the Fortescue technique)
- Phase Components Method (based only on the Kirkhhoff laws)

The two methods are not alternative the one to the other and cannot be directly compared. It is however important to know advantages, disadvantages and limits of both methods as below described.

Network Analysis

SYMMETRICAL COMPONENTS METHOD	PHASE COMPONENTS METHOD
Advantages: - Is a powerful analytical tool and also conceptually useful - In case of symmetrical networks the calculation of unbalanced conditions is simple because the system is converted in balanced systems easy to solve - Reduces the size of the linear system involved with the problem and requires limited computing power - Used by many years in industry and engineering for short circuit and load flow analysis and so widely validated	Advantages: - Based only physic laws and then rigorous but also simple and intuitive - For general applications with balanced or unbalanced systems and with symmetrical and unsymmetrical systems (for instance overhead lines with overhead earth wires or underground cables with screens or armors with their grounding systems) - Can be used with problems that involves currents to earth (fault currents distribution)
Disadvantages: - Can be uses only for symmetrical systems or when the assumption of symmetric three-phase system is acceptable. It could be anyway used with quasi symmetrical systems like the common transmission power lines (overhead lines and cables). On the opposite, usually this method cannot be used with distribution lines, with many single-phase loads or generators - Can be used for short circuit analysis, power flow analysis, transient stability and so on, but not for fault current distribution when grounding systems are involved	Disadvantages: - Increases the size of the linear system involved with the problem and requires more memory resources and computing power

Network Analysis

Taking into account the memory resources and computing power of modern PC, the main disadvantage of the PCM is today overcomed.

The PCM is often a feasible approach and in any case sometimes the only applicable method.

Network Analysis

The PCM (as for the SCM), requires a complete description of the multi-phase and multi-conductors network.

The network is represented using multi-port cells connected using multi-port buses.

A multi-port cell can represents a network component. With a convenient set of components is possible to represent any practical condition.

NETS Components

NETS includes mainly the following components:

- Feeders
- Ideal Voltage or Current Sources
- Transverse Impedances (load, fault)
- Longitudinal Impedances (fault, switch)
- Transformers
- Overhead Lines
- Overhead or Underground Cables

Feeders

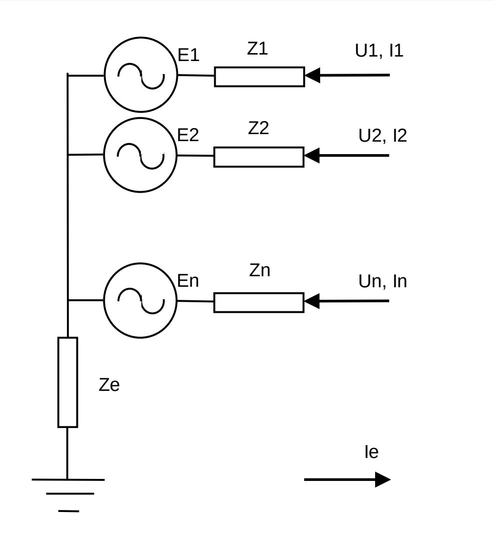
The Feeder can represents a generator or a network. In a three-phases network the longitudinal impedances can be calculated using the formulas:

$$Z = |Z|(\cos\varphi + j\sin\varphi)$$

$$|Z| = \frac{V^2}{S_{cc}}$$

$$\cos\varphi = \frac{1}{\sqrt{1+(X/R)^2}}$$

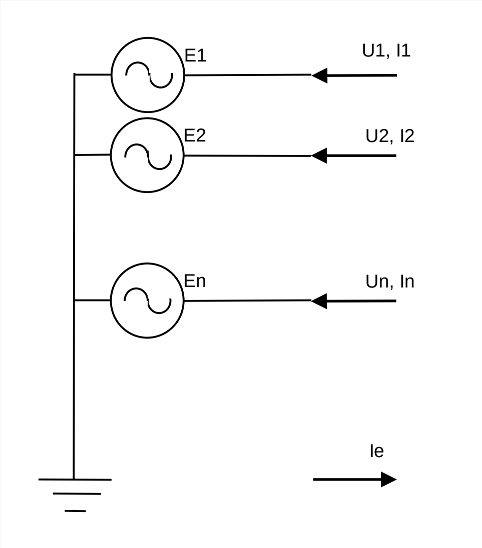
The short circuit power S_{cc} depends on the rated voltage, for instance 400 GVA at 400 kV, 180 GVA at 230 kV, 80 GVA at 132 kV. The ratio X/R is in the range 10 - 30 for transmission networks and 3 - 10 for distribution networks.



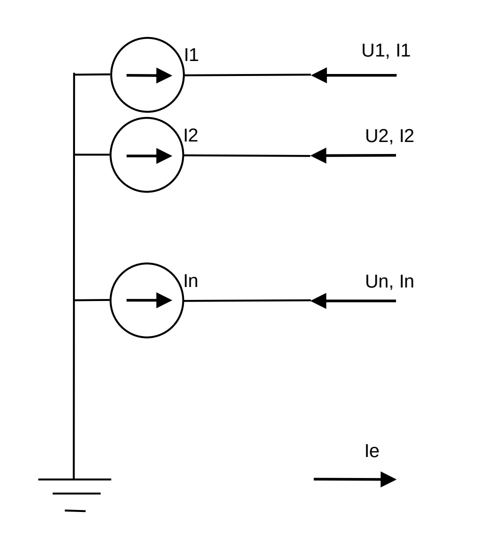
Voltage and Current Sources

The Ideal Voltage or Current Source can be useful to represent ideal conditions with impressed voltages or currents.

Ideal Current Sources can be used to impress single phase to earth fault currents.



Ideal Voltage Source



Ideal Current Source

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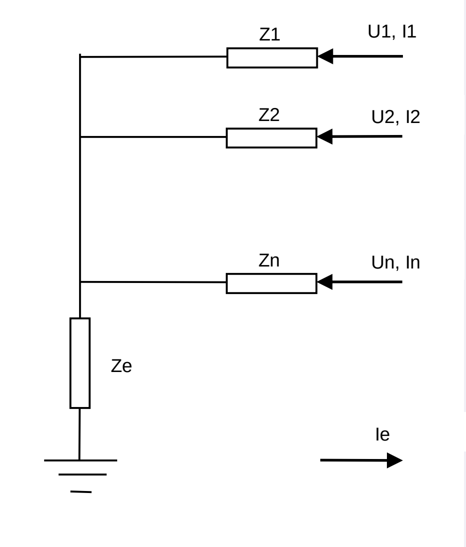
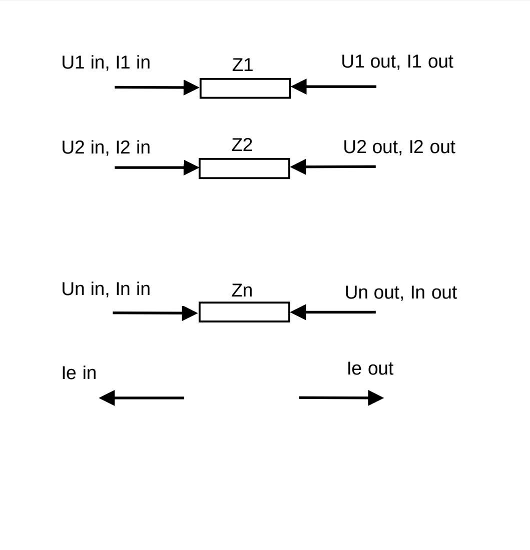
Impedances

The Transverse Impedance can be useful to represent loads or faults.

The Longitudinal Impedance can be useful to represent phases interruption or switches.



Transverse Impedance



Longitudinal Impedance

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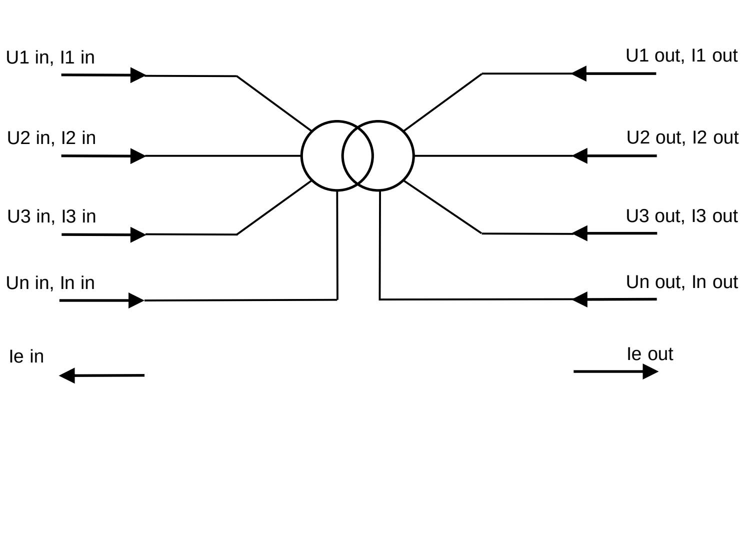
Transformers

The Transformer can represents single-phase or three-phases transformers.

The three-phase transformers can have the usual connections (Yy, Yd, Yz, Dy, Dd, Dz) and angle group (0 to 11).

The transformer parameters are calculated on the base of the data in the library.

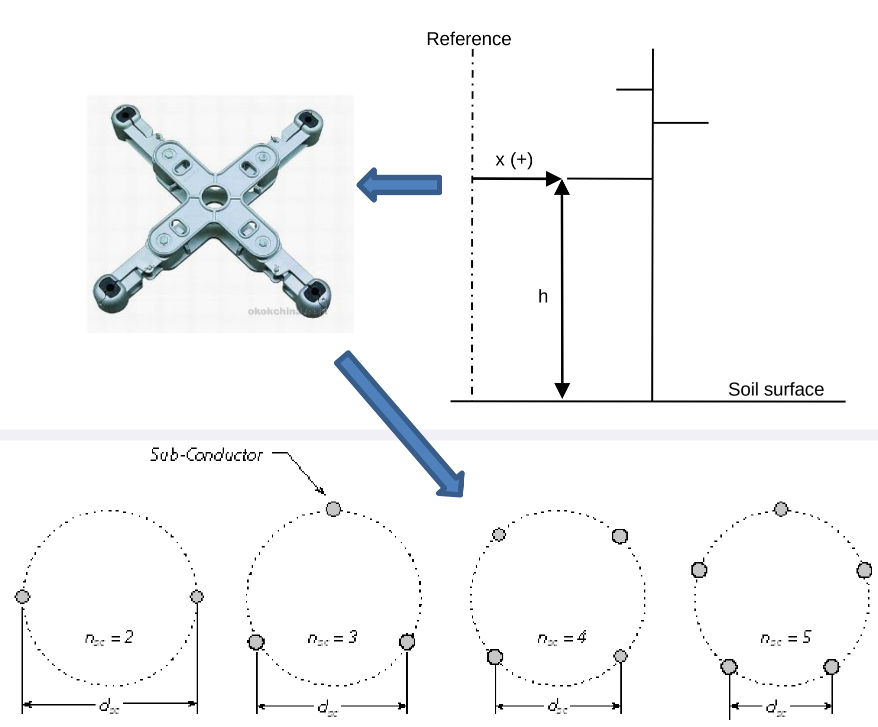


Overhead Lines

The Line can represent a chain of spans of an arbitrary long overhead line.

Each conductor can represents a phase conductor (single or bundled) or an overhead earth wire.

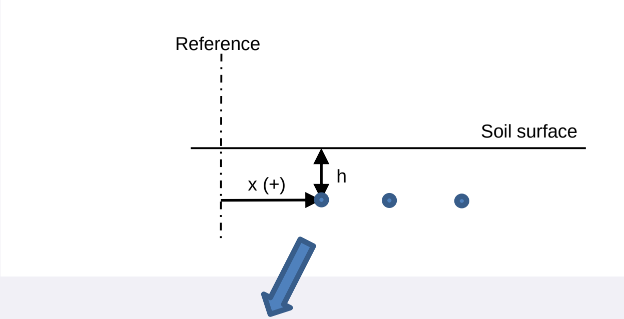
The line self and mutual parameters are calculated on the base of the conductors data and location.

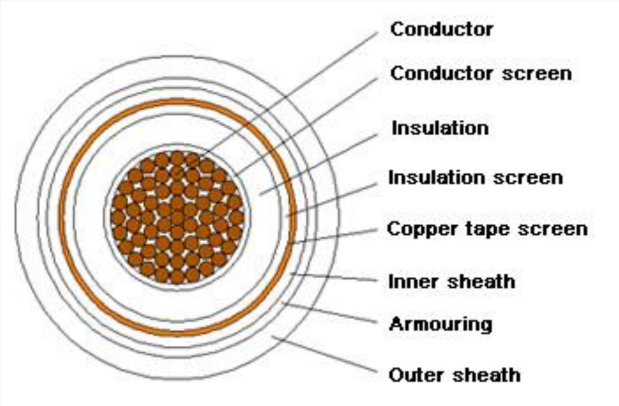


Cables

The Cable can represents an arbitrary long overhead or underground cable line.

Each single cable can includes core, screen and armor. The cable self and mutual parameters are calculated on the base of the cables data and location.





Also pipe-type cables can be represented.

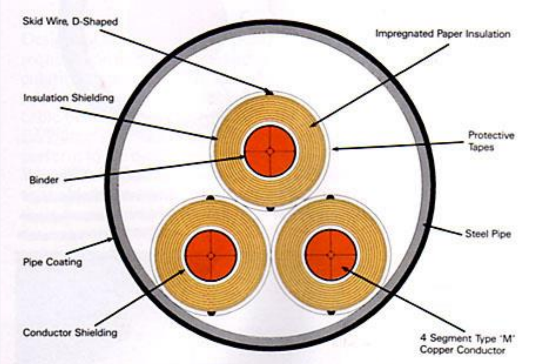
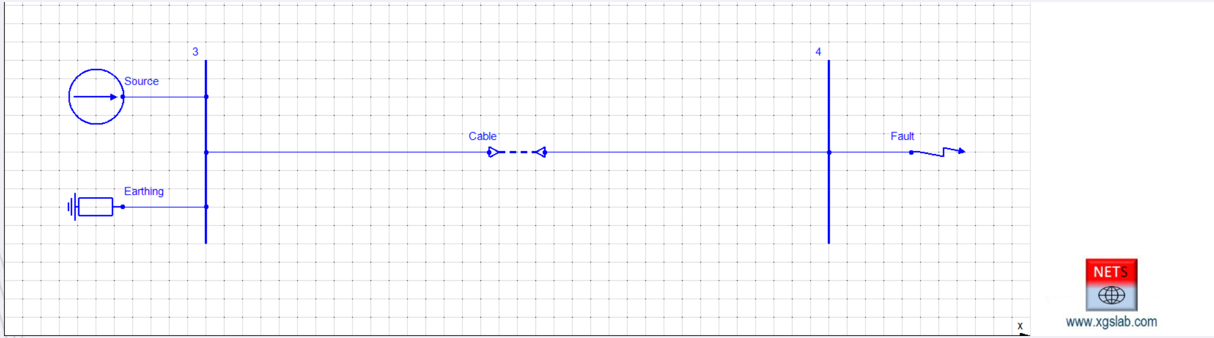


Figure 3: High Pressure Pipe-Type Cable

Application 1



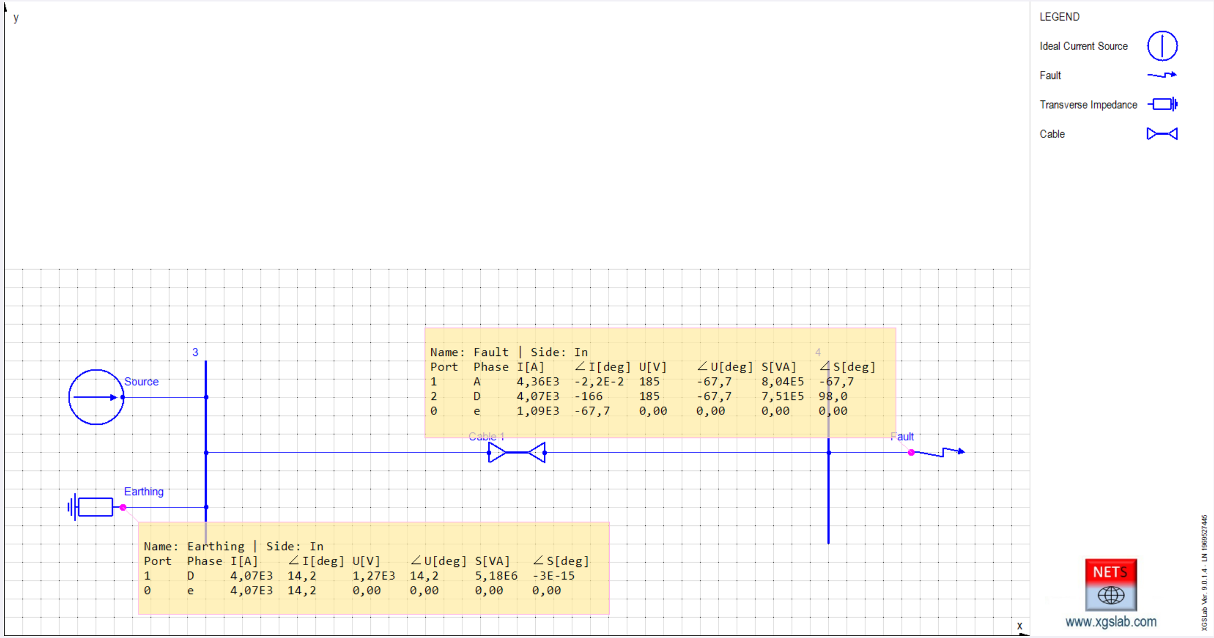
Main data:

- Rated voltage of the system: 20 kV (distribution system)
- Single-phase to earth fault current at the start cable: 4354 A
- Resistance to earth at the start cable station: 0.313 Ω
- Resistance to earth at the end cable station: 0.17 Ω
- Cable length: 5000 m
- Cables: single core with screen and armor (solid bonding system)

Application 1

Scenario 1
n. 3 single core cables

Split factor
Sf = 1090/4354 = 25%

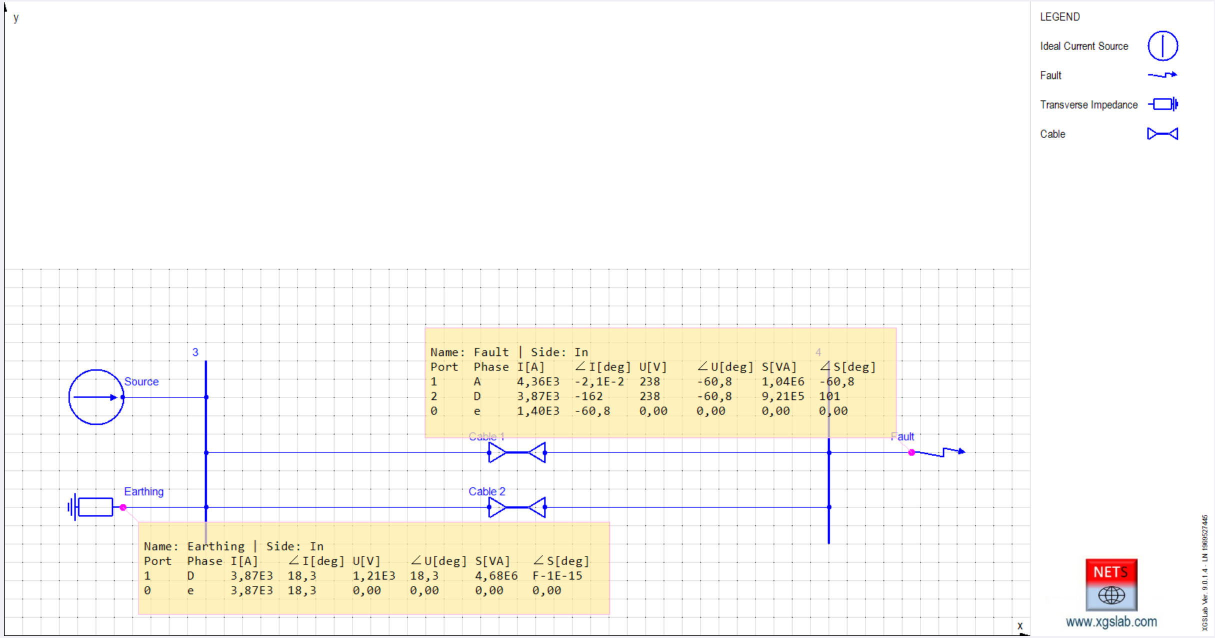


Application 1

Scenario 2
n. 3 single core cables
+
n. 3 single core cables

Uncoupled (far)
and in parallel

Split factor
Sf = 1400/4354 = 32%



Result is unexpected.

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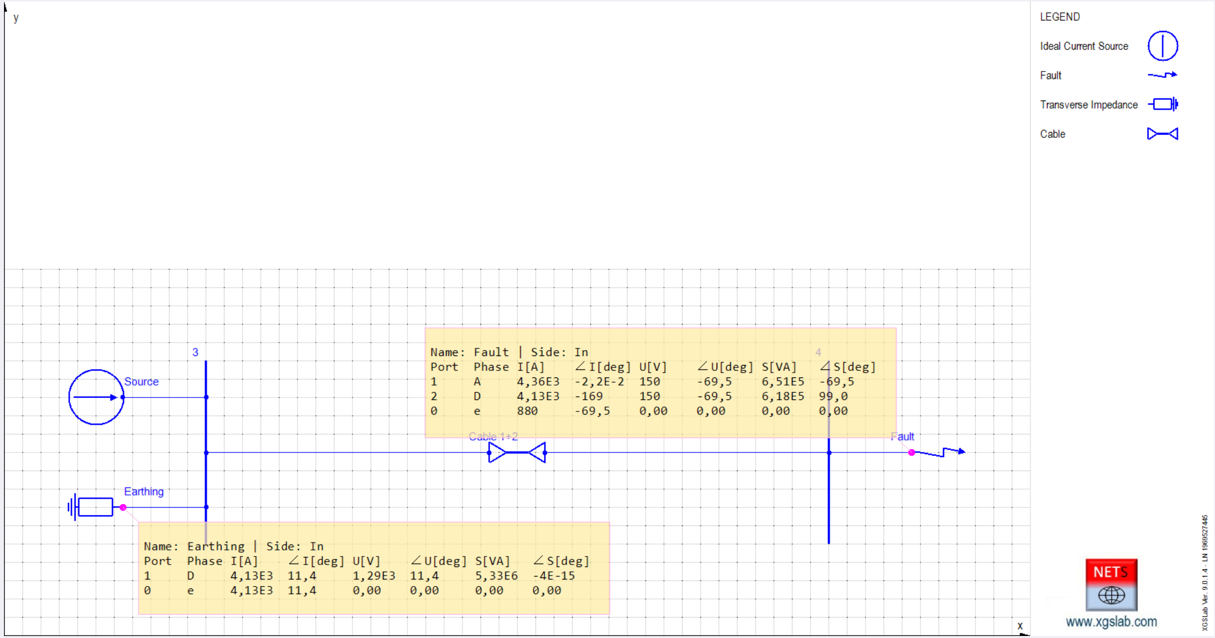
Application 1

Scenario 3
n. 3 single core cables
+
n. 3 single core cables

Coupled (close)
and in parallel

Split factor
Sf = 880/4354 = 20%



The effect of coupling between close cables is relevant.

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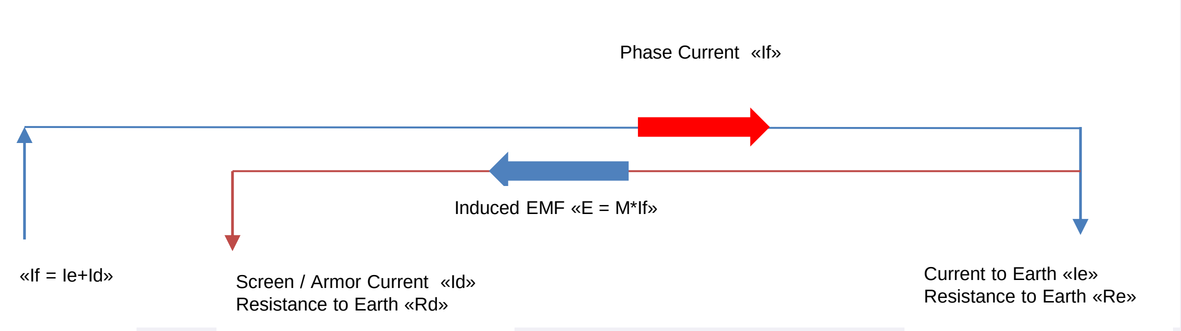
Application 1

Currents balance.

The balance depends on mutual coupling between core and screen / armor and on the impedances of screen / armor, and grounding systems.



Scenario 1
n. 3 single core cables

$$S_f = 1 - \frac{I_d}{I_f} = 1 - \frac{M + R_e}{Z_{s/a} + R_e + R_d}$$

Scenario 2
n. 3+3 single core uncoupled cables

$$S_f = 1 - \frac{I_d}{I_f} = 1 - \frac{M + 2R_e}{Z_{s/a} + 2R_e + 2R_d}$$

Scenario 3
n. 3+3 single core coupled cables

$$S_f = 1 - \frac{I_d}{I_f} = 1 - \frac{2M^* + 2R_e}{Z_{s/a} + 2R_e + 2R_d}$$

Example
Re = Rd = 1 Ω
M = j9 Ω
M* = j12 Ω
Zs/a = 0.5+j12 Ω

Scenario 1: Sf = 0.27
Scenario 2: Sf = 0.30
Scenario 3: Sf = 0.23

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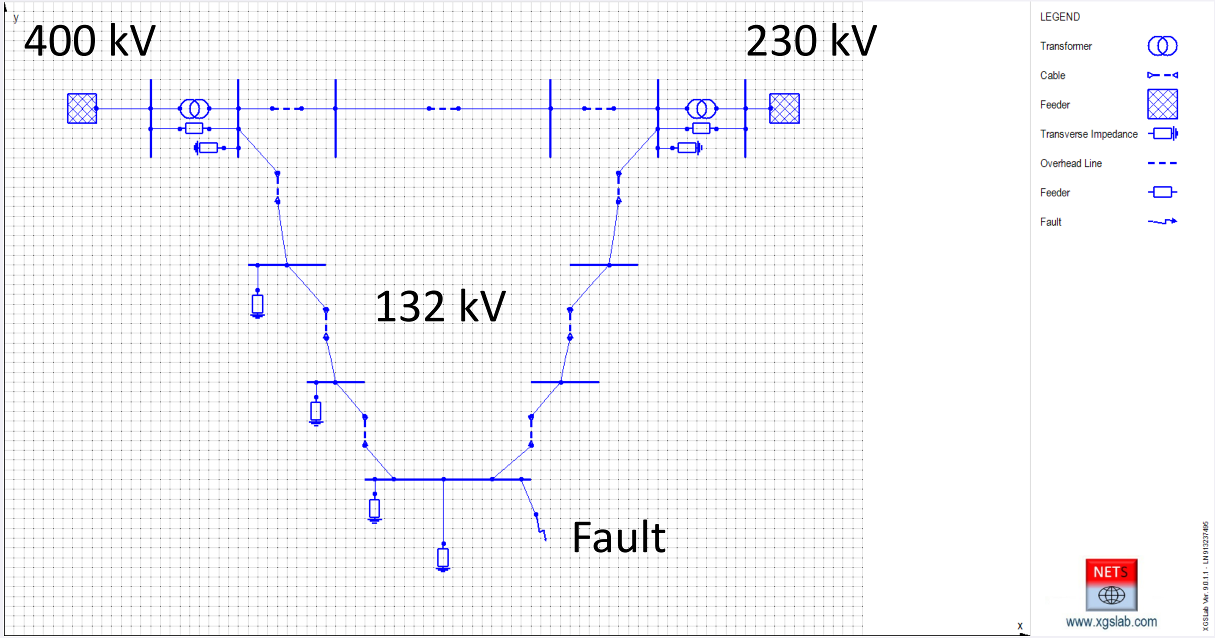
Application 2

Complex Scenario with:
1 Feeder 400 kV
1 Tr 400/132 kV
1 Feeder 230 kV
1 Tr 230/132 kV
1 Overhead line 132 kV
2 Underground cables 132 kV (with transpositions)

Split factor NETS
Sf = 334/2240 = 14.9%

Split factor OpenDSS®
Sf = 14.7%



Conclusion

Modern programs based on the phase components method like XGSLab^{TM} – NETS are able to represent in a very realistic way complex scenarios with full meshed, unsymmetrical, unbalanced multi-conductor systems that involve currents to earth.

It's than possible an accurate calculation of the fault currents distribution and in particular of the split factor related to a specific grounding system.

Conclusion

It’s then possible the calculation of the right value of the expected current to earth in a grounding system and in this way it’s possible to avoid expensive over-sizing or dangerous under-sizing.

The examples confirm the importance of a realistic simulation of the actual conditions because the calculation is often non trivial and results are sometime unexpected.

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Thanks for your attention.