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Cathodic protection of a buried pipeline by solar energy

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Résumé – *La protection cathodique est employée intensivement sur les canalisations en acier dans l'industrie de pétrole et de gaz. C'est une technique de prévention contre la corrosion qui transforme la canalisation entière en cathode d'une cellule de corrosion. Deux types de systèmes de protection cathodiques sont couramment appliqués. Les systèmes de protection galvanique utilisent les anodes galvaniques, également appelées les anodes sacrificielles, qui sont électrochimiquement plus électronégatives que la structure à protéger et les systèmes à courant imposé, par le biais d'un générateur qui débitera un courant continu de l'anode vers la structure à protéger. L'article proposé contribue au dimensionnement d'un système de protection cathodique, par courant imposé, avec appoint électrique d'énergie solaire, appliqué à un pipeline.*

Abstract – *Cathodic protection is employed intensively on the steel drains in oil and gas industry. It is a technique of prevention against the corrosion which transforms the structure into a cathode of a corrosion cell; Two types of cathodic protection systems are usually applied: The galvanic protection systems use the galvanic anodes, also called the sacrificial anodes, which are electrochemically more electronegative than the structure to be protected, the other system is by imposed current, powered by electrical generator with D.C. output towards the structure to be protected. The object of this study is to design a cathodic protection system by impressed current supplied with solar energy panels applied to a pipeline.*

Keywords: Corrosion - Cathodic protection - Impressed current - Buried pipeline - Photovoltaic.

1. PRINCIPLE OF CATHODIC PROTECTION

The principle of cathodic protection is based on the idea to reverse the electrochemical role of the structure to be protected by supporting a cathodic reduction on its level, and by deferring the reaction of oxidation on another structure which we accepts the degradation. A thorough grasp of the subject can be found on two major references, [1, 2].

2. DESIGN OF THE CATHODIC PROTECTION SYSTEM FOR A PIPELINE

The well know cathodic protection system is implemented for a pipeline, used or fluid processing [3], mainly described by some characteristics, summarized in **Table 1**.

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Table 1: Some characteristics of the pipeline [3]

Material	Steel X60	**Isolation resistance :**	8000 Ωm
Length	292 km	**Linear isolation resistance**	3340 Ωm
External diameter	0.762 m	**Longitudinal isolation resistance**	$7.49\ 10^{-6}$ Ωm
Surface to protect	$699020 m^2$	**Attenuation coefficient**	$47.35\ 10^{-6} m^{-1}$
		Characteristic resistance	$158.16\ 10^{-3}$ Ω

The elements which constitute a cathodic protection system by impressed current supplied with solar energy are as follows, (Fig. 1). As a remark, the system proposed is not the only one and not the only used in industry, the one chosen serve as purpose to develop further optimized combination of solar and cathodic elements.

- An impressed cathodic current system consisted of one or several stations laid out in a box including: electric meter, circuit breaker, rectifier of transformer, output voltage, voltmeter, ammeter.

- Photovoltaic generator made up of the following elements:
  - Photovoltaic modules of solar cells
  - A control and regulation system.
  - A storage system.
  - An inverter from D.C. to A.C.

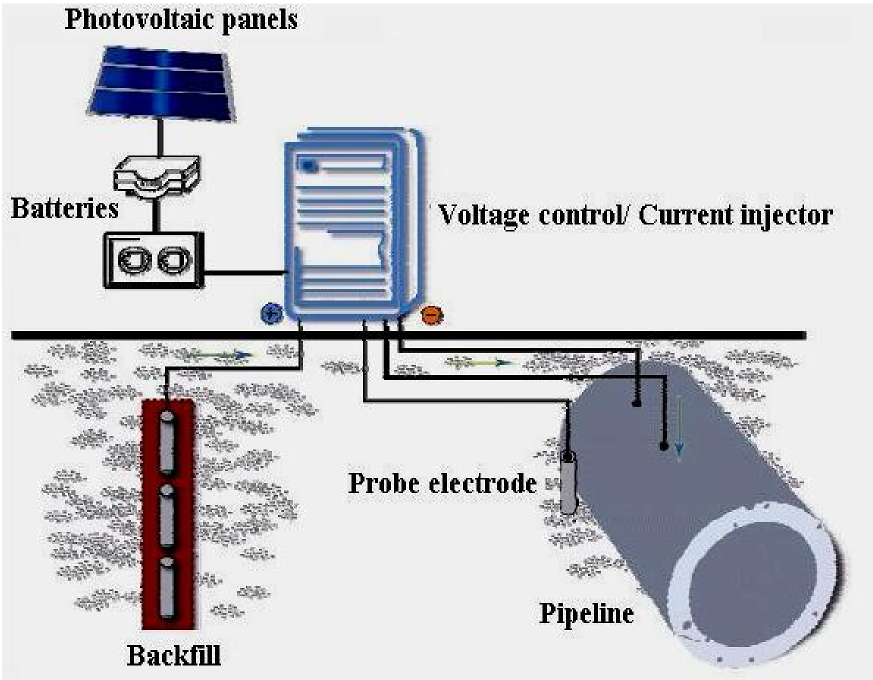

Fig. 1: Schematic design of the impressed cathodic protection

3.DESIGN AND CALCULATION

The essential of cathodic protection is based on two parameters, the evolution of the potential and the current of protection. The formulas used for the calculation of the potential and the current are deduced from the resolution of the well know Laplace equation [4] for the evolution of the potential along the pipeline [5].

Table 2: Current and voltage of the cathodic protection system

General formula	
$E_x = E_s \,ch(a \times x) - I_s \times g \times sh(a \times x)$	(1)
$I_x = (E_0 / g) sh(a \times x) + I_0 \times ch(a \times x)$	(2)
$E_s = E_L \, ch(\alpha L)$	(3)
$I_s = (E_L / \gamma) \, sh(\alpha L)$	(4)
Used formula	
$I_x = \dfrac{E_s}{g} \dfrac{sh\left[a\,(L - x)\right]}{ch\,a\,L}$	(5)
$E_x = E_s \dfrac{sh\left[a\,(L - x)\right]}{ch\,a\,L}$	(6)

The resistance per unit length or resistance load is expressed as R expressed as resistance in Ω m² divided by πD, D the diameter of pipeline.

According to the general formulas (3) (4) the maximum length that be protected, according to the criteria of cathodic protection, is estimated by the following formula:

$$E_s = E_L \, ch(\alpha L) \;\Rightarrow\; L = (1/\alpha) ch^{-1} (E_s / E_L)$$

The results are shown in figure 2 and figure 3.

The steps elaborated to the design are:

1. Estimate the cathodic protection voltage and current according to equations (3) and (4) and estimate electric power requirement per day.

2. Estimate the optimal angle of the photovoltaic plane sensor to reach the maximum of electrical energy output. We used a numerical algorithm which makes it possible to determine the optimal angle orientation for any geographical site.

3. Design the anodic backfill: The backfill is used to inject the current of cathodic protection in the ground. The mass of the backfill is calculated so the installation has one lifespan of 15 to 20 years.

There are two types of configurations [6]; the surface and in-depth backfill. To choose the configuration of the backfill, we calculate the critical value of the soil resistivity, i.e. value below which the backfill considered can be set up.

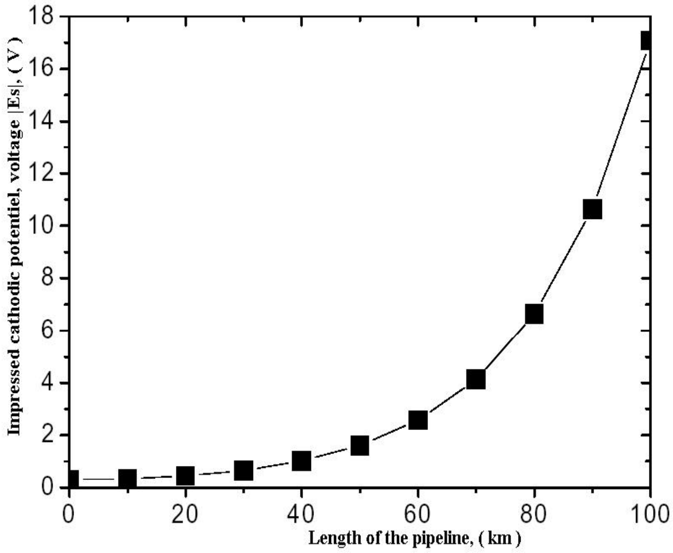

Fig. 2: Evolution of the potential according to the protected length

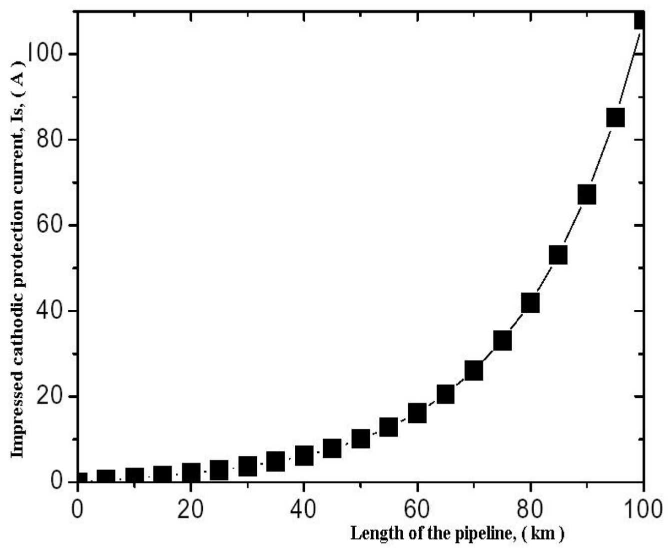

Fig. 3: Evolution of the current following the range of protection

On figure 4, we translates the values of the resistivity limits for the use of a bed of anodes according to the range of the impressed current stations, thus for 25 km lengths, the limiting resistivity is located between 150 Ω m and 155 Ω m.

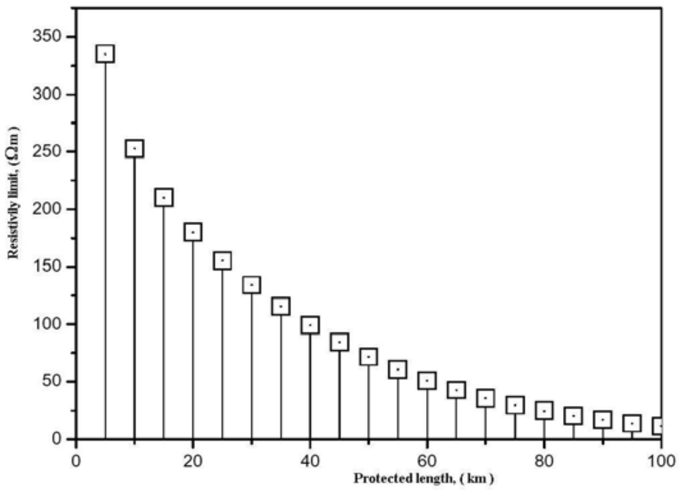

Fig. 4: Resistivity limit for the design of the backfill type

4. NUMERICAL RESULTS

In order to obtain an efficient and costless numbers of branches and thus numbers of modules per branch, the nominal voltage of the solar generators is limited to 24 V.

The results of calculation are gathered in **Table 3** and **Table 4**. We found that the mass of the backfill remains the same 14.4 tons, and the numbers of anodes required are 5, indeed this result rises from the homogeneous position of the transformers-rectifiers, i.e. the length for which the single station is designed for is about 25 km.

Table 3: Numerical results of the design of the backfill

Station	Length (km)	Anode Design (m)	Depth of the anode (m)	Anode spacing (m)	Single anode Design (m)	Length of the connecting cables (m)	Ground Resistivity (Ω m)
1	25	385	425	95.87	1.525×0.0508	1208.68	1 999.16
2	75	611	651	152.37	1.525×0.0508	1773.68	3 002.79
3	125	386	426	96.12	1.525×0.0508	1211.18	2 006.17
4	175	38	78	9.12	1.525×0.0508	341.18	276.00
5	25	23	63	13.62	1.525×0.0381	56	151.98
6	275	2	42	3.12	1.525×0.0381	14	28.65

Table 4: Numerical results for the design of photovoltaic panel

Current Protection (A)	Nominal Current (A)	Output Voltage (V)	Number of modules	Number of batteries
2.807	3.650	24	10	14

5. CONCLUSION

The results shows, that the impressed current configuration by the solar photovoltaic panels ensures the protection of the pipeline, cathodic protection criteria are reached.We deduced this following observation:

- The method is applicable for various types of grounds. The system can be implemented with effectiveness, since the number of modules is acceptable; 10 modules with 14 batteries.
- The range of the protection potential is broad and the system can be adapted for different material constituting the pipeline
- Output current are controlled and can be varied
- The output current is high enough to protect the pipeline with low costs.

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