Feasibility of Using Impressed Current Cathodic Protection Systems by Solar Energy for Buried Oil and Gas Pips

Talebzadegan Mohsen, Abodi Ali, Riazi Iman

Abstract ***Cathodic protection mostly used to protect buried structures of oil and gas pipes in oil and gas industries from corrosion. Cathodic protection by impressed current method includes the formation of an electrolyzed system in which anode and cathode is obtained by direct current generator. installing one or more anodes of cast iron adjacent to a structure and the structure and the anode(s) are connected respectively to negative and positive poles of the supply. In the present study, by collecting actual soil data of the region, mechanical specifications of oil transfer pipes and their coating in Ahwaz region and also using available calculations and manuals regarding types of anodes and solar panels and batteries in the market a region-specified solar Cathodic protection method was designed. By calculations, the best type of solar panel (AT-50), number of panels and their voltage and produced current were obtained 42, , 52.2V and 40.04 A, respectively. The proposed battery is sealed lead acid type with number, voltage and current of 4, 48V and 250 A, respectively.***

Keywords : Cathodic protection-impressed Current-buried pipe

I. INTRODUCTION

The great reliance of industrial countries on energy resources, especially oil fuels and their excessive consumption, takes away huge resources that have been formed within earth layers over centuries. Since the underground energy resources are extracted by human on a fast pace and will come to an end in very near future, today generations are bound to shift their focus towards energy resources with longer life cycle and develop the related knowledge.

Simple technology, environmental-friendliness, and above all,is the reservation of fossil fuels or change that to worthwhile material, using petrochemical techniques are major reasons that introduces solar energy as a reliable alternative to the existing energy resources. Cathodic protection first introduced by Humphry Davy in 1824 in London. Independent researches were conducted afterwards focusing on embedded structures in soil [1]and liquids [2].

Similar research in Algeria [3] regarding Cathodic protection on embedded pipes by solar energy came to the following results. The number of panels and their voltage and produced current were obtained 15, 24 V, 3.65 A, respectively. Fourteen batteries were used in this research.

A. A.Photovoltaic Phenomenon

Photovoltaic is a phenomenon in which and without using any mechanical mechanism, solar energy is converted to electricity. Any system using such phenomenon is called photovoltaic system. The phenomenon is theoretically based upon particle theory of light energy. Photovoltaic cells are quite often made of semi-conductive materials such as silicone found in sand and gravel. When the cell is subject to light, a portion of light will be absorbed by the semi-conductive materials and the resulting energy moves free electrons, which finally recharges the electrical current.

B. Cathodic Protection Design for a Steel Pipe Line

The pipe line network survey used to apply solar cathodic protection system relative to Oil pipe line network of Ahwaz Region owned and managed by National Iranian South Oil Company.Special care was taken to select and use realistic parameters during design stage in order to achieve actual results. The parameters are presented in Tables (1) to (3).

Table (1): Soil Parameters

Parameter	Quantity
Soil Moisture	70%
Soil Temperature ^{0}C	35
Soil pH	7.5
Average Groundbed Special Resistivity Ω/Cm	ρ =1200
Average Groundbed Special Resistivity along Soil and Pipe Embedment Depth Ω/Cm	ρ <4000

Table (2): Mechanical Characteristic of Steel Pipeline

Weight per length (kg/m)	Outside surface (m^2)	Pipe Length(M)	Nominal pipe diameter(inch)
5.42	9.85	52	2
17.25	317.41	6000	6
25.38	4818.21	7000	8
	SUM=8000.47		

Table (3): Assessment of Steel Pipeline Coating and Features

Pipe line Characteristic	Type and Quantity
Pipe Material	Carbon steel API-5L
Coating Type	
Deterioration of Pipe Coating	8%
Coefficient of Embedded Piping Extension	200%

C. Design and Calculations

The design of cathodic protection systems basically depends upon the amount current into the system and protection voltage. The detailed system design and assessment are discussed below.

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D. Calculation of Current into the System

Considering the soil special resistivity of the region ($\rho < 4000$) and referring to Table (4), which is essentially derived from Ref. [4], the current density required for a bare pipeline is determined to be 10 mA. Also, by assessing the extent of deterioration of the pipeline coating as per visual observations, the type of coating applied and the extension coefficient of embedded pipeline network, one can calculate the maximum current requirement for an impressed current cathodic protection system

Table (4): Current Density Required by Cathodic Protection System

Electrolyte Type	Required Current in Area Unit of Bare Pipeline(mA/m^2)	Soil Special Resistivity (Ω/cm)
Sea Water	100	25-100
Highly Saline soil	25	100-1000
Highly Corrosive Soil	10	1000-5000
Corrosive Soil	5	5000-10000
Low Corrosive Soil	1	>10000

$$I = S \times i \times K \times C \quad (1)$$

where:
I: maximum current required by system
S: pipe side surface
i: current density as required by system with bare structure
K: extension coefficient of embedded petroleum pipeline network
C: damage coefficient
Finally, using relation (1) and values derived from the related Tables (2),(3), the required current into the system was determined I = 12.8 A.

E. Determination of Number of Anodes

By selecting metal oxide coated titanium (mixed metal oxide 150 2.5×50) according to the specifications of standard anodes (ref. Table 5) as the system anode, the number of anodes required can be determined using Eq. (2).

Table (5): MMO Anode Characteristic

Type	ISO2.5x50S
Electrolyte Type	soil
Length	50 Cm
Diameter	2.5 Cm
Side Surface	0.039 Cm
Weight	0.56 Kg
Maximum Current Output	4Amp
Consumption of One Anode per Ampere in year per kilogeram	0.0045
Anode Efficiency E_F	0.7

$$N = I_t / I_n \quad (2)$$

where:
N :number of anodes required
I_t: maximum current required by system
I_n: anode current output capacity

Then, by using relation (2), the number of anodes required by the system is determined to be 4 anodes, which is a high number taking into account the ground bed resistivity,so in order to reduce the resistivity and increase the current output, anode useful life and system reliability, the number of anodes was increased to 5 (N = 5).

F. Calculation of Minimum Voltage Required by System

The required voltage to a cathodic protection system can be calculated by Ohm's Law as follows:

$$V_{min} = I_t (R_w + R_N + R_C + R_P + R_E) + V_B \quad (3)$$

The required voltage is determined by using current required by the system in Amp (I_t), lead wires resistance in ohmR_w, anode bed resistance in ohm (R_N), coating resistance in ohm (R_C), Pipeline resistance in ohm (R_P), soil resistivity between groundbed and pipeline which is negligible (R_E), return voltage between groundbed and pipeline, almost 2 V (V_B). Pipeline resistance in ohm (R_P)is calculated by Eq. (4) for each pipe and the results will be summed. In Eq. (4), W represents the weight of one foot of pipe with diameter N.

$$R_P (N") = (3.3/4w) \times 10^{-3} \times L \quad (4)$$

Finally, total pipe resistance is determined by adding upR_P ,0.52 Ω.
To calculate pipe coating resistance, the following relation is used:

$$R_C = r_{cs}/S \quad (5)$$

The required coating resistance R_C = 0.5 Ω is calculated using total coating resistance R_C in ohm, coating surface unit resistance (r_{cs}) and side pipe surface in (S).
Cable resistance is calculated by Eq. (6)

$$R_w = \rho L/S \quad (6)$$

If the ground bed length is supposedly 50 m, considering the available standards that emphasize the use of wires with suitable size (i.e. anode wire of double-coated type with PVC coating and section of $1 \times 35mm^2$, lead wire of N-Box type to pipe $1 \times 25mm^2$ and return wire of $1 \times 16mm^2$ and lead wire steel to N-Box of $1 \times 16mm^2$), the approximate amount of wires required was determined.
By using data from Table (7) , the total wire resistance in this study was determined R_W= 0.15 Ω

Table (6):Wire Resistance

Wire Section(mm^2)	Wire resistance per length (Ω)
16	0.00108
25	0.00069
35	0.000439
50	0.000345

In order to determine groundbed resistance, first the exact bed length with anodes spacing of 2.5m center to the center taking into account 40 cm empty spaces at the beginning and end of the groundbed was calculated in foot.
Then, by referring to groundbed resistance graph for a ground with groundbed soil special resistance of ρ = 1000Ω and consulting available references for special soil resistance coefficient of the groundbed resistance ρ=1200Ω, groundbed

resistance was obtained R_N = 62 Ω.
Now by using current and total resistance values, we can determine the voltage required for the impressed current cathodic protection system from Relation (3) as V =37.74V.

G. Calculations Related to Solar Panels and Batteries

Solar panels generate electricity only when they are subject to solar radiations. In order to generate electricity without solar radiations, sun presence during different months of a year needs to be determined.
The maximum power to be generated by panels per second in order to supply the cathodic system and battery saving to consume during non-presence of solar radiations is calculated through the following equation:

$$P_p = \left(24/h_{pr}\right) \times P_s \times 1.6 \qquad (7)$$

Where by using maximum power generated by panels (P_p) in W, duration of solar radiation overnight in hrs on Dec. 21st (h_{pr}) and power required by Cathodic protection system in W (P_s) (in this case W=483 w), the amount of power required by panels is determined to be almost 1855 W.
The actual voltage, current and the power required to be generated by the panels per second is given in table (7).

Table (7): Panels power supply

subject	Quantity
Voltage	40.4 Amp
Current	38.05 V
Power	1855

Considering the amount of voltage, current output capacity and power required by solar panels, their dimensions and the economic aspects of any choice, High Power AT50 Solar Modules, consisting of silicone, multi-crystalline cells with the required features, was selected.
A solar panel is generally composed of 30 solar cells in series whose characteristics are given in Table (8)

Table (8): Characteristics of Solar Panels AT50

Subject	Quantity
Open circuit voltage	21.50 V
Short circuit current	3.30 A
Voltage in MPP	17.50 V
Current in MPP	2.86 A
Nominal Power	50 W
Number of cells	39
Solar cell sizes	135×67 mm
Dimension	430×970×34 mm
Weight	5.4Kg

In order to obtain the required voltage and current for the panels, according to Table (1), a combination of series and parallel configurations of AT50 panels is required to be used. First, agrid of 14 strings, producing a current of 38.05A with 3 panels in series along each string with the aim of supplying potential difference of 40.4 V, is wired, then the strings are wired in parallel and a set of 42 panels is developed.
With adequate solar radiations available, the batteries are charged by panels to supply the required energy to the system during nights or days when sunlight is unavailable. The selected battery type was Sealed Lead Acid type, which seems to be an appropriate choice due to its long useful life, which is almost as long as that of cathodic protection system. The battery should supply power to the system for 14 hours overnight (Table 10). Four 12 V, 250 A Sealed Lead Acid type batteries are required.

H. Numerical Results:

The general results of calculations are given (9) and (10).The results indicate that the selection of anode was an appropriate decision for 5 items. Also, one should not forget the fact that such results were partly due to site consistency i.e. the site protection depth was cautiously taken into consideration.

Table (9): Numerical Results of solar Generator Design

Type of Panel	AT250-17.5V – 2.86 A
Number of AT 250 panels	42
Generated voltage	52.2 V
Output current	40.04 A
Generated power	2102 W
Size	42×0.43×0.97=17.5 m^2
Weight	226 kg
Type of battery	Sealed lead acid 12V-250 Ah
Number of batteries	4
Battery Voltage	48 V
Battery Current	250 Ah
Battery Size	4×0.53×0.24×0.225

Table (10): Numerical Results of Cathodic Protection Design

Subject	Quantity
Minimum current required by system	7.867 A
Number of anodes required	5 Ω
Pipe resistance	0.765Ω
Coating resistance	0.51 Ω
Cable resistance	0.17 Ω
Voltage required by system	48V
Power required by system	755W
Protection depth	8979.1m
System lifespan	32 Years
Ground bed resistance	1.52Ω

CONCLUSIONS

1. Reducing costs related to electrical energy consumption at site and saving electricity consumption
2. Generate-to-consume capability, reduction in electricity transmission and distribution costs and no need for comprehensive electrical grid
3. Capability to install and operate system with different powers compatible with consumer requirements
4. Long lifespan and easy to operate
5. Capable of saving energy in batteries and supplying energy for hours without solar radiations
6. Controlled and changeable output current
7. Since protection potential is broad, the system can be adopted for different pipelines/different materials

Notations:

English notations	
pipe side area m^2	S
current density required for uncoated surface	I
network extension coefficient	K
damage coefficient	C
maximum current required for protection (Amp)	I_t
anode current passage (Amp)	I_n
bed length (m)	L
Resistance (Ω)	R
system voltage (v)	V
panel generated power (w)	P
power required for protection Cathodic system (w)	P
Greek notation	
density kg/m^3	ρ

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