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Electricity Distribution and Underground Networks

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Distribution networks: a key infrastructure component

- Distribution constitutes a local infrastructure system that is determinant of the quality of the electricity delivered.
- Given the fundamental role played by electricity in our everyday life, distribution network performance is an important element of the quality of life.
- These networks constitute a major investment and are generally built to last 40 years. The choices made must take this service life into account.
- Many companies are faced with major network renewals.

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Important changes in society

- Increasing urbanisation leads to rising density of electricity delivery.
- The public has increasing expectations of the environment.
- The increasing importance given to micro-generation and local production is changing the role of distribution networks.

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Towards an underground network?

- Where networks have mainly been developed above ground, the question of moving them underground arises.
- How should we address this question without neglecting any aspects?

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Moving towards an underground distribution network: what are the major aspects ?

- A new network design
- Work and equipment to reconsider
- An improved level of quality:
- Better public safety,
- Reduced impact on the visual environment,
- A change in operating principles,
- A light but high level maintenance
- A transition to be organised,
- New competencies and skills
- Essential economic aspects.

2 different aspects : MV networks and LV networks

- At medium voltage, the primary impacts of undergrounding are on quality and network structure with a secondary impact on the environment; the design must be part of an overall plan.
- At low voltage, the major effects of undergrounding are on the environment and on safety; it can be carried out in a more piecemeal fashion but affects the connections of houses to the network; it enables non-technical losses to be reduced.

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DESIGN OF UNDERGROUND NETWORKS

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The design of underground networks

- Overhead and underground networks differ in the relationship between carrying capacity and cost.
- Criticality of the network master plan
  - overhead and underground routes differ,
  - underground, ability to locate the structures: keeping to the public domain is of interest.
- Loopable MV networks
  - Open loop and double-feeder structures
- Network remote control is of interest.
- Spur LV networks, simple and robust

Characteristics of cables and conductors

Type of conductor	Resistance ohm/ km	Reactance ohm/ km	Capacitance µF/km
240mm² Alu	0.16	0.10	0.34
150mm² Alu	0.26	0.11	0.28
95 mm² Alu	0.41	0.12	0.21
148mm² aster	0.22	0.36	
75mm² aster	0.43	0.36	

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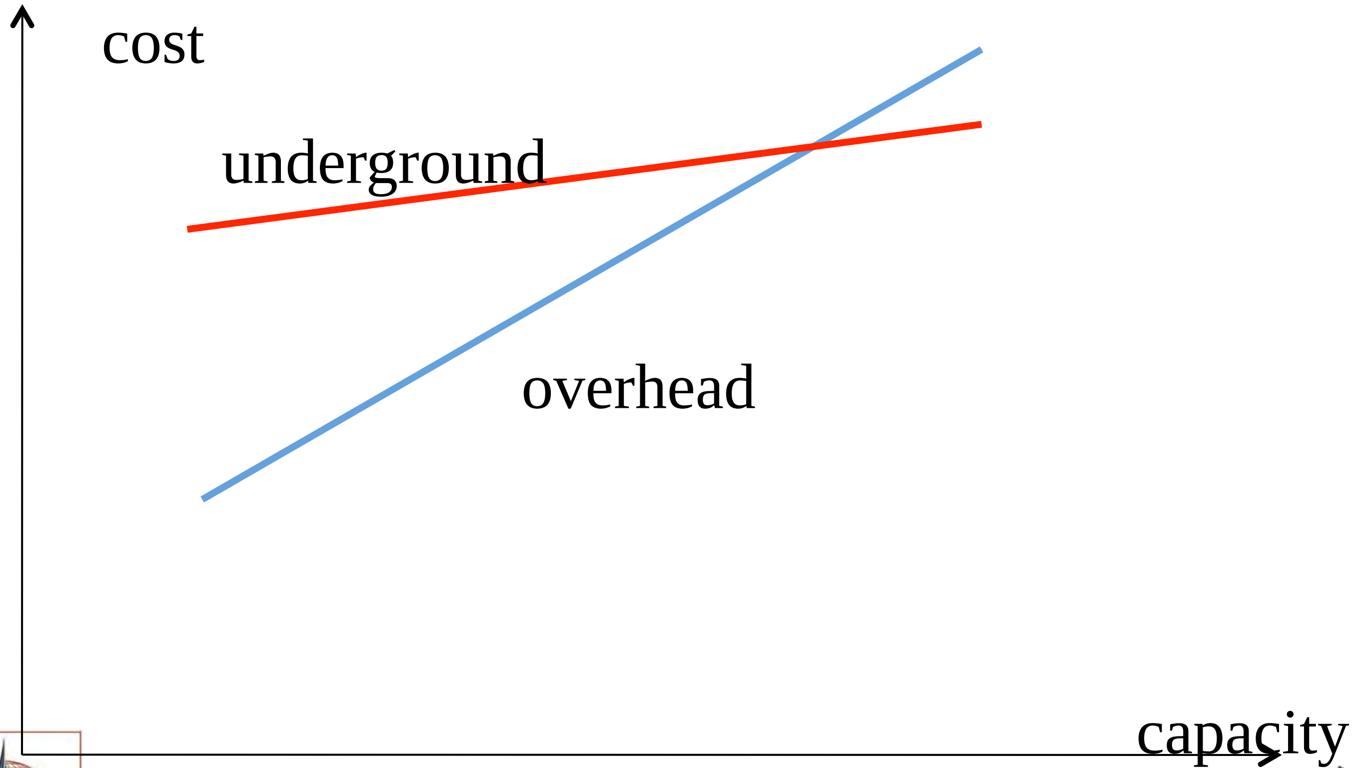
Cost-capacity relationship, overhead and underground



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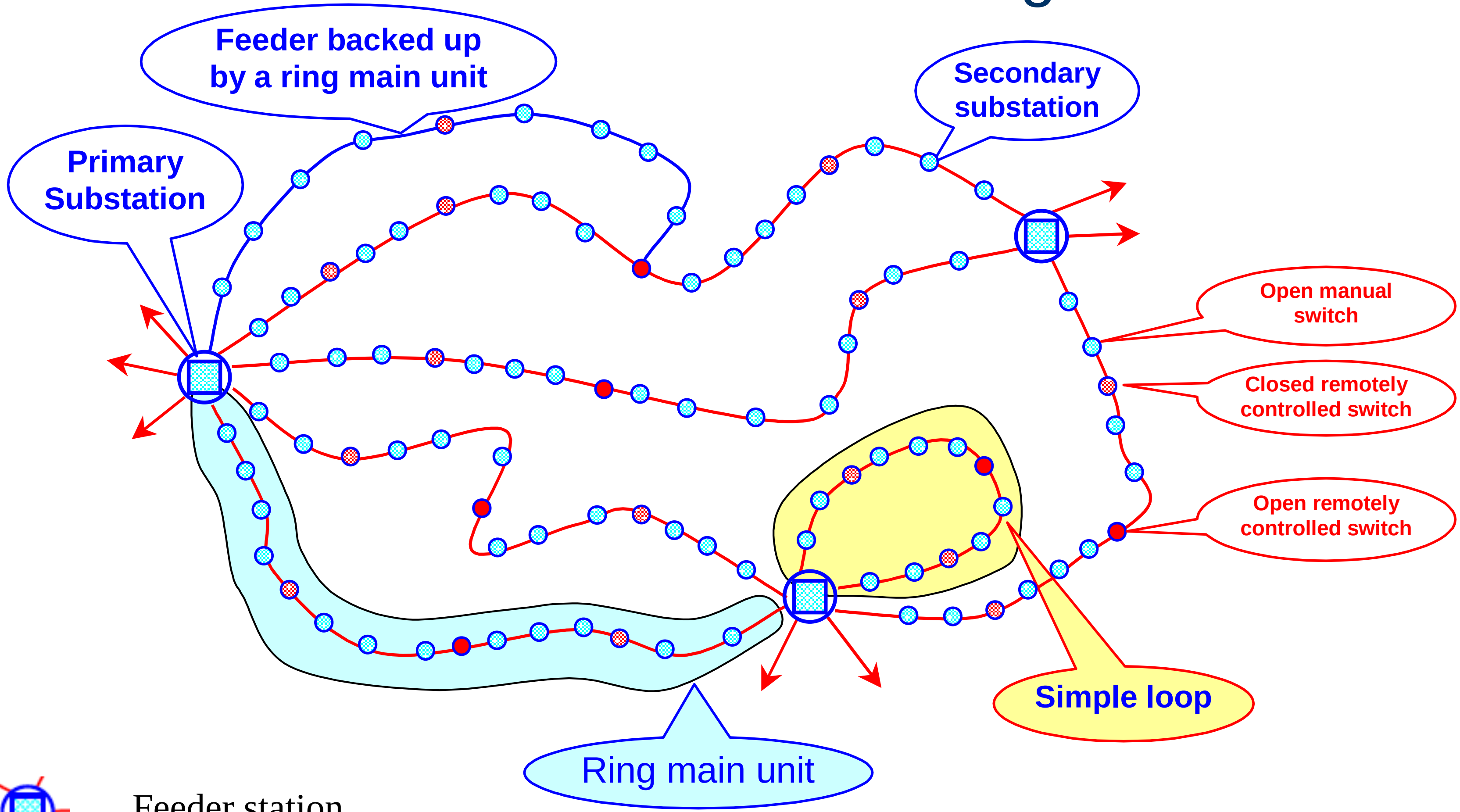
Traditional structure of an MV underground network



Feeder station

Remote controlled station

Feeder break station

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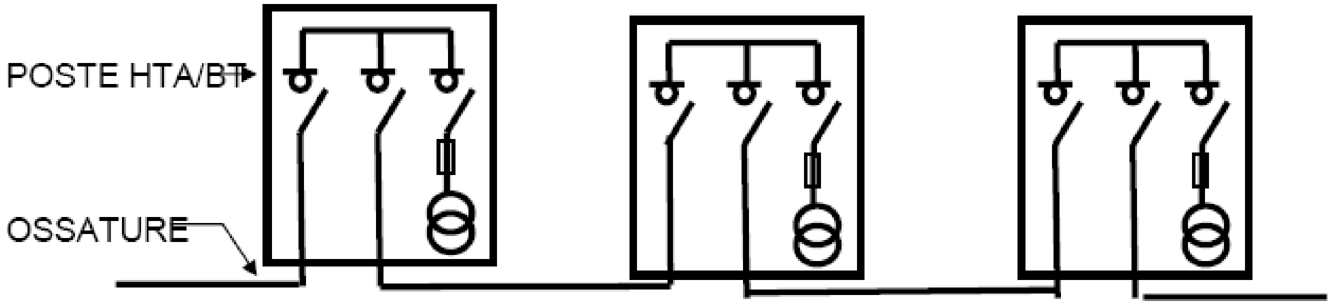
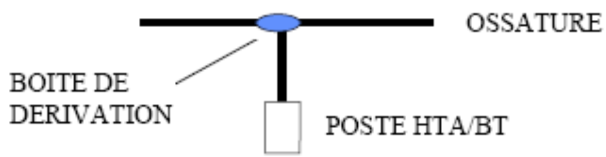
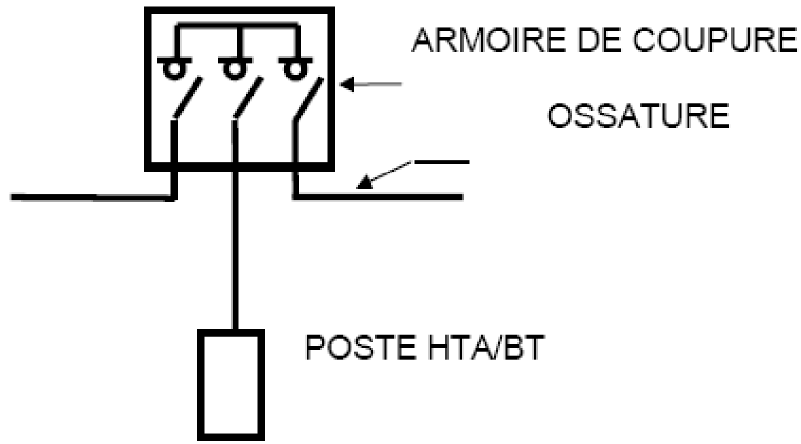
Structure of feeder break stations

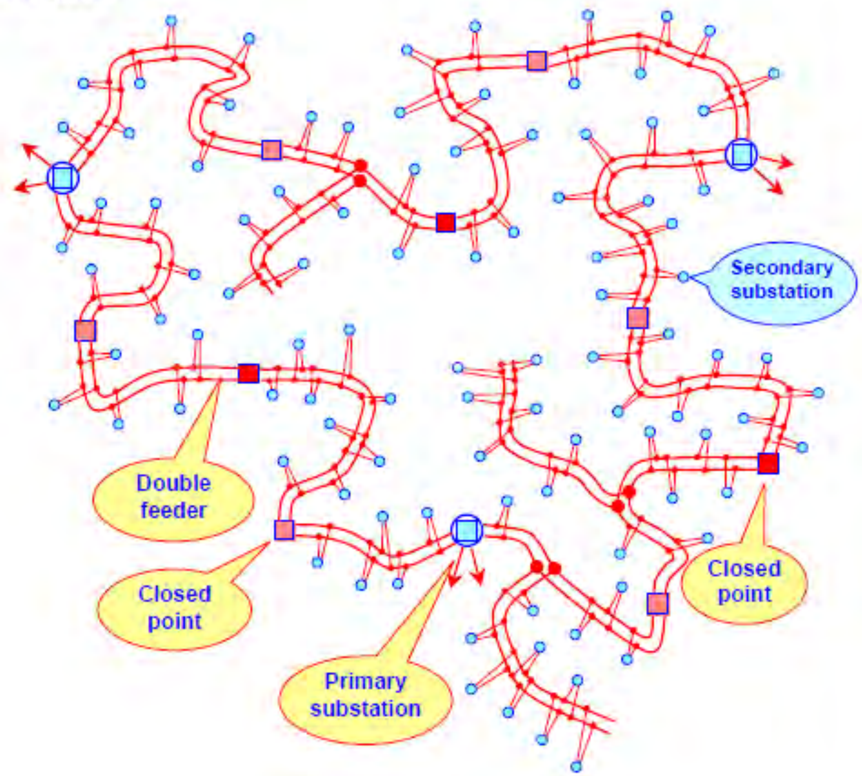






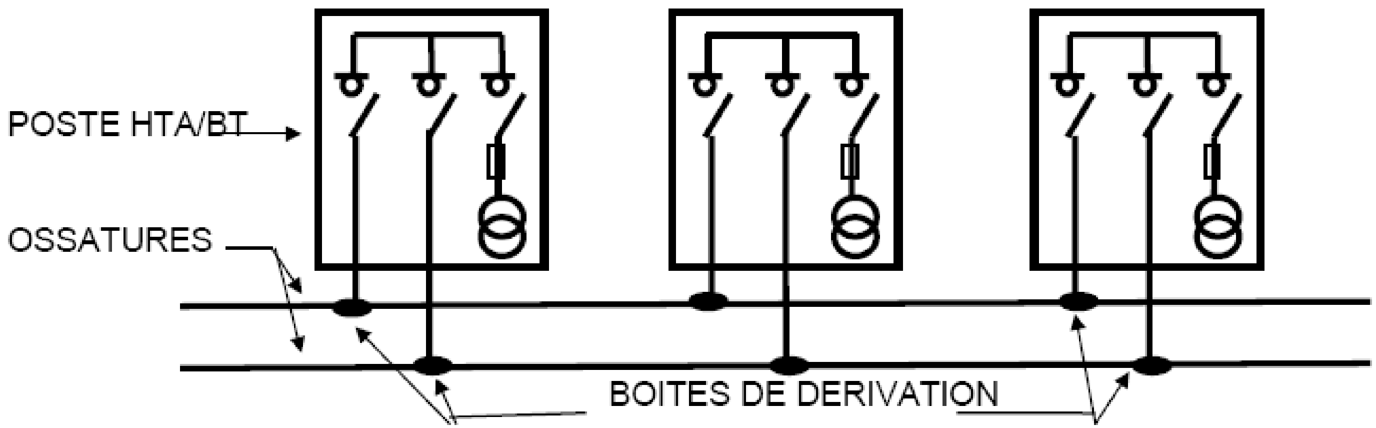
Double feeder structure for urban areas

- Very good quality
- Operation is costly and time consuming
- Each feeder is limited to 6 MVA to enable load transfer
- Good back up between primary substations
- When a primary substation is lost, transfer swithes need to be disabled



Structure of a double-feed network

Structure of double-feed stations



In general, the stations have an automatic system to switch to the second feed in the event of a fault on the first.

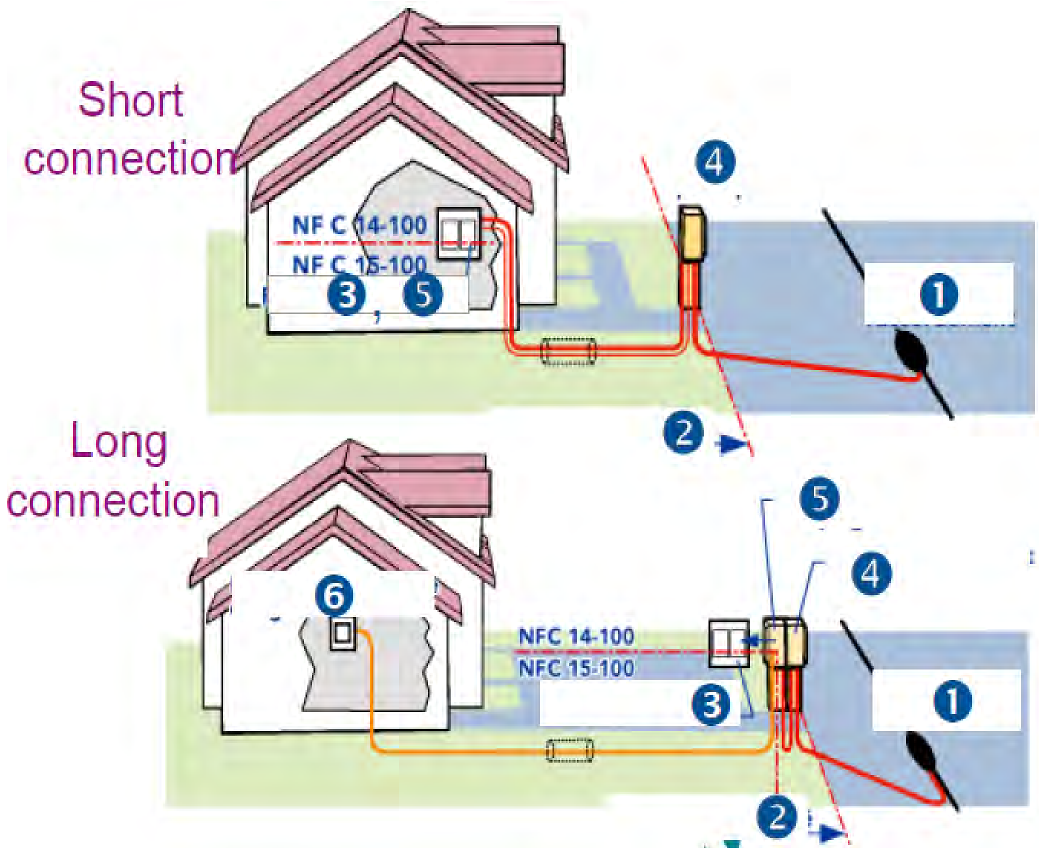
LV underground

- Spur networks are to be preferred.
  - The small number of faults does not justify looping.
- The number of connections, and hence circuit breaker boxes, should be limited.
  - Connections constitute a week point.
  - Tangent and double tangent boxes are reliable.
- Provide several connection points for restoration of supply in the event of a fault by means of temporary links in several, well-positioned boxes.

LV underground

- Provide for easy physical separation between the public network and the inside installation.
  - Especially for fault finding,
- provide for regular earthing of the neutral if the earthed neutral option is selected.

Individual connections



1 : connection to network

2 : limit of property

3 : supply point

4 : network box

5 : customer switch and meter

6 : customer emergency device

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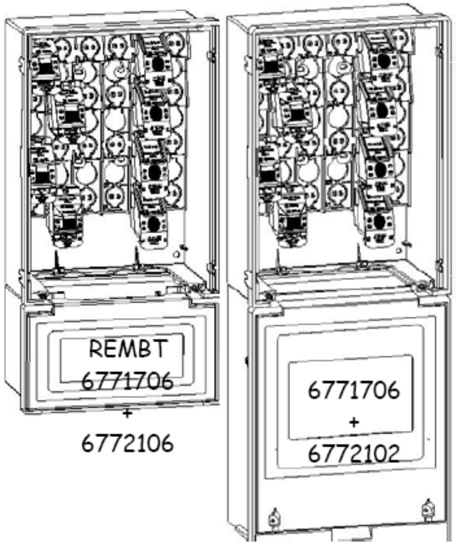
LV boxes:

equipment to be defined according to the chosen network structures.



FROM OVERHEAD TO UNDERGROUND

Different network structures

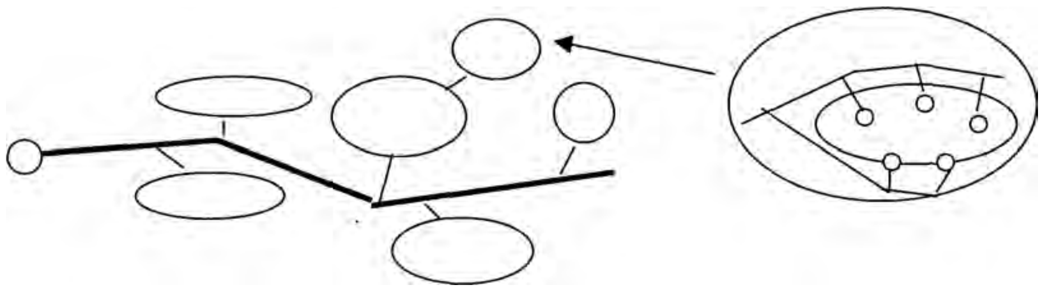
- A normal underground connection is by 2 ways (open or closed loop) because of the long repair times.
- The majority of overhead connections are spurs, making the power cut time close to the time to repair (unless backup generator sets are used).

From overhead to underground

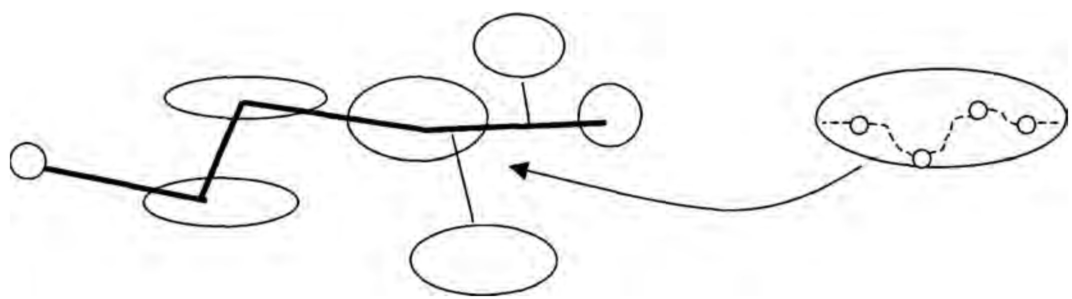
- The MV underground network is not simply a buried overhead network.
  - a master plan must be constructed for modification of the network, defining a medium-term objective,
  - the cost of transformer sub-stations must be taken into account in order to define the LV/MV network balance.

MV overhead/underground:
2 concepts that can be different

Overhead network: it passes at a distance from housing and spurs supply the houses.



Underground network: it passes through the heart of the village, following roads and streets.



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LV networks adapted to the MV/LV sub-stations

The high cost of transformer sub-stations adapted to the underground MV network leads to:

- an increase in the unit power of the sub-stations,
- a consequent increase in the length of the LV network.

This implies an overall redesign of the LV networks.

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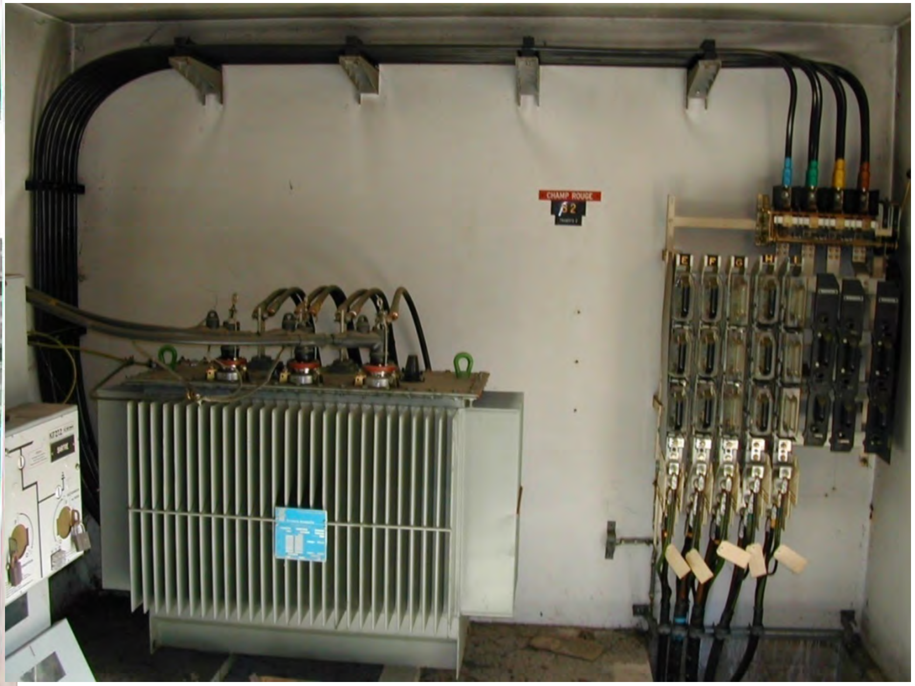

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WORK

Underground work

- Quality of cable laying and of the realisation of accessories
  - special qualification and approval of accessory fitters,
  - quality assurance of contractors
- Environmental control
  - narrow trenches,
  - directional drilling,
  - optimisation of the cable-trench pair.
- Cost control
  - reuse of excavated material,
  - narrow trenches.

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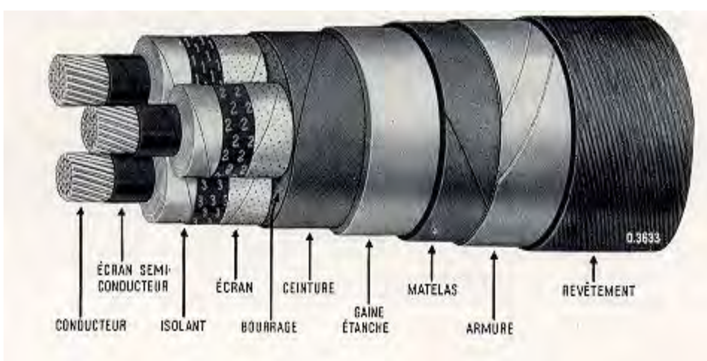
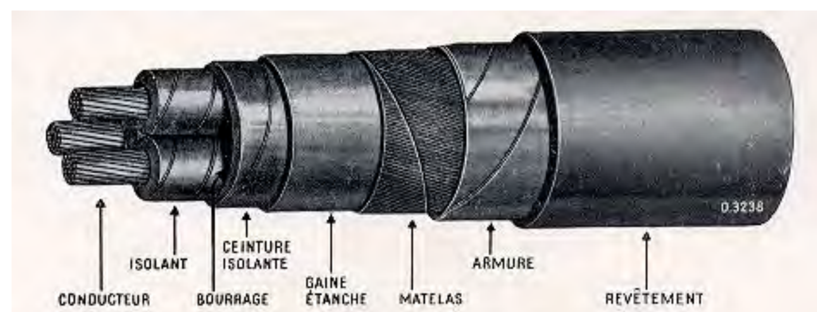
MV underground cables





Accessories for MV cables

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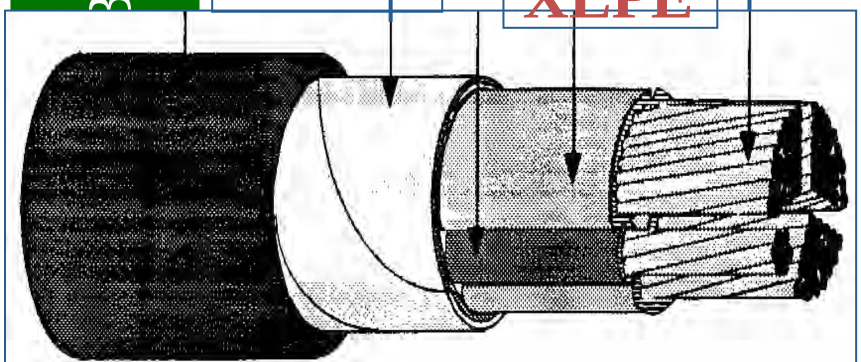
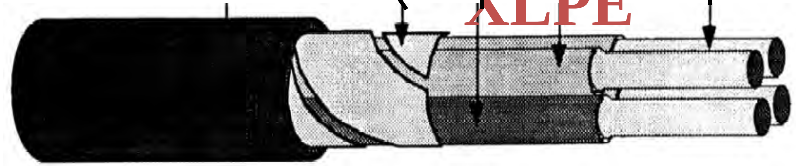
LV cables

Network link



Customer connection



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LV cables accessories

Cable laying with a trencher

Traditional cable laying in a trench

The regulatory provisions are very important.
They determine the depth of excavation and the distances between cables and from other structures.
The constitution of the sheathing of the cables determines the conditions of backfilling.

MV/LV substations

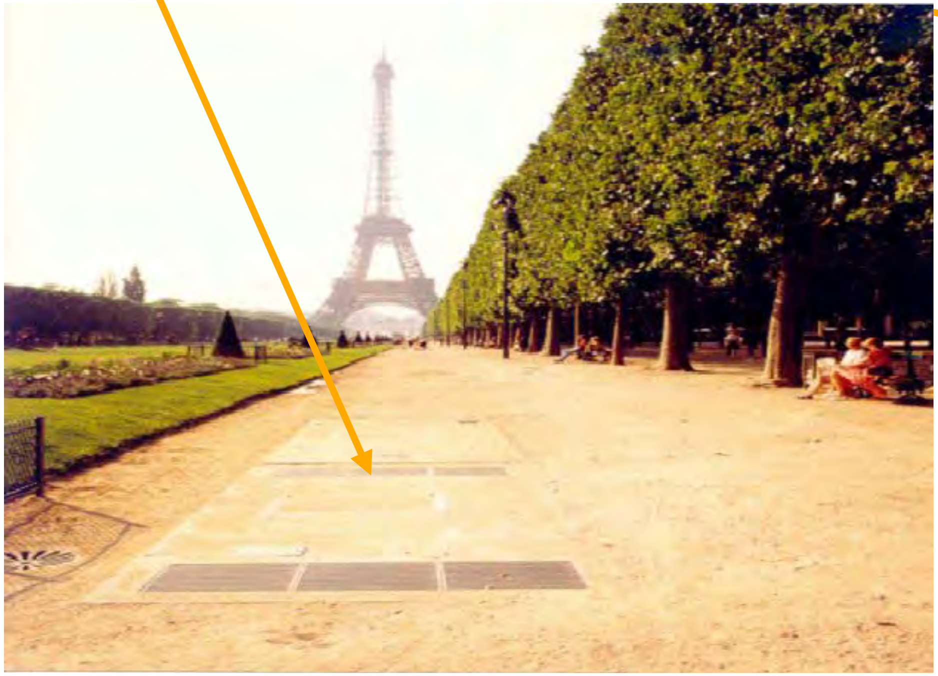
MV/LV substations

- In a cabin (masonry housed sub-station)

MV/LV substations

Buried

Plinths (foot of post)



QUALITY

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The quality of supply with underground MV networks

- low sensitivity to climatic risks,
- the network is generally looped, making it easier to restore supply,
- voltage variations can be better controlled,
- the impact of atmospheric voltage surges is more limited,
- power cuts are longer in the event of a major incident.

Sensitivity to climatic risk

risk	overhead	underground
Wind	- -	++
Frost	- -	++
Snow	- -	+
Storm	- -	++
Flood	+	-
Earthquake	-	- -
Freezing conditions	+	-

Origin of cable faults

- External failure
  - Mecanical shock :
    - accidental damage by people excavating near the cable
  - Water penetration
  - Workmanship error when installing the cable and accessories
- Internal failure
  - Manufacturing failure
  - Local overheating
  - Insulation aging

Fault target → less than 2 failures per year and per 100km

Reliability of overhead and underground networks compared

Average number of MV faults per 100 km on EDF networks	**Rural**	**Urban**
Underground networks	1.29	3.15
Overhead networks	4.03	

Average number of LV faults per 100 km on EDF networks (outside Paris)	**2005**	**2006**
Underground networks	3.24	3.17
Overhead networks	3.23	4.12

Comparison of MV fault durations on overhead and underground networks

Typical times to locate and repair and power cut durations seen by users

		Overhead	Underground
BACKBONE	Average time to repair	**6 hours** (cables more difficult to manipulate, live work)	**10 to 15 hours**
BACKBONE	Power cut duration seen by the user	**1 to 2 hours maximum** (operation of protection devices and network switching)	**30 min to 1 h maximum** (operation of protection devices and network switching)
SPUR	Average time to repair	**2 to 4 hours** (incidents often isolated, manipulations easier)	**10 to 15 hours** (little difference in structure from the backbone)

SAFETY

The main risks of overhead lines

- direct contact when handling long objects (agricultural, public works),
- risk when pruning tress close to lines,
- risk when construction work is carried out alongside the route,
- risk of electrocution when carrying out fraud,
- risks in connection with fallen cables.

The main risks of underground lines

- connected with the fact that equipment under voltage cannot be seen,
- poorly prepared groundwork, leading to damage to cables,
- confusion between cables and pipes,
- error when locating a cable before working on it.

Out of sight , out of mind !

A favourable situation for underground

- the risk of direct contact is eliminated,
- the pruning and tree trimming question are solved,
- in general, the earthing of underground networks is good,
- precise and up-to-date mapping is required,
- procedures for opening trenches are required, guaranteeing that underground users are informed of existing structures where the work is carried out.

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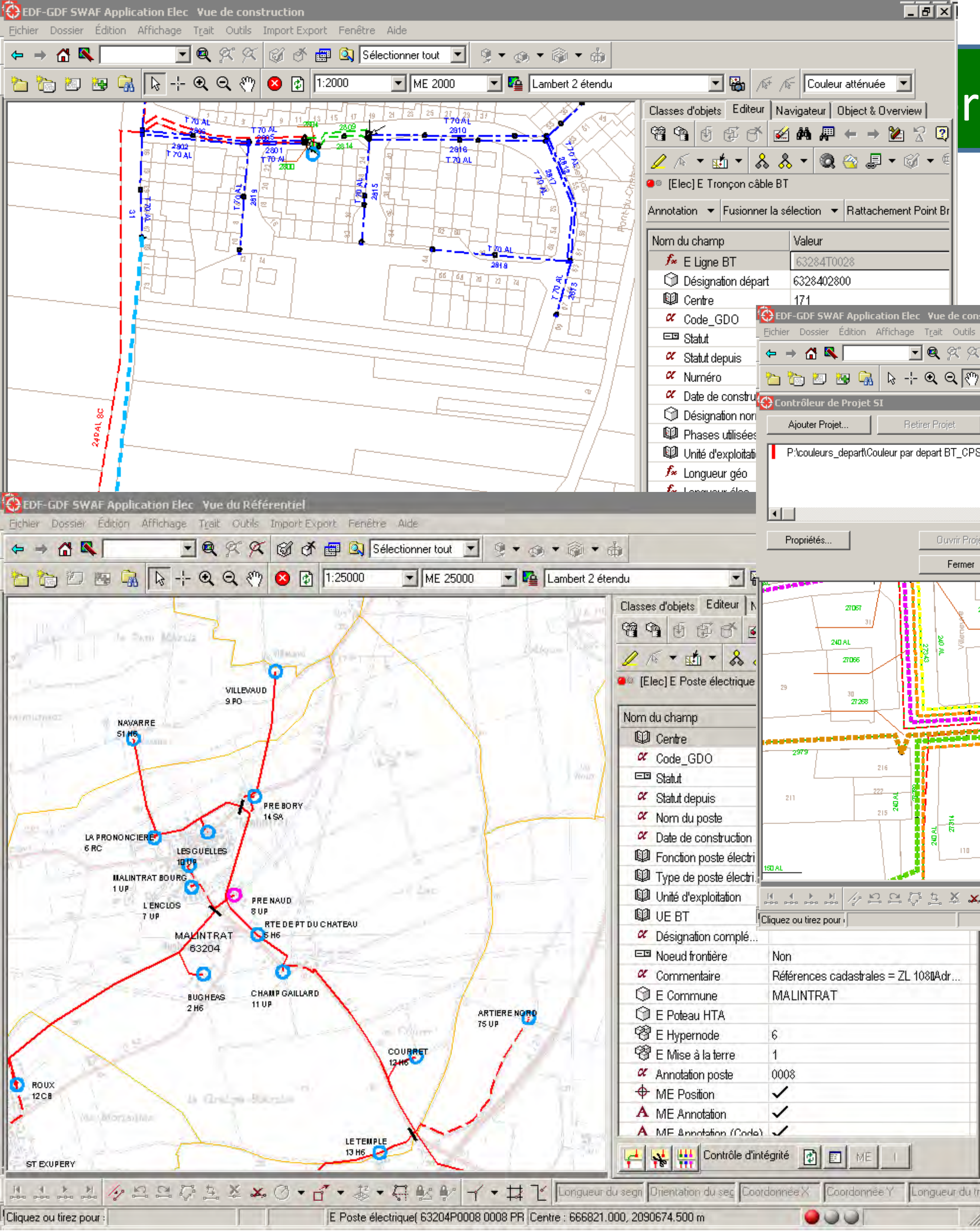
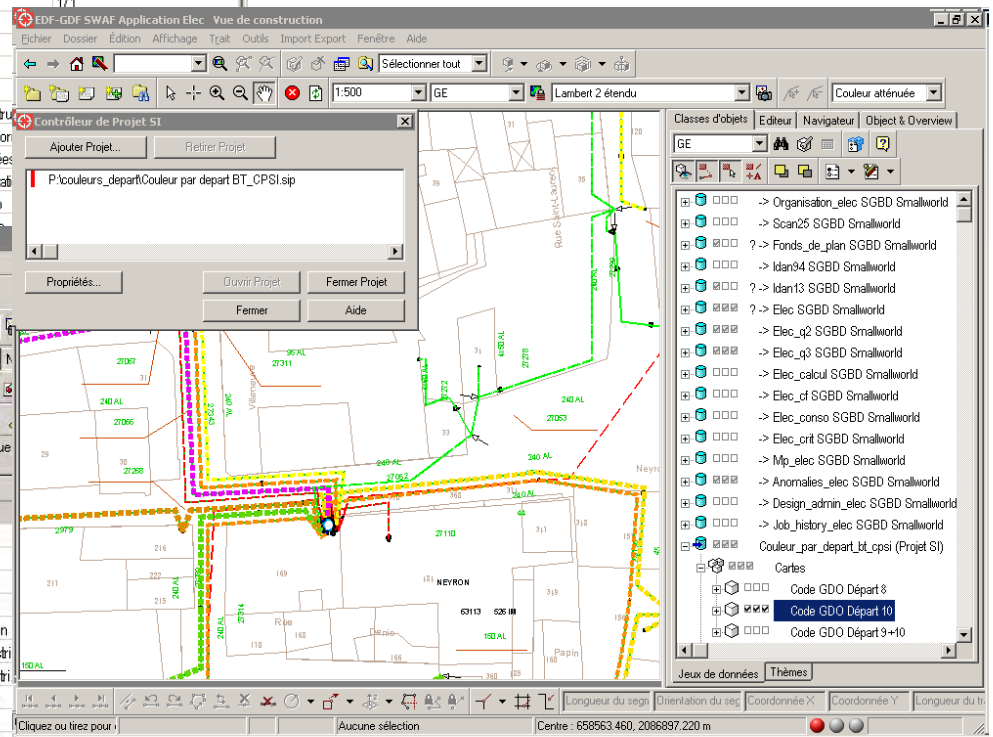
Medium scale mapping





Marking of structures at scales from 1/50000 to 1/1000

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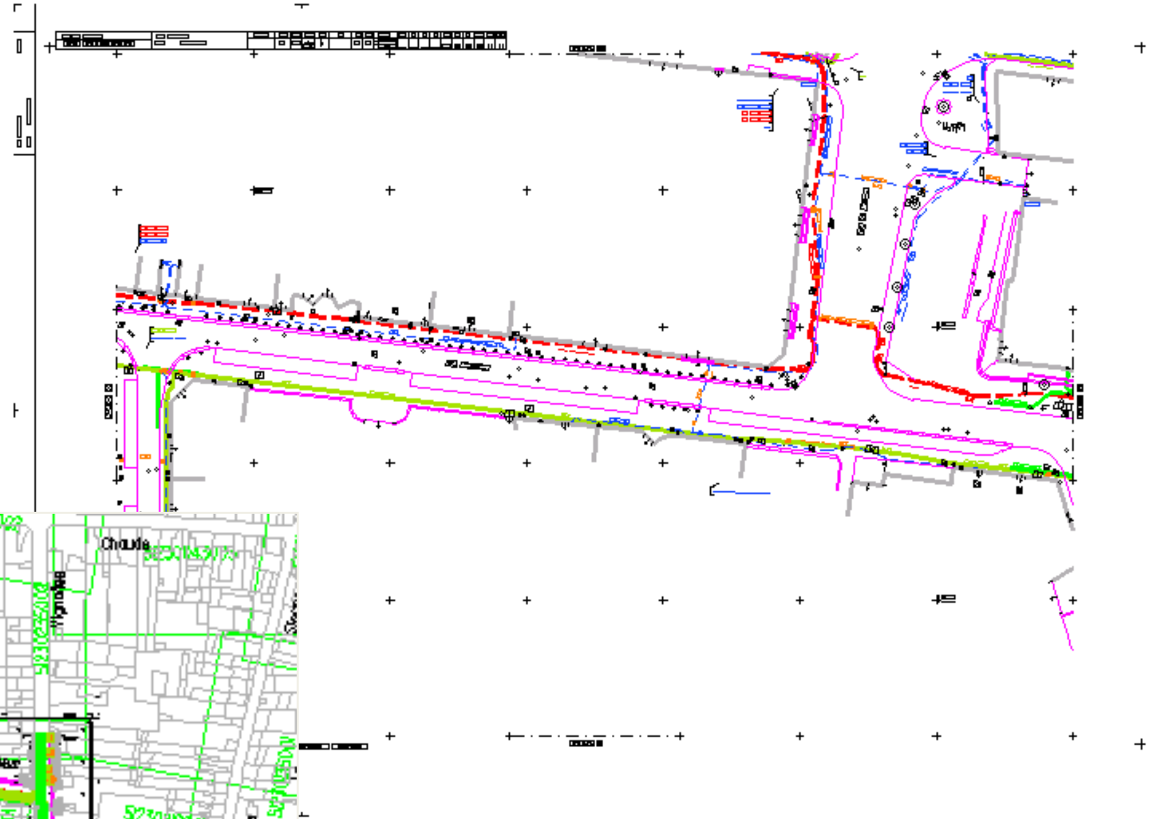
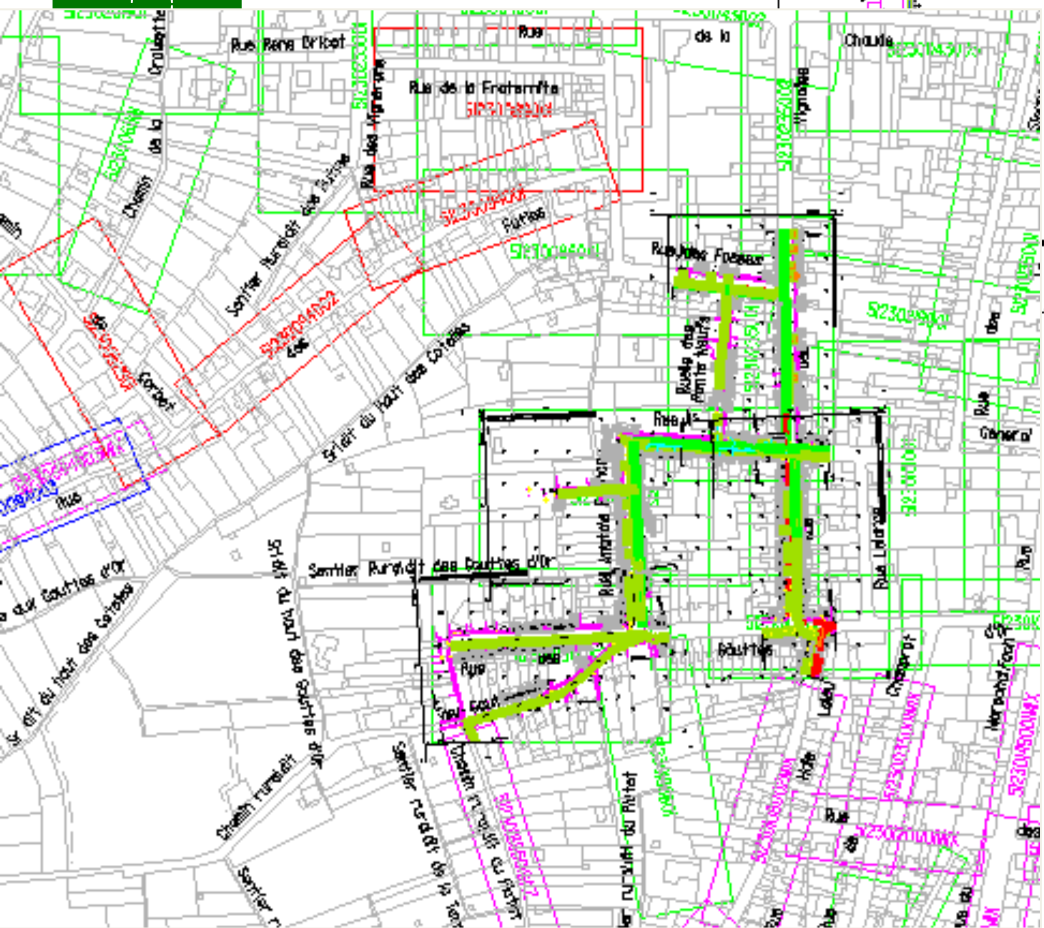
Large scale mapping





Scale between 1/200 and 1/500

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Mapping

- look into the possibility of cost sharing between underground users,
  - GIS with a background plan and a dedicated layer for each underground user,
- involvement of the public administrators,
- do not undertake costly data acquisition without having a robust updating procedure,
- define the conditions under which maps are made available.

The conditions of use of the underground environment: key safety elements

- regulations must define the conditions of use of the underground environment and the laying conditions,
  - right of use of the underground environment, initial installation, intervention on an incident,
  - how the cable is protected, matched to the intrinsic safety of the cable,
- regulations must define the rules for the exchange of information between users in the event of work underground.

THE ENVIRONMENT

The environment

- Undergrounding reduces the visual impact of the network.
- This assumes that MV/LV substations are appropriately designed
  - substations in buildings,
  - masonry substations,
  - prefabricated substations.
  - A reserved area policy is required.
- LV underground networks supply houses via connection boxes.
  - Integrate the boxes into the urban fabric.
  - In general, large numbers of individual or collective connections must be remade.
- Reduction of electromagnetic fields.

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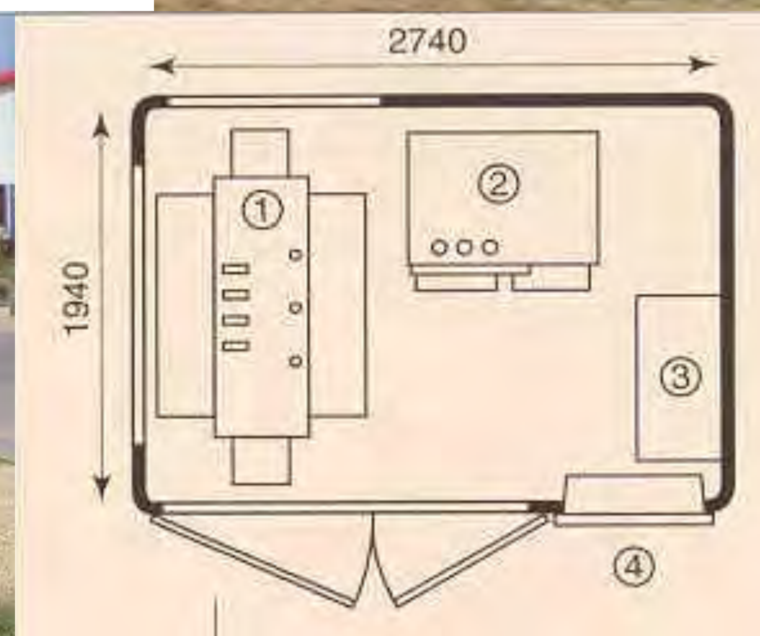
Integration of MV/ LV equipment in the environment



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LV network: before and after

Outward appearance to be worked on with the decision makers,

OPERATION ON NETWORKS

Operation

- The protection plans of MV networks must be adapted to take account of the increased capacitive currents.
- New fault correction procedures
  - fault location: no visual aid,
  - fault finding: specific equipment.
- Procedures for making safe for work on or near the structures
  - positive identification of the structures,
  - verification of the absence of voltage.
- Traceability of the structures
- The risks of serious failure
  - multiple faults,
  - cable galleries.
- New skills to be acquired

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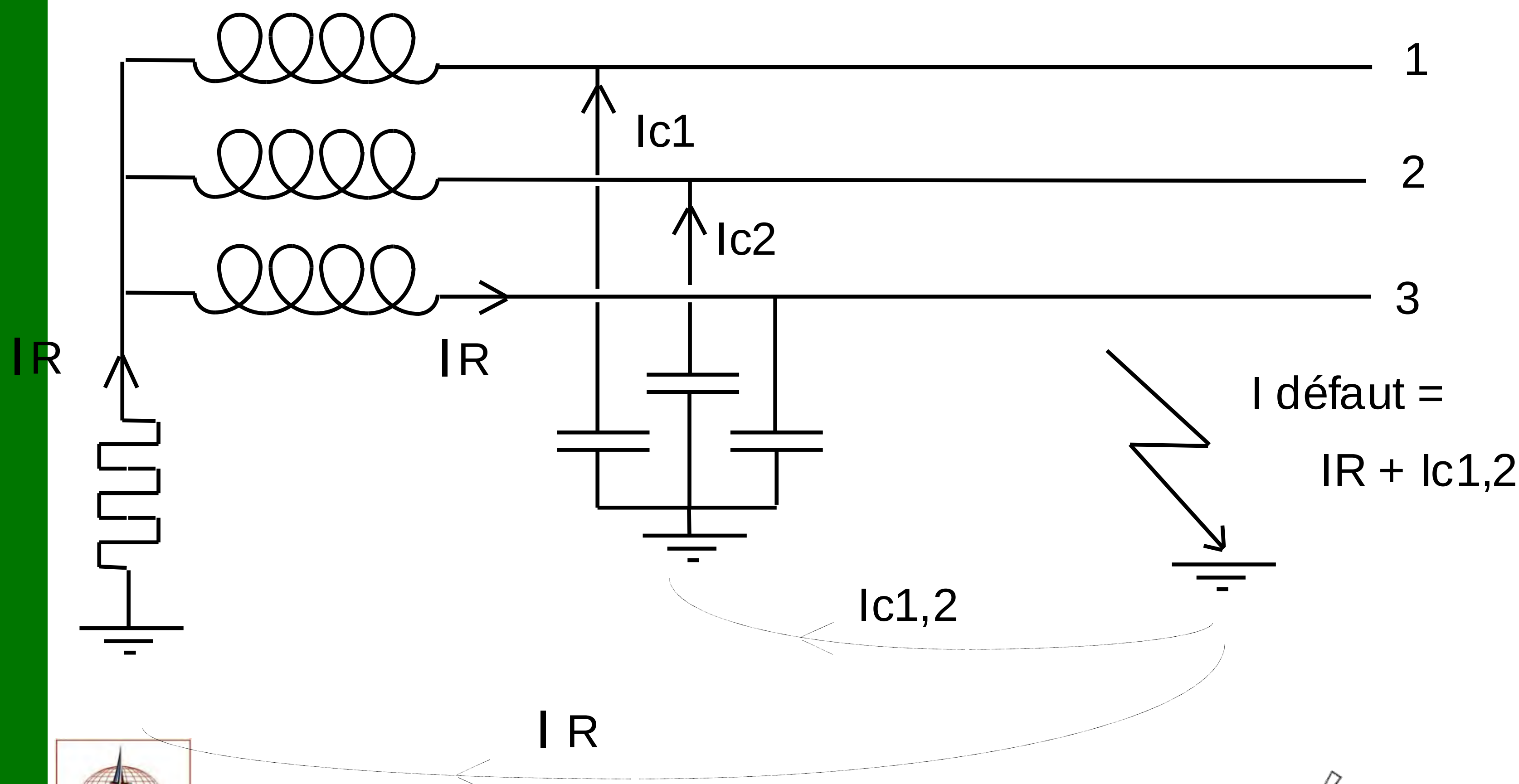
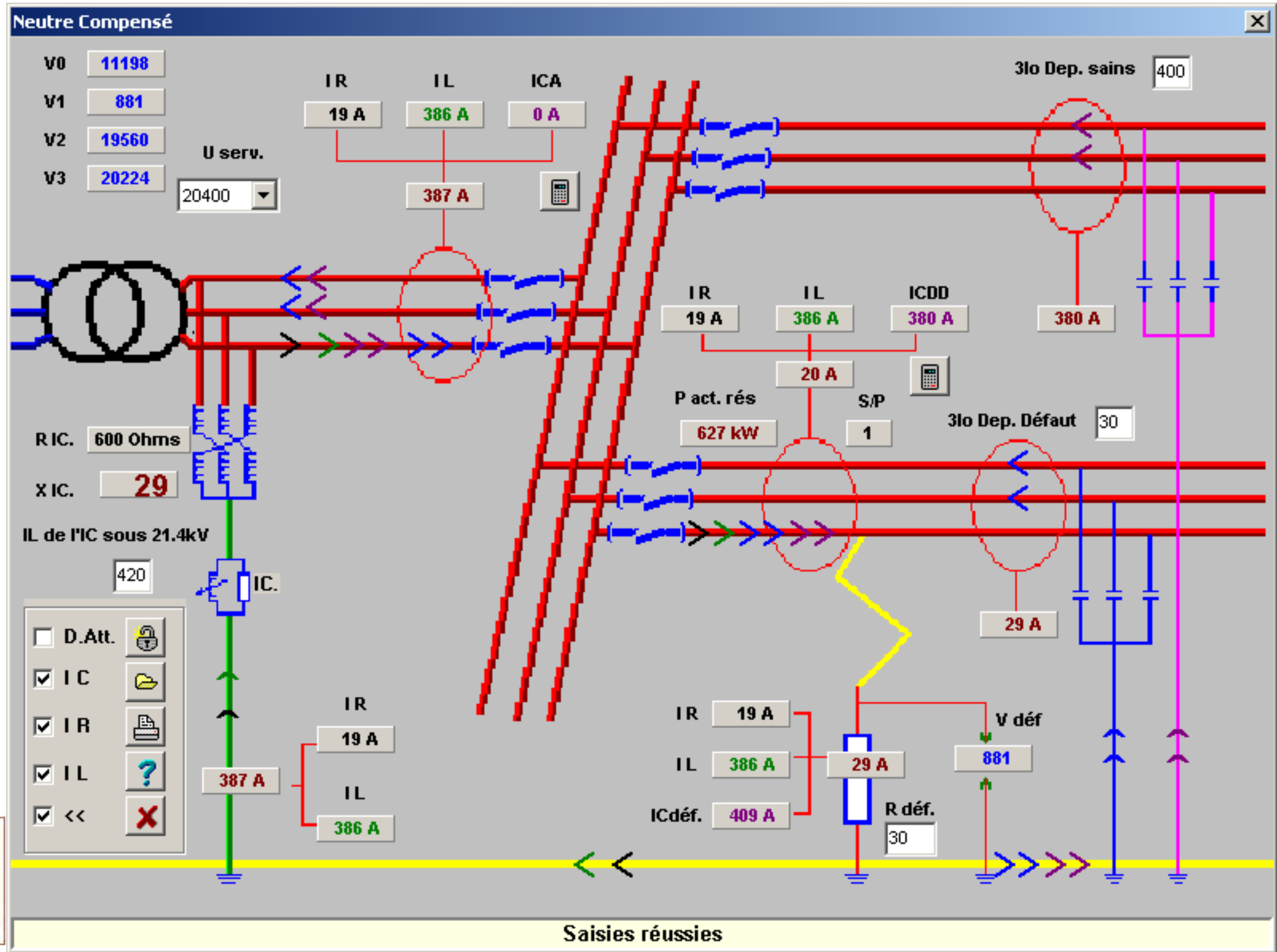
On an underground MV network, which is more capacitive than an overhead network, the capacitive currents that arise in the event of a fault must be taken into account.



Current paths under fault conditions on an underground MV network

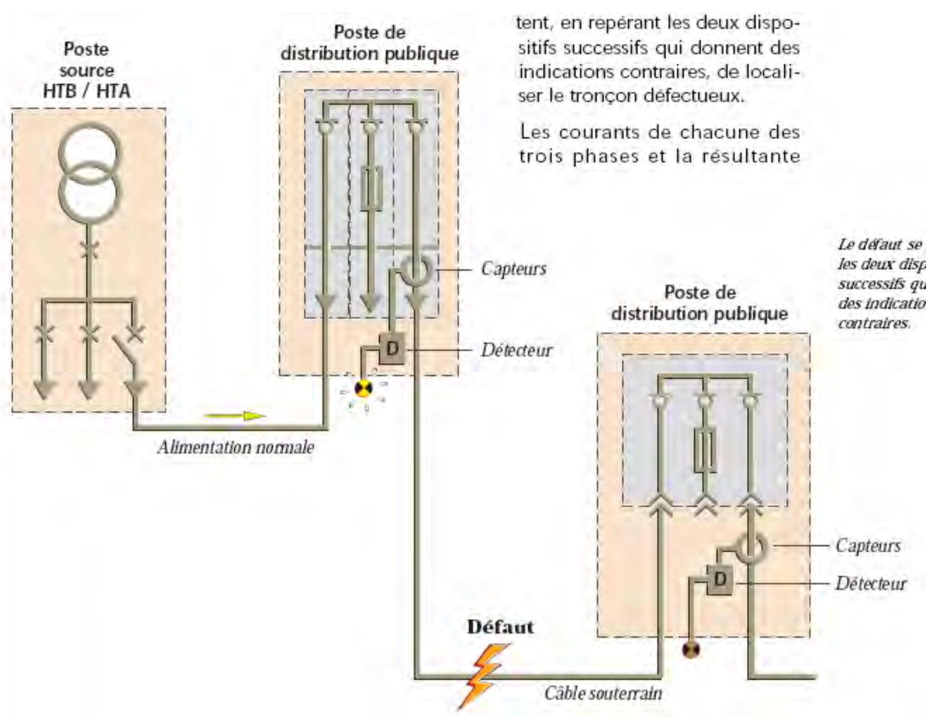


Choice of the MV neutral regime

- The choice depends on the company's general options.
- Compensated neutral allows low fault currents and the consequent voltage rises to be limited.
  - This is useful for mixed underground/ overground networks.

Fault location

- The closure of a circuit breaker on a faulty cable should be avoided: this ages the cable prematurely.
- Fault current indicators can be an aid to locating the fault.



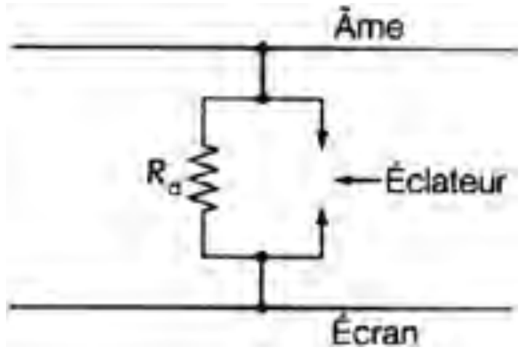
The fault indicator lights when it detects a fault current.

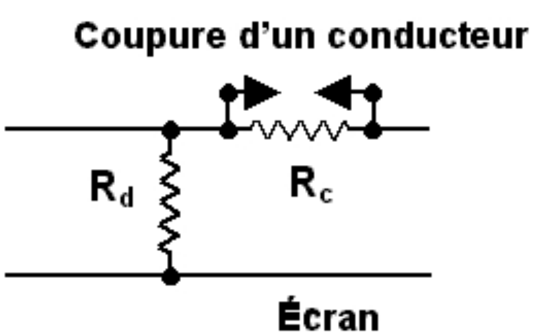
Fault finding

- The operator must have a vehicle available equipped with equipment for precise fault location and the associated competent teams
- The fault location procedure includes 3 steps :
  - Definition of the failure mode
  - Pre location
  - Precise location

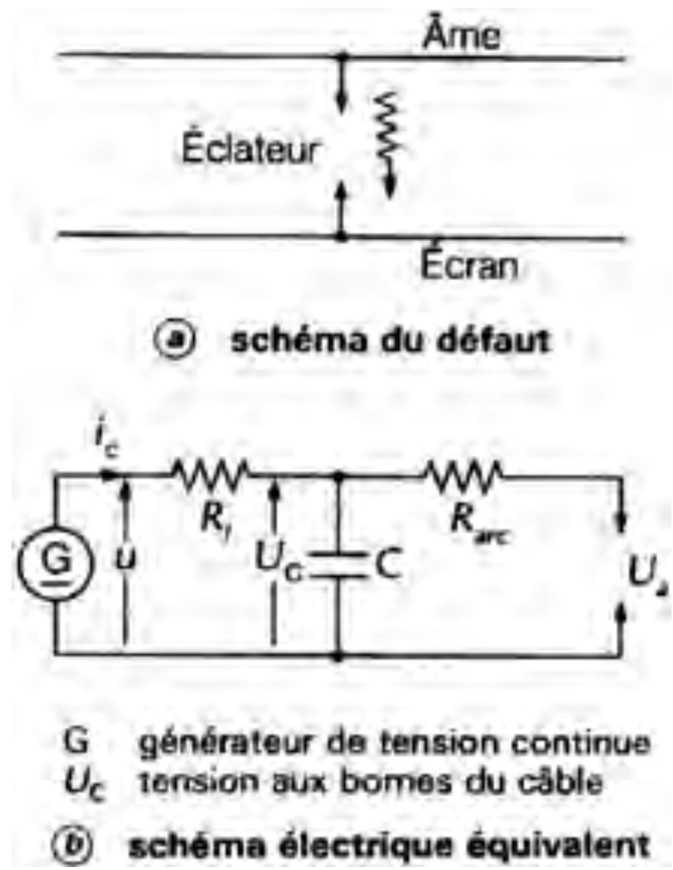
Failure mode on cables

Resistive insulation failure





Intermittent insulation failure



Work on existing structure and safety

- There is no certainty, seen from the outside, that the voltage on a cable has been switched off.
- Intervention procedure:
  – location on the map,
  – identification by means of a measuring instrument,
  – earthing before work,
  – check that ends are earthed.

Traceability

- Any defect in the materials used is very costly:
  - the materials can no longer be seen so no visual inspection is possible,
  - replacements are expensive: excavations…
- To limit inconvenience:
  - improve/extend traceability of components,
  - use the mapping as a support.

Serious failures

- These risks exist, above all, in urban areas with a high density of structures, often bundled: galleries, multi-tube ducts etc.
- Take fire protection measures, separate structures,
- devise reconnection schemes for different configurations of losses of structures.

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MAINTENANCE OF UNDERGROUND NETWORKS

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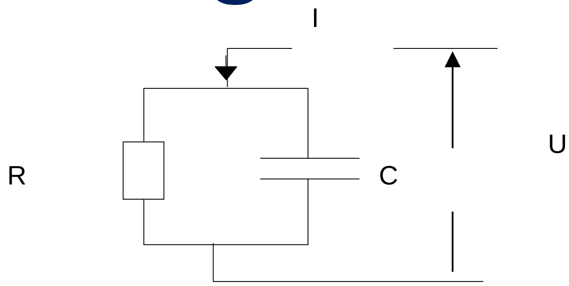
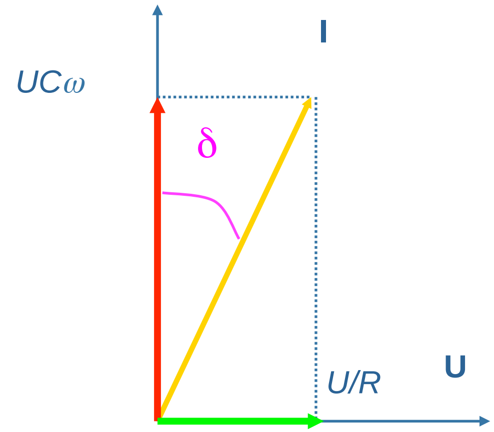
A light maintenance but needing high level skills

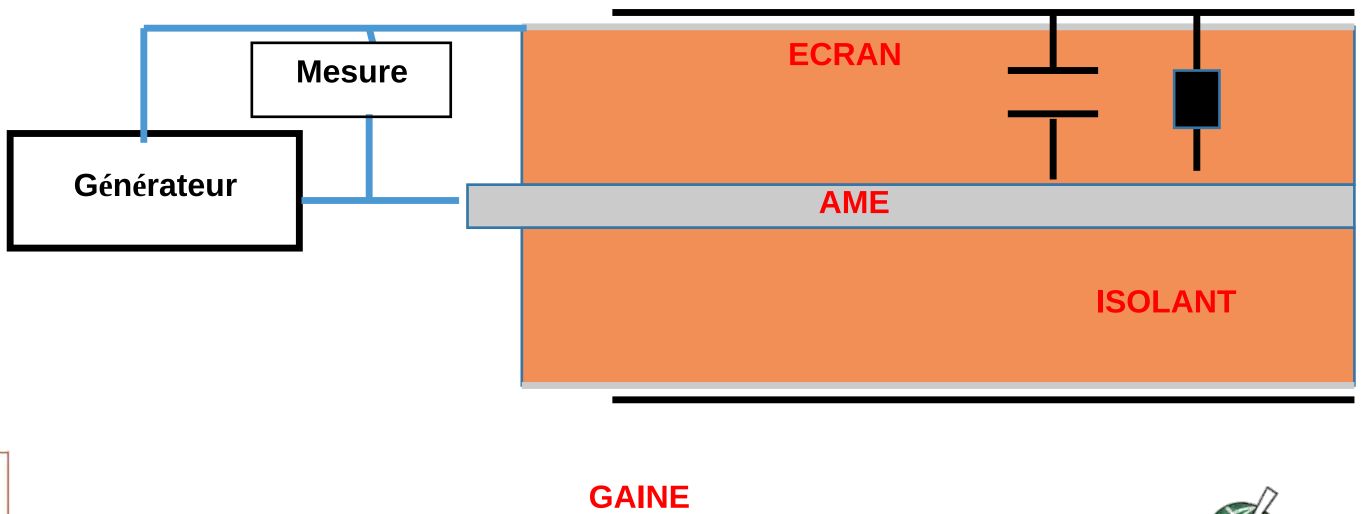
- Off line monitoring method to identify aging links
    - The link must be out of service
  - – Measure of tang Delta
  - – Partial discharge measurement
- New technologies for on line monitoring
  - – Possibility of monitoring on service links

Tangente Delta measurement

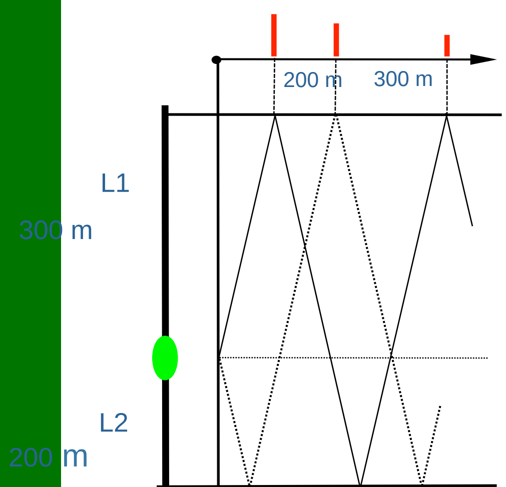




$$tg\delta = \frac{1}{RC\omega}$$



Partial discharge measurement



COMPETENCIES & SKILLS

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New competencies and skills

- Work: new contractors must be engaged while retaining the resources required for operation of the remaining overhead networks.
  - Importance of quality control.
- Operation:
  - Fault finding
  - Mapping
  - Skills enriched with new techniques

ECONOMIC ASPECTS

The economic aspects are pivotal

Three very different situations:

- the design of a new network,
- the renewal of an obsolescent network,
- undertaking a voluntary undergrounding operation.

The design of a new network

- The financial commitment results from the additional cost of an underground network relative to an overhead network of the same performance.
- It is appropriate to take account of the optimised carrying capacity, which can differ in terms of margin from overhead to underground.

The renewal of an obsolescent network

- The financial commitment results from the additional cost of an underground network relative to an overhead network identical to the existing network
- and from the cost of inserting this network in the pre-existing infrastructure.
- However, it does permit generally higher performance to be obtained.

Undertaking a voluntary undergrounding operation

- The decision is generally external in origin.
- Reconciling environmental objectives and improvement of service
  - quality of supply,
  - network capacity often increased.
- Incorporating the action in a global electricity master plan
- Favouring coordinated actions
  - electricity, telephone,
  - revision and renovation of public lighting,
  - sharing of civil engineering costs.

The economic aspects: investment costs

- Distinguishing the linear cost from the system cost
- Per kilometre, a new underground network does not cost a great deal more than an overhead network.
- However, the additional lengths imposed by undergrounding must be taken into account.
- Undergrounding an existing network is expensive because it leads to essential work being carried out.
  - Consequences: it is preferable to take the approach of constructing new underground networks in a more or less systematic manner.

The economic aspects: investment costs

- The cost of the MV/LV sub-stations and revisions of connections is an important cost factor.
  - Multiple dwellings: vertical network inside the building
  - Individual houses: penetration
- Account must be taken of modifications to customers' internal installations.

The economic aspects: investment costs

on the basis of French information

- Make-up of the price of underground networks:
  - cable: 1/3

  (the cross-section is not a determinant element of the price)
  - trench: 2/3
- The key components of the price of the trench:
  - depth and width,
  - protection required for the cable: sheath, sand etc,
  - method of backfilling (reuse of excavated material),
  - resurfacing.

Economic aspects: operating costs

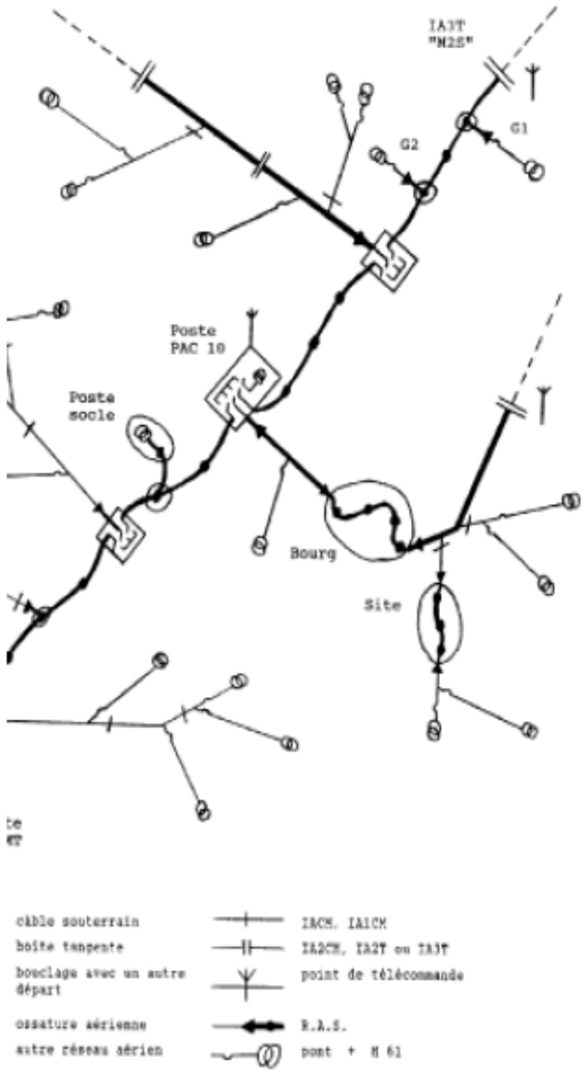
- Repairs:
  - frequency depends on failure rate,
  - repairs take longer underground and require groundwork.
- Supervision and work:
  - underground, necessity to carry out repairs,
  - overhead, fitting of protectors,
  - overhead, moving of the network on the request of third parties, depending on occupancy rules.
- Safety:
  - underground, elimination of overhead working.

The economic aspects: maintenance costs.

- Underground network:
  - low maintenance costs,
  - Monitoring measures at end of life to optimize renewal process.
- Overhead network:
  - rising pruning costs,
  - rising indemnity costs at time of construction,
    - visual impact, damage.

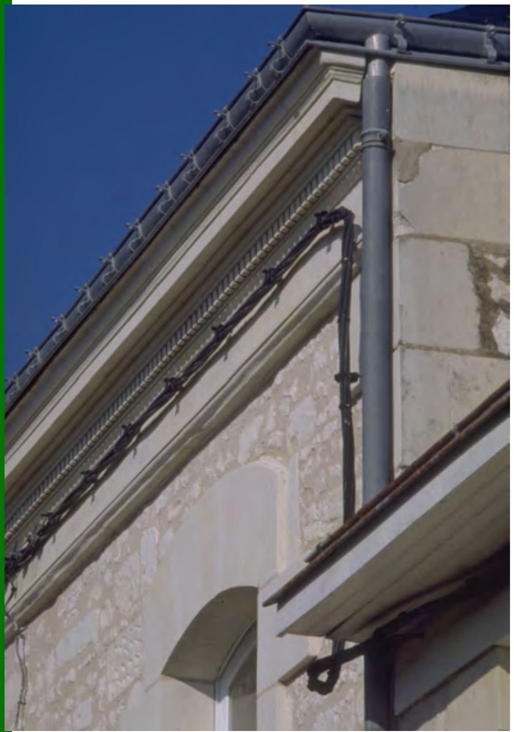
AN INTERMEDIATE SOLUTION:

- MV underground
  - medium voltage is the key element to be made safe,
  - the visual impact of overhead is high.
- LV in overhead twisted cables
  - twisted cables show excellent insulation performance,
  - the network is discrete and can be hung on façades in towns,
  - this solution does not require all connections to be revised,
  - this solution can share support with public lighting or even the telephone system.

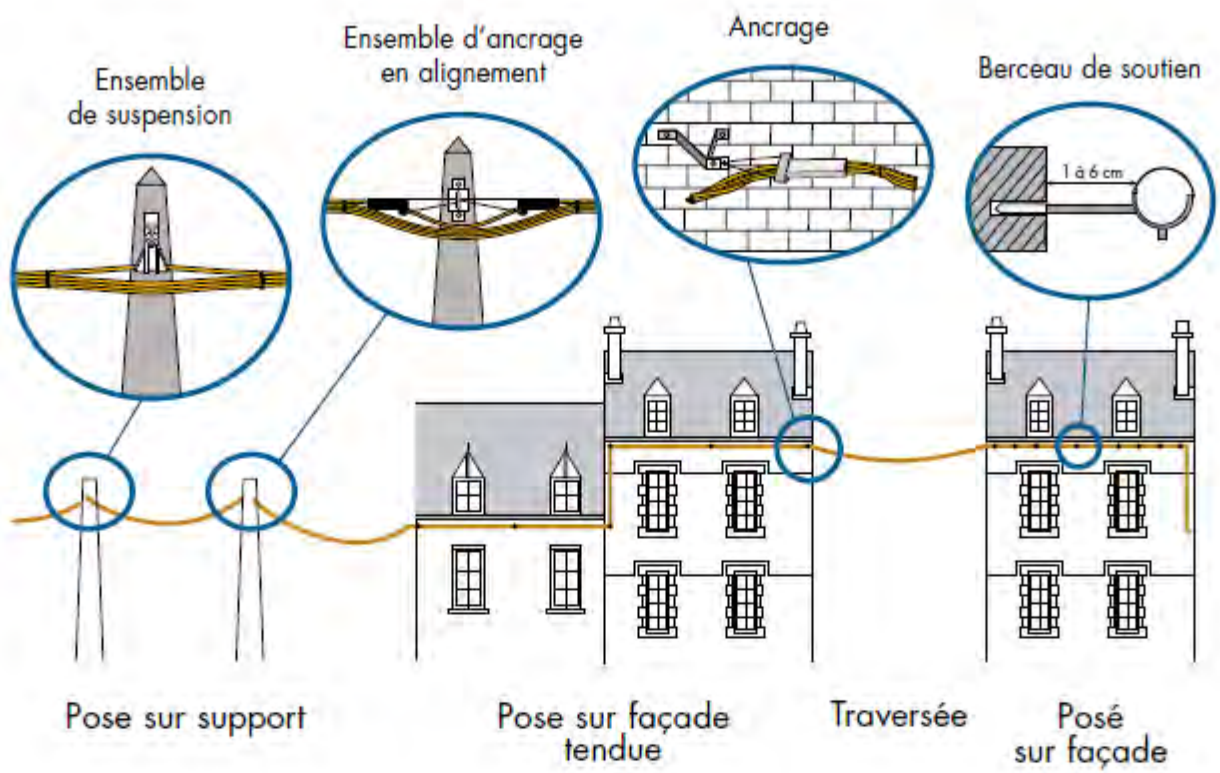


When an underground MV network is selected as the service supply solution primarily for reasons of quality of distribution, network structures permitting a progressive transition from overhead to underground, prioritising the backbones that are responsible for the incidents with the most serious consequences for customers.

The overhead LV network, pre-assembled or façade-mounted



LV overhead twisted cables technology



The choices made in France

- A commitment for new work
  - in MV: 90 % of new work underground,
  - in LV: 2/3 of new work underground or on façade.
- A national plan for the reduction of the vagaries of climate by undergrounding the MV networks in sensitive areas.
- Strong actions on unit costs
  - cables and implementation.
- Generalisation of master plans.

conclusion

- Devising an undergrounding programme is a major project that must deal with all aspects:
  - economic and financial,
  - major technical choices,
  - internal (distributor's) and external (contractors') competencies and skills,
  - preparation of medium-term plans