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ICCP cathodic protection of tanks with photovoltaic power supply

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Abstract. Corrosion is the result of the electrochemical reaction between a metal or composite material usually having conducting current properties. Control of corrosion related defect is a very important problem for structural integrity in ground based structures. Cathodic protection (CP) is a technique to protect metallic structures against corrosion in an aqueous environment, it is employed intense on the steel drains in oil and gas industry, specifically to protect underground tanks and pipelines. CP is commonly applied to a coated structure to provide corrosion control to areas where the coating may be damaged. It may be applied to existing structures to prolong their life. There are two types of cathodic protection systems: sacrificial (galvanic) anode cathodic protection (SACP); the other system is Impressed Current Cathodic Protection (ICCP). Majority of the structures protected employ impressed current system. The main difference between the two is that SACP uses the galvanic anodes which are electrochemically more electronegative than the structure to be protected - the naturally occurring electrochemical potential difference between different metallic elements to provide protection; ICCP uses an external power source (electrical generator with D.C.) with inert anodes, and this system is used for larger structures, or where electrolyte resistivity is high and galvanic anodes cannot economically deliver enough current to provide protection. The essential of CP is based on two parameters, the evolution of the potential and the current of protection. A commonly accepted protection criterion used for steel is a potential value of minus 850 mV. ICCP system consist of anodes connected to a DC power source. As power sources may be used such as solar panels, wind turbines, etc. The object of this study is analysis of the possibilities and operating parameters of ICCP system supplied with photovoltaic solar panels. Photovoltaic generator made up of the following elements: photovoltaic modules of solar cells, a control and regulation system, a storage system..

1 Introduction

Corrosion is the result of the electrochemical reaction between a metal or composite material usually having conducting current properties. When two metals having different potentials are coupled together, current will flow. Variations in the metal may be the result of temperature, stress, metal composition or the presence of impurities. In general, as the soil resistivity becomes lower, ground water chemistry can also impact soil aggressiveness, so the corrosion of a buried metal becomes easier. Corrosion will occur at the point where positive current leaves the metal surface.

There are two basic mechanisms by which metals in electrolytes corrode:

• Electrolytic Corrosion
• Galvanic Corrosion

Electrolytic corrosion is a result of direct current from outside sources entering and then leaving a particular metallic structure by way of the electrolyte. A corrosion cell is a circuit consisting of an anode, a cathode, an electrolyte, and an electrical contact between the anode and cathode. In underground work, this type of corrosion is often referred to as stray current corrosion and results from currents entering the soil from sources of DC.

To live a long and productive existence, propane tanks and metallic piping need protection. The first line of defense against corrosion is coating the steel tank like many of the manufacturers do in the factory. The second line of defense is cathodic protection, which is now well established on a large variety of immersed and buried metallic structures as well as reinforced concrete structures, and provides effective corrosion control [1]. It can extend the life of an underground tank by helping to prevent corrosion and rust. Cathodic protection systems prevent the oxidation process from occurring by creating a current flow from the cathodic protection system to the structure. This system prevent corrosion for many years.

2 Cathodic protection

Control of corrosion related defect is a very important problem for structural integrity in ground based structures. In some cases, cathodic protection (CP) is required by policy or regulation for example in case of cathodic protection for tanks. Problem of protection against corrosion has been described in many publications. Review of numerical methods applied for corrosion protection issue can be found at [2, 3]. Cathodic protection

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works by preventing the anodic reaction of metal dissolution occurring on the structure under protection. It is a technique to protect metallic structures against corrosion in an aqueous environment, it is employed intense on the steel drains in oil and gas industry, specifically to protect underground tanks and pipelines.

CP is commonly applied to a coated structure to provide corrosion control to areas where the coating may be damaged. It may be applied to existing structures to prolong their life. There are two types of cathodic protection systems:
• Sacrificial anode cathodic protection (SACP);
• Impressed Current Cathodic Protection (ICCP).

Majority of the structures protected employ impressed current system. The main difference between the two is that SACP uses the galvanic anodes which are electrochemically more electronegative than the structure to be protected – the naturally occurring electrochemical potential difference between different metallic elements to provide protection. ICCP uses an external power source (electrical generator with DC) with inert anodes, and this system is used for larger structures, or where electrolyte resistivity is high and galvanic anodes cannot economically deliver enough current to provide protection [4, 5]. The power source must be able to deliver direct current (DC) and examples are transformer rectifier units, solar generating units etc.

The essential of CP is based on two parameters, the evolution of the potential and the current of protection. A commonly accepted protection criterion used for steel is a potential value of minus 850 mV [6].

3 ICCP system

Galvanic protection works well with small tanks usually meant for residential and small commercial applications [7]. A magnesium anode has the power of a 1 volt battery [8]. In many applications, the potential difference between the galvanic anode and the steel structure is not enough to generate sufficient current for cathodic protection to occur. For larger structures, or where electrolyte resistivity is high, ICCP systems (fig. 1) are used, 'cause galvanic anodes cannot economically deliver enough current to provide protection.

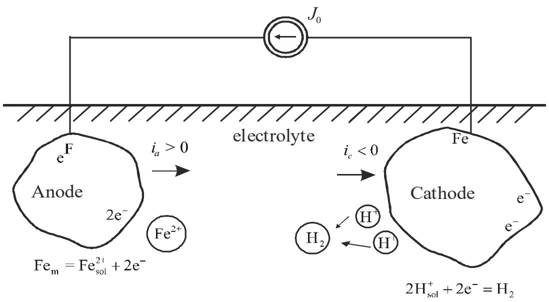

Figure 1. ICCP system – current source connected between cathode and anode [8].

There are basically three types of anode materials:
• Inert or non consumable anodes
• Semi-consumable anodes
• Consumable anodes

ICCP system consist of anodes connected to a DC power source. As power sources may be used such as solar panels, wind turbines, etc. The object of this study is analysis of the possibilities and operating parameters of ICCP system supplied with photovoltaic solar panels. Photovoltaic generator made up of the following elements: photovoltaic modules of solar cells, a control and regulation system, a storage system.

In ICCP systems since the driving voltage is provided by the DC source there is no need for the anode to be more active than the structure to be protected. Typically, the DC output will be in the range 15–100 V and 5–100 A, but 200 V/200 A units are also known.

Anodes for ICCP systems are available in a variety of shapes and sizes. Typical anodes are titanium coated with mixed metal oxide (MMO) or platinum, silicon cast iron, graphite and other materials. The output of the ICCP system should be optimised to provide enough current to provide protection to the protected structure.

One of the most important parameters in the design of cathodic protection systems is the electrical resistivity of the environment. Resistivities encountered for tank environments vary from 1 ohm cm for brackish river water to greater than 500,000 ohm cm in non-porous granite [1]. One of the protection criterion based on field experience, is that a negative potential change of 100 - 300 mV from the free corrosion potential is a good measure of adequate protection. Another condition depending on normal component of current density says that for bare metal in the ground, a current of 11 to 22 mA/m^2 of bare metal-electrolyte surface has been found sufficient, except under extreme or extraordinary conditions [8].

4 Equations and mathematics

Corrosion is a continuous process, practically independent of the operating status of the protected steel structure. When using ICCP systems it is important that their use is continuous and that it requires a constant supply of electricity. In spite of the fact that the power grid failures are negligible, such situations arise due to repairs and random events. A properly chosen photovoltaic system is a kind of an independent source of electricity. A photovoltaic set may be the primary or emergency power supply of the ICCP system. In case of using PV as an emergency source, we should take into account the frequency and duration of potential disruptions in energy supply. Energy must be saved in a storage system which is powered by a low power solar set. In the case of using the solar system as a primary energy source, a PV system should be selected with energy storage system in such a way as to provide one hundred percent coverage of the demand for energy by the ICCP system throughout the entire period of operation. We encounter here the daily and annual variability in the production of energy by the solar PV system. Therefore, the solar PV system should be "oversized" so as to be able to power the ICCP system in the most unfavourable sunlight in the area. This requires the optimization of the photovoltaic panel in terms of its performance, as well as batteries for the capacity ensuring the operation during the periods of unfavourable conditions of sunshine.

The problem can be solved by a simple balance sheet method, taking into account the transmission losses, the energy consumption of the system and the efficiency of the system components including storage.

For the solar PV system as the primary power source of the ICCP we have a formula evaluating the availability of energy E based on the worst sunlight in E_{min}

$$E_{pv} = A_{pv} * \eta_{pv}(T_0) * E_{min} * B \qquad (1)$$

where:

A_{pv} - active surface of photovoltaic cells

$\eta_{pv}(T_o)$ - conversion efficiency of photovoltaic cells for the ambient temperature (T_o) corresponding with E_{min} period

E_{min} - minimum annual daily amount of solar radiation on a surface inclined at an angle optimal for its duration

B - safety factor for solar PV systems from 1.5 to 2.5 (for installation operating in continuous mode)

It is assumed that the extra energy E is stored in the system of accumulating batteries. Its storage efficiency is η_{ak}, and it is sufficient for B•24 hours to cover the power demand of the ICCP system and the energy needs of the solar PV system controller and the transmission losses.

The formula is

$$E_{el} = \eta_k\left((E_{pv} - E_{pw} - E_l) * \eta_{ak} * \frac{T_{ak}}{24} + \right.$$
$$\left. + (E_{pv} - E_{pw} - E_l) * \frac{T_d}{24}\right) \qquad (2)$$

where:

E_{pv} - the amount of energy produced by photovoltaic cells

η_k - efficiency of a photovoltaic controller

E_{pw} - energy used for the solar PV system needs

E_l - energy losses in transmission lines in the solar PV system

T_d - time of work when the ICCP is directly powered by a PV set

T_{ak} - operating time when using the battery it can be assumed that T_d = time from sunrise to sunset, while T_{ak}=24h - T_d

Battery capacity Qa must be chosen in such a way that the battery capacity can supply the ICCP system for (B•24)/η_{ak} hours.

Table.1. Assumed current levels and energy needs (DC output 48V) .

level	protection current	ICCP set efficiency	ICCP set power needs	ICCP set day energy needs
	mA/m^2	%	mW/m^2	mWh/m^2
I	0,03	80	1,152	27,648
II	0,20	80	7,680	184,32
III	4,00	80	153,6	3686,4
IV	30,00	80	1152,1	27648

The amount of energy defined in this way should correspond to the ICCP electricity needs. Based on the sample data the four levels of operating parameters of the ICCP system of the protected surface have been chosen. All the data in the table refer to one square meter of the protected surface. Table.1.

After determining the power of electricity necessary for the proper functioning of the ICCP system in all sample ranges, the efficiency and performance of devices that generate current flow and the appropriate parameters for individual cases have been calculated. The data refer to 1m^2 of surface of a metal underground tank or part of tank (bottom). Calculations were done for solar exposure conditions of the city of Krakow. Polycrystalline silicon solar cells with an efficiency of conversion of sunlight into electrical energy is amounting to 16% were taken into account for the analysis. The efficiency of the solar controller was assumed as 90%, the losses on the electrical wiring of PV system as 4% [10]. The optimum angle of inclination of cells which ensures the best possible power generation, based on the insolation and the solar PV cell temperature coefficient is between 58° and 68° (depending on the parameters of the cell) [9]. The results are shown in Table 2.

Table.2. Parameters of PV panels

level	Protection current	PV unit power needs	power using coefficient	The unit area of PV cells	battery capacity
	mA/m^2	W/m^2	%	m^2/m^2	mWh/m^2
I	0,03	0,0310	12,2%	0,216*10^{-3}	81,7
II	0,20	0,220	12,2%	1,440*10^{-3}	576,0
III	4,00	4,40	12,2%	28,82*10^{-3}	11520,0
IV	30,00	31.00	12,2%	216,1*10^{-3}	81600,0

For example; I - for the tank with an area of 700m^2 and the required protection current density of 0.3 mA/m^2 (good anti-corrosion coating), use a cell with an active area of 1,512m^2 and batteries with a capacity of 567 Wh.

II - for the tank or steel structure with an area of ground contact of 700m^2 and the required protection current density of 4.0 mA/m^2 (poor anti-corrosion coating), use a cell with an active area of 20,16m^2 and batteries with a capacity of 8,064 kWh.

5 Conclusions

The above considerations permit on the basis of a second formula to estimate the size of the photovoltaic cells needed for the ICCP grid power supply system protecting the surface of 1m^2 of the metal underground tank (construction). It is clear that the size of the panels required for a particular case is directly dependent on the solar energy available in a particular area. But for the territory of Poland it can be assumed with high probability that the size calculated for the conditions of Krakow will be sufficient due to the relatively low variability of solar radiation in the whole of the country. However, you should pay special attention to the specific local conditions (frequent dense fog and shade, especially during the winter period), determining the need for a larger field of PV cells and increased battery capacity by increasing the rate of battery work (B) to coefficient 2.5. In a situation when the batteries work at ambient temperature, it is important to take into account the battery temperature coefficient for the calculation of their size.

Selection of PV cells inclination angle should be performed taking into account the temperature coefficient of PV cells used.

The relatively large area of cells per 1m^2 of the protected surface is determined by a very low rate of capacity utilization of the solar ratio which amounts to 12.2%, but unfortunately this is a requirement to guarantee virtually 100% coverage of electricity demand by the ICCP system. Thus, the use of solar systems will be well founded for the ICCP systems of low protection current density, and away from the power grid, where the cost of the power supply connection compensates for the use of a relatively expensive solar power system.

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