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7th International Conference on Insulated Power Cables

French experience in aluminium laminated screens

Paper A1- 4
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Jicable '07 CREATED IN 1982

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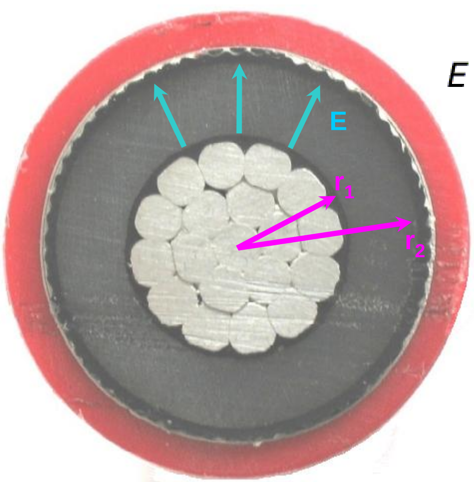
Functions of the metallic screen / sheath

Electrical functions

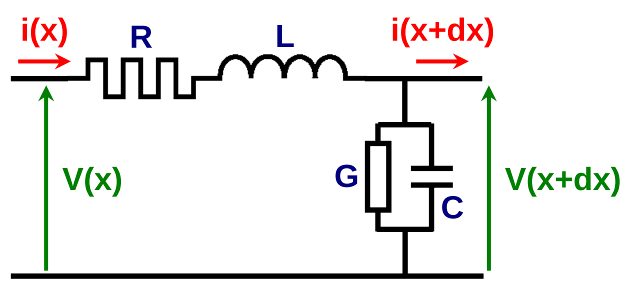
- Equipotential screen
- Capacitive current collection/draining
- short-circuit draining

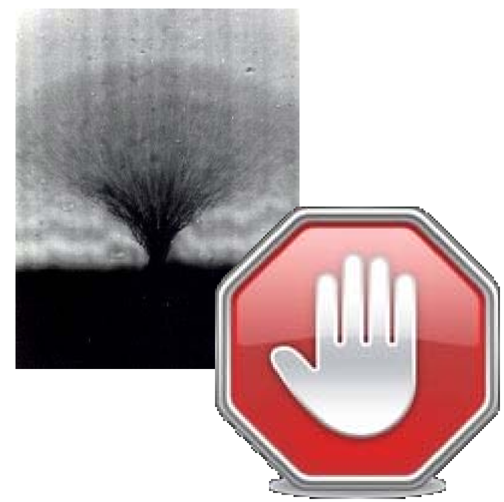
Protection functions

- Water barrier
- Mechanical protection



$$E(r) = \frac{V}{r \ln(r_2/r_1)}$$





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Design of the metallic screen / sheath

Main designs for HV cables

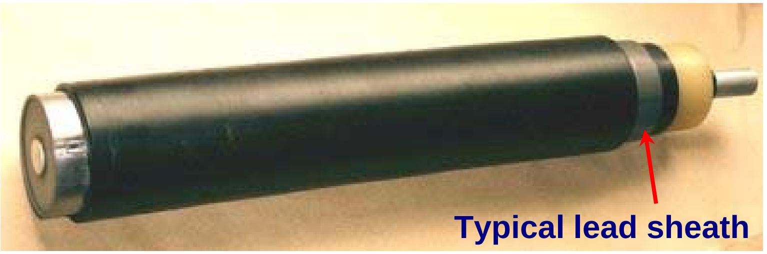
- To provide moisture barrier function
  - Extruded sheath
    - Lead sheath
    - Aluminium corrugated sheath
  - Longitudinally welded corrugated sheath
    - Aluminium sheath
  - Longitudinal tape (laminated foil)
    - Copper or aluminium
    - Stuck with overlap or seam welded
- To provide short-circuit draining (but not watertight)
  - Copper helically lapped tapes
  - Concentric wires
    - Copper or Aluminium

Typical solutions

- Lead sheath
- Aluminium corrugated sheath
- Aluminium laminated foil

Possibility to combine concentric wires

- For large short-circuit currents



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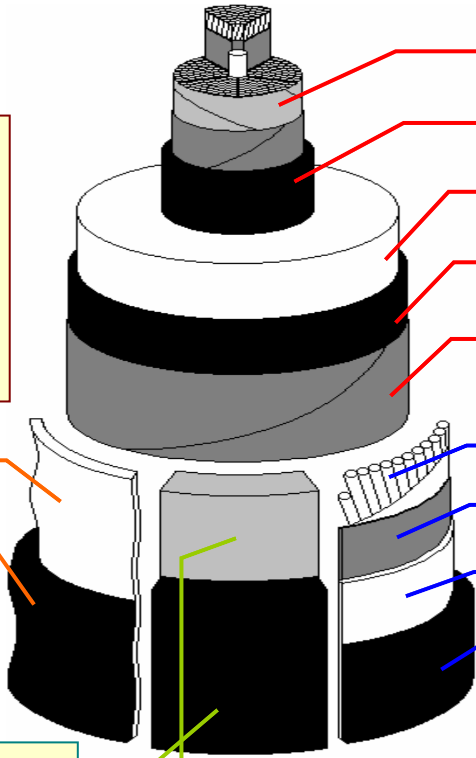
Main features of the typical solutions



Corrugated aluminium sheath

- ☺ mechanical strength
- ☹ gap between S.C. and tube
  (poor heat transfer)
  (no longitudinal water tightness)
- ☹ large external diameter

Extruded lead sheath

- ☺ well-known industrial process
- ☺ bending radius
- ☺ poor risk of corrosion
- ☺ connection to the accessories
- ☹ weight
- ☹ not environmental friendly

Laminated aluminium foil

- ☺ weight
- ☺ good thermal behaviour
- ☺ compact cable

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Essential bonding of the foil to the outersheath

Thin aluminium foil must be bonded to a polyethylene outersheath

- To improve the mechanical behaviour
  - No crease of the foil in case of low bending radius
  - No crack in case of mechanical impact
- To prevent any risk of corrosion of the metallic foil

Design according to short-circuit current intensity


NORME INTERNATIONALE
INTERNATIONAL STANDARD

CEI
IEC
949

Calcul des courants de court-circuit admissibles au plan thermique, tenant compte des effets d'un échauffement non adiabatique

Calculation of thermally permissible short-circuit currents, taking into account non-adiabatic heating effects

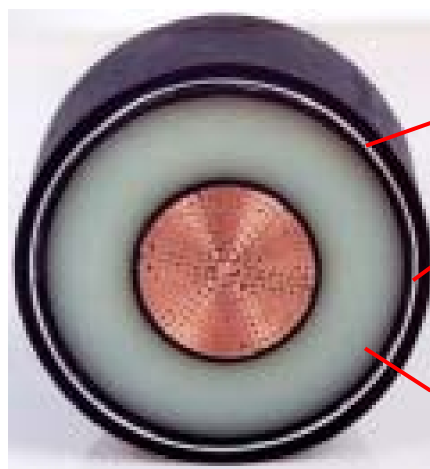
IEC

Calculation of thermally permissible short-circuit currents

IEC 60949 Publication

- High temperature step of the metallic screen / sheath due to the short-circuit current flow
- Adiabatic heating
  - Heat is retained inside the metallic component
- Non adiabatic heating
  - Some heat transfers into the adjacent materials during the short-circuit

Favourable configuration of extruded cables with laminated foil



Excellent conductivity of aluminium (thermal and electrical)
$K = 148\ A.s^{1/2}.mm^{-2}$

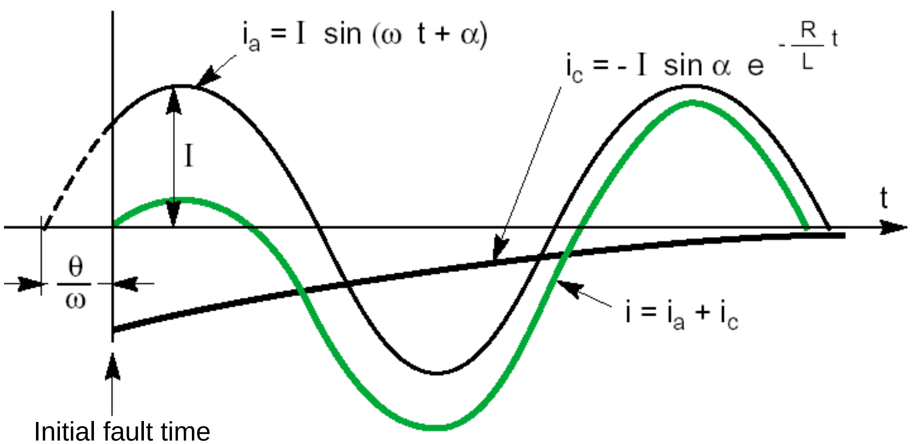
Good contact between metallic component and adjacent materials

High permissible temperature for XLPE insulation at the end of short-circuit ($\theta_f = 250°C$)

Assumption of maximal asymmetry of short-circuit

Transient operating

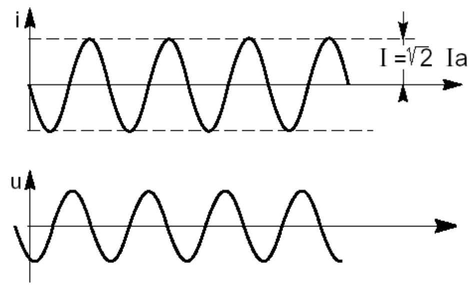
- As for the switching of a R-L circuit
- Resulting short-circuit current
  - Alternative sinusoidal part (i_a)
    - depending on the electric angle characterized by the offset between initial fault time and the voltage wave origin
  - Continuous part (i_c)
    - with decreasing depending on R/L value



Reference: Cahier Technique Schneider Electric n°158

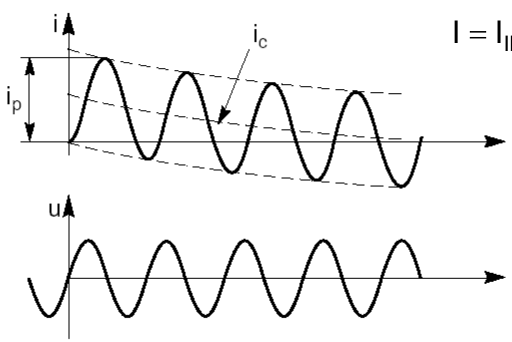
Two extreme configurations

- Symmetry ($\alpha = \varphi \approx \pi/2$)



- Asymmetry ($\alpha = 0$)
  - French design takes into account this penalising configuration
    - τ = aperiodic time constant, depending of grid impedance

$$I = I_{IEC}\sqrt{1+\frac{\tau}{t}}$$



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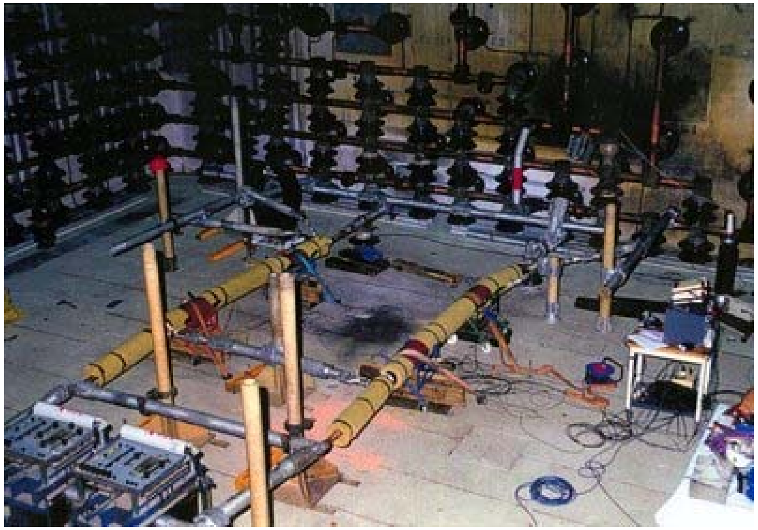
French HV short-circuit data



Short-circuit test

- 3 shots
  - 1st: conductor temperature = 90±4°C
  - 2nd and 3rd = 80±4°C
- Visual inspection between shots
  - No test loop damage, especially at connections

Networks characteristics

Voltage level (kV)	Intensity (kA)	Duration (s)	Aperiodic t (s)
36/63 (72.5)	8	1.7	0.2
52/90 (100)	10.3	1.7	0.2
130/225 (245)	31.5	0.5	0.16
230/400 (420)	63	0.5	0.07
	40	0.5	0.06

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French transmission grid

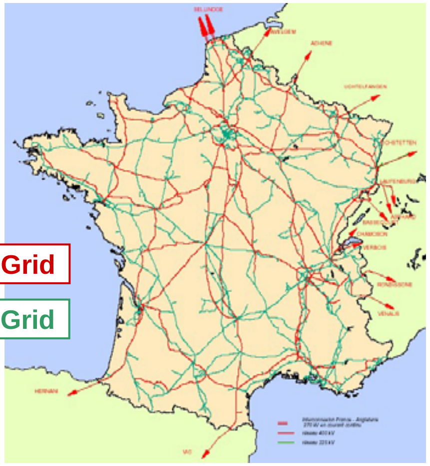
RTE: French Transmission System Operator

- Four main voltage levels: 400, 225, 90 and 63 kV
- Lines in service (km of circuits, end 2006)

Voltage level (kV)	400	225	150	90	63	Total
Overhead Lines (km)	21012	25490	1061	15048	33807	96418
Underground Lines (km)	3	902	2	406	1945	3258
Total	21015	26392	1063	15454	35752	99676

Reference: RTE 2006 Annual review report

RTE Gestionnaire du Réseau de Transport d'Electricité



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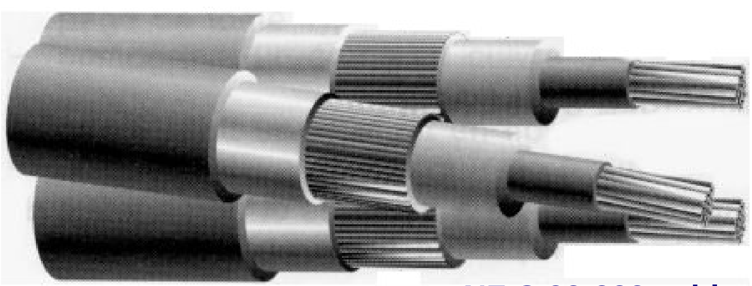
French medium voltage cable experience

NF C 33-226 cable



NF C 33-223 cable

EDF Distribution Grid

- Medium voltage cables: 20 kV
- Very optimised design
- Extensive use of XLPE insulation and watertight aluminium foil
  - NF C 33-223 since 1979
  - NF C 33-226 since 2003
- Installation of 6000-8000 km of 3-phase circuits per year

Mechanical laying in rural area

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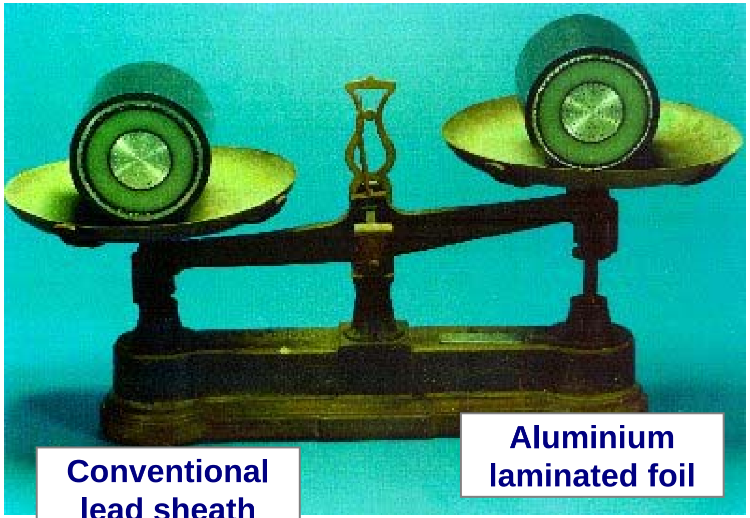
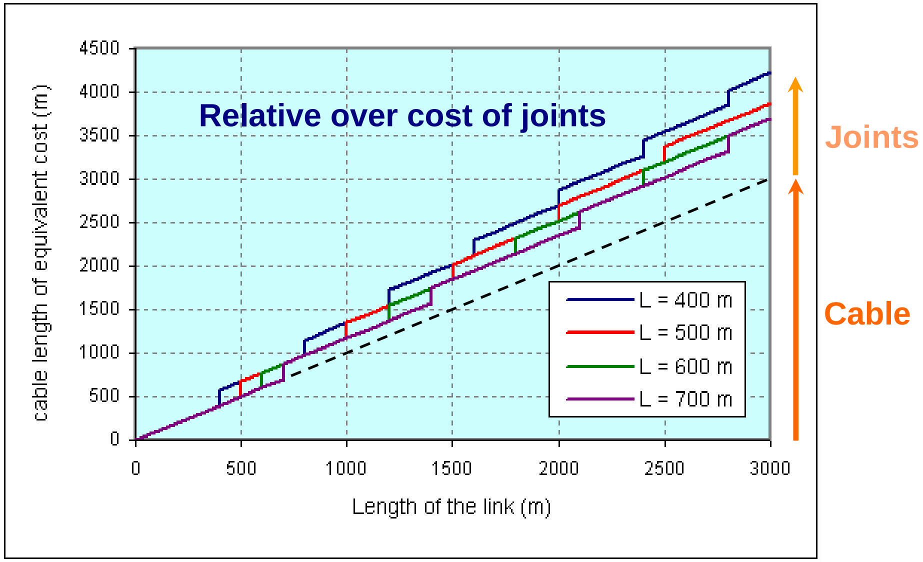
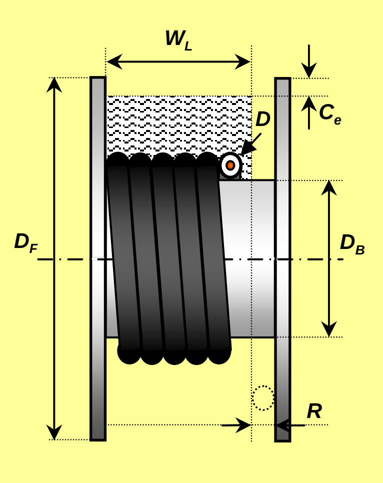
Development of HV laminated aluminium design

Designs leading to lighter cables to reduce the number of joints

- Aluminium conductors
- Aluminium laminated sheath
  - progressive replacement of lead by a moisture barrier offering similar performances and equivalent reliability
    - 90 kV: first qualification in 1997
    - 225 kV: first qualification in 2002
    - 400 kV: first qualification in 2002







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Specific French tests

Bending
3 times at 25 (d+D) ± 5%
d: conductor diameter,
D: outer cable diameter

Heating cycle
20 cycles
Conductor T°: 100 ± 4°C
Sheath T° ≥ (Conductor T° - 15°C)

Inspection
No evidence of cracking, splitting and no visible distortion. No annular wrinkling. No separation of the metal sheath from laminated protective coverings.

Impact
27 ± 1 kg / 27 ± 1 cm
4 impacts on 10 points on overlap or weld and on the opposite side.

Bending

Abrasion
48±2 kg - 4 cycles

Inspection
No evidence of cracking, splitting and no visible distortions. No annular wrinkling.

Corrosion
pH = 8.5
3000 h at 80±2°C

Inspection
- No evidence of corrosion of the metal screen
- No presence of water under the metal screen
- No separation between the metal screen and the oversheath or overlap

A primary set of tests

- to assess the watertightness of cable designs after exposure to mechanical stress

Others tests to assess

- mechanical properties only
  - impact test and abrasion test
- radial watertightness after shrinkage
- radial watertightness after short circuits

Long term test

- 200 m loop of cable with accessories
  - 1.7 U_0, 6000 hours / 250 thermal cycles

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HV cable system installation

Improvements made possible by lighter cables and small diameters

- HV mechanical laying in rural area
- Generalization of laying in ducts
- Laying in directly buried HDPE ducts
- Long length with water pulling

Mechanical laying in rural area

HDPE ducts, directly buried

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Conclusion

Example

- 800 mm² Alu 52/63 (72.5) kV
- For a same permissible short-circuit current intensity
  - Same ampacity if single point or cross bonding (low eddy-current losses, good heat dissipation)

	Aluminium laminated foil	Lead sheath
Screen / sheath thickness (mm)	0.5	2.55
Overall cable diameter (mm)	64.8	68.9
Total linear weight (kg/m)	4.71	9.60
Screen / sheath weight	5.3	53.3

Reliable industrial solutions

- Many developments and specific tests have passed intrinsic issues
  - Strong bonding between foil and outersheath
    - Up to 2 mm thick foils
  - Perfect complex seam welding of laminated moisture barriers for EHV cables
  - Proven connections for accessories
- Many advantages
  - Weight, delivery length on drum,
  - Global economical interest
  - Good thermal behaviour (ampacity)
  - Environmental alternative to lead
- Aluminium laminate screen has been extended to all voltage levels (63-400 kV)
  - Sole design expected in RTE specification since 2005