MV CABLE OFF LINE DIAGNOSTIC AT ERDF: FEEDBACK OVER 5 YEARS GLOBAL DEPLOYMENT EXPERIENCE

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ABSTRACT

ERDF started in 2007 MV cable off line diagnostic deployment all over France. Then in 2012, after 5 years of diagnostic activities, ERDF asked for experience feedback analysis in order to identify actions needed to improve the efficiency of diagnostic operations.
The paper presents the main results of this analysis.

INTRODUCTION

ERDF started in 2007 MV cable off line diagnostic deployment all over France, applying solutions proposed by EDF R&D [1]. For that purpose, network maintenance teams were equipped with 21 diagnostic systems that allowed covering major urban centres in 23 geographic areas. Diagnostic tools allow performing VLF tan delta (TD) and partial discharges (PD) measurements and are associated with a fault location system in a van that can be chosen between 2 providers. Measurements are collected in an excel file that proposes an automatic interpretation of the results.
Automatic analysis summary is displayed on 3 failure risk levels (low, intermediate, high).
It is important to notice here that, during the considered period, each local entity was free to manage cable diagnostic activity. So, different organisations and policies have been applied locally. Experience feedback presented here aimed to identify best practices, problems encountered and improvements to be planned.

Figure 1: National repartition of diagnostic systems

MAIN RESULTS OF THE EXPERIENCE FEEDBACK

Intensity of diagnostic activity

The global number of diagnostic performed was obviously influenced by the fact that regional teams were progressively equipped with diagnostic systems. Most of the diagnostics performed in the beginning of the deployment aimed to help with weak transition joints replacement. Local network operating agencies involved in such a policy performed diagnostic through quite "industrial" programs, mainly based on tan delta (TD) measurements. Some of them reached more than 300 cable sections per system per year. The target was short time failure prevention, fixed by operators. Then, pre selection of cable sections became more difficult. Some agencies were considering that diagnostic efficiency was not sufficient. The number of weak point removed per diagnostic performed previously higher than 20% fell down through 10% in some cases. Activity decreased and diagnostics performed "on demand" became the tendency. Activity increased again when diagnostics were decided by local asset management agencies. Thus both TD and PD measurements were used for cable section ranking. As time measurement is twice longer, about 150 cable sections per year per system are generally reached.
A few diagnostics were provided by ERDF to external companies for commercial purpose. Nevertheless, the number of cable sections measured in that case is increasing and can exceed 20 per year for local teams involved in such practices.

Organization

Measurement team

Few operating agencies created dedicated teams gathering the functions needed to organize and perform diagnostic activity, with generally 3 persons involved:

- cable section pre selection and measurement scheduling,
- network operation,
- measurements.

Such autonomous teams proved their efficiency to hold on programs focused on short time failure prevention. Nevertheless, skills for cable section selection appeared not sufficient in this kind of structure.

In most of the regions, measurements were performed by local maintenance agency. Operators are skilled but not specialized in diagnostic measurement. In that configuration, it is more difficult to reach the same level of operators' skills as in dedicated teams.

Diagnostic demand and cable section selection

Most of the diagnostic demands come from local asset management agencies. The global organization efficiency appears better when diagnostics are asked and scheduled by those entities. Diagnostic are mainly focused on cable sections concerned by replacement programs. Following diagnostic results, priority could be redefined to finally apply the best renewal decision. Moreover demands from different actors could be more easily centralized and taken into account. Thus diagnostic could be used to verify the relevance of renewal demand based on operators' feedback experience or in case of road maintenance works performed by cities.

Management of diagnostic program

Specific tools have been designed locally for operation scheduling and results collection. Some of them have been detected to be nationally deployed to improve general efficiency. The following example (Figure 2) illustrates a database developed to manage diagnostic operations performed by the different regional agencies involved in the program. A main file generated by asset management gives a global overview of the cable section scheduled and measurements results in term of risk level.

Cable section characteristics needed for automatic risk calculation is automatically extracted from national Geographic Information System (GIS) data base.

Each technical maintenance team completes the database with detailed measurement reports.

So results of automatic risk calculation can be reconsidered afterwards if needed.

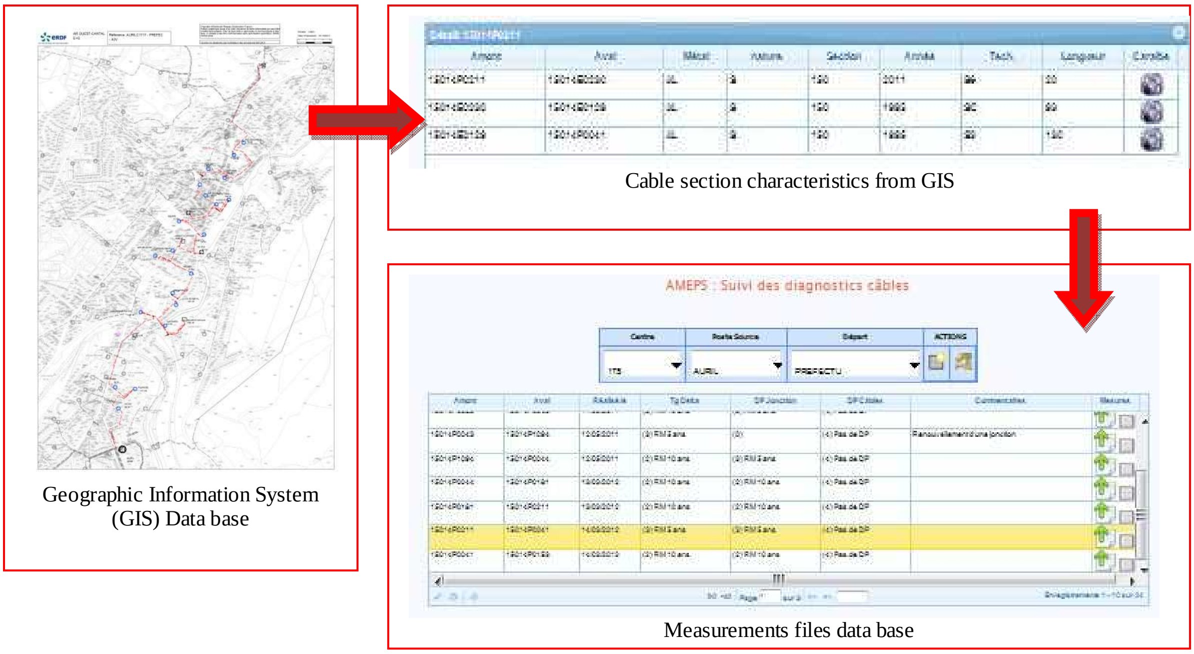

Figure 2: Diagnostic management data base example

Economical efficiency

As off line diagnostic is resource consuming, economical efficiency has to be carefully considered. When diagnostics are performed mainly under the demand of operators, efficiency is measured by the ratio of number of weak points removed to the number of diagnostics performed. So when this ratio fell down below 20%, interest of diagnostic campaign was reconsidered. Regarding a global asset management approach, accurate preselecting of cable section appeared a crucial way to improve the economic efficiency of diagnostic programs. The evaluation for the off line project showed that benefits from the use of the 21 vans could lead to a NPV from 100 to more than 200 M€ depending on the hypothesis. This is mainly due to renewal delayed when diagnostic shows that the cable section is in a good condition.

For the new PILC replacement program the payback targeted is lower. Indeed, if all the PILC cable sections are replaced in a relative short time (20 years), the postponement possibilities are limited.

For this program, asset management built a renewal criterion (CR), which is an equivalent benefits to costs ratio. Diagnostic is used to increase economic efficiency. Risky cable sections are identified and replacement of the healthy ones is avoided. So accuracy of interpretation became also a key point of economic efficiency Measurements are performed only on cable sections selected with the higher "Length*CR" values. The estimated number of cable sections for witch diagnostic is profitable is about 15% of the PILC cable sections. It represents 50% of the total length of PILC.

The diagram Figure 3 illustrates the principle of increasing efficiency using CR and then diagnostic.

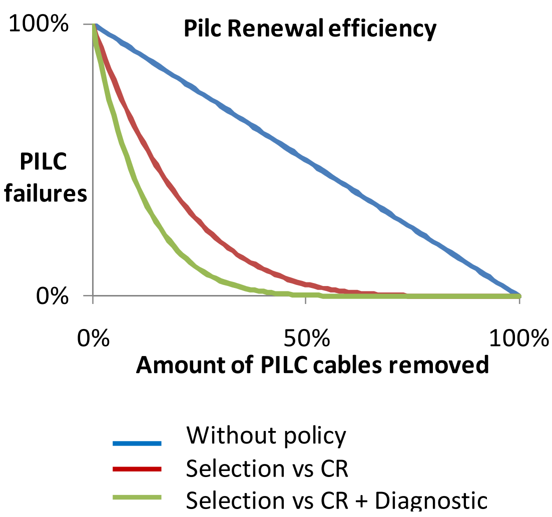

Figure 3: PILC renewal efficiency diagram

Measurement results interpretation

Diagnostic method

ERDF applies 2 diagnostic protocols. One using only tan delta (TD) measurements is mainly dedicated to identify weak transition joints (water penetration). The second one is combining TD measurements and partial discharges (PD) measurements. An automatic calculation is performed using measurement results to give a risk level assessed on 3 stages: Low, Intermediate and High (respectively blue, orange and red in Figure 4).

Criteria used for TD assessment:

- Mean Tan delta @ 0.5 Uo
- Voltage dependence of Tan delta
- Time stability of Tan delta @ 1.5 Uo (standard deviation)

Criteria for PD:

- Inception at nominal voltage or lower
- Inception under 1.5 Uo and remaining at Uo
- PD distribution along cable length (PD Map)

	CALCULÉ	REPORT RÉSULTATS DE MESURES							CALCULÉ		
Mesures											
				6 KV	12 KV	18 KV	.. KV	tension de claquage	Δtgδ%/ΔU	Ecart type%	Risque électrique
Tangente Delta	Tg sain	Ph1	Tg X1E-3	17,2	18	18,6			0,68%	0,47%	Risque faible
	2,69		C(nF) à 12 KV			écart type (X1E-3) à 18 KV					
			263 nF			0,087					
	Tg critique	Ph2	Tg X1E-3	19	20,8	21,3			1,01%	0,04%	Risque faible
			C(nF) à 12 KV			écart type à 18 KV					
			261 nF			0,008					
	19,2	Ph3	Tg X1E-3	20,2	21,6	23			1,16%	0,28%	Risque modéré
			C(nF) à 12 KV			écart type à 18 KV					
			265 nF			0,065					
Décharges Partielles	Phase	Localisation			câble/ accessoire	U apparition	Niveau Max à 12 KV	Niveau Max à 18 KV	Nombre de DP		Risque
	Ph 1	115 m.		145 m.	Câble papier	6 KV	2100 pC	6100 pC	Elevé		Risque élevé
	Ph 1	420 m.			Câble papier	12 KV	2100 pC	3000 pC	Faible		Risque modéré
	Ph 1	40 m.		440 m.	Câble papier	18 KV		2100 pC	Elevé		Risque modéré
	Ph 2	420 m.			Câble papier	6 KV	2800 pC	2800 pC	Elevé		Risque élevé
	Ph 2	110 m.		160 m.	Câble papier	12 KV	3000 pC	3400 pC	Elevé		Risque élevé
	Ph 2	50 m.		590 m.	Câble papier	12 KV	2000 pC	2200 pC	Faible		Risque faible
	Ph 3	420 m.			Câble papier	6 KV	2200 pC	2200 pC	Elevé		Risque élevé
	Ph 3	105 m.		160 m.	Câble papier	12 KV	3200 pC	3400 pC	Elevé		Risque élevé
	Ph 3	588 m.			accessoire	18 KV		2700 pC	Faible		Risque faible
	Ph 3	40 m.		680 m.	Câble papier	18 KV	950 pC	950 pC	Elevé		Risque modéré

Figure 4: Example of automatic calculation level

In case of low risk level, no action is requested excepted new measurement in 10 years. In case of intermediate risk level, verifications such as termination influence and repetition of measurements in 5 years to identify evolution are asked. In case of high risk level replacement of the weak section is considered. When weakness (water penetration) is identified by TD criteria, the voltage measurement is progressively increased to reach breakdown. The method is designed to limit the voltage constraint which is applied only when a weakness is identified.

Risk assessment accuracy

Analysis of accuracy needs failure statistics on cable section that has been measured. Fortunately cases of failure after diagnostic are rare, so statistics remain partial.

Nevertheless, it is easy to state the relevance of water ingress risk assessment because verdict is given by breakdown occurring while voltage is increased. About

90% of the breakdown sequences applied on mixed cable sections are successful. Analysis of lower results figures showed that sequences are performed even though all criteria are not gathered.

Automatic risk calculation with 3 risk levels appears adapted to deal with the existing configurations (XLPE, PILC or Mixed cable sections). Ranking of cable sections is globally satisfactory, specifically for high and low levels.

Results for intermediate level are mitigated mainly for threshold effect reasons. A problem specifically occurs when a section is classified as intermediate when measurement results are very close to high level behaviour. In that case, accuracy is very dependent on operator experience. Skilled operators are able to give an accurate interpretation in most of these cases.

The only cases of negative feedback occurred with XLPE cable sections and water ingress assessment with TD measurement (PD is not adapted for that). The first reason is that the automatic calculation was not designed to treat XLPE cable sections extremely degraded by water penetration. In this case, specific instable measurement behaviour leads to misinterpretation. The second one is due to identification of the XLPE degradation in mixed cable section. Obviously measurement values are fixed by the PILC section. The third reason is the accuracy needed for XLPE diagnostic, which is much higher than for PILC section. This is a matter for the measurement procedure but also for the description of the cable section characteristics.

As a result of this feedback, works have been started in order to improve XLPE assessment. The aim is to have a more accurate characterization in order to allow identification of water ingress impact in complex or/and long cable section.

For that, studies are performed in order to characterize the evolution of the TD values over time, length attenuation and to use dielectric frequency domain spectroscopy.

The evolution of the measured value over time will be used to give low voltage criteria. This will be usefull to avoid voltage measurement constraint on weak cable sections and to avoid misinterpretation of TD versus voltage behaviour due to instability. Figure 5 shows dependence of mean TD value versus duration of measurement sequences.

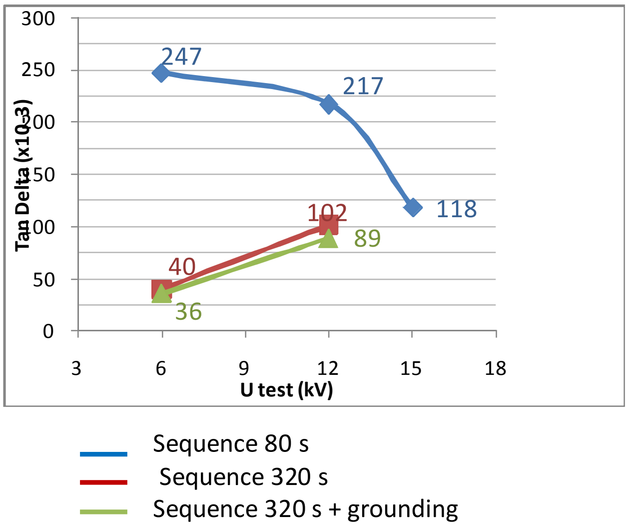

Figure 5: TD mean value for cable section for different measurement sequence durations

Characterization of decrease of sensibility over length will be used to identify a weak point in a long healthy cable section. Figure 6 shows evolution of TD value when 6 m long weak cable section is alone and when it is inserted in 200 m healthy cable section.

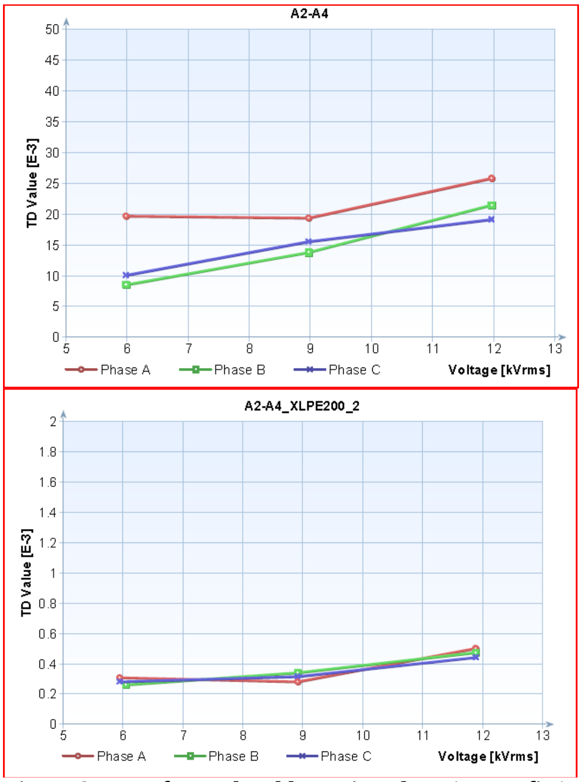

Figure 6 : TD of a weak cable section alone (Upper fig.) and inserted in a 200 m cable section (Lowest fig.).

Dielectric frequency domain spectroscopy will be used to define new tools and criteria using frequency behaviour. Figure 7 shows frequency response of different degradation region of the same cable.

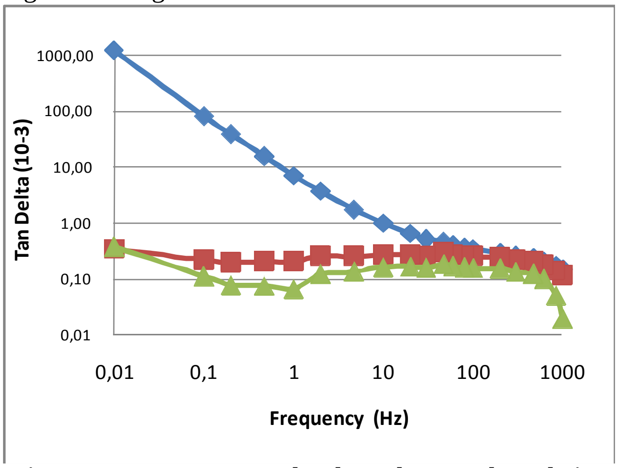

Figure 7: Frequency TD value dependence vs degradation level

Measurement systems and operators' skills

Measurement Systems

Local technical maintenance agencies are free to chose the measurement system among the two providers selected by ERDF. Feedback helped to pin point that reliability problems have been frequently noticed for one of the providers. For the second one, it appears that the sensitivity of the device leads to severe difficulties for measurement interpretation. In some configurations automatic PD detection and location have to be revised by operator. This is time consuming and increases the competence level required.

Providers have been asked to improve their systems for the mentioned weakness. Works are in progress. Meanwhile the specification used for the selection of the diagnostic systems will be reinforced and adapted for the next purchases to take benefits from the technical improvement.

Operator Skills

A rather high level of technical competence is needed to perform diagnostic, especially for PD measurement and its interpretation. Feedback shows that a specific training effort is required to allow a relatively great number of operators to acquire the needed competences. Moreover, organisations have to take in account maintenance of skills, specifically when operators are involved in multiple tasks. A new training formula will be started in 2015.

CONCLUSION

Since 2007 ERDF has deployed MV off line underground diagnostic, progressively all over France. The most involved local organisations take great benefits from applying the diagnostic method, first for weak joints removing program then for general replacement program led by asset management agencies.

The experience feedback shows that the method gives global satisfaction for short time failure and also for ranking the different types of cable sections (XLPE, PILC and Mixed) for renewal operations. Feedback allowed identifying improvements for automatic risk calculation. Cable section selection can be been improved with a new technical and economic criterion (CR). For the new PILC removing program, final ranking of operations will be done according diagnostic results. Work on a health index for classification is still in progress [2].

XLPE assessment is an increasing matter for cable replacement. So works have been launched to identify water penetration in XLPE. It remains a challenge for long and/or complex cable sections. Thus new criteria and new tools have to be studied. We are working with IREQ and SINTEF for that purpose.

As acquisition and maintenance of diagnostic operators' skills is fundamental, a new training program will start in 2015. Improvements asked by ERDF to diagnostic system providers for technical devices and also for services are expected to increase measurement efficiency and accuracy.

Meanwhile developments for on line diagnostic to prevent short time failure are in progress [3].

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