IEEE – cable workshop – Bern 14/04/2010 : short-circuit protection for combined overhead line - cable circuits

Powering a world in progress

Luc Uyttersprot

Why, when shall we use mixed conductor technologies ?

- Crossing of an area which is too wide for an overhead line span

  Examples : river, lake, fjord, etc...
- Crossing of an urbanised area

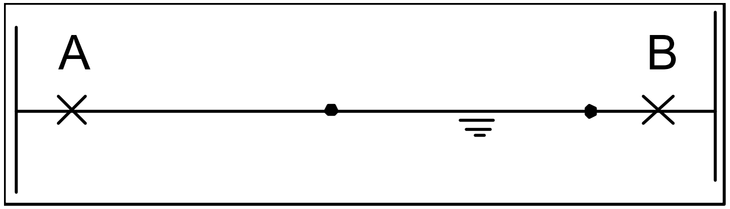
  This can be the case for an existing substation originally located outside the city but today included in the conurbation
- Difficulties to insure clearances associated with an overhead line

  Here are some examples :
  - Connection of several circuits to a Gas Insulated Substation;
  - Connection of a generation plant to the grid
- Speeding up the process to gain permission

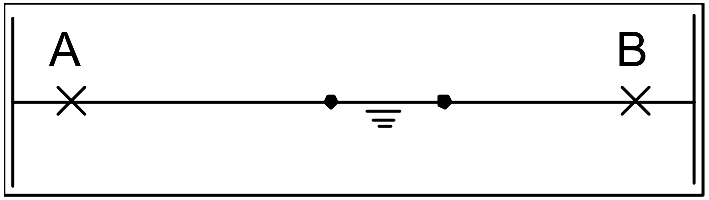
  It is normally easier to get the permission for an underground cable circuit than for an overhead line. This can be critical for an industrial plant or for a generation plant seeking a connection with the grid

Configurations

- 2-ended circuit with cable section at one end

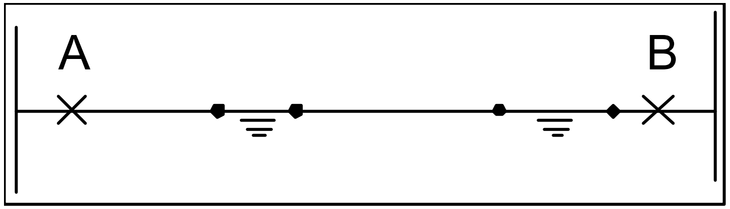


- 2-ended circuit with cable section between 2 overhead lines

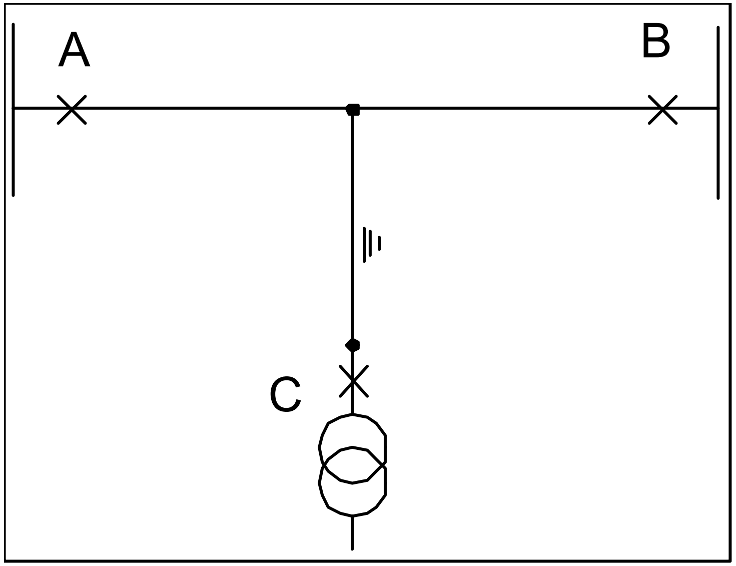


Configurations (continued)

- 2-ended circuit with multiple cable sections

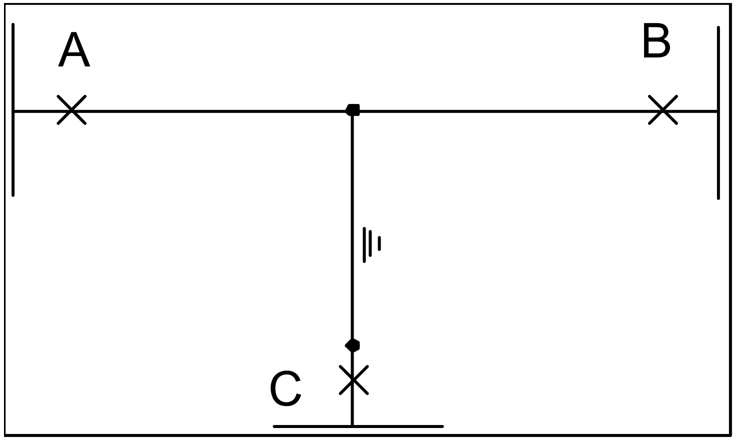


- 3-ended circuit with a transformer tap at one end connected with an underground cable



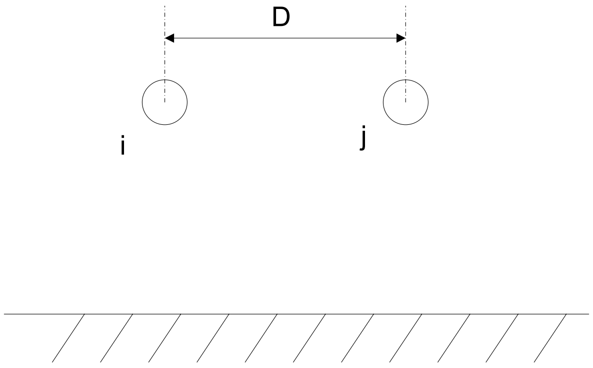
Configurations (continued)

- 3-ended circuit with all branches connected to a busbar and with one branche in underground cable



Calculation of serie sequence impedances of OHL

1. Modified Carson's equations :



- Self impedance of a conductor with an earth return :

$$Zii = R + 0{,}000988f + j0{,}0029f \log_{10}\frac{De}{GMRc}\ \Omega/km$$

With :
R = conductor AC resistance;
GMRc = geometric mean radius of a single conductor
f = frequency
De = equivalent spacing of the earth return path = $216\sqrt{\frac{p}{f}}$
With p= earth resistivity (Ωcm²/cm)

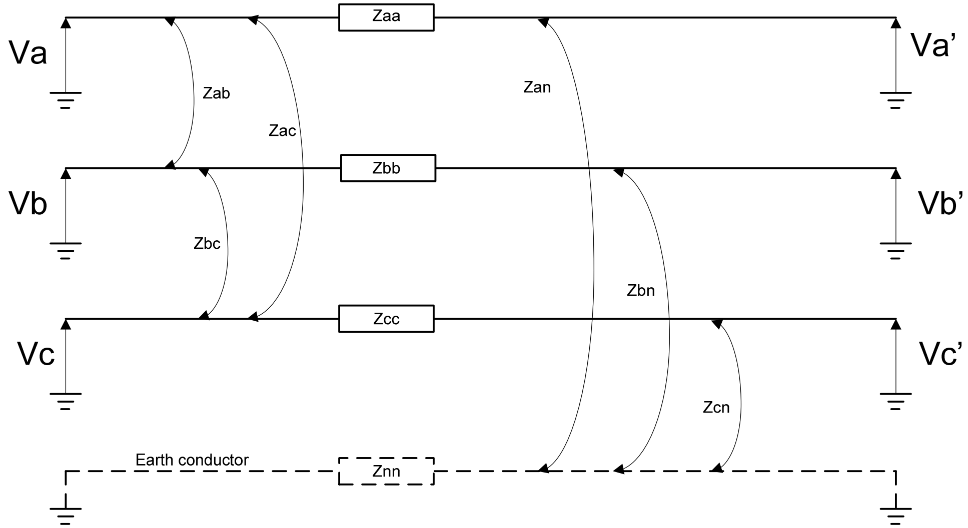
- Mutual inductance between 2 conductors :

$$Zij = 0{,}000988f + j0{,}0029f \log_{10}\frac{De}{D}\ \Omega/km$$

With :
D=spacing between the parallel conductors

Calculation of serie sequence impedances of OHL (continued)

2. Primitive impedance matrix for a single circuit OHL with an earth conductor :



With Zii= self impedance of conductor i

Zij= mutual impedance between conductors i and j

$$\Delta V = Z * I$$

$$\begin{pmatrix} \Delta Va \\ \Delta Vb \\ \Delta Vc \\ 0 \end{pmatrix} = \begin{pmatrix} Zaa & Zab & Zac & Zan \\ Zba & Zbb & Zbc & Zbn \\ Zca & Zcb & Zcc & Zcn \\ Zna & Znb & Znc & Znn \end{pmatrix} * \begin{pmatrix} Ia \\ Ib \\ Ic \\ In \end{pmatrix} = \begin{pmatrix} Zcc & Zcn \\ Zcn & Znn \end{pmatrix} * \begin{pmatrix} Ia \\ Ib \\ Ic \\ In \end{pmatrix}$$

Calculation of serie sequence impedances of OHL - continued

3. Reduction of the matrix

We can eliminate the last row and the last colum :

$$\begin{pmatrix} \Delta Va \\ \Delta Vb \\ \Delta Vc \end{pmatrix} = Zred * \begin{pmatrix} Ia \\ Ib \\ Ic \end{pmatrix} \quad \text{with} \quad Zred = Zcc - Zcn * Znn^{-1} * Zcn^{T}$$

4. Sequence impedance matrix

$$Zseq = A^{-1} * Zred * A \quad \text{with} \quad A = \begin{pmatrix} 1 & 1 & 1 \\ 1 & a^2 & a \\ 1 & a & a^2 \end{pmatrix}$$

Sequence impedances of OHL - continued

4. Examples :

Item	Characteristics			Calculations (Ω/km)		Measurements (Ω/km)	
	Section (mm²)	Type	Circuit	Z1	Z0	Z1	Z0
150 kV OHL	504 & 445	AMS-Z & AMS	double	0,082 + j 0,403	0,254 + j	0,067 + j 0,419	0,176 + j 0,929
150 kV OHL	445	AMS	double	0,078 + j 0,409	0,304 + j 1,261	0,099 + j 0,470	0,401 + j 1,396
230 kV OHL			single	0,060 + j 0,472	0,230 + j 1,590		
380 kV OHL	2 * 705	AMS-2Z	double	0,031 + j 0,304	0,226 + j 0,867		

Calculation of sequence impedances of underground cable

1. Grounding methods for the sheaths

- Single point bonding

+ : no heating effect due to

  circulating currents in the sheath

- : overvoltages at the free end

  dangerous ground potential difference
  between both ends is limited by
  the presence of a ground conductor

- Solid bonding

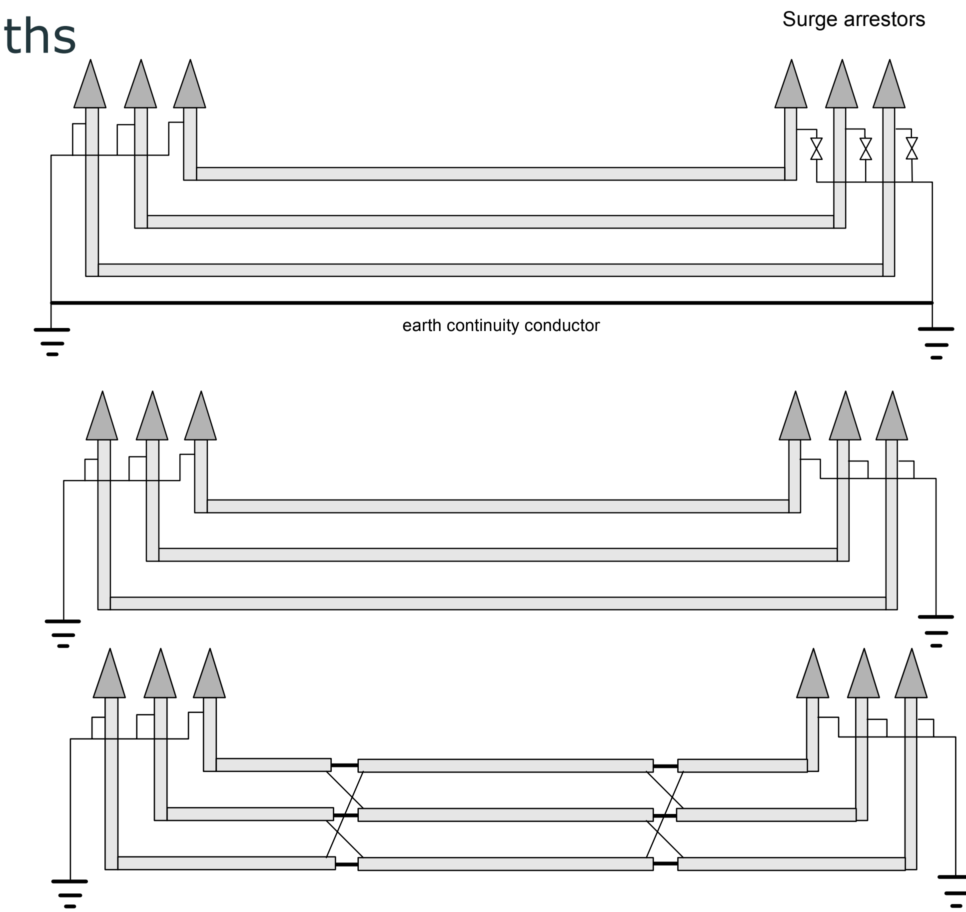
+ : no overvoltage on the sheath

- : circulating currents in the sheath

- Cross bonding

+ : no overvoltage on the sheath;

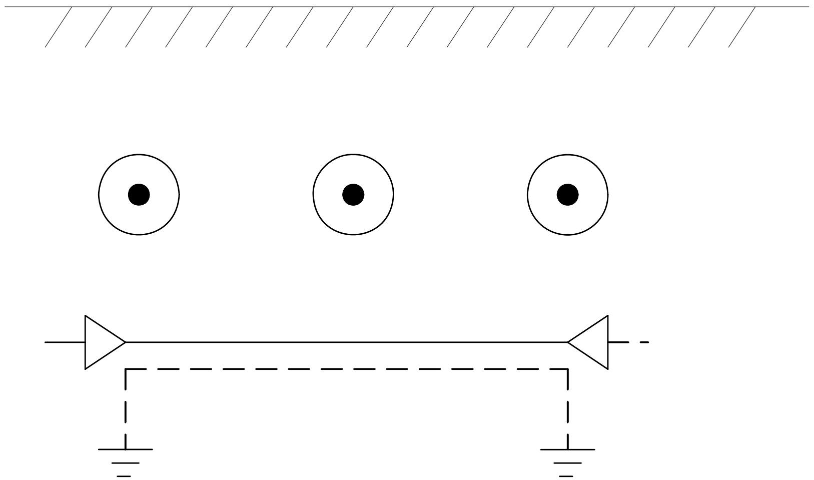
  limited circulating currents in the sheath



The grounding method will have an impact on the zero-sequence impedance

Calculation of serie sequence impedances of underground cable - continued

2. Configuration
   - 3 solid dielectric single phase underground cables
   - Solid grounding

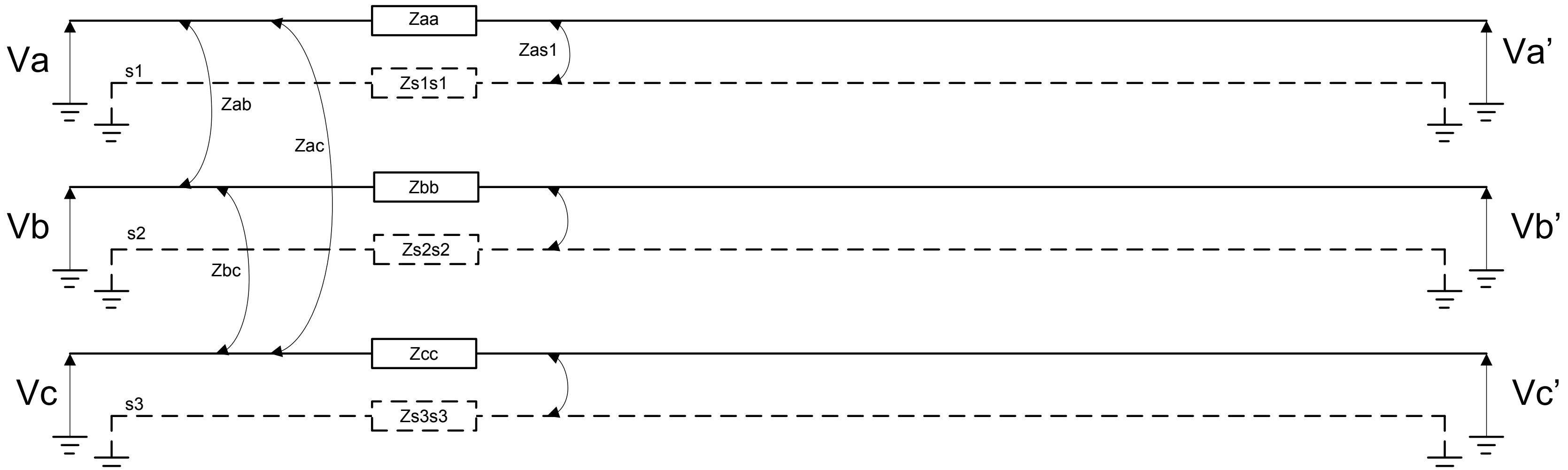


3. Primitive impedance matrix

   We have to take into account following impedances :
   - Self impedance of each conductor
   - Mutual impedance between 2 conductors
   - Self impedance of the sheath
   - Mutual mpedance between conductor and shield

Calculation of serie sequence impedances of underground cable - continued

Primitive impedance matrix :



$$\begin{pmatrix} \Delta Va \\ \Delta Vb \\ \Delta Vc \\ 0 \\ 0 \\ 0 \end{pmatrix} = \begin{pmatrix} Zaa & Zab & Zac & Zas1 & Zas2 & Zas3 \\ Zba & Zbb & Zbc & Zbs1 & Zbs2 & Zbs3 \\ Zca & Zcb & Zcc & Zcs1 & Zcs2 & Zcs3 \\ Zs1a & Zs1b & Zs1c & Zs1s1 & Zs1s2 & Zs1s3 \\ Zs2a & Zs2b & Zs2c & Zs2s1 & Zs2s2 & Zs2s3 \\ Zs3a & Zs3b & Zs3c & Zs3s1 & Zs3s2 & Zs3s3 \end{pmatrix} * \begin{pmatrix} Ia \\ Ib \\ Ic \\ Is1 \\ Is2 \\ Is3 \end{pmatrix} = \begin{pmatrix} Zcc & Zcs \\ Zcs & Zss \end{pmatrix} * \begin{pmatrix} Ia \\ Ib \\ Ic \\ Is1 \\ Is2 \\ Is3 \end{pmatrix}$$

Calculation of serie sequence impedances of underground cable - continued

4. Matrix reduction

$$\begin{pmatrix} \Delta Va \\ \Delta Vb \\ \Delta Vc \\ 0 \\ 0 \\ 0 \end{pmatrix} = \begin{pmatrix} Zcc & Zcs \\ Zcs & Zss \end{pmatrix} * \begin{pmatrix} Ia \\ Ib \\ Ic \\ Is1 \\ Is2 \\ Is3 \end{pmatrix}$$

We can eliminate the 3 last rows and the 3 last colums :

$$\begin{pmatrix} \Delta Va \\ \Delta Vb \\ \Delta Vc \end{pmatrix} = Zred * \begin{pmatrix} Ia \\ Ib \\ Ic \end{pmatrix}$$

with $Zred = Zcc - Zcs * Zss^{-1} * Zcs^{T}$

Calculation of serie sequence impedances of underground cable - continued

5. Sequence impedances matrix

$$Zseq = A^{-1} * Zred * A \qquad \text{with} \qquad A = \begin{pmatrix} 1 & 1 & 1 \\ 1 & a^2 & a \\ 1 & a & a^2 \end{pmatrix}$$

6. Example
   - 230 kV single conductor cable
   - 1200 mm² Cu
   - Earth resistivity : 100 Ωm
   - f=60 Hz
   - Trefoil configuration
   - Solid bonding
   - No earth conductor
   - External radius : 0,0538 m

Example - continued

$$Z := \begin{pmatrix} .079 + .8169i & .0592 + .6766i & .0592 + .6766i & .0592 + .7383i & .0592 + .6766i & .0592 + .6766i \\ .0592 + .6766i & .079 + .8169i & .0592 + .6766i & .0592 + .6766i & .0592 + .7383i & .0592 + .6766i \\ .0592 + .6766i & .0592 + .6766i & .079 + .8169i & .0592 + .6766i & .0592 + .6766i & .0592 + .7383i \\ .0592 + .7383i & .0592 + .6766i & .0592 + .6766i & .2151 + .7383i & .0592 + .6766i & .0592 + .6766i \\ .0592 + .6766i & .0592 + .7383i & .0592 + .6766i & .0592 + .6766i & .2151 + .7383i & .0592 + .6766i \\ .0592 + .6766i & .0592 + .6766i & .0592 + .7383i & .0592 + .6766i & .0592 + .6766i & .2151 + .7383i \end{pmatrix}$$

$$Zcc := \begin{pmatrix} .079 + .8169i & .0592 + .6766i & .0592 + .6766i \\ .0592 + .6766i & .079 + .8169i & .0592 + .6766i \\ .0592 + .6766i & .0592 + .6766i & .079 + .8169i \end{pmatrix} \qquad Zcs := \begin{pmatrix} .0592 + .7383i & .0592 + .6766i & .0592 + .6766i \\ .0592 + .6766i & .0592 + .7383i & .0592 + .6766i \\ .0592 + .6766i & .0592 + .6766i & .0592 + .7383i \end{pmatrix}$$

$$Zss := \begin{pmatrix} .2151 + .7383i & .0592 + .6766i & .0592 + .6766i \\ .0592 + .6766i & .2151 + .7383i & .0592 + .6766i \\ .0592 + .6766i & .0592 + .6766i & .2151 + .7383i \end{pmatrix} \qquad A := \begin{pmatrix} 1 & 1 & 1 \\ 1 & -.5 - .866i & -.5 + .866i \\ 1 & -.5 + .866i & -.5 - .866i \end{pmatrix}$$

$$Zred := Zcc - Zcs \cdot Zss^{-1} \cdot Zcs^{T} \qquad Zseq := A^{-1} \cdot Zred \cdot A$$

$$Zseq = \begin{pmatrix} 0.174 + 0.09i & 0 & 0 \\ 0 & 0.041 + 0.132i & 0 \\ 0 & 0 & 0.041 + 0.132i \end{pmatrix}$$

Calculation of serie sequence impedances of underground cable - continued

7. Other examples

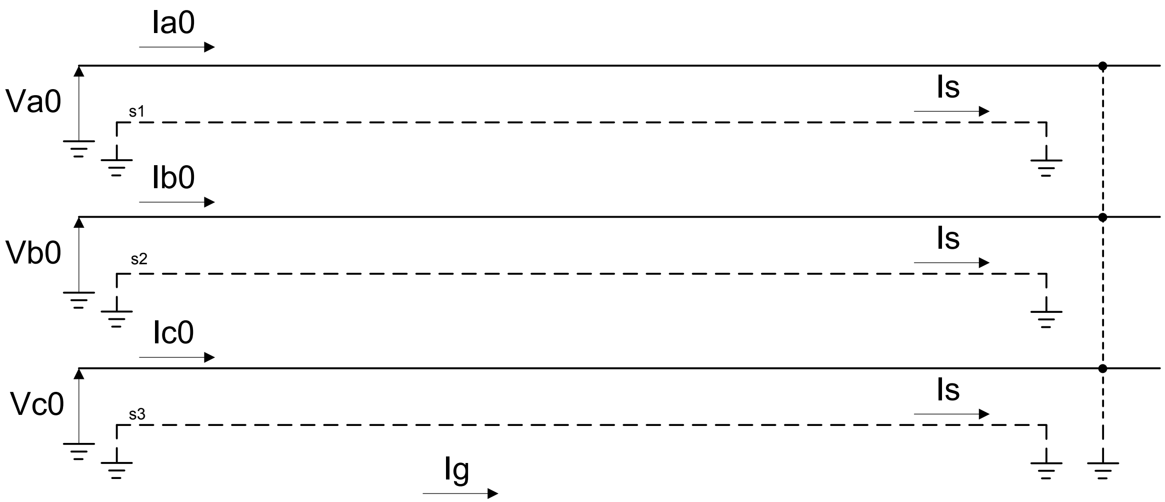
Item	Characteristics			Calculations (Ω/km)		Measurements (Ω/km)	
	Section (mm²)	Type	Bonding	Z1	Z0	Z1	Z0
150 kV	800	Alu (XLPE)	cross bonding, earth conductor	0,047 + j 0,115	0,084 + j 0,070	0,041 + j 0,124	0,134 + j 0,109
150 kV	2000	Alu (XLPE)	cross bonding, earth conductor			0,023 + j 0,109	0,156 + j 0,124
230 kV	1200	Cu (XLPE)	solid bonding, no earth conductor	0,041 + j 0,132	0,174 + j 0,09		

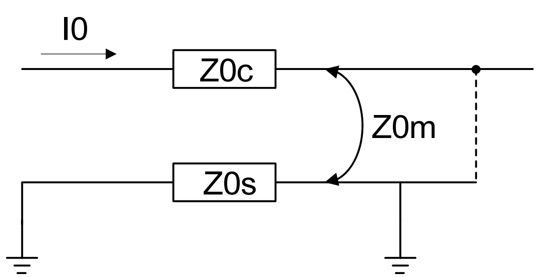
Comparison of serie sequence impedances of OHL and underground cable

Item	Z1 (Ω/km)	Z0 (Ω/km)
150 kV OHL	0,067 + j 0,419 = 0,424 ∟81°	0,176 + j 0,929 = 0,946 ∟79°
150 kV cable	0,041 + j 0,124 = 0,131 ∟72°	0,134 + j 0,109 = 0,173 ∟39°
230 kV OHL	0,060 + j 0,472 = 0,476 ∟83°	0,230 + j 1,590 = 1,607 ∟82°
230 kV cable	0,041 + j 0,132 = 0,138 ∟73°	0,174 + j 0,09 = 0,196 ∟27°

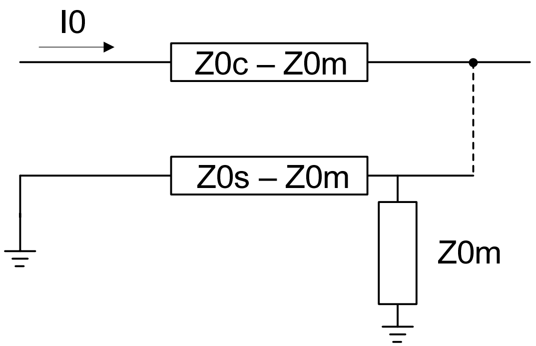
Calculation of serie sequence impedances of underground cable - continued

8. Direct calculation of Z0 for simple configurations :





equivalent to



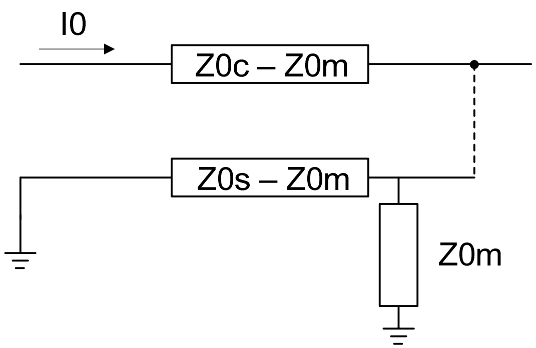
With : Z0c = Z0 conductor

Z0s = Z0 sheath

Z0m = Z0 mutual

These values are calculated based on Carson's equation

Direct calculation of Z0 for simple configurations - continued



- Current return in the sheath only : $Z0 = Z0c + Z0s - 2 * Z0m$
- Current return in the ground only : $Z0 = Z0c - Z0m + Z0m = Z0c$
- Current return in the sheath and in the ground :

$$Z0 = Z0c - Z0m + \frac{(Z0s - Z0m) * Z0m}{Z0s} = Z0c - \frac{Z^2 0m}{Z0s}$$

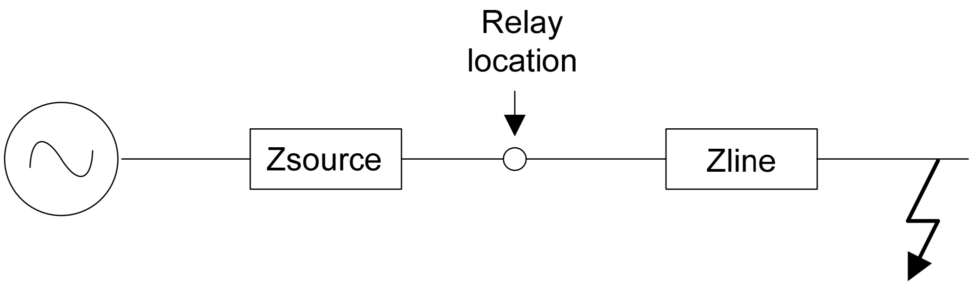
Protection of cable and mixed conductor circuits

- High speed tripping is required because excessive heating can damage the cable
- Most faults on cable are single phase faults

$$\Downarrow$$

Protections with high ground – fault sensitivity are required

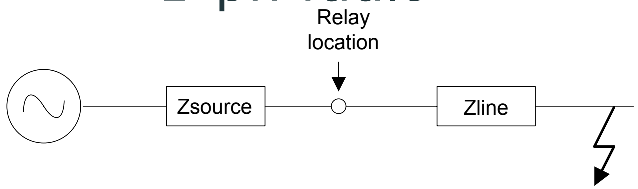
Distance protection applied to cable and mixed conductor circuits – distance calculation

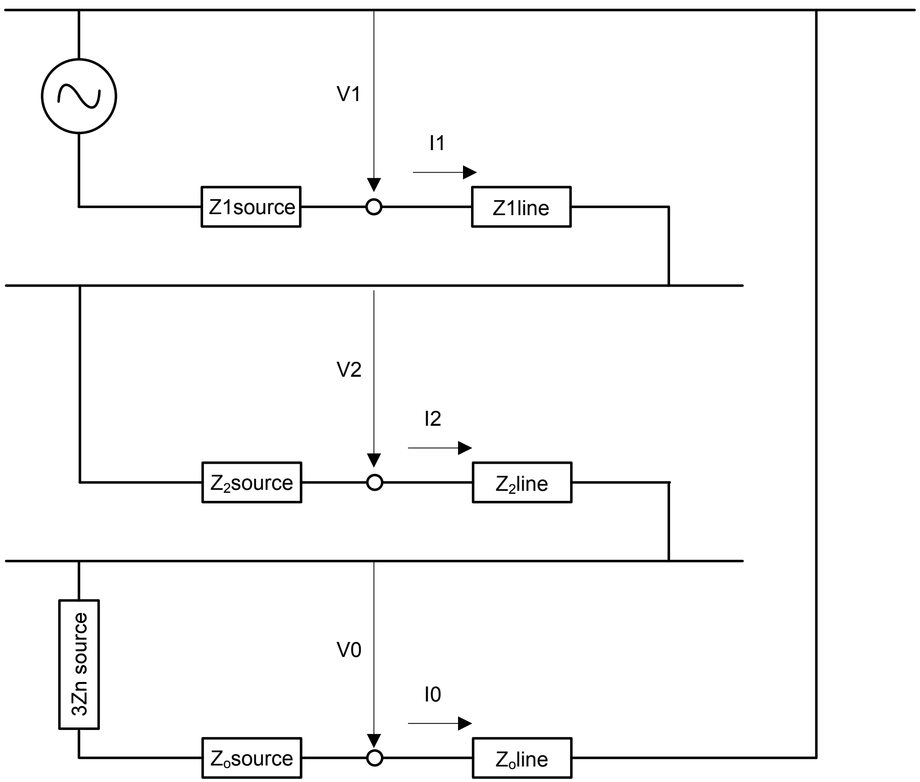


- 3-ph fault
  - Measures : Vph-n and Iph
  - Calculation : $\dfrac{Vph - n}{Iph} = Zline$
- 2-ph fault
  - Calculation : $\dfrac{Va - Vb}{Ia - Ib} = \dfrac{Zline * Ia - Zline * Ib}{Ia - Ib} = Zline$

Distance calculation

- 1-ph fault





$$V_1 + V_2 + V_0 = Z1L * I1 + Z2L * I2 + Z0L * I0 =$$

$$= Z1L * Ia + Z0L * I0 - Z1L * I0 =$$

$$= Z1L * \left[Ia + In * \left(\frac{Z0L - Z1L}{3 * Z1L} \right) \right] =$$

$$= Z1L * [Ia + k0 * In]$$

$$Z1L = \frac{Va}{Ia + k0 * In}$$

$$\text{with} \quad k0 = \frac{Z0L - Z1L}{3 * Z1L}$$

k0 factor

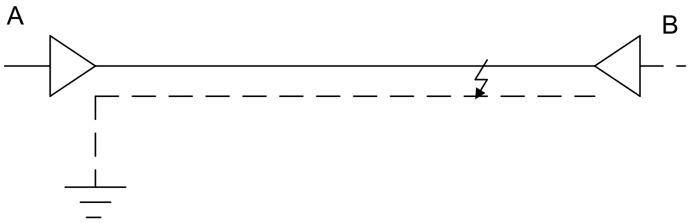
$$k0 = \frac{Z0 - Z1}{3 * Z1}$$

Item	Z1 (Ω/km)	Z0 (Ω/km)	k0
150 kV OHL	0,067 + j 0,419	0,176 + j 0,929	0,409 ∟-3°
150 kV cable	0,041 + j 0,124	0,134 + j 0,109	0,240 ∟-81°
230 kV OHL	0,060 + j 0,472	0,230 + j 1,590	0,792 ∟-1,4°
230 kV cable	0,039 + j 0,127	0,172 + j 0,084	0,351 ∟-91°

Conclusion :

- k0 factor OHL ≠k0 factor for cable (angle, amplitude)
- use of a distance protection which accepts complex k0 is mandatory
- for mixed conductor circuits, the use of a distance protection with more than one k0 is mandatory

Application of k0 for an underground cable – single point bonding



Distance relay at A

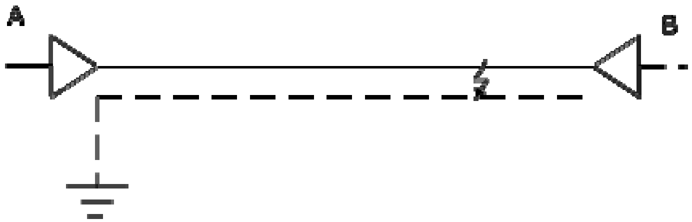
- In case of an internal fault (single phase), the fault current returns in the sheath only : $Z0 = Z0c + Z0s - 2 * Z0m$
- Z0 is proportional to the distance to the fault which implies that k0 is a constant
- For an external fault, there is no current in the sheath
  $Z0 = Z0c - Z0m + Z0m = Z0c$
- There is a discontinuity in the compensated loop impedance between internal and external fault at B :

$$Zcomp = \frac{Va}{Ia + k0 * In} = \frac{2 * Z1L + Z0L}{3 * (1 + k0)}$$

Z0int < Z0ext $\Longrightarrow$ Zcomp int < Zcomp ext

Z1 can cover the whole cable between A and B

Application of k0 for an underground cable – single point bonding



Distance relay at B :

- For an internal fault at B, the impedance measured by the relay is not zero because the fault current is returning to the source via the sheath and end A.
- Internal fault at A : there is no current in the sheath :

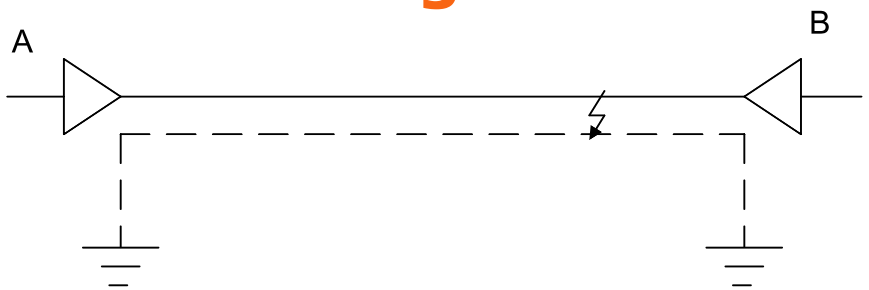
$$Z0 = Z0c - Z0m + Z0m = Z0c$$

- External fault at A : there is also no current in the sheath;

$$\Downarrow$$

there is a continuity in the compensated loop impedance at end A between internal and external fault; it is thus not possible to cover with Z1 the whole cable

Application of k0 for an underground cable – solid bonding



- In case of an internal fault, the fault current returns in the sheath and in the ground in parallel :

$$Z0 = Z0c - Z0m + \frac{(Z0s - Z0m) * Z0m}{Z0s} = Z0c - \frac{Z^2 0m}{Z0s}$$

- Z0 is not proportional to the distance to the fault which implies that k0 is not a constant
- For an external fault, there is also current in the sheats (because the sheaths are grounded at both ends)

$$Z0 = Z0c - \frac{Z^2 0m}{Z0s}$$

- There is continuity in the compensated loop impedance between internal and external fault; it is thus not possible to cover with Z1 the whole cable nor at end A, nor at end B

Distance protection applied to cable and mixed conductor circuits – conclusions

- Z0 is not very well known
- k0 is not a cosntant for internal faults on the cable section (see solid bonding)
- k0 cable ≠ k0 overhead line

$\Downarrow$

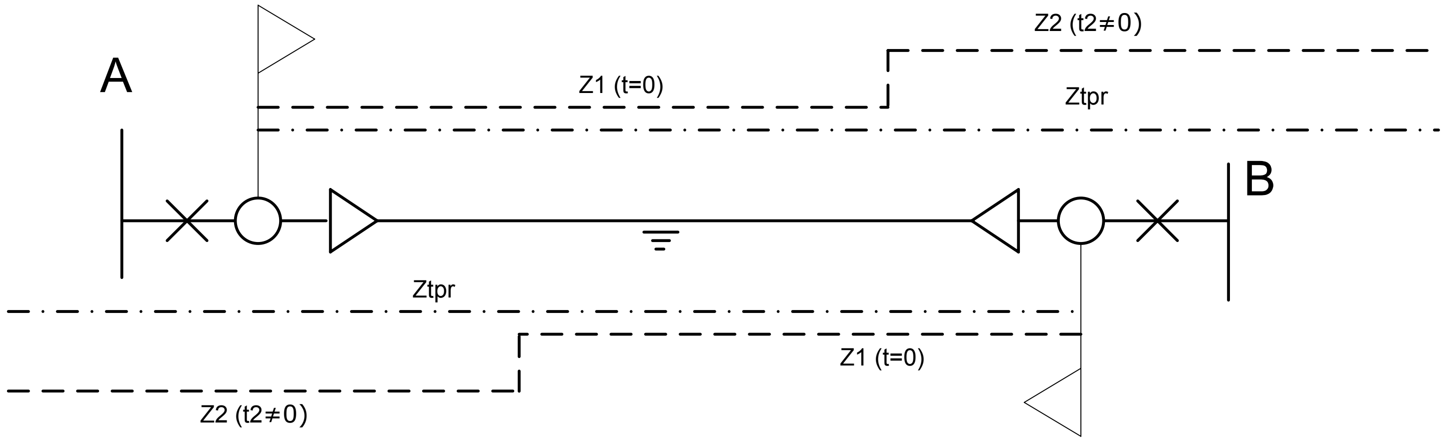
Distance protection can not guarantee a fast tripping for faults on the cable

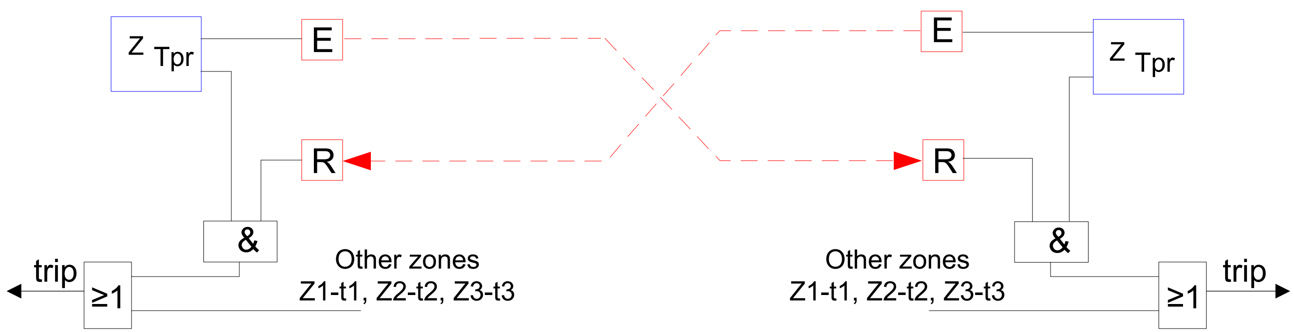
Application of distance protection with teleprotection

- Benefits
  - Usual benefits :
    - Instantaneous trip of all faults between both ends;
    - Good sensitivity for high resistance faults
  - Benefits associated with mixed conductors circuits
    - The uncertainty associated with the k0 factor disappears
- Drawbacks
  - Necessity to have a communication
- All classical schemes are available :
  - Permissive schemes (under and overreach)
  - Blocking schemes

  Overreach schemes give advantage over underreach schemes : due to the low serie impedance of the cable, it is easier to set an overreach zone

Application of distance protection with teleprotection - POTT





Application of distance protection with teleprotection - pros and cons

Pros :

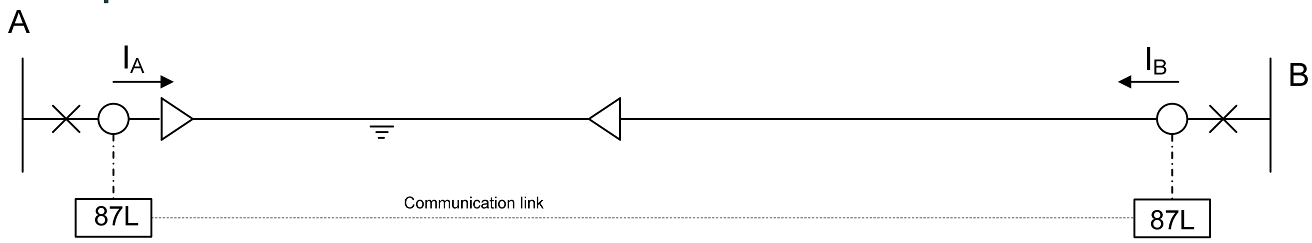
- Less dependent on cable characteristics then distance protection without teleprotection;
- Very good selectivity
- Low bandwidth requirement for the communication channel (in comparison to current differential protection)

Cons :

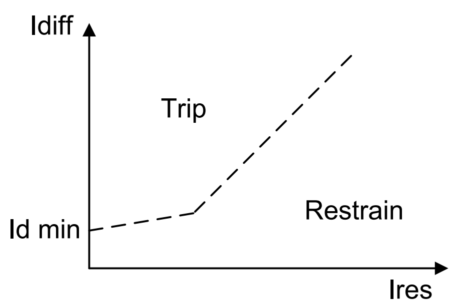
- Dependent on communication channel for the teleprotection
- Lower sensitivity then current differential

Application of current differential protection

- Principle : Kirchoff law $\vec{I}_A + \vec{I}_B = 0$



- Trip characteristic



$$I_{diff} = \left| \vec{I}_A + \vec{I}_B \right|$$

$$I_{restrain} = \left| \vec{I}_A \right| + \left| \vec{I}_B \right|$$

- Protection is stabilized against :
  - Errors due to CTs
  - CT saturation
  - Errors in the measurements made by the relay
  - Charging current in the underground cable

Application of current differential protection - pros and cons

Pros :

- Good sensitivity;
- Less dependent on cable characteristics then distance protection;
- Very good selectivity

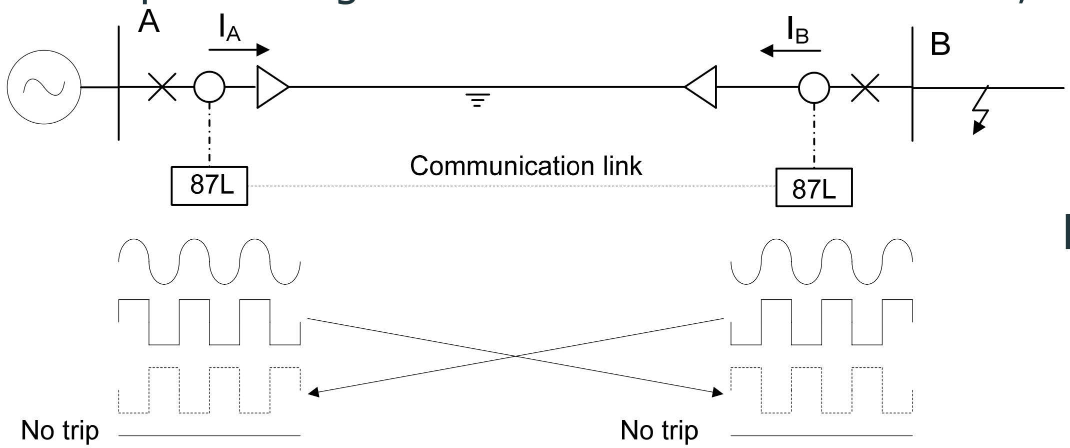
Cons :

- No back up protection
- Totally dependent on communication channel

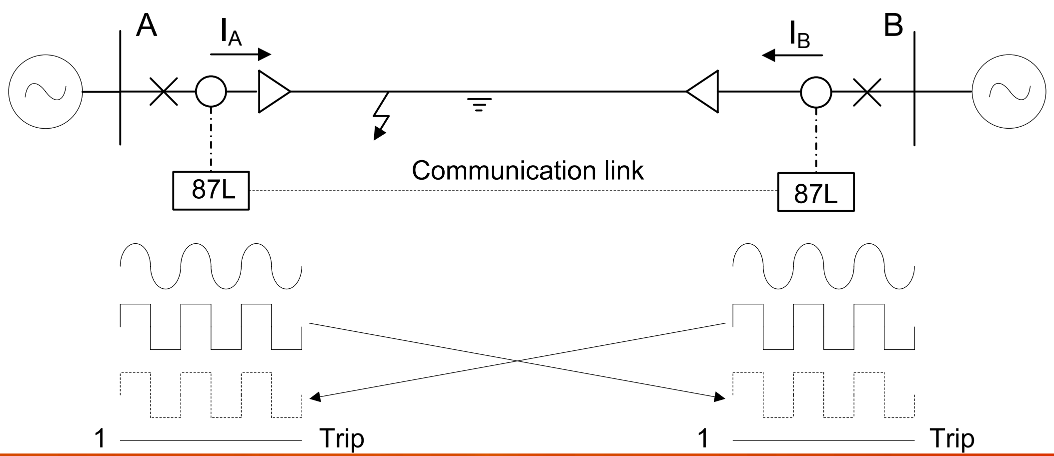
Application of phase comparison protection

Principle :

- Phase angle comparison between the currents at both ends
- When phase angle difference is above the level, there is a trip



External fault



Internal fault

Application of phase comparison protection - pros and cons

Pros :

- Less dependent on cable characteristics then distance protection;
- Very good selectivity
- Low bandwidth requirement for the communication channel (in comparison to current differential protection)
- Less sensibility regarding CT saturation (in comparison to current differential protection)

Cons :

- No back up protection
- Totally dependent on communication channel
- Lower sensitivity then current differential ?

Communication channels

Dedicated optical fibers :

- Immune to EMI, ground-potential rise : bit error rate is very low
- High bandwidth (very suitable for current differential protections)
- Direct optical interface on the protection relay
- High reliability and availability
- High security
- Maintenance costs are low
- Investment for the communication link is comparable to classic twisted copper pairs
- Not cost effective if hired optical fibers (low use of the available bw especially in case of teleprotection)

Communication channels - continued

Multiplexed optical link

- Immune to EMI, ground-potential rise : bit error rate is very low
- Bandwidth is a bit lower than direct optical fibers but still very suitable for current differential protection
- No direct interface on the protection relay
- Reliability is lower than direct optical fibers due to the presence of the mux/demux
- High security
- Maintenance costs are low
- Cost effective if hired optical fibers (better use of the available bw especially in case of teleprotection)

Communication channels - continued

Dedicated twisted pair

- Immunity to EMI, ground-potential rise is a problem; bit error rate is higher
- Risk of interferences with other pairs in the same cable
- Low bandwidth (not very suitable for current differential protections, suitable for teleprotection, phase comparison)
- No direct interface on the protection relay
- Low security
- Interesting only if the twisted pair is existing; otherwise it is better to install an optical fibers cable

Communication channels - continued

Digital leased line

- Immunity to EMI, ground-potential rise is an issue; bit error rate is higher
- Medium bandwidth
- Not very suitable for current differential protection because transmission delays from A to B and B to A could be different
- Evolution of telecommunication networks is towards IP : this means possible variations on the transmission delay;
- No direct interface on the protection relay
- Reliability, security are questionable

Communication channels - continued

Power Line Carrier

PLC is usable on mixed conductor circuits but :

- Signal loss is higher than for OHL
- Signal losses due to the different characteristic impedances for the cable and the overhead line

Mixed conductors circuits - autoreclose

Majority of faults
on OHL are non-permanent
on cable are permanent

=> The ideal solution is AR for faults on OHL and no AR for faults on cable

Different factors shall be taken into account :

- Short-circuit widhstand of the cable (conductor – external fault, conductor + shield – internal fault) ?
- Ratio OHL – underground cable for the circuit ?
- Safety for people (no AR gives the highest safety)
- Cost for a dedicated protection system on the cable (to discriminate a fault on the cable section) : installation, maintenance
- Continuity of service
- Power quality
- Operation of the network
- Non – availability of the circuit (use of a dedicated protection on the cable section will reduce the duration of the interruption in case of a fault)

Mixed conductors circuits - autoreclose

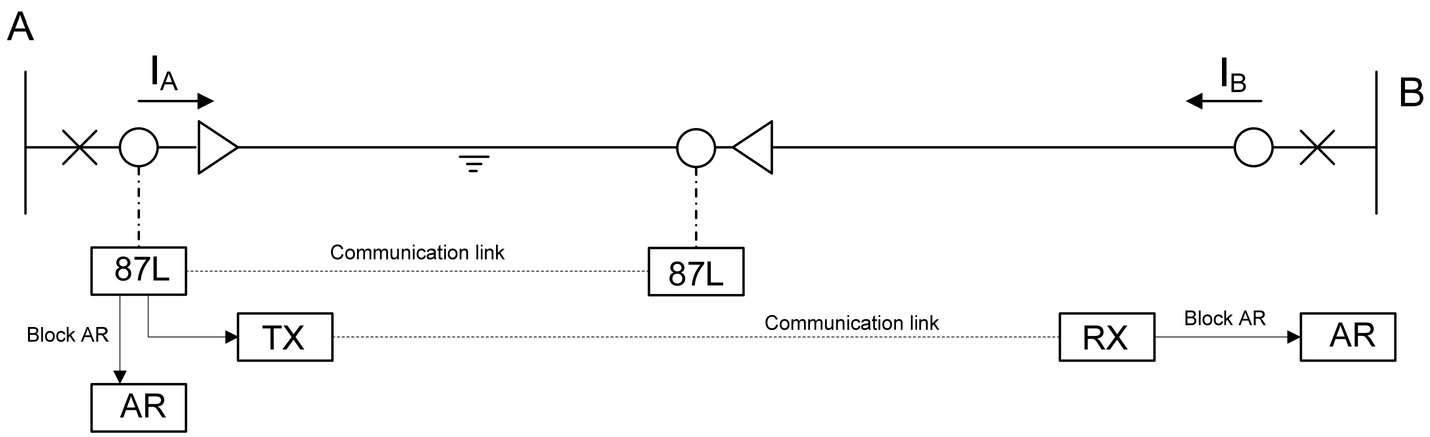
Questions :

- AR or not ?
  - 1-ph, 3-ph or both ?
    - If AR, with or without blocking for fault on the cable ?

      If blocking, with or without protection relay at the transition between OHL and cable ?

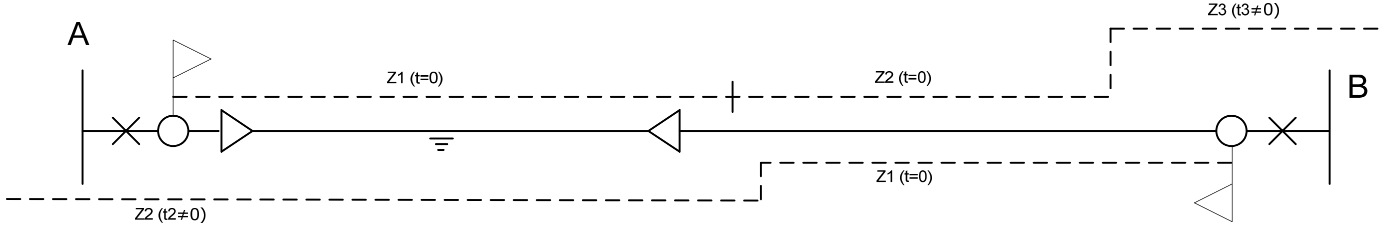
Protection to discriminate a fault on the cable section - With protection at the transition

- Cable differential protection
- Phase comparison protection
- Distance protection with communication scheme : normally not used because it requires VT's at the transition



Protection to discriminate a fault on the cable section - Without protection at the transition

Possible for 2-ends configurations and with the cable at one end of the circuit :



End A :

- Z1 covers the whole cable (a bit further) without delay; trips CB at A, blocks AR at A; sends remote tripping to B, sends blocking to AR at B;
- Z2 covers 80% of the circuit (cable + OHL)without delay; trips CB at A, start AR at A
- Z3, Z4 as usual

End B :

- Z1 covers 80% of the OHL; trips CB at B, starts AR at B; sends remote tripping to A and start AR at A
- Z2 covers the busbar at A

AR without blocking

- Example : short siphon
  - The probability to have a fault on the cable is low because the length of the cable is short
  - Impossibility to discriminate a fault on the cable without protection at the transition
  - Very high costs associated with the communication link to the siphon
- Constraints for the cable (example Elia : main 1 and main 2 protection)

Maximum allowed time to eliminate the fault			
Voltage (kV)	Base (ms)	Main 1 or main 2 doesn't work (ms)	Communication link fails (ms)
380	100	100	100
220	120	120	400
150	120	120	400

Maximum constraint for the cable		
Voltage (kV)	Internal fault with AR - conductor + shield (ms)	Permanent external fault with AR - conductor (ms)
380	100 + 100	100 + 100
220	120 + 400	120 + 400
150	120 + 400	120 + 400

Conclusion :

•Cable conductor shall be dimensioned for a permanent external fault; absence of blocking has no impact;

•Cable sheath shall be dimensioned for a permanent internal fault; absence of blocking will increase the time duration of the fault current in the sheath

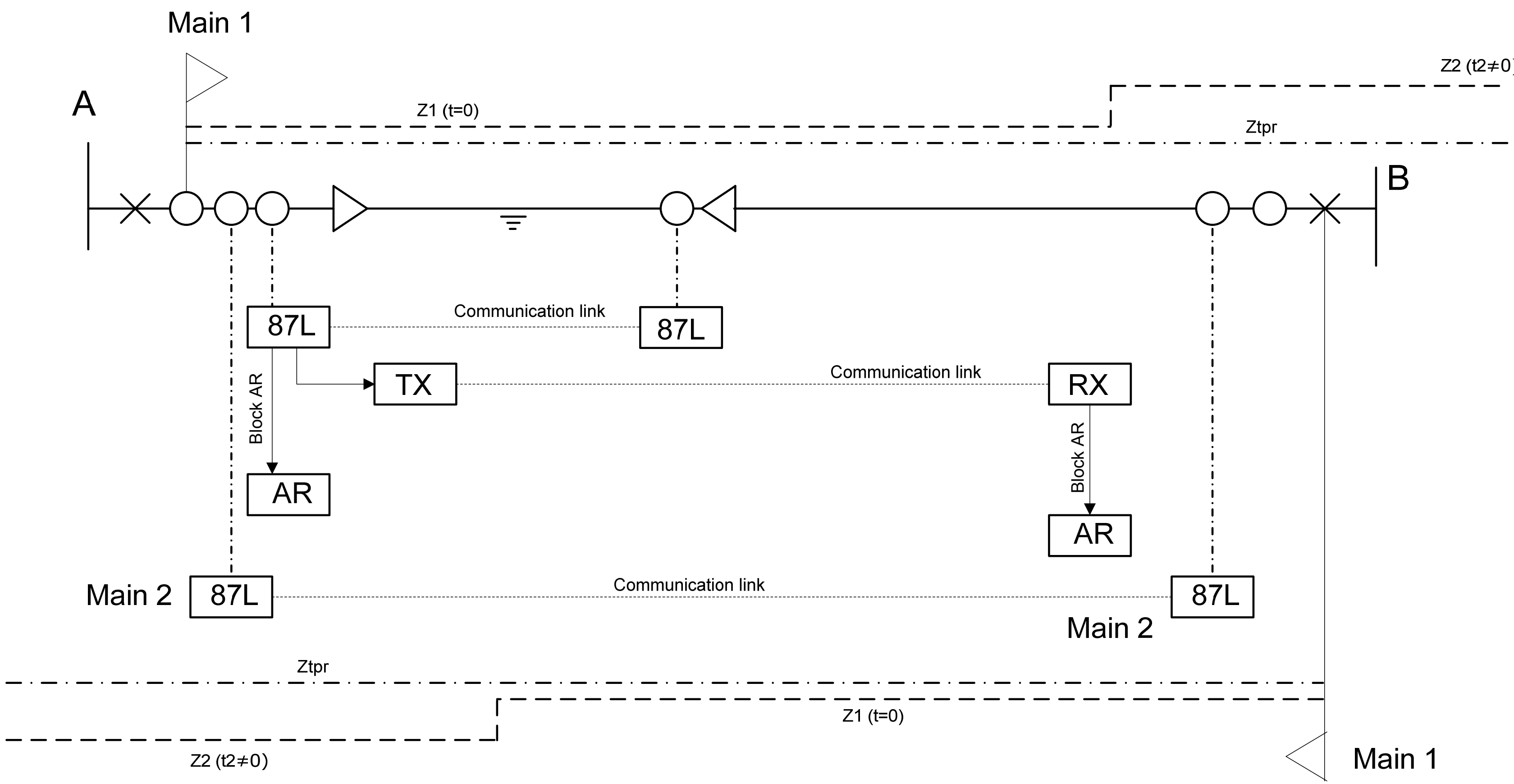
Example

Protections for the circuit (at each end):

- Main 1 : distance protection with POTT; Main 2 : current differential protection

Cable fault discrimination to block the AR :

- Current differential protection



Design of the transition

- CT : usually ring CT’s
- Electronic equipments are installed in cabinet :
  - Heating
  - Ventilation (preferably natural)
  - Good isolation (internal temperature ≤ 55 °C

- Power supply

  Modern relays require DC power supply; this means a battery + charger and a source to feed the charger; different possibilities :
  - LV connection to an utility :

    + : easy from a technical point of view;

    - : high cost if the distance to the utility’s network is high
  - VT :

    + : cost is usually lower than a connection to an utility

    - : maintenance cost
  - Other possibilities : windturbine, solar cels

Design of the transition – power supply

Examples :

Power supply - sizing

- Loads

  Digital protection relay => permanent load : ca 20 W (DC via battery)

  Heating of the cabinet : ca 100 W (AC)

- Required autonomy for the battery

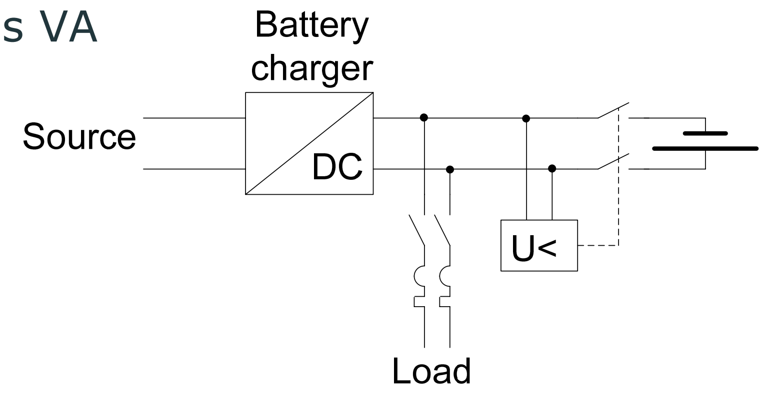
  As high as possible because availability of the source is far from guaranteed :

  - Windturbine, solar cels don't work permanently
  - VT : not available during maintenance of the circuit
  - LV network : not available during works

  But the autonomy is limited by the source that will charge the battery (excepted for LV network) :

  - VT : standard is 1000 VA, 10 kVA with special VT
  - Windturbine, solar cels : a few hundreds VA

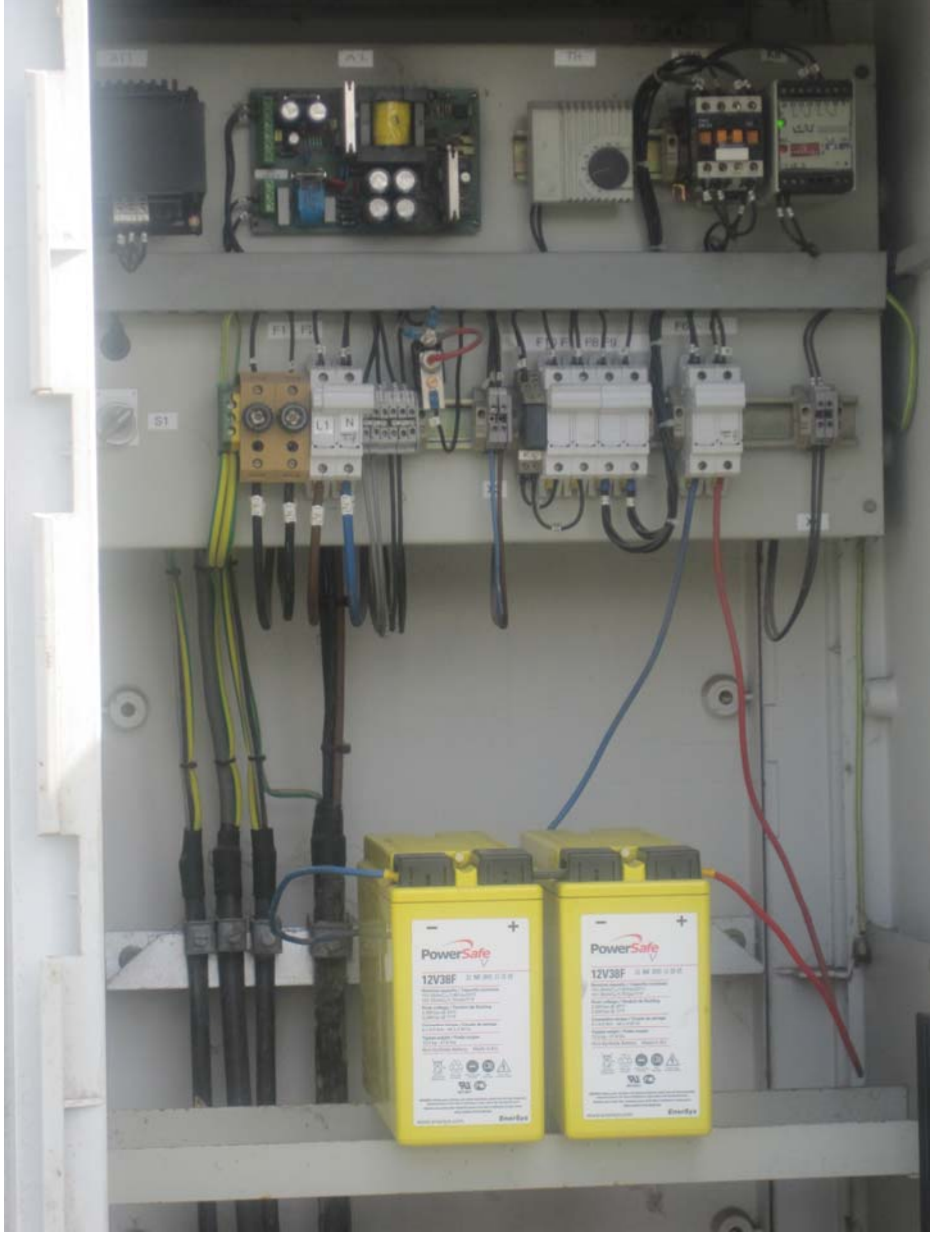
- Possible solution




VERBRANDE BRUG - WILSELE (WP)
150-47


LFCB 102

Charger + battery

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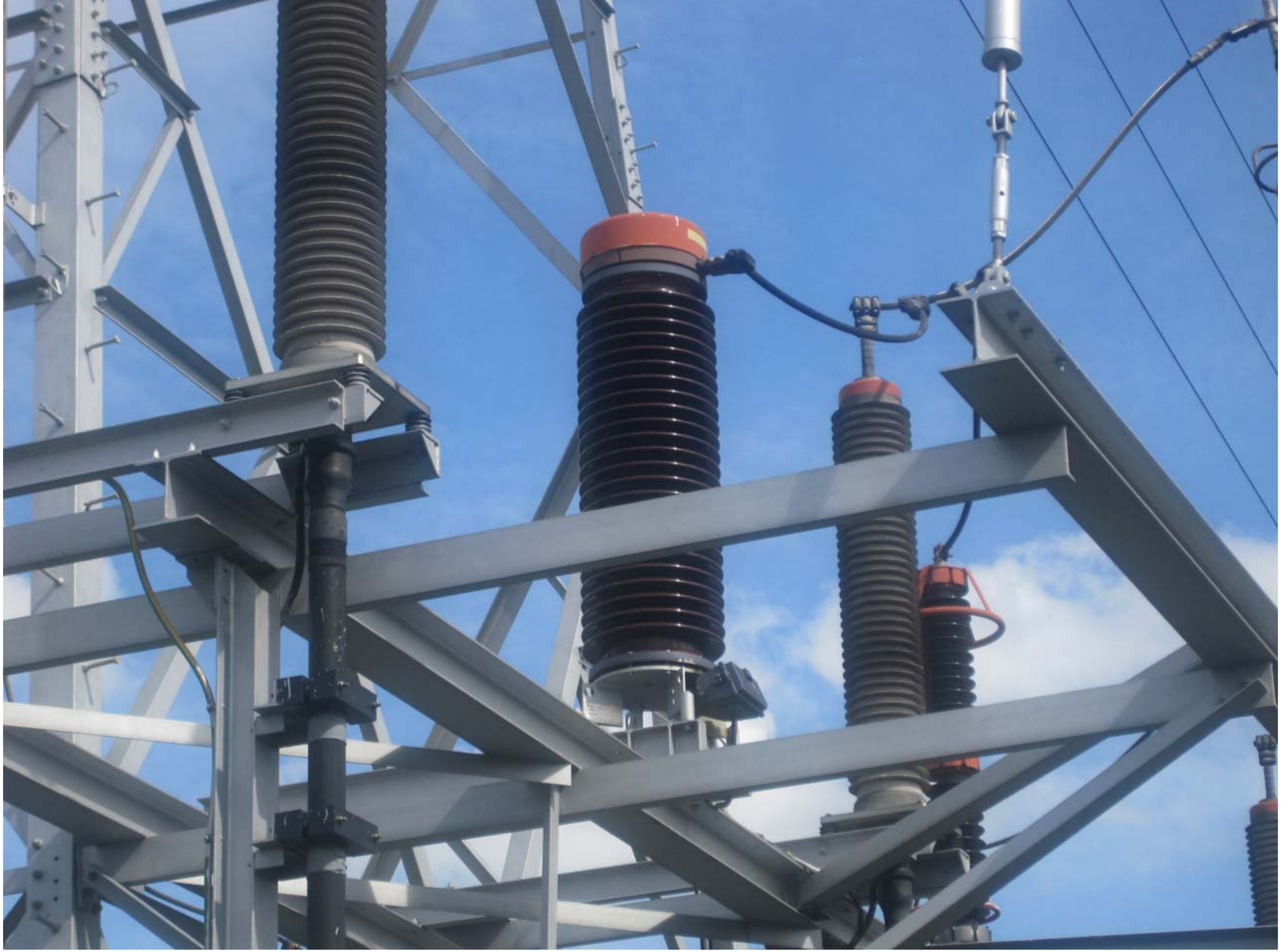
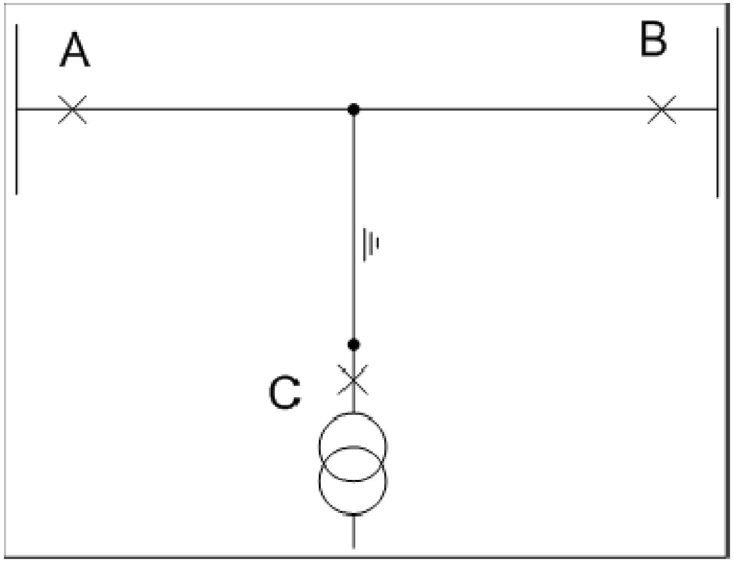


Policy regarding AR and necessity to discriminate a fault on the cable section – Elia's example

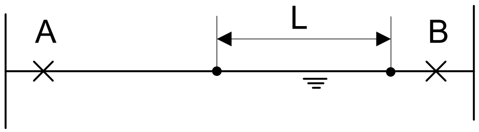
General : underground cables are dimensioned to widhstand AR on fault (internal and external, conductor and sheath)

3-ended circuit with a transformer tap at one end connected with an underground cable



- Autoreclose
- Dedicated current differential protection on the cable to block the autoreclose at all ends in case of a fault on the cable
- Reason : importance to restore the interconnection between A and B as soon as possible in case of fault on the cable

Policy regarding AR – Elia's example



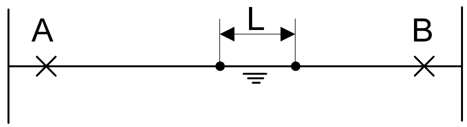
- L<1 km : AR without blocking for fault on the cable
  Reason : low risk for fault on the cable section
- L<40% of the circuit :
  - AR
  - Dedicated current differential protection on the cable to block the autoreclose at all ends in case of a fault on the cable

  Reason : number of faults on the OHL > number faults on the cable
- L>40% of the circuit and [interconnection or industrial customer]
  - AR
  - Dedicated current differential protection on the cable to block the autoreclose at all ends in case of a fault on the cable

  Reason : importance of the circuit
- L>40% of the circuit and [nor interconnection & nor industrial customer]
  - No AR

  Reason : less importance of the circuit

Policy regarding AR – Elia's example



- L<1 km :
  - AR without blocking

  Reason : probability to have a fault on the cable is low
- L>1 km and [interconnection or industrial customer]
  - AR
  - Dedicated current differential protection on the cable to block the autoreclose at all ends in case of a fault on the cable

  Reason : importance of the circuit
- L>1 km and [nor interconnection & nor industrial customer]
  - AR without blocking

  Cost to implement a dedicated protection for fault on the cable is high

References

- Electrical Transmission and Distribution Reference Book – Westinghouse Electric Corporation, 1964
- Protection of High-Voltage AC Cables – Demetrios A. Tziouvaras, Schweitzer Engineering Laboratories
- Cigre Working Group B5.23 – Technical Brochure “Short circuit protection of circuits with mixed conductor technologies in transmission networks” (to be published in 2012)