AGING OF THE CONTROL SYSTEM OF THE EDF PRIMARY SUBSTATIONS

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ABSTRACT

The instrumentation and control equipment for the HV/MV substations of EDF's distribution system may reach 25 years of age, but studies which have just been carried out show that with a few simple upgrades, they may work for yet a number of years.
Indeed, with their old design, they use robust electronic components that can be replaced fairly easily. Furthermore, removing a large number of instrumentation and control equipment from substations linked to the development of their MV neutral point grounding, constitutes an opportunity for establishing a stock of spare parts which makes it much easier to maintain the remaining installations in operational conditions.

INTRODUCTION

There are three generations of instrumentation and control equipment in the HV/MV substations of EDF's distribution system.
The oldest, developed at the end of the 1950s, used electromechanical relays supplied with a voltage of 127 V=. It has experienced two major developments, firstly when electronic components were progressively substituted with electromechanical relays at the beginning of the 1970s, and secondly when substations were systematically remote-controlled.
The second generation, combining completely electronic protection cases with two computers to create certain automation functions (frequency metered load shedding, centralised remote control of rate changes and reclosure of outgoing feeders) as well as remotely controlling and blocking events, started to be deployed in 1986. It is characterised by a 48 V= power supply which permitted the change to a telephonic type of wiring.
Now, a new completely digital generation has emerged.
These three EDF HV/MV substation instrumentation and control series are successively named conventional series, series 86 and PCCN (for Digital Instrumentation and Control Series, in French language "Palier de Contrôle Commande Numérique").
Electronic equipment from the conventional series, the oldest of which is 25 years old, and equipment from series 86, the oldest of which is 20 years old, therefore currently exists in EDF's HV/MV substations. The question of whether to replace and/or maintain them in operational condition is thus posed, which has motivated an evaluation study on their aging.

THE FLEET OF EQUIPMENT IN OPERATION

There are a little over 2,250 HV/MV substations on EDF's distribution system, which breaks down into approximately 1,500 conventional series substations and 750 series 86 substations.
Three suppliers shared the market for conventional series substation protections (the distribution between the suppliers is approximately 70, 20 and 10%).
Four suppliers, the first three plus a fourth, provided the protection equipment for the series 86 substations (their market share was respectively 50, 25, 15 and 10%).
Approximately a third of the total fleet of protections is currently estimated to be over 15 years old.
Two types of computer equip the series 86 HV/MV substations. Firstly, Remote Terminal Units that are also identical in the conventional series substations and which provide the aforementioned automation functions and secondly, computers dedicated to lockout states and which also allow local control thanks to their integrated type mimic diagram.
There are three types of remote terminal unit (two suppliers) and three types of state lockout computers (three suppliers).

THE AGING CONDITION

Feedback

No major increase in the level of breakdowns for the oldest equipment has been highlighted, which means that the characteristic rise of the "bathtub curve" for the level of reliability for a piece of equipment based on its age has not yet been reached.
This comment is valid for all of the equipment, whether it concerns protections or computers.
In the case of protections, it was noted that their levels of breakdown are more or less the same (0.5%), regardless of the supplier and whether conventional series equipment or series 86 equipment was used. However, this is easily explained by the fact that the technology used, i.e. the installation of discrete electronic components on printed circuits, is identical for each assembly.
At the same time, the levels of breakdown, which are very low, are approximately the same (0.4%) for the different types of computers.

Visual evaluations of electronic circuit boards

Visual evaluations were carried out a little over one year and have allowed approximately twenty five substations to be inspected which, in essence, were equally shared between conventional series substations and series 86

substations.
The advanced age of the equipment and the severe environmental constraints were among the selection criteria for the sites visited. For practical reasons of equipment availability, it was only possible to carry out visual evaluations on the protection equipment.
The main conclusion was that the protection equipment had a good overall condition, however, with a few disparities.

Electrochemical capacitor aging

It is well known that these components deteriorate over time and that the process is accelerated with temperature. In the present case, it was noted that most of these components were damaged, but however without causing any actual malfunctions. Actually, their role is mainly to filter any possible interference. However, replacing them must be planned.

Figure 1: damaged chemical capacitor

Whiskers

On many occasions, it was possible to detect needle or nodule type "whiskers", particularly on the diode pins. Although these whiskers may exceed one millimetre in length, they do not present any particular danger, given the space between the tracks of the printed circuits and the components (2.54 mm spacing) and the technology used (no SMC component).

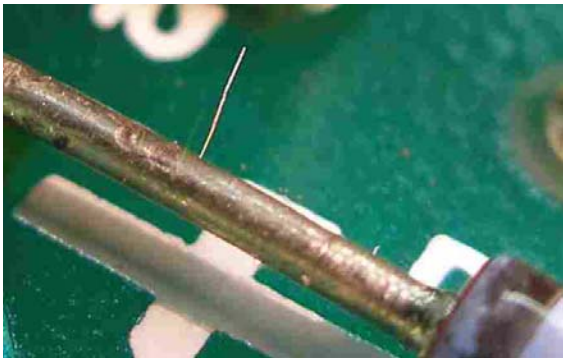

Figure 2: whisker on a diode

Conventional series equipment

The power supply of 127 V= is unsuitable for electronic components. To bring it back to a value that is acceptable for electronic circuits, all of the suppliers chose to insert a pulldown resistor and a zener diode. This creates a heat source which accelerates the aging of the electrochemical capacitors and an alteration of the printed circuits.
This alteration which results in brown stains on the support and/or varnish is, however, unlikely to cause any real failures.

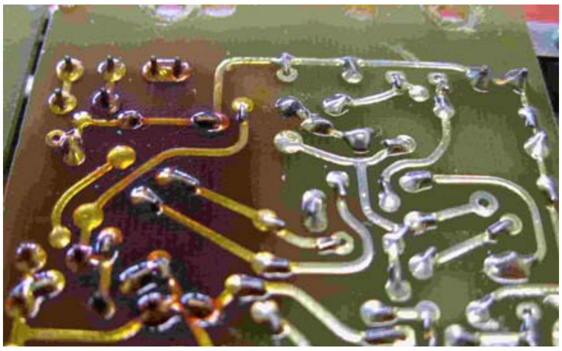

Figure 3: brown stains on the printed circuit

It is important to note that series 86 equipment is supplied with a voltage of 48 V=. In these conditions, the pulldown resistor does not exist or has a much lower value and it was possible to check the excellent condition of the series 86 protections, however with the exception of one case of manufacturing.

Importance of the environment

In some substations, we were confronted with electronic circuit boards that were covered with a great deal of dust.
This dust has at least one unfavourable effect; it prevents the correct natural cooling of the components. Another effect may be the risk of short-circuit if proved that the dust was conductive: an addition laboratory evaluation is planned in relation thereto.

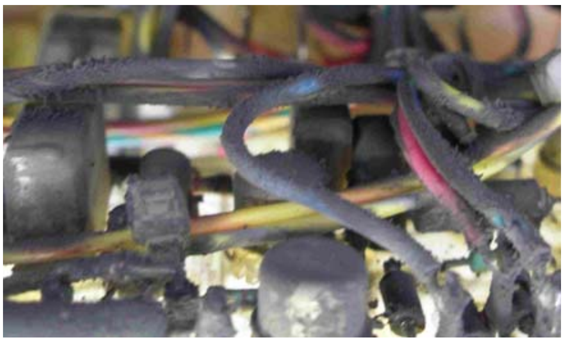

Figure 4: electronic circuit board covered with dust

Particular case of remote terminal units
As remote terminal units are inaccessible in the substations in operation, visual evaluations were carried out on the equipment located in the training and maintenance sites.
These evaluations did not highlight any particular problem. On one hand, only a small amount of circuit board deterioration was noted due to numerous manipulations which is explained by the particular character of the sites visited, and on the other hand, superficial heating of certain components was noted, which was already known but accentuated by large amounts of dust deposits.

Summary
The visual evaluations allowed a certain number of anomalies to be detected that are easily remedied via simple actions, such as for example, replacing the protections' electrochemical capacitors and removing dust from the electronic circuit boards.
Due to their design, these evaluations also allowed it to be noted that certain protections were easy to repair and others a lot more difficult to repair.
Finally, it was possible to declare that all of the equipment evaluated was over 75%[1] satisfactory and up to 95% satisfactory in the case of remote terminal units. However, an exception is noted; that of a specific type of protection, which presents a high risk of short-term failures, but which does not often occur on the system.

Component evaluation

These evaluations were twofold. On one hand, they detected any possible signs of aging on the components in operation for 20 to 25 years, and on the other hand, they identified the causes of failure for the faulty components sampled on the equipment that had broken down.
They took place in several stages; checking of electrical characteristics, radiographic inspection and opening of cases (examination with a scanning microscope). They produced the following results.

Evaluated components	Condition	Sanction
4 Tantalum capacitors	In operation	Aging
24 Electrochemical capacitors	In operation	Aging
12 Transistors	In operation	OK
3 Diodes and 1 Diode bridge	In operation	OK
1 Integrated circuit	In operation	OK
6 Integrated circuits	Faulty	External stress

With the exception of tantalum and electrochemical capacitors where aging is proven and which must be replaced, none of the components showed internal signs of aging. Any failures reported were of external origin, electrical overloads or electrostatic discharges, irrespective of the component technology: none of the faulty components showed traces of aging.

Figure 5: aging tantalum capacitor placed in a severe thermal environment

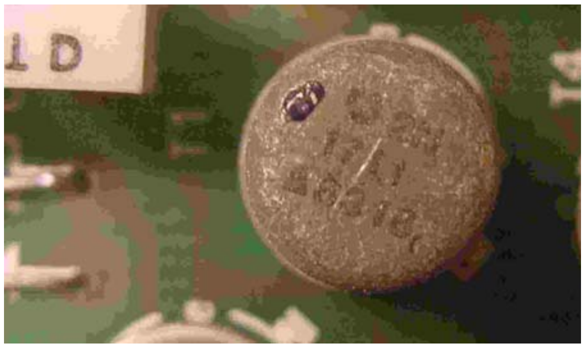

Figure 6: transistors with corroded cases but that have maintained all of their electrical properties

Accelerated aging tests

To attempt to evaluate the protections' residual lifetime, an accelerated aging test campaign was organised.
Protections are supplied and placed in a dry oven where the temperature is stabilised at 87°C (according to Arrhenius' law, one month of operation in an oven corresponds to 3.5 years of normal operation).
An original system was developed which allows the correct operation of the protections to be checked: an electronic circuit board with a microcontroller develops the single-phase and three-phase sine-wave signals with variable amplitude and duration and checks the open or closed state of the contacts.
Presuming that the protection operating thresholds, which are at maximum intensity and constant time, are respectively Sph and So for the phase and homopolar thresholds and that their time delay is T, the protections' operation is automatically checked in the following way:

1 EDF R&D developed criteria that allows electronic equipment to be graded based on its condition (presence/absence of harmful and/or redhibitory defects)

The signal's amplitude	The signal's duration	Sanction
1.1 So	0.9 T	Non-operation
0.9 So	1.1 T	Non-operation
1, 1 So	1.1 T	Operation
1.1 Sph	0.9 T	Non-operation
0.9 Sph	1.1 T	Non-operation
1, 1 Sph	1.1 T	Operation

The system is able to supply and monitor eight protections simultaneously and the results are recorded on a PC. Signal injections are scheduled to take place every 6 hours and the series of single-phase signals is sent successively to each of the protections' three current inputs.

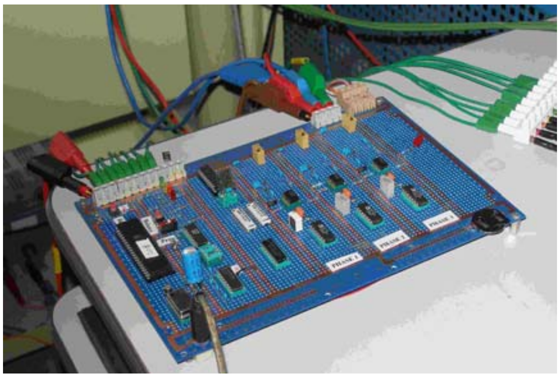

Figure 7: the installation's control board

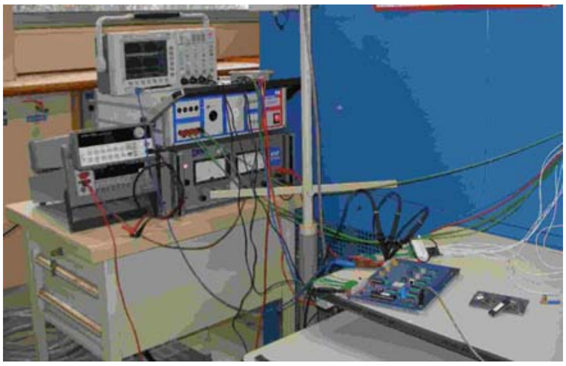

Figure 8: fault injection system

Several series of tests are planned. Currently, eight conventional series protections are being tested, of which some have had their electrochemical capacitors replaced and others left as they are after being removed from the system. They are over 20 years old.
After over one month of tests, no breakdown and no malfunction were noted and a two-month extension of the tests is planned (simulating 10 years of operation in total).

Conclusions

All of the investigations, evaluations and tests showed that the conventional series and series 86 equipment is still able to operate for a long time, via a few simple maintenance and upgrade actions.

A POLICY TO BE IMPLEMENTED

The studies carried out on the aging of the conventional series and series 86 instrumentation and control equipment for EDF's HV/MV substations showed that their lifetime may greatly exceed 25 years, however, the question of repairing them in the event of a breakdown may arise:

- Will we still have spare components for a long time?
- As manufacturing of the equipment will be stopped, won't there be a risk of dangerously increasing repair costs?

We can be reasonably optimistic for the following reasons at least:

- The electronic components used for most of the equipment, the protections in particular, are discrete current components (resistors, capacitors, diodes and transistors);
- Changing a number of HVMV substations to a new compensated MV type of neutral point grounding will be combined with replacing their instrumentation and control, which will allow a significant stock of spare parts to be established (for standard exchange).

But this also means that a maintenance policy in operational conditions must be implemented. In particular, the following questions will have to be answered:

- Will the planned removal rate allow a sufficient stock of spare parts to be established?
- Which substations must be changed first, on one hand, to eliminate the few rare high-risk pieces of equipment, on the other hand, to establish the stock of spare parts?
- Equipment by equipment, which detailed upgrade and storage guidelines and which equipment organisation should be implemented for the upgrades, possible repairs and for managing the stock of spare parts?