Volume : 2 | Issue : 11 | Nov 2013 • ISSN No 2277 - 8160

Research Paper | Energy

# Effect of soil resistivities for different geometrical anodes on design photovoltaic for cathodic protection system

**Dheya N. Abdulamer** — Energy and Renewable Energies Technology Center, University of Technology, Iraq

**ABSTRACT**

*This research examines the impact of factors engineering dimensions of the anodes in different soils on solar energy system design as a major source of impressed current required for cathodic protection of 100 m oil pipeline steel. This paper deals with various resistance of the soils starting from (50 Ohms.Cm) in the north to (5000 Ohms. Cm) in the south of the land of Iraq. The results showed that the anodes of lengths (48, 24.9 and 6.02 cm) in low-resistivity soils (50 Ω.cm) require low potentials (2.77, 2.82 and 3.08 V) respectively. One solar panel (13 W) is fair enough in the low soil resistivity (50 Ω.cm).*

**KEYWORDS : : Solar Energy, Photoelectric current, Impressed Current Cathodic Protection**

## 1. Introduction

Many thousands of miles of steel pipeline have been laid under, or in contact with, the ground for the long-distance transport of oil, natural gas, etc. Obviously corrosion is a problem if the ground is at all damp, as it usually will be, and if the depth of soil is not *so* great that oxygen is effectively excluded. Then the oxygen reduction reaction

$$O_2 + 2H_2O + 4e \rightarrow 4OH^-$$

and the metal corroding reaction can take place , causing the pipe to corrode.

$$Fe \rightarrow Fe^{++} + 2e$$

One obvious way of protecting the pipe is by covering it with some inert material to keep water and oxygen out. The end sections of the pipes are left uncovered ready for welding and the welds are subsequently covered on site. Coverings rarely provide complete protection - rough handling on site frequently leads to breakages of the film, and careless wrapping of welds leaves metal exposed [1]. One of the most effective means of corrosion prevention is **cathodic protection.** Cathodic protection is an electrochemical technique in which a cathodic potential is applied to an engineering structure in order to prevent corrosion from taking place, and this implies that Ohm's law, can be used to control the potential, as well as the current [2].

When two different metals are immersed in the same electrolyte solution they will usually exhibit different electrode potentials. If they are then connected by an electronic conductor, there will be a tendency for the potentials of the two metals to move towards one another, they are said to mutually polarise. The polarisation will be accompanied by a flow of ionic current through the solution from the more negative metal (the anode) to the more positive metal (the cathode), and electrons will be transferred through the conductor from the anode to the cathode. It is said to be cathodically protected [3]. Cathodic protection can be used for all eight different forms of corrosion and may, in some situations, completely stop corrosion. One cathodic protection technique employs a galvanic couple: the metal to be protected is electrically connected to another metal called a **sacrificial anode** [4]. The sacrificial anode technique uses the natural potential difference that exists between the structure and a second metal in the same environment to provide the driving voltage. No power source is employed. Moreover, the dissolution of the second metal, that is, the sacrificial anode, provides the source of electrons for cathodic polarization of the structure. Thus, the sacrificial anode must be spontaneously anodic to the structure, that is, be more negative in the galvanic series for the given environment. Thus, in principle, zinc, aluminum, or magnesium could be used to protect steel, and iron to protect copper [5].

The other principal method of applying cathodic protection is the impressed current technique. Impressed current cathodic protection systems are used throughout the world to provide cathodic protection for pipelines, ship hulls, offshore production platforms, water and wastewater treatment equipment, tank farms, and underground storage tank systems [6]. Figure (1) illustrates the use of an external power supply to provide the cathodic polarization of the structure.

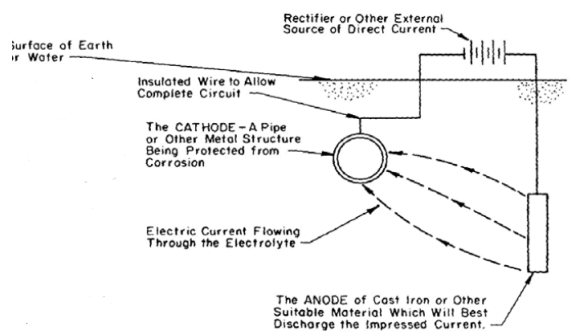



**Fig. (1) : Impressed Current Cathodic protection technique**

The circuit comprises the power source, an auxiliary or impressed current electrode, the corrosive solution, and the structure to be protected. The power source drives a positive current from the impressed current electrode through the corrosive solution and onto the structure. The structure is thereby cathodically polarized (its potential is lowered), and the positive current returns through the circuit to the power supply. Thus, to achieve cathodic protection, the impressed current electrode and the structure must be in both electrolytic and electronic contact. The power supply is usually a transformer/rectifier that converts AC power to DC. Typically, the DC output will be in the range 15–100V and 5–100 A. Thus, fairly substantial driving voltages and currents are available. Where mains power is not available, diesel or gas engines, solar panels, or thermoelectric generators have all been used to provide suitable DC [5]. Solar energy have been used in this research because of it represents clean energy and it is good solution for protect 100 m of steel pipelines at the land very far from power station.

## 2. Theoretical background

Before the system is designed, certain preliminary information must be gathered. The steps required when designing impressed current cathodic protection systems are as follows:

### 1. Current requirement:

A critical part of design calculations for cathodic protection systems on existing structures is the amount of current required per square foot (called current density $I_i$) to change the structure's potential to - 0.85 volt. A well coated structure will require a very low current density (about 0.05 milliampere per square foot); an uncoated structure would require high current density (about 10 milliamperes per square foot). The average current density required for cathodic protection is 2 milliamperes per square foot of bare area. Current requirements can be calculated using equation (1), based on coating efficiency and current density desired. The efficiency of the coating as supplied will have a

direct effect on the total current requirement.

$$I = A\ I_i\ (1 - CE) \cdots\cdots\cdots\cdots\cdots (1)$$

(2) Selecting anode. As with the galvanic system, the choice of anode is arbitrary at this time economy will determine which anode is best. The anodes used most often are made of high silicon chromium-bearing cast-iron (HSCBCI). When impressed current-type cathodic protection systems are used to mitigate corrosion on an underground steel structure, the auxiliary anodes often are surrounded by a carbonaceous backfill.

The backfill materials commonly used include coal coke breeze, calcined petroleum coke breeze, and natural graphite particles. The backfill serves three basic functions:

(a) it decreases the anode-to-earth resistance by increasing the anode's effective size,
(b) it extends the system's operational life by providing additional anode material, and
(c) it provides a uniform environment around the anode, minimizing deleterious localized attack.

(3) Calculated number of anodes needed to satisfy manufacture's current density limitations. To determine the number of anodes needed to meet the current density limitations, use equation -2

$$N = \frac{I}{A_1\ I_1} \cdots\cdots\cdots\cdots\cdots (2)$$

(4) Calculated number of anodes needed to meet design life requirement. Equation -3 is used to find the number of anodes:

$$N = \frac{L_f\ I}{1000\ W} \cdots\cdots\cdots\cdots\cdots (3)$$

(5) Calculated number of anodes needed to meet maximum anode groundbed resistance requirements. Equation -4 is used to calculate the number of anodes required [7]:

$$R_a = \frac{\rho * K}{N\ L} + \frac{\rho * P}{S} \cdots\cdots\cdots\cdots\cdots (4)$$

**Table. 1: Shape functions (K) for impressed current cathodic protection [7].**

| L/d | K | L/d | K |
|---|---|---|---|
| 5 | 0.0140 | 20 | 0.0213 |
| 6 | 0.0150 | 25 | 0.0224 |
| 7 | 0.0158 | 30 | 0.0234 |
| 8 | 0.0165 | 35 | 0.0242 |
| 9 | 0.0171 | 40 | 0.0249 |
| 10 | 0.0177 | 45 | 0.0255 |
| 12 | 0.0186 | 50 | 0.0261 |
| 14 | 0.0194 | 55 | 0.0266 |
| 16 | 0.0201 | 60 | 0.0270 |

The soil resistivity's (50, 600, 1000, 5000 Ω.cm) were represent moderate to severe conditions of large extent of land in north Iraq – Turkey pipeline extending from Nineva to Um – Qaser in Basrah as shown in the table 2. This condition without effect of bacteria and any obstacle [8].

**Table. 2: Soil resistivity in the large extent of Iraq land [8].**

| Concentration NaCl % | NaCl content g/l | Conductivity µΩ/cm | Resistivity Ω.cm |
|---|---|---|---|
| 0.01 | 0.1 | 200 | 5000 |
| 0.05 | 0.5 | 1000 | 1000 |
| 0.1 | 1 | 1666.66 | 600 |
| 1 | 10 | 20000 | 50 |

(6) Determined total circuit resistance. Determining the total circuit resistance which will be used to calculate the rectifier size needed.
(a) Calculate anode groundbed resistance. Use equation -4.
(b) Calculate groundbed header cable resistance. The cable is typically supplied with a specified resistance in ohms per 100 feet. The wire resistance ($R_W$) then is calculated from equation -5:

$$R_w = \frac{Ohms\ (L)}{1000\ f} \cdots\cdots\cdots\cdots\cdots (5)$$

(c) Calculate structure-to-electrolyte resistance using eq – 6 :

$$R_c = \frac{R}{A_c} \cdots\cdots\cdots\cdots\cdots (6)$$

(d) Calculate total circuit resistance. To calculate the total resistance, equation -7 is used :

$$R_T = R_a + R_w + R_c \cdots\cdots\cdots\cdots\cdots (7)$$

(7) Calculate required voltage $V_{req}$. Equation -8 is used to determine voltage output (Vrec) of the rectifier:

$$V_{req} = I\ R_T\ 150\% \cdots\cdots\cdots\cdots\cdots (8)$$

Besides the more common rectifiers being marketed, a solar cathodic protection power supply (for D.C. power) may be considered for remote sites with no electrical power. Three factors that should be considered when specifying a solar cathodic protection power supply are:

1. The cost of the solar cathodic protection power supply in dollars per watt of continuous power.
2. The solar cathodic protection power supply's much higher initial cost compared to selenium rectifiers operated by A.C. power.
3. The additional maintenance required for a solar cathodic protection power supply, mainly to keep the solar panels free of dirt deposits [7].

**3. Design of impressed current cathodic protection system**

The procedures have been used involve sequence of operations which start with calculation of the total current required (I) for protecting steel pipe which has been briefly described as indicated in the table (3). Equation.(1) has been used for determined (I). Ground bed anode resistance $R_a$, wire resistance $R_w$, pipeline to soil resistance $R_c$ and the total circuit resistance $R_t$ have been estimate by using equations (4, 5, 6 and 7) respectively. The data obtained from these equations depend mainly on the variations of anode shape factor (K), anode dimensions and soil resistivity (ρ). These variations taken from tables 1 and 2 respectively. Data of soil resistivity derived from table (2), represents soil resistivity in the large extent of Iraq land. Number of anodes supposed to be constant and equal into twenty anodes uniformly distributed along 100 m oil steel pipeline. The center-to-center spacing between anode backfill columns (S) is 15 ft. These numbers of anodes corresponding to 0.00135 paralleling factor (P). Equation. 8 was used to evaluate of rectifier voltage $V_{rec}$ that should be employed for generate current density required to shift voltage in to cathodic polarization. Energy per day of solar panel can be calculated using the following equation 9.

$$W_p = \frac{1.2\ h\ w_L}{I} \cdots\cdots\cdots\cdots\cdots (9)$$

While equation (10) is used to estimate battery capacity for 24 hours along the year .

$$B_c = \frac{1.2\ h\ w_L\ d_a\ d_d}{0.58 * 0.6\ V_n} \cdots\cdots\cdots\cdots\cdots (10)$$

Number of PV panels and Batteries required can be estimated by the following equations [9];

$$N_{PV} = \frac{W_p}{P_{\max}} \cdots\cdots\cdots\cdots\cdots (11)$$

$$N_B = \frac{B_c}{200} \cdots\cdots\cdots\cdots\cdots (12)$$

Arrangement of impressed current cathodic protection system using solar panels can be shown in the Figure.(2).

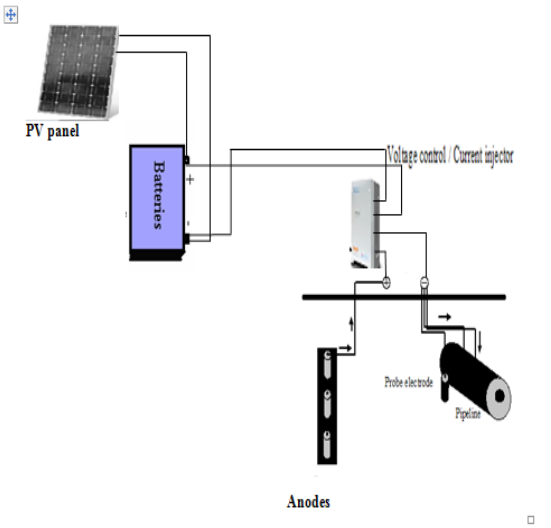



**Fig. (2): Impressed current cathodic protection using solar energy**

The output current from photovoltaic power station designed for 15 year under the following conditions that mentioned in the table (3), which represents the main consideration for design impressed current cathodic protection for 100 m oil pipeline.

**Table (3): Boundary conditions for design ICCP using solar energy**

| Structure | Description |
|---|---|
| Steel pipe | $d_s$ = 30 cm<br>$L_s$ = 10000 cm<br>CE = 85%<br>$R_c$ = 2000 Ω.cm<br>$I_i$ = 6 mA |
| HSCBCI anode | Case 1:<br>d = 12 cm<br>L = 48 cm |
| | Case 2:<br>d = 10 cm<br>L = 24.9 cm |
| | Case 3:<br>d = 12 cm<br>L = 6.02 cm |
| Wire | $R_w$ = 0.15 Ω/1000ft<br>$L_w$= 2500 cm |
| PV module | Model: LJ-C12/308<br>Size: 520* 520 * 22 mm<br>$P_{max}$= 13 W<br>$V_{oc}$= 13.8 V<br>$I_{sc}$=1.17 A |
| Battery | Deep cycle 12V/ 200 Ah |

## 4. Results and Discussion

For three cases of anodes, the effect of shape factor on the resistance of anode in the different soil resistivity's shown in the figures (3, 4 and 5) respectively. In the high soil resistivity (5000 Ω.cm), increased shape factor lead to increase anode resistance and high values of anode resistance (4.75, 8.68 and 34.2 Ω) respectively were found. Little increase in the anode resistance occurs at the other soils and behavior of this linear relationships between shape factor and anode resistance approximately changed to straight line.

Voltage required to shift current in to cathodic polarization are shown in the figures (6, 7 and 8) which are represents the relationship between required voltage and shape factor in the different soils. As previously figures, the same behavior can be found, where the values of voltage increased with increment of shape factor. For all three case of anodes, as the anode length decreased so rectifier voltage that increased, except minimum values of voltage about (2.76-2.96 V) existed in the (50 Ω.cm) soil resistivity.

Huge numerical data obtained to evaluate the number required of photovoltaic panels and batteries that provides exactly power to protect 100 m oil pipeline against corrosion in the different soil which have various electrical resistivity. In this context, figure (9) shows the relationship between number of solar panels required and shape factor in different soil resistivity. As expected, values of solar panels required increase with increasing of shape factor and high number of solar panels required for high soil resistivity (5000 Ω.cm). While the number of solar panels decreased with falling of soil resistivity's to (1000, 600 and 50 Ω.cm) as shown in figures (9, 10 and 11) for all three cases of anodes.

Batteries number depend mainly on the calculated required power ( total current per surface area by the voltage required). Figures (12, 13 and 14) show the relationship between number of batteries with shape factor. Because of high soil resistivity (5000 Ω.cm), so high number of solar panels and batteries required to adjust in to required power for cathodic protection. In contrast, number of batteries required decrease during filling of soil resistivity.

Anode dimension and anode shape factor have great effect of the values obtained of solar panels and batteries number. In general, number of solar panels and batteries increased with increasing the anode shape factor and decreasing the length of anode.

## 5. Conclusions

Design of impressed current cathodic protection for 100 m oil pipeline steel using solar energy based on various factors. High soil resistivity (5000 Ω.cm) require high potentials (7.8, 11.9 and 38.32 V) at (48, 24.9 and 6.02 cm) lengths of anode respectively. Number of solar panels and batteries required depend on the load (required power). High number of solar panels necessary in the high soil resistivity, these values increased with increment of shape factor, at the same time, these values increased with decrease of anode length.

## List of symbols

| | |
|---|---|
| I | total protective current |
| A | total structure surface area |
| $I_i$ | required current density |
| CE | Coating efficiency. |
| N | number of anodes required |
| $L_f$ | life in years |
| W | Weight of one anode in pounds. |
| Ra | anodes' resistance |
| Rs | structure-to-electrolyte resistance |
| $A_c$ | coated pipe area in square feet. |
| $R_T$ | total circuit resistance. |
| ρ | soil resistivity in ohm-centimeters |
| $d_s$ | Diameter of steel pipe |
| $L_s$ | length of steel pipe |
| d | anode diameter |
| $R_w$ | wire resistance |
| $L_w$ | wire length |
| L | effective anode length |
| $d_b$ | anode/backfill diameter |
| $A_1$ | anode surface area |
| $I_1$ | maximum current density output |
| | Energy per day of solar panel |
| $W_P$ | number of working hours |
| h | required load (watt) |
| $W_L$ | number of cloudy days |
| $d_a$ | deep discharge |
| $d_d$ | mean of battery potential |
| $V_n$ | Energy of required load (watts). |
| $W_L$ | Battery capacity |
| $B_c$ | Number of PV panels |
| $N_{PV}$ | Maximum power of solar panel used |
| $P_{max}$ | Number of batteries required |
| $N_B$ | High Silicon Chromium Bearing Cast Iron |
| HSCBCI | center-to-center spacing between anode |
| S | |
| $R_c$ | coating resistance |

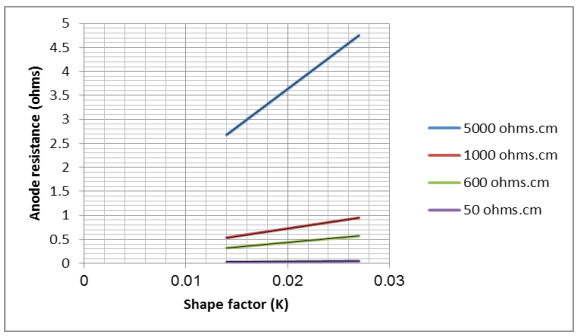



**Figure (3): Ra Vs shape factor at 48 cm length of anode**

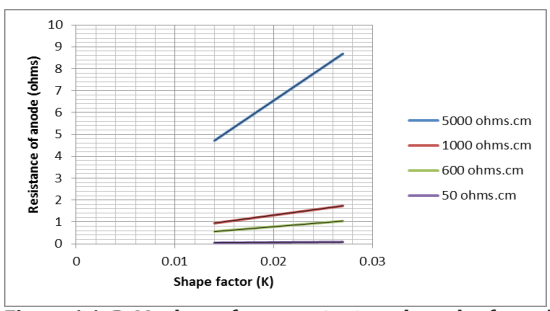



**Figure (4): $R_a$ Vs shape factor at 24.9 cm length of anode**

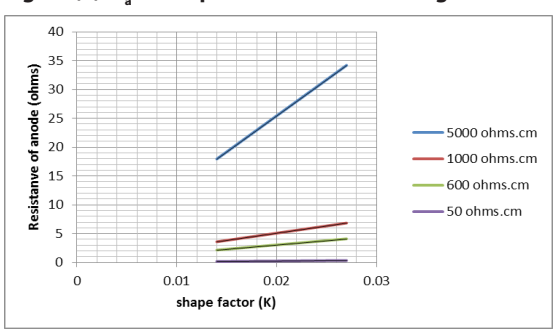



**Figure (5): $R_a$ Vs shape factor at 6.02 cm length of anode**

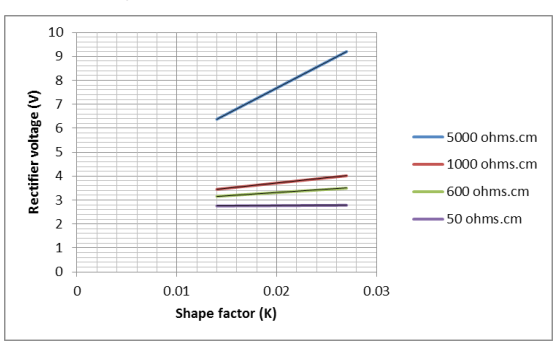



**Figure (6): $V_{req}$ VS shape factor at 48 cm length of anode**

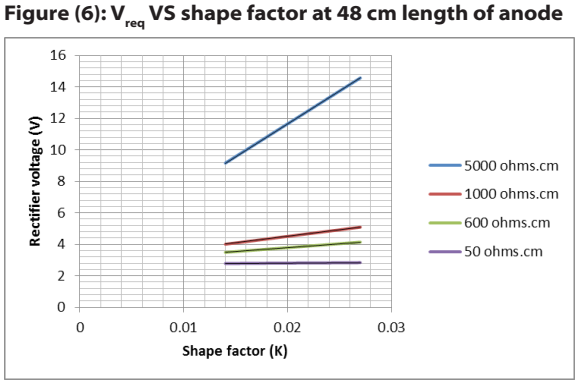



**Figure (7): $V_{req}$ VS shape factor at 24.9 cm length of anode**

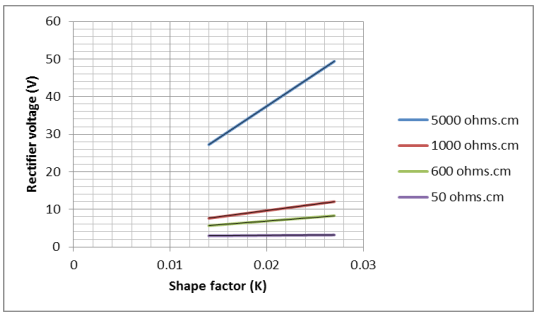



**Figure (8): $V_{req}$ VS shape factor at 6.02 cm length of anode**

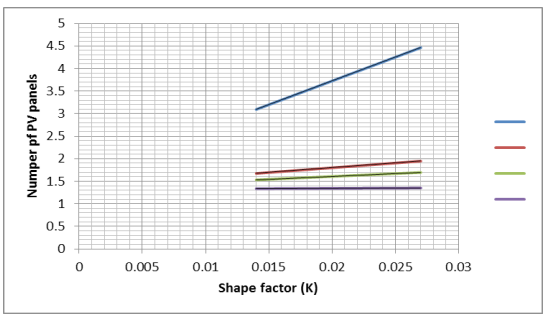



**Figure (9): $N_{pv}$ Vs shape factor at 48 cm length of anode**

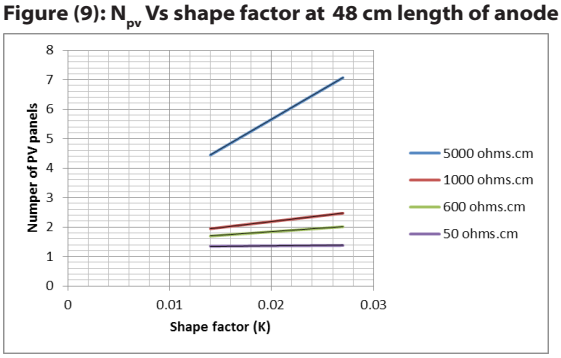



**Figure (10): $N_{pv}$ Vs shape factor at 24.9 cm length of anode**

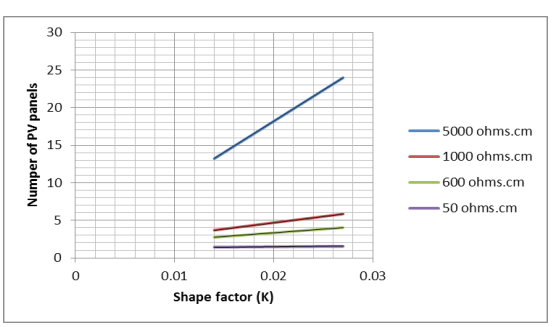



**Figure (11): $N_{pv}$ Vs shape factor at 6.02 cm length of anode**

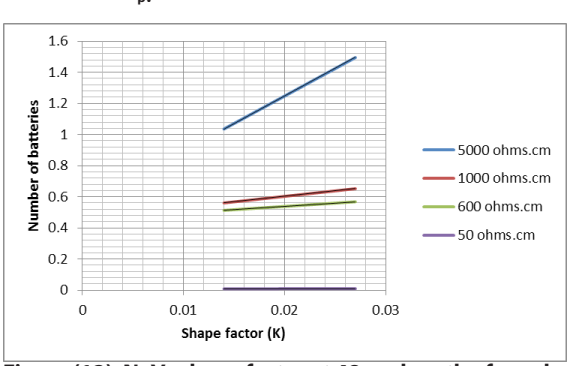



**Figure (12): $N_b$ Vs shape factor at 48 cm length of anode**

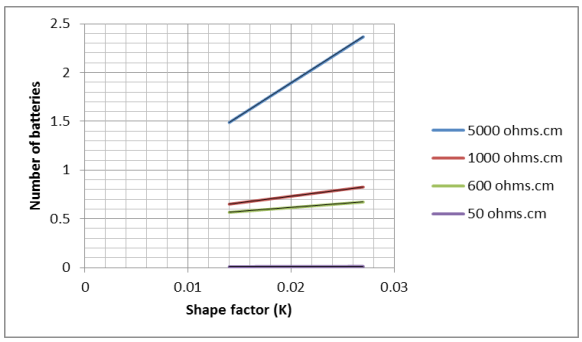



**Figure (13): $N_{pv}$ Vs shape factor at 24.9 cm length of anode**

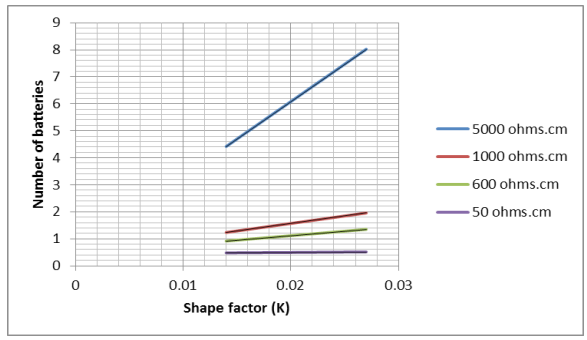



**Figure (14): $N_{pv}$ Vs shape factor at 6.02 cm length of anode**


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