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Validated Numerical Modeling of Cathodic Protection for Submerged Pumps

Case study: ADE- Adrar.

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***Abstract*— Cathodic protection is a very effective method to prevent corrosion of buried structures. The method has been successfully used in the oil and gas industry for decades. In this paper, we investigate the applicability of the cathodic protection method to immersed pumps. The system considered in the study is powered by photovoltaic cells. A model was developed to simulate the system using a finite elements method. This paper describes the methodology used to develop the model and presents preliminary results.**

***Keywords*— Photovoltaic Conversion, Cathodic Protection, Corrosion, Submerged Pumps, Finite Elements.**

I. Introduction

Any material submerged in the ground, permeable to air and water, can sustain severe deterioration by different types of corrosion in the course of time. In the ground, metals are in the form of complex but stable chemical combinations called ores. These ores are in a thermodynamic state of balance according to the physicochemical conditions of the ground. By transforming these ores, man breaks their thermodynamic balance. Thus metals tend is to find a stable combination by a series of electrochemical reactions which is the very essence of corrosion [1]. In our work, we are interested in the corrosion that attacks the submerged pumps used by the Algerian company of water (Algérienne Des Eaux, ADE-Adrar).

II. CORROSION OF SUBMERGED PUMPS

Corrosion is only a return voyage of metal towards its origins. To fight against corrosion, it is necessary to prevent metal from beginning this return voyage. This is done by methods of protection, either by a passive protection (by interposition of a barrier between metal and the aggressive environment), or by an active protection (cathodic protection) or a complete protection (by combining passive protection with active one as an economy and safety measure). On the level of ADE-Adrar, there are several hydraulic works. Different types of pumps are then used and submerged to 48 m in depth. The pumps powers lie between 37 and 75kW with rates of flow water between 30 and 60 l/s. The lifetime of used pumps is approximately estimated at five years only. Fig.1 presents photos of submerged pumps in a state of corrosion. The second photo of Fig.1 shows a corroded pump of ADE, so it cannot be used again.

Fig.1 Examples of the pumps deteriorated by corrosion

III. CATHODIC PROTECTION

A. Principle of method

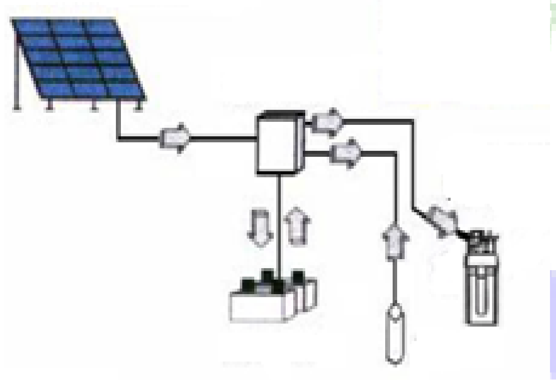
The principle of cathodic protection is based on the idea of reversing the electrochemical role of the structure to be protected by supporting a cathodic reduction on its level, and by deferring the reaction of oxidation on another structure which we can tolerate its degradation. More detailed information about the subject can be found in two principal references [2, 3].

The cathodic protection allows protecting a metal against corrosion. In order to modify the potential of the metal to protect, we use an anode installed in the same electrolyte. The used anode can be of two kinds: anode with potential that is more electronegative than the protected metal (sacrificial anode method) and anode coupled with generator of direct voltage that imposes a potential difference between the two metals (imposed current method).

B. *Methods of modeling cathodic protection*

The PROCOR software for sizing and simulation of cathodic protections allows verifying the required principal sizes in order to optimize the protection system [4]. Information resulting from numerical simulation can be confronted with measured data too. There are other types of modeling software such as COMSOL Multiphysics by finite elements method.

The study is based on the system developed by S. KHARZI (CDER-Algeria) [5]. The elements which constitute the cathodic protection system by imposed current delivered by photovoltaic system are represented in Fig. 2. The photovoltaic solar system is the best solution for supplying electricity in order to prevent corrosion of metallic structures, pipelines, submerged pumps, storage reservoirs and other exposed equipments.



Structure to protect

Fig.2 Cathodic protection system powered by photovoltaic solar energy

In our research project, under the direction of M. ALLALI, entitled: Energy optimization of an electrical network by the integration a renewable resource: Case study: ADE-Adrar. My task done in this project is to protect the submerged pump used by cathodic protection; the pump is of type Lorentz PS 600 HR-07. The domains of application are:

- Drinking water supply
- Pond management
- Irrigation
- Livestock watering
- Pressurizing system

The characteristics of this pump are:

- Fast, failure-free installation
- Excellent serviceability
- High reliability and life expectancy
- Short Return of Investment (ROI) cycle
- Lower Total Cost of Ownership (TCO)

We will use this pump in drilling of ADE (Tililane 4), where the pump is cannot be use because of its deterioration by corrosion, we use this type of pump to increase the lifetime more than five years, we can used it for 15 to 20 years.

IV. MODELING

A. *Theory*

The potential distribution within the electrolyte of a galvanic system is fundamentally based on the continuity equation for conservation of charge in the electrolyte [6, 7]:

$$-\nabla i = \frac{\partial q}{\partial t} \quad (1)$$

In a steady state system we have: $\frac{\partial q}{\partial t} = 0$ and $\nabla i = 0$

The relationship between the electric field intensity and the electric potential is presented in the following equation:

$$E = -\nabla \emptyset \quad (2)$$

The Ohm's law is presented by:

$$i = \sigma E \quad (3)$$

Where σ: is the electrical conductivity of the electrolyte, and the electric field is related to the electrochemical potential $\emptyset$ by:

$$E = -\nabla \emptyset \quad (4)$$

From the above, the continuity equation becomes:

$$\nabla \sigma \nabla \emptyset = 0 \quad (5)$$

and for constant, isotropic conductivity this yields:

$$\nabla^2 \emptyset = 0 \quad (6)$$

which is Laplace's Equation for the potential distribution within the electrolyte.

B. *Problem Description and Geometry*

The amount and rate of corrosion can be correlated to the electrochemical potential distribution within a system. The goal of this project is to develop a finite element model that can be used in conjunction with experimental data to characterize the corrosion of a galvanic couple in an electrolyte [6, 8]. The model geometry proposed is a simple model of coplanar electrodes as shown in Fig. 3. It was developed to represent the electrolyte of the system being model.

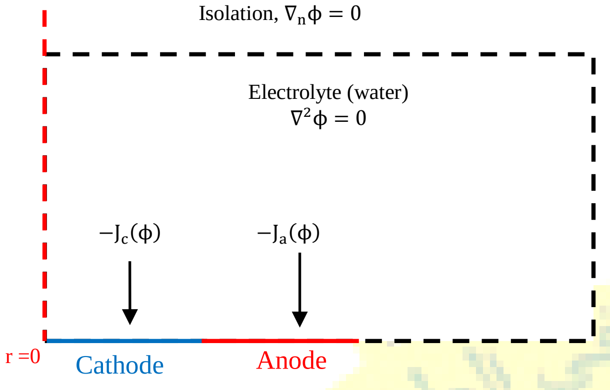


Fig.3 Model geometry of system:
Electrolyte domain with axial symmetry

The cathode is our pump, is made of steel, it protect by anode which is made of zinc.

C. Initials values

The electrolyte potential initial value is set to the same value as in the boundary condition at anode. In Subdomain Settings, the electric conductivity of water at temperature 20°C is 1.1µS /cm [9]. The parameters values according to the couple galvanic, zinc/ steel are given in [10].

D. Boundary conditions

This project utilized the finite element program COMSOL Multiphysics to solve Equation (6) for selected systems [11]. The governing equation for the potential must be solved subject to appropriate boundary conditions. The Butler-Volmer equation gives the total current density at any electrode-electrolyte interface as:

$$i_{net} = i_{anodic} + i_{cathodic} = i_0 exp[a_{anodic}\, zF(\emptyset - \emptyset_0)/RT] - i_0 exp[-a_{cathodic}\, zF(\emptyset - \emptyset_0)/RT]$$

Where:

i_0 : the exchange current density,

a_{anodic}, $a_{cathodic}$: the transfer coefficients for the anodic cathodic reactions, respectively,

$\emptyset_0$: the equilibrium electrode potential,

z : the number of electrons involved in the reaction,

F : Faraday's constant,

R : the gas constant,

T : temperature.

V. RESULTS AND DISCUSSIONS

Solving the Laplace equation (6) allows us to draw the distribution of potential. Figure 4 shows a revoved surface of the electrolyte potential and total current density.

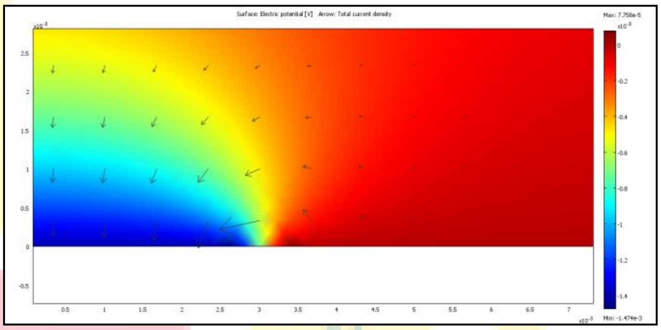


Fig. 4 Surface and arrow plot of electric potential and total currenr density

The figure 5 show the distribution of potential, the potential varie from the chatode to anode, which means that potential of zinc is more important than that of steel.

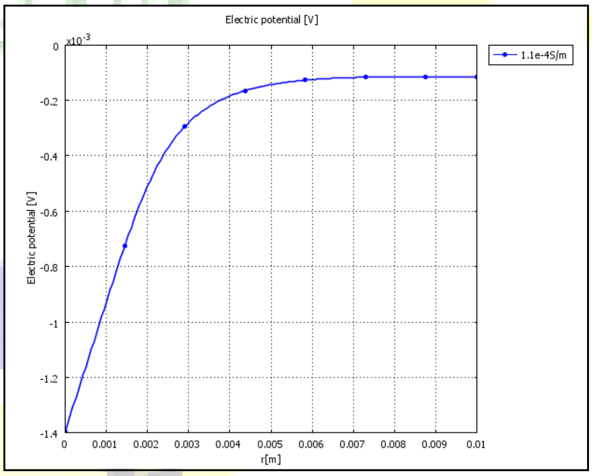


Fig.5. Distibution of electric potential for constant electrical conductivity

VI. CONCLUSIONS

The cathodic protection of steel with zinc is calculated in this work by COMSOL Multiphysics. We notice that, the operating electrode potential which is the difference between the electric potential and the electrolyte potential, as an important factor for the corrosion. The method has been successfully applied for submerged pumps as used in the oil and gas industry.

Zinc is often used in contact with steel, apparently the corrosion product of zinc, in this case, the fact behave as a more noble surface than steel, the protection of steel with zinc is ensured.

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