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EARTHED CIRCUITS, GROUNDED CIRCUITS AND CATHODIC PROTECTED CIRCUITS

EXPERIMENTAL «ZERO METHOD» USED TO INTERPRETE THE OBVIOUS REGULATION INCOMPATIBILITIES

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Abstract This document presents the different effective technical solutions for mass and earth circuits, partially experimented since 1992, and fully since 1995, in different sites: GDF, SPMR and SPSE. The efficiency of those solutions is very satisfactory, in regards to personnel and facilities safety, of cathodic protection and of the protection against lightning effects. Another part of the protections which are not presented here are related to the hardening of high current and weak current systems to cope with lightning secondary effects in sensitive sites. In fine, SPSE Company presents its experience on the subject.

I - GENERAL PRINCIPLES

I-1- Cathodic protection equipment works

A cathodic protection equipment's (fig. 1-) purpose is to develop a direct Voltage-Current couple on the buried pipeline to protect it against corrosion. The effect of this protection is limited in distance, within ten to fifteen kilometers on each side of the anodic field and it varies {1} in regard to several electrical and geological parameters. There are generally several equipments distributed on strategic places providing 5 to 50 ADC under 10 to 50 VDC, whose "Minus" polarity is connected to the pipe, and the "Plus" polarity to the buried anode field, distant of several hundred meters from the protected pipe.

I-2- Cathodic protection equipment conception

These continuous current power supplies are in fact alternative current rectifiers with semiconductors connected on the local mains power supply adapted by an isolating transformer.

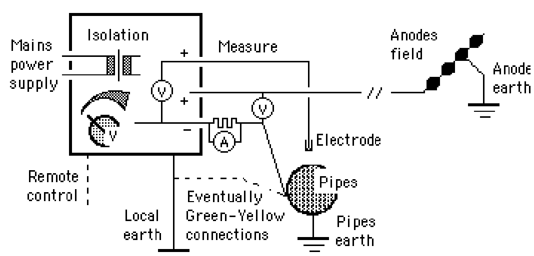

fig. 1- Cathodic protection equipment set

These rectifiers can be controlled or not by a specific electronic part, they can also be cycled "in and out of order" for some types of On-Off functioning. The adjustment of the current is made manually by the supervision agents, during their patrol, according to indications from the Voltmeter and the Ammeter on the control panel, or by remote control auxiliary circuits. A reference electrode placed near the pipe allows measuring the effective polarisation voltage {2} on a Voltmeter.

The cathodic protection equipment casing is connected to the local grounding for personnel safety. When the cathodic protection equipment is installed in a complex (Tank farm, Pumping Station etc …) some existing Green-Yellow connections connect the pipes to the meshed earth system associated with the cables of valve actuator (as an example) and with the cathodic protection generator casing.

I-3- Protection against the lightning for the cathodic protection equipment

In particularly, lightning exposed sites require effective protection.

As a reminder, the equipotentiality of the masses in a site is in accordance with the regulations required for the goods and personnel safety according to the 14 November 1988 decree. Furthermore, the low voltage electrical installation have to comply with the construction rules defined in the UTEC 15 100 norm of March 1991.

The lightning protection for a cathodic protection equipment is only advisable and its installation answers essentially to the needs of maintenance. In France, only classified sites have to comply with the January 28th 1993 decree on the lightning protection.

II - ELECTROMAGNETIC COMPATIBILITY (EMC) AND LIGHTNING SCHEME

The totality of the circuits of cathodic protection are outlined in fig. 2- (all values in Ω are given for example).

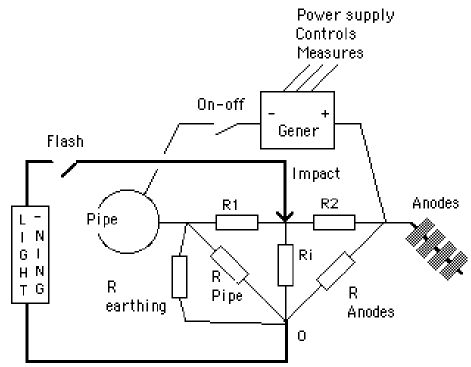

fig. 2- Lightning equivalent scheme

R1 - Resistor between pipe and lightning impact dot (7 Ω)
R2 - Resistor between anodes field and lightning impact dot (20 Ω)
R Earthing - Ground plane system resistor (8 Ω)
R pipe - Resistor to the earth for the pipe (5 Ω)
Ri - Resistor of earth from the dot of impact (12 Ω)
R Anodes - Resistor to the earth for anodes (2 Ω)

In this example, a supposed impact of a 10 KA lightning current shows 44,5 KV at the dot of impact and an 9,5 KV overvoltage into the cathodic protection equipment which will be consequently damaged.

III - OTHER EMC DIAGRAM - ZERO METHOD

The zero method {3} is an innovation which allows for solving EMC problems in large sophisticated electrical installations. Its principle is « sensitive equipment can not work correctly in a complex installation if its own references are not radioelectrically clean". This simplistic concept involves the HF equipotentiality where there is no HF voltage between 2 references (v = 0 for masses, energies, signals etc …) and there is no HF current in these reference connections (i = 0), this is by experimenting in the industrial range 10 KHZ to 10 MHZ, as in all other range of frequencies for particular applications (DC to GHz).

The zero method is coherent with the EMC standardizations for equipment and unit systems, and facilities and personnel safety. It helps in making good choices when apparent incompatibilities are observed.

The application of the zero method then entails "Zero" failure for the exploitation, against the auto-interferences or against the lightning effects, observed immediately with the setting of the corrections, and confirmed in long term by experience. This method is easy to understand, rapidly set up, and is also inexpensive.

The analysis by the zero method considers the equivalent of fig. 3- :

- A structure for setting the framework, connected to the ground for personnel safety
- A main input power supply
- The Negative polarity power connection to the pipe (or to several pipes)
- The Positive polarity power connection to the anodes field, often realized by a loop for redundancy

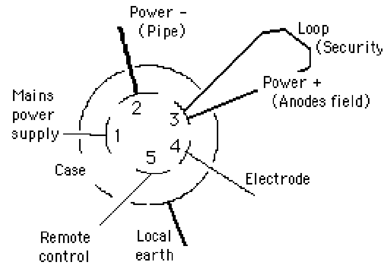

fig. 3- Bond of electromagnetic aggressions

- The possible insertion of a On-Off system allows for the polarization current to cut off abruptly. It is generally interconnected to the simplest power polarity, to open the departure "pipe"
- The arrival of the measuring reference electrode potential
- Remote control circuits

We see in the preceding diagram the different HF voltages developed between the case and the different entries or exits, or more generally by circular permutations between all the different references. The radioelectrical level noises confirm it and indicate the following to us :

- The cablings sensivity to observe disturbances,
- The image level of disturbances from the lightning, in correlation with the electromagnetic wave reception from the environment (radiofrequencies for example).

The foreseen protections objective is to eliminate these voltages and to derive the lightning currents towards inert circuits, out of the sensitive system that is the cathodic protection rectifier and its annex circuits in this study. The difficulty is not to displace known problems, **with all consequences of the return.(this is not clear to me)**

IV - DIFFERENT PSEUDO - AUTONOMOUS EARTHED CIRCUIT CONCEPT

An other analysis of the different circuits shows that 4 earthed circuits must be considered in a cathodic protection equipment fig. 4 - :

- The circuit of atmospheric discharges
- The earth and mass circuit of the site for personnel safety
- The earth circuit of the buried pipe
- The earth anodes circuit

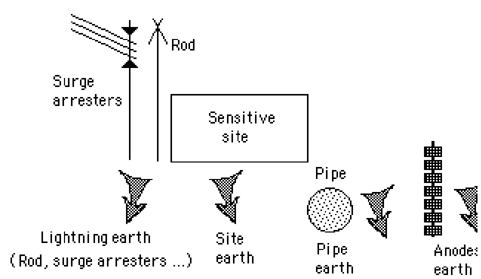

fig. 4- Functional earthed circuits

The measurement of each earth resistor can be made with the traditional 3 stakes method, or more conveniently with a direct method using a Tellurhommeter as an alternative current Ohmmeter.

IV-1- Cathodic protection failure

It appears in fig. 5- and 6- that part (sometimes the quasi-totality) of the protection current of the buried pipe goes through {4} the meshed earthed system.

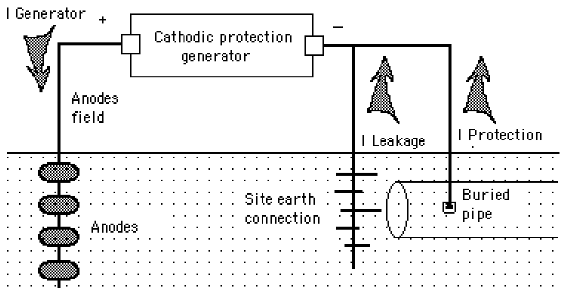

fig. 5- Derived currents in a site

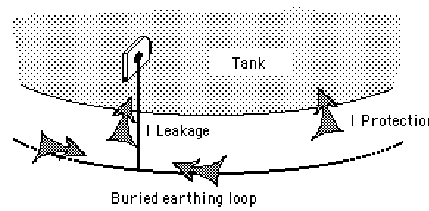

fig. 6- Into the tank bottom

We meet an identical situation (fig. 6-) with a tank bottom protection where the grounding is made by a naked cable in a trench bottom.

IV-2- Lightning protection

The functioning of the lightning surge arresters 20 KV and/or the flow of the lightning flash through a rod is going to create violent transitory currents in the ground. Experience shows that it is not conceivable that these currents take the pipelines as conductors, the risks of the coating damage being high. It is the same for sensitive circuits that have to ignore the presence of these high currents (zero method).

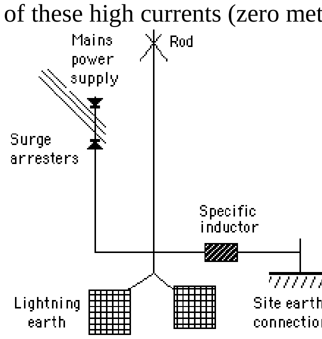

fig. 7- Derivated atmospheric charges

In this study (fig. 7-), a pair of redundant metallic plates (each about 1,5 m2) transfer correctly the atmospheric charges in the soil by using the surface and the capacitor effects. Stakes can't offer the same HF performances.

A specialized inductor inserted between the interconnection of the lightning earth and the meshed system will separate fictitiously the Low-frequency spectrum witch will flow to the earth system. This inductor behaves as an earth cable of classical size, whose loops would be rolled around a specialized magnetic nucleus.

V - RESOLUTION OF EQUIPOTENTIALITY PROBLEMS WITH INSULATING JOINTS

It is sometimes necessary to make a total isolation for the direct current between pipes into a site and external interconnection pipes (fig. 8-). This possible isolation is made with insulating joints (that are furthermore sometimes shunted by connections, the total isolation being only made temporarily during measures {5} of cathodic protection voltage).

The measure of radioelectrical interference directly on an active joint shows practically always a no-HF equipotentiality between the two edges. To satisfy both the HF equipotentiality and the absence of trouble in cathodic protection, it is necessary to shunt the isolating joint with the help of capacitors with short connections (not realised from a distance in the specialised measuring PC case), according to the following plan where 2 capacitors insure a redundancy.

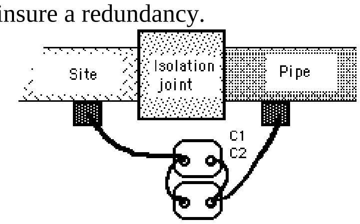

fig. 8- Continuity of the mass plan in HF domain

We can leave in place the surge arresters that are often installed on these insulating joints. They will constitute a supplementary security, but their action will be exceptional (short connections are recommended).

VI- RESOLUTION OF EQUIPOTENTIALITY PROBLEMS INTO THE SITE

The metallic mass interconnection is mandatory, in conformance with normalised connections, they remain unchanged and in place.

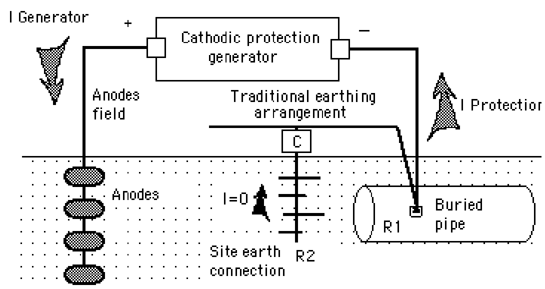

fig. 9- Pseudo - isolation for earthed circuits

On the other hand, the connection of the meshed system "in fact" with the earth potential (including the lightning ground) will have to comprise a pseudo-isolating function (fig. 9-) in the space of the polarization voltage.

This function can be filled by several capacitors with adapted value for circumstances, shunted possibly by surge arresters like zener diodes, … to insure the safety.

In the case of the protection of small tank bottoms < 15 m of diameter, we are currently studying the possibility to insert in each descent to the grounding cable, a set of capacitors and surge arresters.
In the case of the protection for great tank funds > 15 m of diameter (the connection to the earth being realized in fact by the flat bottom, equally for the personnel and goods safety, by resistor and capacitor to the ground), we study the suppression of the grounding cable associated with these tanks.

The following dimensional study intends to determine present general electrical values in order to find the actual realisation values. In first hand, we consider linear relationships with constant and simplified parameters according to the amplitude of the flowing current and the frequency spectrum.

An exhaustive study will have to be undertaken later in different aspects of no-linear or probable variability retained parameters so as to appreciate some influence over them.

VII - PRESENT ELEMENTS

We suppose a buried pipe set (or equivalent) is presenting a resistor R1 to the earth, for example 8 Ω. We suppose that a classic site referenced to the earth by its meshed mass system and its different well (not clear) earth presents an earth resistor R2, for example 2 Ω. We insert between these 2 earthing systems an equipotential connection for alternative current, insured by a capacitor C.

The other security devices in parallel on C do not intervene in this study.

VII-1- Researched equations

We can describe a set of electrical relationships existing between these 3 components (fig. 10-). The study of which frequency the capacitor C is a sufficient short-circuit. The aim is to have an impedance to the earth is appreciably near the meshed system impedance or on buried pipes.

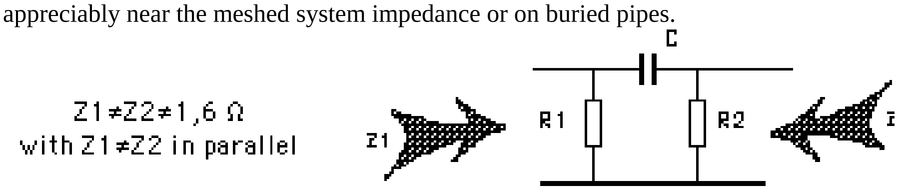

fig. 10- Impedances of earth circuits

The research of the equipotentiality for high frequency alternative currents in the area of the cathodic protection concerns 2 main circuits :

- The connection to the earth of the meshed earthed system,
- The insulators inserted joints between pipes.

VIII- THEORETICAL STUDY

VIII-1- Evolution of the impedances according to the frequency

$$\frac{1}{z} = \frac{1}{R_1} + \frac{1}{R_2 - \frac{j}{Cw}} = \frac{1}{R_1} + \frac{R_2 + \frac{j}{Cw}}{R_2^2 + \frac{1}{C^2 w^2}} \qquad \frac{1}{z} = \frac{R_2^2 + \frac{1}{C^2 w^2} + R_1 R_2 + \frac{jR_1}{Cw}}{R_1\left(R_2^2 + \frac{1}{C^2 w^2}\right)}$$

$$|z| = \frac{R_1\left(R_2^2 + \frac{1}{C^2 w^2}\right)}{\sqrt{\left(R_2^2 + \frac{1}{C^2 w^2} + R_1 R_2\right)^2 + \frac{R_1^2}{C^2 w^2}}}$$

VIII-2 - Graphs

From this general equation, we can trace 3 evolution curves of the impedances :

Xc = f(F)
Z1 = f(F), Clear totality impedance of the side Z1
Z2 = f(F), Clear totality impedance of the side Z2, obtained by Z1-Z2 permutation

Remain Z is the equivalent impedance for Z1-Z2 in parallel

VIII-3- Defect voltage

We can furthermore calculate the different voltages that are going to appear on component R1-R2 and C when a defect will make pass 10 A rms for example in the meshed earthed system (fig. 11-).

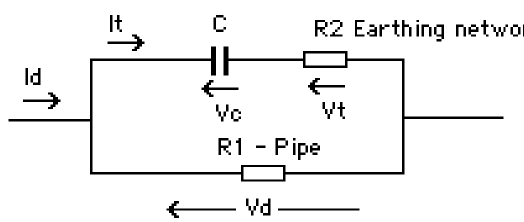

fig. 11- Equivalent circuits when a defect occurs

- Defect voltage : Vd V rms
- Current in the circuit of earth of the meshed earthed system : It A rms
- Current in the circuit of the driven buried : Ip A rms
- Voltage between conduct and earth : Vp V rms
- Voltage to milestones of the capacitor : Vc V rms

Relationships are following :

$$Vd\ rms = 10 * |Z_1| \qquad Vp\ rms = I_p * R_2$$

$$I_t\ rms = \frac{Vd}{R_1} \qquad V_c\ rms = \frac{I_p}{Cw}$$

$$I_p\ rms = \frac{Vd}{\sqrt{R_2^2 + \frac{1}{C^2 w^2}}}$$

IX - NUMERICAL APPLICATIONS FOR THE PSEUDO - ISOLATION OF THE MESHED SYSTEM

IX-1- Example in Pumping Station

We can take a typical value of :

- R1 = 8 Ω, Pipe-earth resistor of the site with its motorizations
- R2 = 2 Ω, resistor of the connection to the earth of the meshed system

The research of module Z1#Z2 shows that a 6 800 µF capacitor is sufficient to insure the equipotentiality from 50 Hz and beyond.

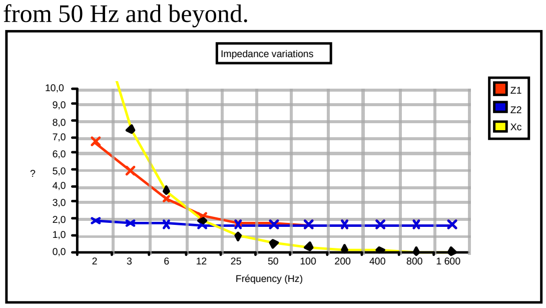

fig. 12- Evolution of the impedances of earth

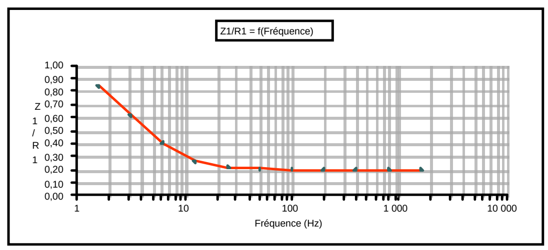

fig. 13- Impedances stability from 50-60 Hz

The curve fig. 12- shows the evolution of the impedances according to the frequency with preceding values. A significant relationship is the evolution of the ratio (fig. 13-) of the module Z1/R1 according to the frequency. We see although the stabilisation of the impedance to 1,6 Ω produces a bit before 50 Hz.

The technological realisation is not problematical since the voltage of isolation is continuous and can therefore use electrolytic capacitors (with weak resistor serie). Of capacitors supplementary HF some parallel insure the stability of the impedance in HF.

IX-2- Varying in valve enclosures for example

We can take a typical value of :

- R1 = 12 Ω, Earth pipe resistor of the site with their motorizations
- R2 = 6 Ω, Connection to the earth resistor of the meshed system

Here, a 2 000 µF capacitor is sufficient to insure the equipotentiality from 50 Hz and beyond. The stabilisation of the impedance about 4 Ω appears a bit before 50 Hz.

IX-3- Personnel and goods safety

The practical value calculation gives the table (fig. 14-) following for a defect current of 10 A rms at 50 Hz (10 A rms to return to 300 or 500 mA) :

R-C	Vd rms	Ip rms	It rms	Vt rms	Vc rms	t ms
8?-2? 6800 µF	16,4	2,1	8,0	16,0	3,7	68
12?-6? 2000 µF	41,2	3,4	6,6	39,8	10,6	36

fig. 14- Voltage of defect under 10 A rms

In TNS Neutral regime (or TNC but it is not recommended for sensitive sites), we notice that the voltage of defect Vd is appreciably the same as Vt.

The observation on the terrain of the quality of the connection to the earth resistor of the meshed system by stake shows that these last ones were not always of good quality, that suitable work of the resistor to the earth of the pipe coating which makes ground office for the complete site.

X - CASE OF INSOLATING JOINTS

We will preserve in first approximation preceding equations where :

- Pipe resistors of the site with their motorization R1 = 8 Ω
- External pipe resistor as compared to the earth : R2 = 5Ω

We no longer need to be interested in the frequency main power supply 50-60 Hz for example, it suffices that the equipotentiality bears to 1 KHZ, The voltage of isolation not being necessarily polarised, and we can use only alternative capacitors with weak HF losses.

Similarly, the constant of time introduced by the capacitor has to be very different constants of time in the presence to not entail trouble in cascade.

The calculation and graphs show that 100 µF (service voltage 250 V rms) is an economic and effective value, the stabilisation of the impedances to 3,2 Ω produced up 1000 Hz. Performances are again very acceptable to 2500 Hz with 50 µF.

X I- DUE EFFECT CYCLE ON-OFF

The cycle On-Off is a procedure that finally injects or not the continuous current in the resistor R2. The presence of the capacitor has for effect to create the transitory complementary current and periods to take into account to undertake the cathodic polarisation measurements.

C (µF)	F (Hz)	Imp (m?)	t (ms)	Delay (s)
30	50	106 103	0,3	0,0015
50	50	63 662	0,5	0,0025
100	50	31 831	1,0	0,005
2 000	50	1 592	20,0	0,1
6 800	50	468	68,0	0,34
10 000	50	318	100,0	0,5

fig. 15- Capacitors and performances

The table fig. 15- gives values of impedance of capacitors for the mains supply 50 Hz and the constant of time (for the cyclage On-Off) relative to a discharge resistor of 10 Ω. Practice values are easily calculated by proportions. The period of 0,4 second does not offer a problem.

XII - PERSONEL AND GOODS SAFETY

The analysis of the diagram fig. 16- shows 4 principal defect currents that can intervene in an installation under cathodic protection :

- Phase - System meshed
- Phase - Site earth
- Phase - Lightning Earth
- Phase - Pipe

Remembering that in a traditional installation, the capacitor C does not exist and it is replaced by a link or by an opened circuit.

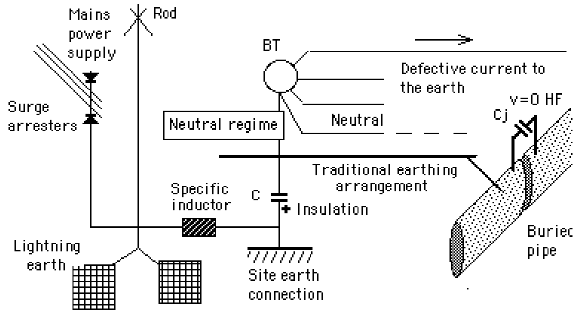

fig. 16- Insurance of the personnel safety

The personnel safety is better insured that in traditional configurations we notice that the creation of a good quality ground for the site and an other for the lightning will not disturb the cathodic protection for the pipe.

XIV- INTERVENTION SPSE

XIV-1- Presentation SPSE

The South-European Pipeline (SPSE) ensures the provisioning of the refineries and petrochemical platforms on the Fos-Karlsruhe axis (769 km) in 3 different countries (France-Switzerland-Germany).

The South-European Pipeline uses 3 main lines, pumping stations, other facilities for storage and delivery of the crude oil.

XIV-2- Introduction

The practical application of the zero method by SPSE since 1992 showed the effectiveness of this method on our facilities. This methodology was used in cathodic protection in order to protect the impressed current equipment against lightning and to deal with problems of earthings.

XIV-3- Problems analysised

Main damage on the impressed current equipment :

- Destroyed diodes.
- Destroyed auto-transformers.
- Release of the safety measures.

The consequences of this damage are the absence of cathodic protection on the lines and the additional expenses of maintenance (the lowest cost : 200 Euros; the highest cost : 5 000 Euros).

The risk of corrosion can be significant depending on the surrounding medium and the time needed for repairs.

Earthing problems

Earthings of the facilities for personal security penalise the underground facilities cathodic protection. Indeed an earthing is the equivalent of a coating defect and calls current.

The cathodic protection of our pipeline 34 inches on the Strasbourg-Karlsruhe section was insufficient on several points. This was more sensitive near the valves enclosures and on the delivery facilities.

XIV-4- Step and study

Impressed current equipment

During the work process, various previous studies impressed some current facilities that were protected against lightning accidents. The implementation of the recommendations of the study reinforced the reliability of the rectifiers.(No accidental statement for 5 years).

Cathodic protection and earthed circuit

In order to reinforce cathodic protection, a study was carried out on the earthed circuits. The aim was to highlight any current loss due to the earthed circuits.

By the insertion of an electrochemical condenser between the ground circuit and the line (from the point of view of the D.C. current only), the pipeline was isolated from the earth circuit. This way the pipeline potential was increased and the protection criterion was reinforced on the whole of the section.

This operation was carried out on valves enclosures because the earthed circuits are simple and easily identifiable.

XIV-5- Assessment

The results were good. The protected facilities didn't suffer any more damage. Currently we plan to treat the totality of our impressed current system because damage is possible on unprotected facilities. These improvements will bring our lines guaranteed quality protection.

Potential measurements on the Strasbourg-Karlsruhe section are satisfactory and the threshold of protection is reached on each point. The solution of insertion of a condenser improves cathodic protection and makes it possible to ensure the safety of people.

This technically satisfactory solution, must however be validated by the French authorities {6} before being generalised on our installations.

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