Improve the Reliability of MV Underground Links by Using Long length Cable

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ABSTRACT

The MV overhead network includes 356 000 kilometers of links. The French Distributor wants to bury these links step by step and in particular in case of renewal. By 2025, Enedis reach 100 000 km of new underground links.

Since several years, EDF R&D considers new solutions aimed at improve the reliability of the Enedis MV network by working on accessories robustness and cables or improve the diagnosis methods. The Enedis feedback and EDF R&D studies show that accessories are the weak point of MV underground links. By the way EDF R&D is studying the degree of freedom during the accessory mounting and others studies to understand the water movement in new used raw materials. The goal is in fine to evaluate the accessories time life.

Enedis asked EDF R&D to propose solutions to bury longer cables to extend the length of each underground section ***to reach 3 000 meters****.*

The aim of lengthening of section is double:

- *Reduce the number of accessories on the underground network to limit future expensive interventions in case of failure. The intrinsic failure rate of cable (for all types) is about 4 times lower than the failure rate of links including accessories,*
- *Reduce the cost of burial working site whose the number is going to increase significantly during the future years.*

INTRODUCTION

The led studies until several years on reliability of MV network for the DNO **show that the weak point of the links is the accessory** which failure rate is really higher (about 4 times more) than the cable failure rate.
It seems pertinent to look for solutions to reduce their number to decrease the failure rate and to improve significantly the reliability of MV grid.

Among various possible solutions, the use of long length cable is a good solution that Enedis wanted to study. This paper gives technical and economic arguments on the interest to use this kind of cables on the MV network.

Different aspects are under consideration:

- The security of the operators (Enedis operators),
- The security of public and the third parts (vehicles, farmers, etc.),
- The ease for intervention on links (repairing for example),
- The ease of link diagnosis (preventive or curative maintenance, even conditional).

GENERAL CONSIDERATIONS

Today, on MV network, the cable length depend on the grid where the cables are to be installed and on their section. In urban area, the difficulties turn around:

- The possibility to dispose of maps of all the others concessionaires
- The necessity to make soil probing
- Study the direction of links to limit the direction modifications

Unfortunately, it seems difficult to use the long length cable in urban area for all these reasons. Enedis has to use cable with a length of 250 to 350 m.

For the rural MV network, the problem is quite different and the possibility to use long length cable is much more important.
The links are often alone in soil on long distances. The nature of soil is favourable to use mechanical media to lay down cables. In brief, the use of long length cable in rural area is an opportunity. But some technical aspects were to be verified and discussed:

- Mechanical behaviour: what is the behaviour in case of use of long length cable?
- Current in screen and management of earth: is it necessary to manage the screens and their earthing?
- Connection of cable section: what kind of equipment?
- Calculation of cable length on the standard drums

MECHANICAL ASPECTS IN CASE OF USING LONG LENGTH CABLES

We know that an increase of the operation temperature of the cable core induces an expansion of the cable if it is free to move, or a mechanical stress if the cable movement is restricted. In practice, we observe a combination of these two effects.
For a long length cable it is important to study those

mechanical forces that might be the result of high loads in order to evaluate their consequences.
In theory we know that if the cable can move freely, the formulae which give the expansion according to the increase of temperature is:

$$\Delta L = \alpha . \Delta T . L_0$$

With:

- ΔL: cable dilatation
- α: dilatation coefficient of cable
- L0: initial length of cable
- ΔT: Heating temperature

If the cable is long the expansion ΔL will be important.

In the second case if the cable is perfectly blocked, then the increase of temperature will result in a pushing force at the end of the cable using the following formula:

$$F = E . A . \alpha . \Delta T$$

With

- E: Young modul
- A: core cross section
- α: dilatation coefficient of cable
- ΔT: Heating temperature

In that case, it is the cross section of cable which is the major parameter.

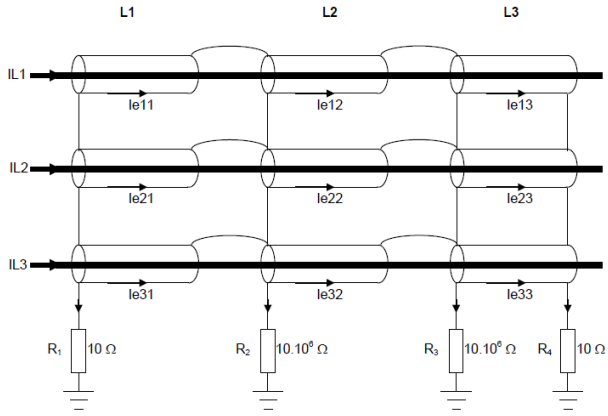
But in the case of a real buried cable, the friction between the ground and the cable resist at the longitudinal expansion. For a sufficiently long length, the friction force is equivalent at the expansion force. Physically we will observe that only a small part of the cable will contribute to the global expansion. The forces of friction and of expansion will balance themselves except its ends.
In theory we can show that for a buried cable the expansion do not depend of the global length but only depends on the friction coefficient and the temperature increase.
Furthermore in real buried cable case there is a phenomenon of « allowed expansion ». This expansion is the expansion of the cable by « snaking », spring effect and moving marginally in the ground. This expansion absorb a significant part of the theoretical expansion force. This allowed expansion can be enhanced by creating an expansion loop.

In conclusion the complete theoretical approach give us more realistic forces for long length buried cable. Those forces are not dependent significantly on the length of the cable. The force is lower if we use an expansion loop.

SCREEN CURRENT AND MANAGEMENT OF EARTHING

A major point to verify was the incidence in case of use long length cables on screen current and elevation of potential in case of fault.
On Enedis grid, the critical value of screen current is postulated at 20A, value commonly adopted for the screen plug of accessories. In function of results, it would be necessary to manage the screens to limit the current or not.

For the calculation, the following scheme was used:



This scheme is complying with the method of connecting the screen and with the accessories earthing.

The hypotheses for the calculation were:

- Il = 497 A (for Al 240 sqmm and winter weather)
- L1=L2=L3 = 3 000 m
- Laying mode: jointed trefoil at -0,80 m

Dimensions of cables were:

	Thickness (mm)	Diameter (mm)
Cross section (Al)		18,3
SCI + ISO + SCE	5,9	30,1
Screen	0,15	30,4
Sheath	2,40	35,2

Two methods were used. The first one is EMTP with a "cable" module which is a FDQ (Frequency Dependant Q-matrix). The second one is an internal development on SCILAB.

The results of calculation using both methods give a screen current nearby 13,5A without management of screens. Due to this value, EDF R&D and Enedis conclude that it is not necessary to manage screen for long length cables.

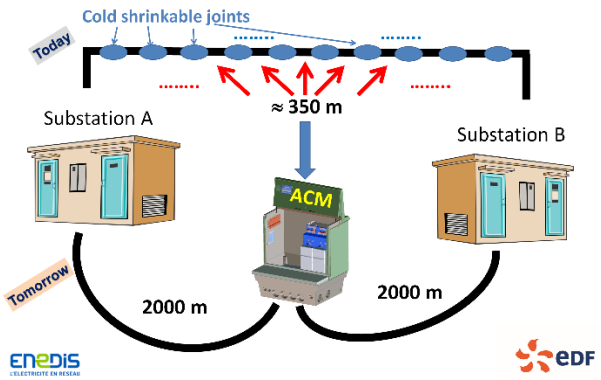
FUNCTIONAL UNIT FOR CONNECTING CABLES

The solution for MV cables connection must be in accordance to these major technical points:

- The security of the operators (Enedis operators),
- The security of public and the third parts (vehicles, farmers, etc.),
- The possibility to manage the network,
- The ease of intervention on links (repairing for example),
- The ease of link diagnosis (preventive or curative maintenance, even conditional).

To answer to all these requirements, EDF R&D propose to use and take advantage of the reliability of an existing small substation already purchased by Enedis, composed of a concrete housing and a simplified MV switchgear (with only 2 Functional Units), and called ACM for "Armoire de Coupure Manuelle" in french. An ACM is a not buried equipment with an easy access allowing all network management operations and monitoring, diagnosis and direct operations on cables.

Hereafter the scheme shows how by using long cables and ACM, Enedis is going to improve the reliability of MV Underground Links while making financial savings.



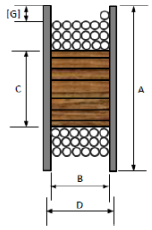
The advantages to use this type of existing simplified substation are:

- No supplementary development required
- Limited cost
- Possibility to manage the network
- Possibility to make diagnosis easily using integrated and dedicated access on each Functional Unit
- Possibility to enhance the MW switchgear for other uses (motorization …)
- Low environmental impact thanks to small dimensions
- Etc.

CALCULATION OF CABLE LENGTH ON DRUM

In a first step EDF R&D has determined the optimal length of cable in function of standard drums used by Enedis. For example for the biggest French drum (JBM type), the cable length vary from 550 m for a tripolar 240 sqmm copper cable to 3300 m for a unipolar 240 sqmm aluminium cable.
These optimized cable lengths are to be compared to the medium length of cable section used currently reaching 350 or 400 m between two accessories.

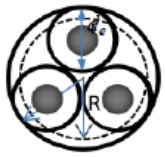
The delivery cable length on a drum is the sum of each spires resulting of winding of cable. It is necessary to calculate the numbers of spires and layers and then use the formulae of "helicoidally superposed concentric layers section".



$$N_s = ENT\left[\frac{B}{d_c}\right]$$

$$N_c = ENT\left[\frac{\frac{1}{2}(A-C)-G}{d_c}\right]$$

In case of trefoil, the total diameter to take into account is calculated as below:



$$d_c = 0.85 \cdot d_e \cdot \left(\frac{1+\cos(30°)}{\cos(30°)}\right)$$

The complete equation to calculate the delivery cable length is complying with the paper Jicable'03 A.10.6:

$$L = \pi \cdot (N_c \cdot d_c + C)\left[N_c \cdot \left(\frac{B}{d_c} - \frac{3}{2}\right) + \frac{N_c - 1}{4}\right]$$

If Enedis decides to use standard drums for the "on site" of cables, the table hereafter indicates the possible lengths for different cable types:

	Type de touret (Drum type)			
	IBM		JBM	
Type de câble	Longueur (m)	Poids (kg)	Longueur (m)	Poids (kg)
240 mm² Cu Unipolaire	1700	5800	1600	5900
240 mm² Al Unipolaire	2500	4500	**3300**	**5860**
240 mm² Cu Torsade	550	5650	550	5950
240 mm² Al Torsade	**700**	**3800**	1000	5600
630 mm² Al Unipolaire	1300	4900	**1550**	**5910**

Longueur = Length / Poids = Weight

The red values show that there is no interest to use drums of this type (JBM) and that a IBM drum is sufficient.
The value under ochre background were optimized.

In conclusion on that topic, we can see that the increase of cable length is possible and the ratio of length compared to previous cable length is from 3 to about 10. **This increase of cable length will have direct impact on economic aspect**.

RELIABILITY CALCULATION

The reliability of a link depends on several factors (the number of accessories, the length of the link, the proximity of concessionaire, and so on).

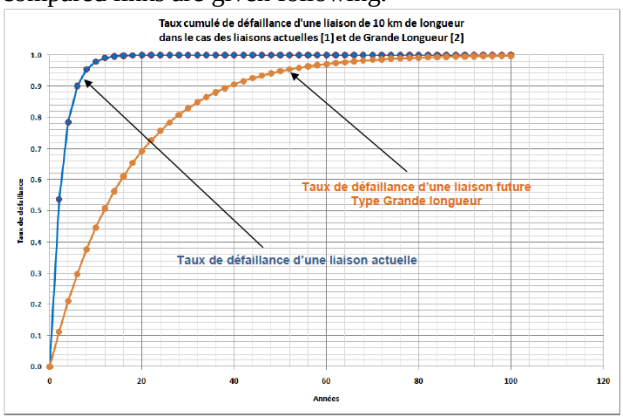
To evaluate the benefits of the use of long length cables, we compared 2 construction links with current lengths and long length cables.

	current	planned
Length (m)	10 000	10 000
Delivery (m)	350	3 300
Nb of sections	29	4
Nb of accessories	28	3

Here, we postulate that there are only cable and accessories and no functional unit.
To calculate the reliability of a link, the fault rates taken into account are the following;

- Terminations: 2.10^{-3} fault/year
- Polymeric cables: 0.1 fault/100 km/year
- Cold shrinkable Joints: 1.3 fault/100km/year

The results of the calculations of reliability of the compared links are given following.



In blue: current situation
In orange: planned situation

As showing, the increase of cable length and the decrease of the accessories number allow to enhance reliability significantly.

ECONOMIC CALCULATION

Increase the cable length is not only a technical challenge but also possibility to make savings on a long period of time (15 years).
A calculation of NPV (Net Present Value) was made to verify the pertinence of long length cable use. We take into account several economic aspects:

- Laying length of cable per year on 15 years (more than 90 000 km)
- Number of links per year (600)
- Medium length of links (10 km)
- Section length (1667 m)

For the calculation of NPV we take into account a factor of 0,485 on the theoretical value due to an "on field" experimentation that has shown differences between theory and practice for the number of section which is much more important in real case but lesser than the current situation with sections of 350 m length.

The results of calculation of NPV by 2 different methods show that Enedis can hope savings from 142 M€ to 285 M€ by using long length cables on a period of 15 years. Regarding these results, Enedis has a vested interest in apply widely this kind of links.

CONCLUSIONS

The ability to use long length cables is now demonstrated. There are different aspects leading Enedis and EDF R&D to promote a new approach with the use of long length cables wherever possible.

Technically, economically and environmentally, nothing impeach the generalization of the use of long length cable on the French MV grid in rural areas.