IMPACT OF AGEING ON THE MV UNDERGROUND ASSET RELIABILITY

Cédric SPELLEMAN
EDF R&D – France
cedric.spelleman@edf.fr

Laurent GAUTHIER
EDF ERD – France
laurent.gauthier@edf.fr

ABSTRACT

With the opening of the market, distribution network managers have to optimize their profitability. One way is cutting down asset replacement strategy, and operating a growing old network. Question is whether asset failure rate is a function of time and how to model it. Asset failure rate is a crucial challenge for distribution network operators in order to optimize investment MV network investments.

The paper focuses on the treatments performed to understand the reasons why the fault rate of underground asset increases in function of the age, but not only due to this factor: environment of the cables, technology of the insulation, impact of the number of joints…

INTRODUCTION

The paper tackles the ageing effect on asset reliability. It focuses on the MV underground cables and describes the methodology used. As the experience feedback covers only 6 years, whereas underground cables life cycle can last more than 40 years, the actuarial method is selected and applied to calculate yearly an artificial rate. It enables to build up the entire lifecycle of underground cables between [0;40] years. The reader may refer to a former CIRED paper [1] that describes in details this method and the databases required. Just to remind quickly the stake, the MV asset ruled by EDF is about 580 000km. Regarding the feedback, the study is based on failures occurred between 2000 and 2005.

FIRST RESULTS OBTAINED FOR A GLOBAL SYSTEM

Firstly all failures occurred on the underground sections have been studied, whatever their causes.

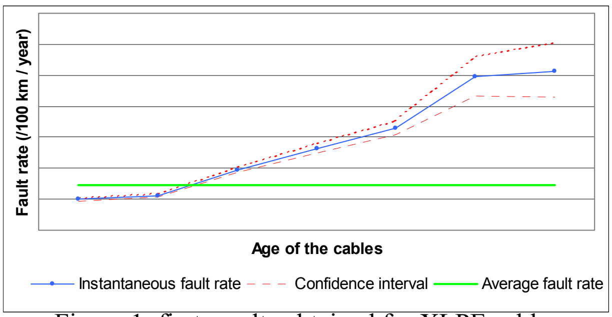

Figure 1: first results obtained for XLPE cables

An increase of fault rate with time can be detected for both paper and synthetic insulated cables (resp. PILC and XLPE cables) as shown on the figure above.

Secondly failures due to third parties have to be removed in order to check whether the increase of the fault rate is actually related to the aging.
The following figure shows the contribution of both internal failures, related to aging, and third party.

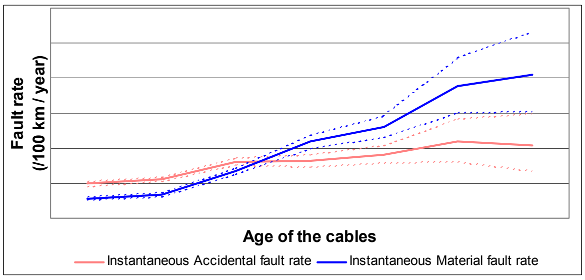

Figure 2: fault rate in function of the cause of XLPE cables

Concerning third party damage, oldest cables have about twice more faults than young cables. As those faults are directly linked to the environment, it means that each point of the first curve refers to a different group of assets. In fact oldest cables are located in urban areas, whereas young cables have been set in rural areas. And the probability for a feeder being damaged by public work is obviously higher in urban environment than in rural one. Those faults are not linked to the aging of conductors, so in order to assess aging, it is necessary:

- To split each family of underground cables into two new groups: one urban, and the other rural (the rural/urban environment is currently based on quality level of each MV feeder and its burying rate),
- To take into account only fault due to the internal degradation of the component.

However those accidental contacts may be useful to evaluate, as their contribution may be reduced for instance by updating maps, or a good communication with the public work companies.
In conclusion of this first step the increase of internal fault detected is not only due to aging, and that we must define more accurate families, not only based on the technology of insulation.

A CASE STUDIED, THE URBAN XLPE CABLES

Here we focus on the XLPE cables located in an urban environment.

Increase of the internal fault rate

Once this new population of "urban cables" has been defined, we find out that the third party damages are independent of the cable age: we're now studying a homogeneous group between 1 and about 25 years old compared to the environment.

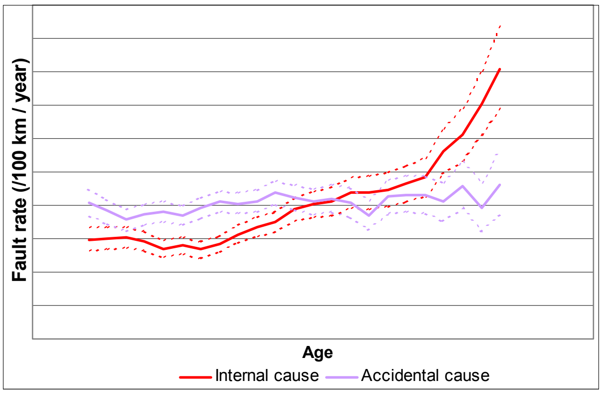

Figure 3: Fault rate of urban XLPE cables
(Joints are not taken into account)

The figure 3 shows that the internal fault rate of XLPE cables set in the same external urban stress increases in function of the age: consequently, for this homogeneous group (between young and old components), the increase of the internal fault rate for cables and joints may be a result of the degradation of components or of any other factors not yet modelled.

How to take into account the joints ?

Then another problem is the treatment of joints. Indeed we have to cope with two difficulties:

- identification of the right failing component: that is to say that the number of failure occurred on joints is slightly underestimate (all failures are daily collected whereas the mean equipment involved isn't yet identified, this information is not always checked after the conductor had been repaired). So we had to apply a corrective rate, based on expert judgements, to allocate some failures identified on "conductor" to "joints",
- joint knowledge : the number and technology of joints aren't identified in our asset database : consequently up to now, all fault rate for joints are calculated per 100 km / per year (in our study, but also in other data handbooks). So the increase of the fault rate (/100 km / year) of joints may be linked not only to aging, but also to the increase number of joints set on the network. So to settle this uncertainty, we calculated from the description of the network in the asset database, the number and technology of joints, and their likely building date, which may differ from the age of the conductors..?

This treatment allowed us to define three kinds of joints:

- 2 types of junction joints connected section of the same technology (PILC or XLPE),
- 1 type of transition joint connected section of different technology (XLPE⇔ PILC) or Overhead and underground sections.

The first purpose is to check whether the number of joints increase with the age of the network described in the asset database.

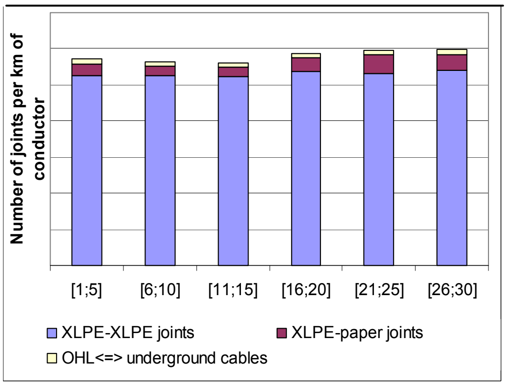

Figure 4: density of joints on XLPE urban network

From the figure 4, we can conclude s, the age of urban XLPE networks don't impact the number of joints. That result confirms the fact that we still have a homogeneous group. For each age interval, the cables have the same density of boxes.
This treatment enables to calculate a fault rate of joints per component (figure 5).

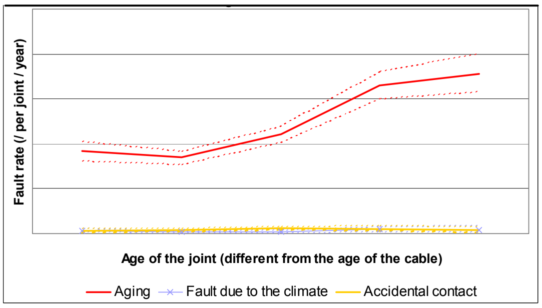

Figure 5: evolution of the fault rate of XLPE joints

Once those treatments (corrective rate and assessment of joints) achieved, we are able to determine the influence of the type of joints and their life expectancy.

The figure 6 shows the final evolution of the faults rates after those treatments, whose purposes were to improve the accuracy of information collected in the asset and fault databases (interval confidence curves have been removed to simplify the understanding).

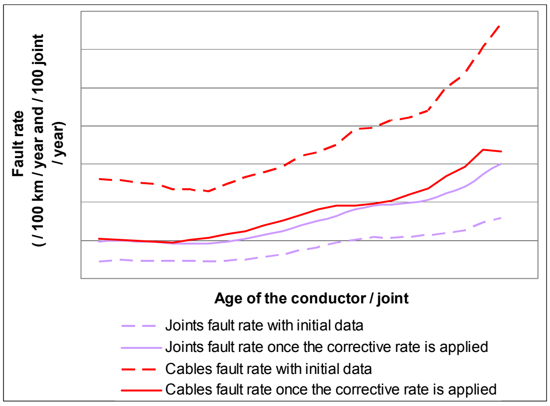

Figure 6: evolution of the internal fault rate of XLPE conductors

Those data can now be used to calculate and compare the reliability of networks, and so be used as input data in investment and asset management tools.

Impact of the type of joint on the network reliability

The purpose is to quantify the influence of the type of joints.

All XLPE sections have been split in two groups depending on their joints:

- sections with only junction joints (XLPE sections connected to other XLPE sections),
- the second group concerns sections with transition joints (XLPE sections connected to PILC or overhead sections)

Figure 7 gives the average values of both conductor and junction of each group.

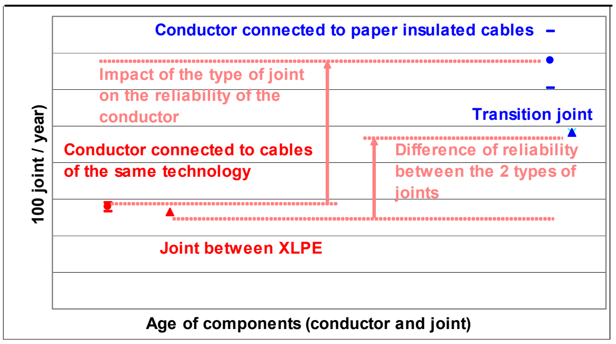

Figure 7: Impact of the type of joints on the average fault rates of XLPE cable

Difference of reliability is detected. First, it reveals that transition joints are about 1.8 times less reliable than junction joints. Secondly the type of joints seems to have an impact on the conductors' reliability (about 2.4 times). Note that both groups have quite the same age (11.5 years old for the "homogeneous network" and 12 years old for the "transition junction network").

Then the next step is to determine the life span of joints and a model for cables, in order to estimate the number of boxes added when failures occurred on the network. Indeed contrary to cables, which considered "as bad as old", joints are replaced after a failure. That is why for cables, we consider the evolution of their fault rate, whereas for joints we will determine their life span. Indeed to forecast the number of failures due to joints, we will use its life span and its standard deviation.

Assessment of the life span of joints

So from the different curves, for each group of cables and joints, we determine the parameters of the Weibull law, traditionally used to describe the life span of components. The fault rate in function of the time depends on three parameters:

$$\lambda(t) = \frac{\beta\,(t-\gamma)^{\beta-1}}{\sigma^{\beta}}$$

where:

- β is called the form parameter and gives the trend,
- σ is called the scale parameter and give the value of the fault rate,
- γ is the origin parameter and can be estimated to zero.

The complete life span is usually describes with 3 Weibull curves. Here we are only interested in the second (constant) and last part (where the fault rate begins to increase). The parameters are obtained with a linear regression (taking the Logarithm of the Weibull expression).

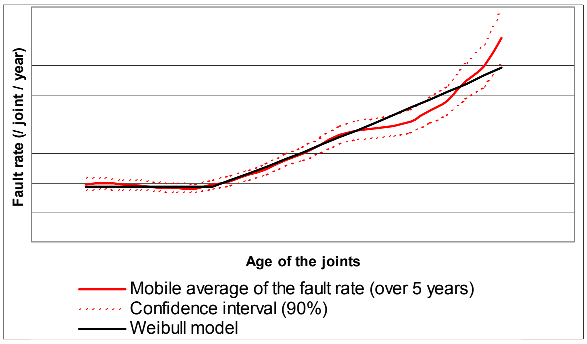

Figure 8: Fault rate and its model of homogeneous XLPE joints

In that case, the model is closely related to the calculated fault rate (the correlation rate is 97.15). Moreover, we can see on the graph that each value of the model (black curve) is contained between the minimum and maximum borders of the confidence interval (χ^2 law at 90%).

This step is in fact common to cables and joints: for cables, we also determine the parameters of the Weibull law. Those parameters are notably used to estimate the future number of joints. The following is, however, related to the assessment of joints' life span.

From those parameters, we can calculate the average, in fact the expected life span, and its standard deviation:

$$Life\ span = \gamma + \sigma\,\Gamma(\frac{1+\beta}{\beta})$$

$$standard - deviation = \sqrt{\sigma^2[\Gamma(\frac{2}{\beta}+1) - \Gamma^2(1+\frac{1}{\beta})]}$$

where Γ *is the Gamma law*

This treatment gives the results shown on the figure below (figure 9):

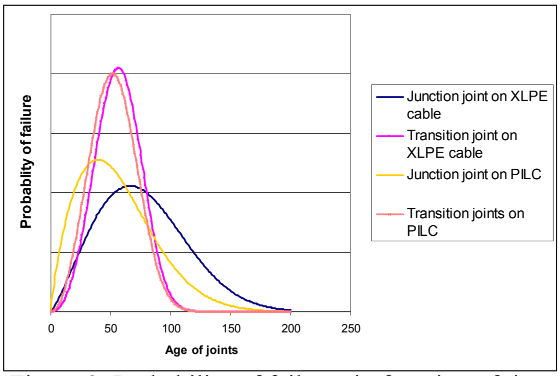

Figure 9: Probability of failures in function of time

The graph above gives the probability of failure for the joints and is calculated with the previous parameters. The average is close to the peak, and the more this peak is narrow, the more all joints will fail at the same time. Here, the peaks are quite wide. In fact it is because the curves give a trend, but we haven't observed yet those peak. In such other studies, for instance the life span of street lighting lamps, the peak was narrow and so the life duration very precise, because all lamps have been observed from the beginning to the end, and more thant 90% of the population has failed during the observation. Here we don't have those two conditions. Moreover, inside one group, we may take into account several sub-groups (different technology stages, several manufacturers…).

Then in this figure, we refer to transition joint on the one hand on XLPE cable, and on the other hand we speak about transition joint on paper-insulated cable. Of course the transition joints link two technologies of conductors, so it is the same joint for both groups. But in the fault database, failures are located on a single section identified by two nodes (a node is notably a joint, but can also be a MT/LV transformer, or a substation). So it is a way to check whether we obtain the same result with those groups: there is a small difference of 6%. Compared to junction joint of paper-insulated cable there is a slight difference.

Assessment of the future number of joints

With those results, we can compare different types of network, and determine whether it is valuable to perform refurbishment or replacement. On the other hand, we can forecast the increase of failures. Indeed:

- each time a failure occurs on a cable, two new joints are added to the network. We must take into account internal cause as third party damages,
- each time a joint failed, it is replaced by two news joints (so we add one joint).

From data presented before, we simulate the increase of the number of joints on a system composed of:

- 100 km of new XLPE cable at the beginning of the simulation,
- and 50 new joints (50 joints per 100 km is about the average for urban cables).

Regarding the joint, we calculate the probability of failures given by the probability density (based on the Weibull parameter obtained before).

For cables, we take into account their evolution with time; we don't consider a constant fault rate.

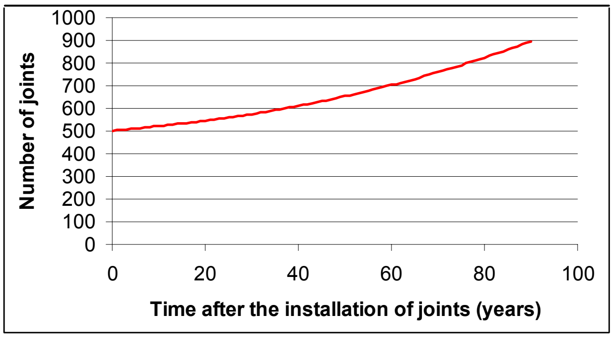

Figure 10: simulation of the increasing number of joints

Of course this increasing number of joints on the network will increase the number of failures. So it is possible to forecast the future number of failures, directly linked to the aging of the conductors, but also indirectly to the increasing density of joints (cf [2]).

CONCLUSION

In this paper we tried to focus on the main and necessary steps that lead to obtain the evolution of failure rate for both cables and joints, taking into account the most important criteria (technology of insulation of cables, environment, and definition of the joints).

The trend obtained with the actuarial method allowed quantifying the evolution for main groups. Of course there is some uncertainty, as the study is based on database and experts judgment, but the next step would be to confirm some results with field tests or in laboratory to confirm whether the behaviour of joints in operation match to the model.

REFERENCES

[1] P.Carer, L.Gauthier, S.Sabeg, C.Spelleman, G.Stawinski, EDF : CIRED 2005, "Impact of ageing on the MV asset reliability"

[2] L.Gauthier, G.Stawinski, D.Dercle, EDF : CIRED 2005 "Stochastic Model Of MV Feeders Quality Of Supply For Investment Strategy Studies"