Return to Session

CORROSION KINETICS OF LV CABLE GALVANIZED STEEL SCREEN AND SOLID ALUMINIUM NEUTRAL

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ABSTRACT

After a short introduction which reminds the different existing corrosion forms, and the degradation expected in case of coupling of galvanized screen and a new solid aluminium neutral, the paper gives the results of a study carried out to evaluate in case of changing the complex screen/neutral of the LV network cable the risk of loss of durability of this new main cable.

KEYWORDS

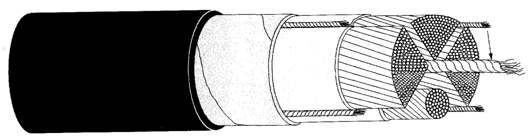
Metallic screen, galvanization, durability, neutral, aluminium, corrosion.

INTRODUCTION

When the engineer wants to change the design of a cable system component, he has to check and validate that the expected lifespan of the complete system will not be diminished.
This concern is shared not only by the utilities but also by the manufacturers. EDF has recently launched a study for cost reduction of LV main cable at the same time as the manufacturers have to face issues with the suppression of the use of "heavy metals" (and lead especially) in the construction of their network cables. It was a great opportunity to optimise the metallic screen and the neutral conductor of the cable.

CONSTITUTION OF FRENCH NF C 33-210 NETWORK CABLE AND NEW ONE

The main underground cable is constituted with an external PVC sheathing, a two galvanized steel tapes with twist lay, three sector shaped phases with reticulated polyethylene insulation, fillers, and a stranded aluminium wires and grease (neutral conductor) with lead sheathing for water tightness.



The new cable design should be constituted with the same elements except the neutral conductor which is constituted only with a solid aluminium conductor whose external diameter would be the one of the actual neutral measured on lead.
The major reason is to ensure the complete compatibility of the system components (accessories interoperability).

This evolution of the neutral conductor should allow to win money because:

- The lead mechanical presses used to sheath the conductor are aged and difficult to maintain,
- The suppression of lead will allow to answer to **environmental** and **health** purposes
- The lead price is summed with the aluminium price (*we can estimate that the final price of neutral would be 15% less than currently*)
- The neutral conductor would be issued from an aluminium wire without any transformation (machine wire)

Modes of degradation to be evaluated

Before changing the design of cable, we have to check its behaviour notably in terms of corrosion kinetics and lifetime. The main questions are:

- Is the lifespan of the new cable longer than the old design one ?
- Is the new aluminium neutral more sensible to the corrosion ?

We know that the penetration of water through the PVC sheathing is a reality. So, in our case, the corrosion is the predominant degradation mode because of metallic components (galvanized steel, aluminium).

THE CORROSION [1]

Corrosion is a deterioration slow or fast, progressive, of a metal related to its environment (air, water, alkaline or acid medium,...). That can affect its aspect, its surface quality or its mechanical, physical or chemical properties.

Corrosion is an electrochemical reaction between metal (or an alloy) and an aqueous phase. It is a complex phenomenon related to the atomic structure of the matter. This one consists of elementary particles carrying electric charges - ions and electrons - and of particles electrically neutral, atoms and molecules.

In metal, some atoms are made up among other things of free electrons able to move inside the metal.
In the aqueous phase, which is a solution, we find:

- positive ions, cations, and negative ions, anions
- neutral molecules, water and various components not dissociated

At the interface metal-water, there is transfer of electric charges which involves electrochemical reactions.

- The metal atom "Me" oxidizes in the form of ions "Me^{n+}" released in the aqueous phase creating a flow of electrons in the direction solution $\rightarrow$ metal (anode current [I_a]).
- The ion or the molecule of the aqueous phase collects electrons of metal to transform itself into another chemical species creating a flow of electrons in the direction metal $\rightarrow$ solution (cathode current [I_k]).

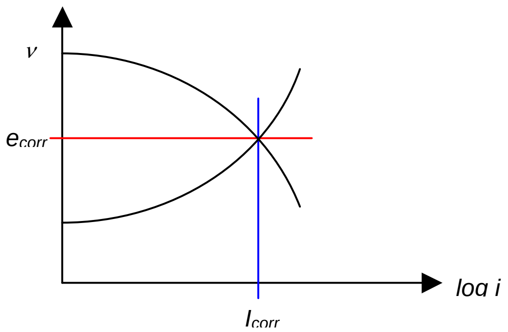
What results in:

$$Me \Leftrightarrow Me^{n+} + ne^-$$

The sum of the anode currents (I_a) is equal to the sum of the cathode currents (I_k), metal being electrically neutral.

The electrochemical reactions in a system result in electrical currents sensitive to the potential differences between two phases: metal - liquid. There is a link between speed reaction-potential and speed of reaction-intensity.

The potential of corrosion e_{corr} of a metal M is defined by the point of intersection of the curves of polarization:



For a given intensity and time, we can thus determine the loss of weight and consequently the speed of corrosion by applying the relation of Faraday:

$$m = \frac{1}{96500} \bullet \frac{A}{n} \bullet I_{corr} \bullet t$$

with m = mass (en kg)
A = atomic mass of considered metal (27 for aluminium)
n = valence (3 for aluminium)
I = I_{corr} (en A) coupling current
t = time in seconds

The intensity of the coupling current depends on several factors: the nature of the electrolyte, phenomena of polarization, the ratio of surfaces of two metals, their distance and the temperature.

This Faraday's law can be used only if corrosion is uniform and if aluminium is put in an aqueous medium what is not the case in the cable except when the moisture of the embankments crossed the PVC sheath. Once moisture is present in contact with the pile formed by the galvanized steel tapes and solid aluminium, the galvanic currents remain very weak.

THE VARIOUS FORMS OF ALUMINIUM CORROSION

Aluminium is a naturally passive metal which is covered with a natural oxide film (alumina) which protects it from corrosion as long as this film is not deteriorated in particular by mechanical or aqueous action.

Generalized corrosion (or uniform corrosion)

This form of corrosion develops in the form of micro punctures of very small diameter. It results in a uniform reduction thickness on all the surface of metal.

It appears if the environment is very acid or on the contrary very alkaline in which the natural oxide film (alumina) is particularly soluble. In these mediums, the destruction of oxide film is often faster than its reconstitution. Aluminium is not then protected any more and uniformly corrodes.

In case of uniform corrosion, we are able to evaluate the speed and the loss of weight of a sample of metal when it is subjected to a **known and stable media**.

Weak point corrosion

Weak point is a localised corrosion which results in the formation on the surface of the metal of some cavities. These cavities are of irregular shapes, their depth and diameter are variable according to parameters such as the medium, the conditions of use...

Aluminium is sensitive to this form of corrosion in particular in the mediums of which pH is close to 7 (neutral pH) i.e. in the majority of the natural environments: water (of surface, sea), moisture of the air.

It occurs when metal is put in contact with these mediums in a permanent or intermittent way. It is a particularly complex phenomenon whose mechanism is not explained yet in spite of many studies. On the other hand, the conditions of initiation and propagation are well-known today.

Contrary to generalized corrosion, it is difficult to evaluate the speed and the intensity of corrosion by variation of weight or measurement of hydrogen. It is evaluated according to three criteria:

- the number of weak points per unit of area (density of punctures)
- the speed of deepening (depth of the weak points according to time)
- the probability of appearance of weak points

Transcrystalline and intercrystalline corrosion

Corrosion inside metal can be propagated in two different ways:

- In any direction. In this case it is called intercrystalline because it affects indifferently all the metallurgical components. It spreads inside the grains. This propagation is also called "transgranular". Corrosion is not "selective".
- According to preferential ways. Corrosion follows the joints of the grains. It is intercrystalline corrosion. Not very consuming metal, the loss of weight is not a reliable indicator. It has effects on the mechanical resistance of metal. It is undetectable with the naked eye.

"leaf" corrosion

The "leaf" corrosion is a form of selective corrosion which is propagated in several parallel plans with the direction of rolling or the spinning. Between these plans, there are remaining thin metal sheets which are not attacked and which are isolated each other by corrosion.

Stress corrosion

This form of corrosion results from the combined action of a mechanical constraint (bending stress, tractive effort) and of a corrosive medium. Each parameter taken independently would not have an effect on metal.

Stress corrosion is a very complex phenomenon and a general theory seems impossible to establish [2].

Galvanic corrosion

The galvanic corrosion of aluminium is very characteristic. It is localised in the zone of contact with other metal. The attack of aluminium is regular and spreads in-depth in the shape of craters more or less rounded.

INVESTIGATION TEST DEFINITION

In order to check the behaviour of the new design of cable, we decided to define an investigation test to verify the phenomenon of corrosion on the neutral conductor and the galvanized steel tapes.

The investigation test is built with combination of:

- Wet / dry phases
- Hot / moderate temperature phases
- Salt fog phases
- rinsing by pulverization

The 24 hours cycle is the following:

- 14 hours under 55℃ and salt fog (**concentration: 25% of [NaCl]**)
- 1 hour at ambient temperature after rinsing
- 8 hours at 10℃ ambient temperature
- 1 hour at ambient temperature

The purpose of the alternation of phases of salt fog atmosphere, rinsing, temperature rise is to accelerate the corrosion of the components.

We introduce a new method **of ageing by comparison** for old and new designs.

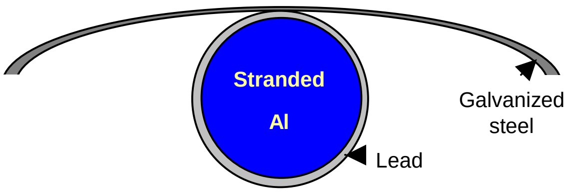
From a theoretical point of view, the test thus makes it possible to strongly attack the zinc (which acts as sacrificial anode), then the lead and finally the steel of the tapes while being based on the potentials of dissolution.

The test carried out on an current cable makes it possible to obtain a signature of the mode of degradation of the complex which will be used as "identity card" to thereafter **compare** the results with the cable of new generation.

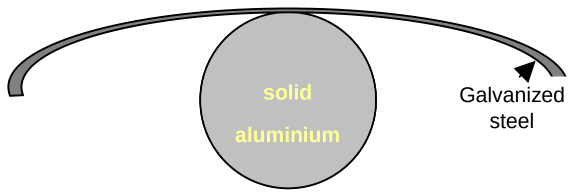
The following table gives the potentials of dissolution in an aqueous medium of the metals considered in the study:

Metal		Dissolution potential in mV / ECS
Lead	(Pb)	- 510
Steel	(Fe)	- 610
Aluminium (1050A)	(Al)	- 750
Zinc	(Zn)	-1 130

Let us now consider the two following constructions:



current NF C 33-210 design



Future Main network cable design

The relative position of two metals on the scale of the potentials of dissolution makes it possible to expect what metal will be the anode. In case of coupling of these metals, the most electronegative metal will dissolve first.

In the two cases considered, **zinc will be thus used as "sacrificial" anode**. And on the future design of cable,

Return to Session

aluminium will then tend to dissolve before steel tapes.

INTER COMPARISON FOR EVALUATION OF THE LIFESPAN

The lifespan of a material depends on its environmental conditions (acid environment, alkaline environment, temperature, moisture...). The temperature influences also significantly the results, the initiation of some phenomena being directly related to this factor.

But, compared with a cable of present generation, we can give objective indications according to the test results, on the relative lifespan of the two constructions of cables.

RESULTS OF THE STUDY

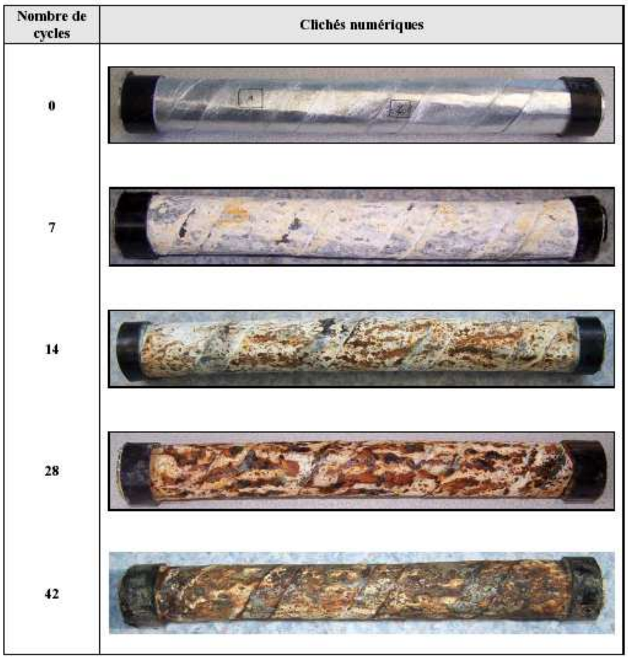
Corrosion of the galvanized steel screen

After each period defined in the test plan (7, 14, 28 and 42 days) it was carried out a visual examination of the samples.

Photographs were taken to be able to appreciate the surface quality of sample after different periods of ageing.

They show an important degradation of the surface quality of the galvanized steel screens. Zinc, as sacrificial anode, disappears gradually to let appear the steel of the tapes which corrodes.

On photography after 7 days, the apparent white powder is zinc oxide. Then the corrosion of iron becomes visible.



The most relevant indicator to check the residual state of the galvanized steel tapes is the measurement of the loss of mass. The mass is measured beforehand on new sample. With each preset stage of ageing, we measure the mass of the tapes. We compare then these masses and we calculate the relative loss of mass:

$$P_{mr} = \frac{m_x - m_0}{m_0}$$

with P_{mr} = relative loss of mass

m_x = mass of tapes at (7, 14, 28, 42) days

m_0 = mass of tapes before test

The results of tests carried out at "CRITT Analyses et Surfaces de Haute Normandie" laboratory give the following results:

From these results, and model of evolution proposed below,

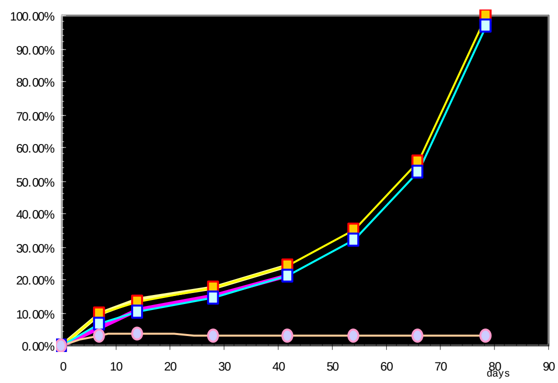
Relative mass loss		
	NF C 33-210	Nouvelle conception
0	0.00%	0.00%
7	9.59%	5.49%
14	14.00%	11.11%
28	17.38%	14.98%
42	24.16%	21.24%

we projected the relative mass loss of the two designs of cable. The evolutions show that the behaviour of two constructions is very close with a light "ignition retard" for the new design.

$$LOSS_{mass\ relative} = A*(1-e^{-at}) + B*(1-e^{-bt}) + C*(e^{t/c}-1)$$
$$(1) \quad (2) \quad (3)$$

with: (1) a first phase of corrosion ignition
(2) a second phase of stabilization
(3) a third phase of catalectic behaviour

relative mass loss modelisation



We can thus conclude from the test results that the behaviour of the galvanized steel screen is almost identical in the two cable constructions. The behaviour in time is slightly better in the case of the new design of cable.

Thickness of zinc variation

The thickness of zinc variation does not bring complementary information. Zinc present in galvanization is used as sacrificial anode and is thus there to dissolve before all the other elements.

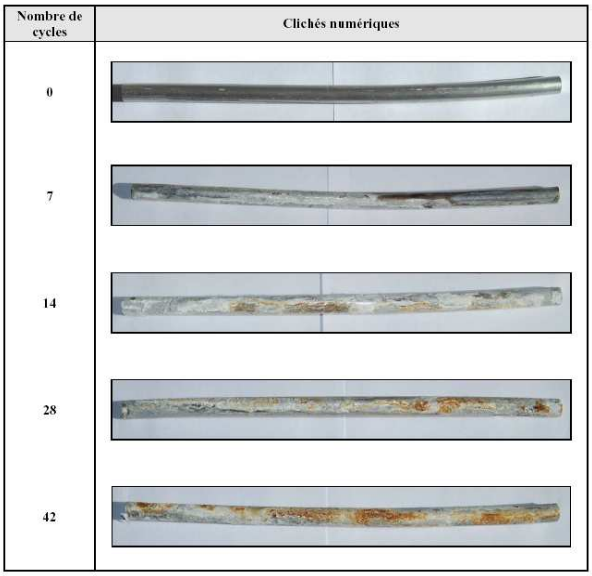
Return to Session

Corrosion of the solid aluminium neutral

The second element which can give us indication on the behaviour of the new complex “screen / neutral” is the relative mass loss of the neutral conductor.

The mostly significant indicator is still the relative mass loss. But to perform the measure, the neutral must be cleaned, the elements of decomposition using the process of degradation amalgamating to a kind of jelly.

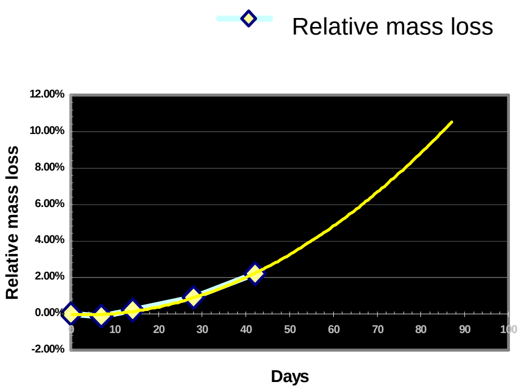
The photographs below show the surface aspect of the neutral conductor after period of test (7, 14, 28 and 42 days).



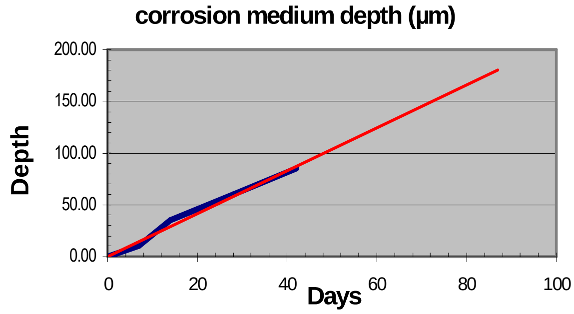
The results of relative mass loss is the following. It can be seen that the behaviour of the corrosion is not the same of the galvanized steel screen. The evolution of mass loss follows an equation like:

$$\text{Relative mass loss} = K.\text{time}^2$$

	Absolute mass loss	Relative mass loss
0	75.72	0.00%
7	75.82	-0.13%
14	75.58	0.18%
28	75.05	0.88%
42	74.04	2.22%



The other indicator measured to evaluate the corrosion of the solid aluminium neutral is the medium depth of the weak points. The diagram below shows the linearity of the depth increase as a function of test duration.

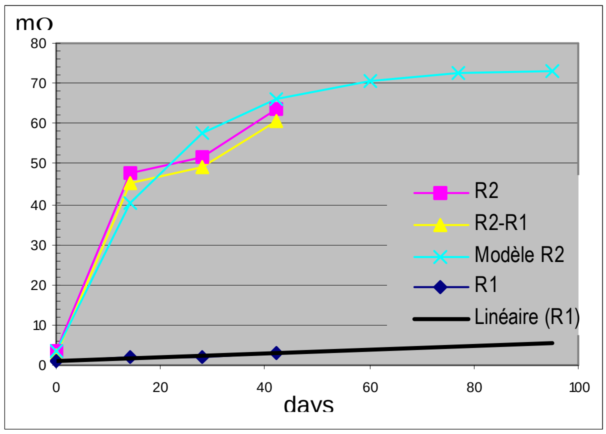


After 42 days of ageing test, the medium depth of weak point is 82 µm to be compared with the diameter of the neutral conductor which will vary from 10 to 14 mm.

Complementary measure to evaluate the ageing of the new complex

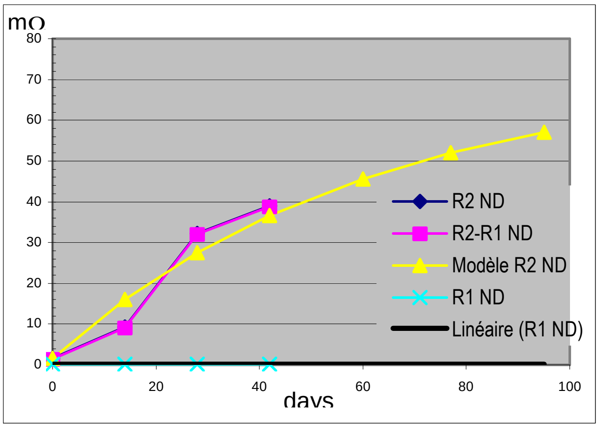
In France, the screen is used to ensure the third part protection. So in case of degradation by corrosion, the resistance of contact has to be as good as possible to evacuate current in case of aggression of sheath by blunt tool.

During the test, measures of resistance of contact between the screen and the neutral was carried out on the two designs to estimate the progression of this value.



Evolution of the contact resistance of the complex screen/neutral of the NF C 33-210 design

Return to Session



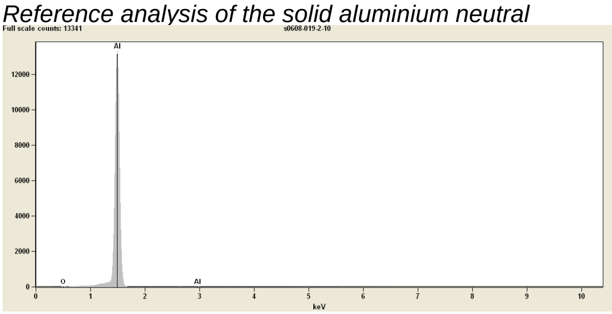
Evolution of the contact resistance of the new complex screen / neutral

These diagrams show clearly that the resistance of contact evolves much less with the new design than with the old one. The absence of lead makes it possible to obtain this result. In case of short-circuit, we can think that the behaviour of the complex will be better than the oldest.

<u>Complementary analysis by SEM and microanalysis X</u>

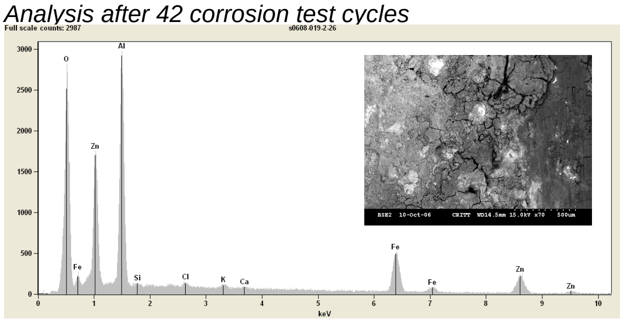
The measure of mass loss gives us information on the global corrosion phenomenon. The analysis performed as well by scanning electron microscopy and X-Rays microanalysis evolves the knowledge of local pitting corrosion which can affect the galvanized steel screen as well as the solid aluminium neutral.

Reference analysis of the solid aluminium neutral



This first spectrum has been performed on the aluminium neutral before the new corrosion test.

Analysis after 42 corrosion test cycles



The iron and zinc are clearly detected on this second spectrum obtained on the aluminium neutral surface after 42 corrosion test cycles. These two elements indicate a corrosion products transfer between galvanized steel screen and the aluminium neutral. The aluminium neutral is also corroded (viewed on microscopic cross sections).

The corrosion behaviour can be summed up by:

- the first corrosion step is characterized by a pitting corrosion phenomenon which affects firstly the galvanized steel screen and also slightly the aluminium neutral
- after 42 corrosion test cycles, the corrosion behaviour of these two materials is a global corrosion type.

CONCLUSION

The accelerated ageing corrosion test has shown that the behaviour of the new complex screen / neutral is almost the same than the old one. By using a solid aluminium neutral instead of multi wires aluminium neutral, the corrosion phenomenon is located at the surface of the solid wire.

The durability of the underground link system is always a major concern for all the actors of the network from the manufacturers to the utilities. And we have to walk on the same way:

the final customer's satisfaction

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GLOSSARY

CRITT: Centre Régional d'Innovation et de Transfert de Technologie
PVC: Polyvinyl Chloride
SEM: Scanning Electron Microscopy