Design Of Photovoltaic Powered Cathodic Protection System

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Abstract: The corrosion caused by chemical reaction between metallic structures and surrounding mediums, such as soil or water .the (CP) cathodic protection system is used to protect metallic structure against corrosion. Cathodic protection (CP) used to minimize corrosion by utilizing an external source of electrical current which forces the entire structure to become a cathode. There are two Types of cathodic protection system (Galvanic current, Impressed current).the Galvanic current is called a sacrificial anode is connected to the protected structure (cathode) through a DC power supply. In Galvanic current system ,a current passes from the sacrificing anode to the protected structure .the sacrificial anode is corroded rather than causing the protected structure corrosion .protected structure requires a constant current to stop the corrosion which determined by area, structure metal and the surrounding medium. The rains, humidity are decrease soil resistivity and increase the DC current .The corrosion and over protection resulting from increase in the DC current is harmful for the metallic structure. This problem can be solved by conventional cathodic protection system by manual adjustment of DC voltage periodically to obtain a constant current .the manual adjustment of DC voltage depends on experience of the technician and using the accuracy of the measuring equipment. The errors of measuring current depend on error from the technician or error from the measuring equipment. the corrosion of structure may occur when the interval between two successive adjustment is long .An automatically regulated cathodic protection system is used to overcome problems from conventional cathodic protection system .the regulated cathodic protection system adjust the DC voltage of the system automatically when it senses the variations of surrounding medium resistivity so the DC current is constant at the required level.

Index Terms: cathodic protection (CP) ,Impressed current cathodic protection (ICCP). Photovoltaic (PV) , Array factor the ratio between PV array size to average daily power required to operate load . State Of Charge (SOC). Load voltage regulator (LVR). Battery voltage regulator (BVR).

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1 INTRODUCTION

THe first practical report use of cathodic protection is generally credited to Sir Humphrey Davy in the 1820s. Sir Humphrey Davys work on protecting the copper sheathing on wooden hulls in the British Navy by sacrificial zinc or iron anodes. In practice its main use is to protect steel structures buried in soil or immerged in water [1].Cathodic protection is the technique to minimize metal surface corrosion by supplying an external current to the corroding metal surface [2]. Ewing (1939) discussed a widely used Conventional CP to measure the potential difference between the protected structure and the electrolyte [3]. bockris and reddy (1970) reported that current leaves the auxiliary anode (called the scarified anode) and enters both cathodic and anodic areas of the corrosion cells[4].The block diagram of regulated CP system is consist of (PV) Photovoltaic array, storage battery ,(LVR) load voltage regulated is a controlled DC chopper circuit and was discussed by both Berde (1990) and Dewan and straughen (1975) [5],[6]. (BVR) Battery voltage regulator was discussed by Anis (1990), selector circuit, (FBC) Feedback circuit as shown in fig (2). [7]

Corrosion types:

1. uniform: corrosion attacks all areas of metal at same rate.
2. localized: corrode some areas of metal at different rates
3. Pitting: highly localized attack resulting in small pits Penetrate to perforation.

Methods to control corrosion

1- Use of corrosion resistant materials (plastic, stainless).
2- Altering the environment.
3- Utilize coatings and linings that electrically insulate the structure from the electrolyte (paints, plastic films).
4- Use of cathodic protection.

Cathodic protection (CP): is a technique used to control the corrosion of a metal surface by making it the cathode of an electrochemical cell For structures such as long pipelines as shown in fig (1). Cathodic protection systems protect a wide range of metallic structures in various environments. The Structures commonly protected are the exterior surfaces of pipelines, ships hulls, on the interior surfaces of water-storage tanks and water circulating systems. There are two basic techniques of cathodic protection. The first technique does not need a power supply to impress current from the sacrificed anode to the cathodically protected area.(called galvanic anode), the anode metal chosen is higher potential compared to the cathode metal (according to galvanic series).these anode are studied by Newman(1973)and it is shown that They are mostly high – purity alloys of magnesium ,zinc, and aluminum . Such a technique is suitable if the current demand is limited so that the galvanic potential difference is sufficient to impress the required current. The second and widely used technique is the impressed current system. A DC power supply is necessary to impress the required current. The DC power is obtained from either a rectifier (if an AC power is available) or a diesel generator. Recently, solar and wind systems have been used to supply DC power to CP systems erected in remote areas where AC power is not available. [8],[9],[10]

2 PRINCIPLES OF CATHODIC PROTECTION

Corrosion in aqueous solutions proceeds by anodic and cathodic electrochemical reactions. No charge builds up on the metal. The anodic and cathodic reactions are equal.

1-Anodic reactions involve oxidation of metal to its ions, e.g. for steel

$$Fe \rightarrow Fe^{2+} + 2e \quad (1)$$

2-The cathodic process involves reduction. In acidic water, where hydrogen ions (H^+) are plentiful

$$2H+ + 2e \rightarrow H_2 \quad (2)$$

In alkaline solutions, hydrogen ions are rare, the reduction of water alkali and hydrogen.

$$2H_2O + 2e \rightarrow H_2 + 2OH^- \quad (3)$$

Anodic reaction produce electrons pass from metal (anode) to cathode that electrons consumed by cathodic reaction. In the water is reduction of oxygen producing alkali at the surface of the metal.

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

Anodic and Cathodic sites are nearby on the surface of a piece of metal. We can change the rate of these two reactions (The anodic reaction and the cathodic reaction). It is equilibrium, when withdrawing electrons or supplying additional electrons to the pieces of metal.

The anodic reaction:
That metal withdraw electrons from its surface, that increase reaction (1)(Anodic reactions) increase corrosion and decrease reaction (2)(The cathodic process) and increase dissolution metal.

The cathodic reaction
When supply metal with electrons from external power supply, that decrease reaction (1)(Anodic reactions), decrease corrosion decrease dissolution of metal , increase reaction (2) (cathodic protection). To prevent corrosion, we have to continue to supply electrons to the steel from an external source to satisfy the requirements of the cathodic reaction. Reducing the rate of the anodic process will increase the rate of the cathodic process. [11]

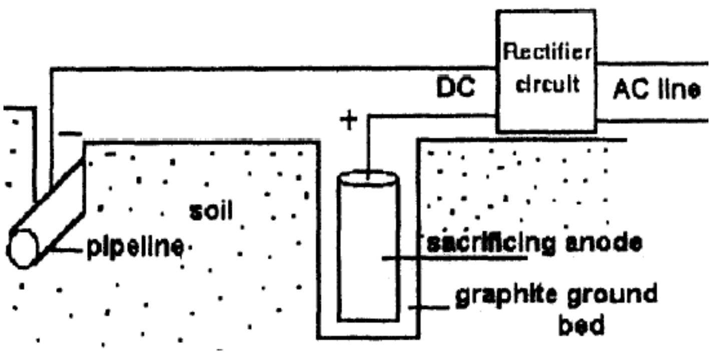

Fig1. *Cathodically protected pipeline schematic diagram*

3 CONVENTIONAL CP SYSTEM

Conventional CP system is protecting a buried pipeline. The DC power is obtained from a solar cell. The regular inspection of a protected structure includes a coating check and measuring the potential difference between the protected structure and the electrolyte to minimize rapid corrosion that result from improperly painting of the metal due to direct contact of both the metallic structure and electrolyte. Experience has shown that when a structure-to-electrolyte potential difference ranges from -0.85 V to -2.0 V relative to copper –copper sulfate electrode. If this voltage exceeds - 0.85V, corrosion takes place. On the other hand, if this voltage becomes below -2 V (over protection), coating may be damaged, especially thin film coatings. [11]

4 REGULATED CP SYSTEM

Fig2. Shows a block diagram of the proposed regulated CP system. The system is composed of the following blocks:

1. Photovoltaic (PV) array: to generate DC power from solar radiation.
2. Storage battery: to store the DC power generated by the PV array (supply DC current at night and on cloudy days)
3. Load voltage regulator (LVR): This circuit is fed from the storage battery and supplies the load with the required voltage under varying climatic conditions. LVR is a controlled DC chopper circuit and the circuit is controlled by a signal received from the feedback circuit.
4. Battery voltage regulator (BVR): The circuit is used to protect the battery against overcharging and deep discharging to prolong battery lifetime.
5. Selector circuit
6. Feedback circuit (FBC). [12]

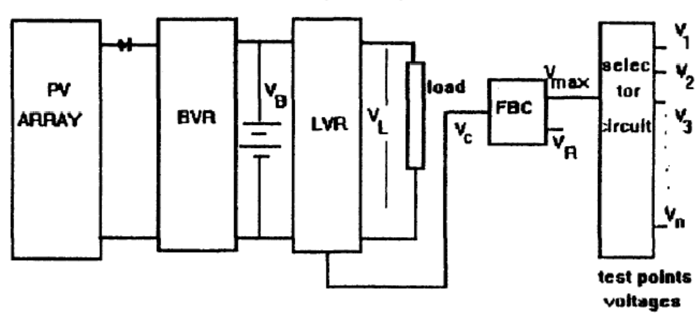

Fig2. *Block diagram of the cathodic protection system*

Tab 1. *Comparison between GS & IS*

Galvanic system (GS)	Impressed system (IS)
Depend on the difference in potential between the anode and structure	Use external power source to drive the current
Anodes : magnesium or zinc	Anodes : high silicon cast iron or graphite
Short anode life , No monitoring and maintenance and No requirement for electrical isolation.	Longer anode life Requires monitoring and maintenance, Electrical isolation required between anode and steel, Current can be controlled

5 CALCULATIONS LAW FOR UNDERGROUND PIPELINE

The following is a sample calculation to determine the requirements for an ICCP system.

Case 1: pipelines require CP on the surface of soil:
Assume the following pipelines require CP
0 inches x 2100 m long Pipeline A
DESIGN PARAMETERS
The following design parameters were utilized in the design of the impressed current cathodic protection system: [13]

Soil Resistivity	50,000 ohm-cm (estimated)
Current Density	20 mA/sq.m
Coating Deficiency	0.05
Electrical Isolation	electrically isolated at each end
Design Life	20 years
Anode Material	High Silicon Cast Iron
Anode Dimensions	67mm x 2133 mm long (28.6 kg)

Consumption Rate Cast Iron 0.50 kg/amp-yr

1-EXTERNAL SURFACE AREA OF EACH PIPELINE TO BE PROTECTED: For underground pipelines, the external surface area (S_A) is calculated as follows: [13]

$$S_A = 3.142\ dl \quad (5)$$

Where: S_A: external surface area (m2)
d: diameter of pipeline = 0.273 m
L: length of pipeline
S_A = 1801 m2

2-ESTIMATED CATHODIC PROTECTION CURRENT

REQUIRED:
Using the calculated surface area and the assumed current density and coating deficiency, the current requirements can be calculated as follows: [13]

$$I = (S_A)(CD)(H) \quad (6)$$

Where:
I: current required (A)
S_A: external surface area (m2)
CD: current density (20 m A / m2)
H: coating deficiency (0.05) I load= 1.8 Amp
3-GROUND BED RESISTANCE TO EARTH
Using Dwight's equation the resistance to earth of the deep ground beds can be calculated as follows: [13]

$$R_V = 0.0016 * \rho[\ln(8L/D) - 1]/L \quad (7)$$

Where:
R_V: resistance to earth of vertical anode (Ω)
ρ : Resistivity of soil (50000 Ω. Cm)
D: anode column Diameter including backfill (0.254)
L : anode column length including backfill (34 m)
RV = 14 Ω
4-RECTIFIER SIZING
Rectifier voltage output is calculated using Ohm's Law (V = IR) as follows: [13]

$$Voltage = IR_V + backvoltage \quad (8)$$

Where:
R_V: resistance to earth of vertical anode (Ω)
I:current required (A)
Rectifier sizing voltage = 25 volt
5-DESIGN LIFE
Assuming the current output from each deep well (one per each rectifier) is evenly distributed between the six anodes, the current output for each anode in the deep well is as follows: [13]

$$A = I / N \quad (9)$$

Where:
A: current output per anode (Amp)
I: total current per groudbed (9.1A) &(9.6A)
N: number of anodes per groundbed (6)
Current output per anode A= 1.5 Amp (groudbed #1) & 1.2 Amp (groudbed #2)

6-The design life of the individual anodes can be calculated as follows: [13]

$$L = WCU / A \quad (10)$$

Where:
L: life (years)
W: Weight of anode (28.6 Kg)
C: Capacity of cast iron in coke breeze (2A. year / Kg)
U: utilization factor of cast iron in coke breeze (0.75)
A : current discharge per anode
The design life of the individual anodes L=28 year
7-LINEAR RESISTANCE OF PIPE

$$R = \rho.L / A \quad (11)$$

Where:
R: the linear resistance of pipe line
ρ :resistivity of steel (2.06*10-5 Ω . cm)
L: length of pipe (2100 cm)
A: area of pipe wall (197 cm2)
Linear resistance of pipe R= $2.196 * 10^{-5}$ Ω
8-Calculation of Conductance:
Assuming a good quality coating with a leakage conductance of $2.5 * 10^{-4}$ siemen/ m^2 in a 1000 Ω . cm soil , conductivity in 50000 Ω . cm soil is 5*10-6 siemens/ m^2
The unit conductance can be calculated as follows: [13]

$$G = (A)(S) \quad (12)$$

Where:
G: unit conductance of pipe to environment (siemens)
A: external surface area
S: conductance (5*10-6) siemens /m2
Conductance G= 9 * 10-3 siemens
9-Calculation of the attenuation constant and characteristic resistance :
The attenuation constant and the characteristic resistance can be calculated as follows: [13]

$$\alpha = (rg)^{0.5} \quad (13)$$

α : Attenuation constant
r: unit linear resistance of pipe
g: unit conductance of pipe to environment
α : The attenuation constant =4.4* 10-4

$$R_G = (r / g)^{0.5} \quad (14)$$

R_G: characteristic resistance (Ω)
The characteristic resistance RG=0.05 Ω

Case 2: pipelines require CP totally buried in the soil:
Design data.
(1) Average soil resistivity is 2000 ohm-centimeters.
(2) Effective coating resistance at 15 years is estimated at 2500 ohms per square foot.
(3) Pipe has a 6-inch outside diameter.
(4) Pipe length is 6800 feet.
(5) Design for 15-year life.
(6) Design for 2 milliamperes per square foot of bare pipe.
(7) Design for 90 percent coating efficiency
(8) The pipeline must be isolated
(9) HSCBCI anodes must be used with carbonaceous backfill.
(10) The pipe will be coated with hot-applied coal-tar enamel and will be holiday-checked before installation.
(11) Anode bed must not exceed 2 ohms.
(12) Electric power is available at 120/240 volts a.c. single phase from a nearby overhead distribution

system.
(13) Current requirement test indicates that 2.36 amperes are needed for adequate cathodic protection. [14]
Computations.
(1) Find the gas main's outside area:
Pipe size = 6 inch.
Pipe length = 6800 ft [14]

$$\text{Pipe area} = L \,\Pi\, d \quad (15)$$

L: Pipe length
D: Pipe size
Pipe area = 6800 x Π A/2 = 6800 Π(6/12) = 10,681 ft^2.
(2) Check the current requirement:

$$I = (A)(I')(1.0 - CE) \quad (16)$$

where
I : total protective current
A : total structure surface area in square feet
I' : required current density
CE : coating efficiency. [14]
I = 10681 (2 mA/sq ft)(1.0 - 0.9)=2136 mA
(3) Calculate the number of anodes needed to meet the anode supplier's current density limitations

$$N = \frac{I}{A_1 I_1} \quad (17)$$

Where
N: number of anodes required
I: total protection current in milliamperes
A : anode surface area in square feet per anode
I_1 is recommended maximum current density output in mA (Recommended maximum current density output for High-silicon chromium bearing cast-iron anodes is 1000 mA/sq ft.) [14]
N= 2360 mA/[(28 sq ft/anode)*(1000 mA/sq ft)]=0.84 anode.
(4) Calculate the number of anodes:

$$N = \frac{LI}{1000\ W} \quad (18)$$

Where
N : number of anodes required to meet the design life
L: life in years
W: weight of one anode in pounds . [14]
N =(15 years)(2360mA)/ [(1000)(60 Ib/anode)]=0.59 anode
Shape functions (K) for impressed current cathodic protection anodes where L is effective anode length and d is anode/backfill diameter. [14]
L/d=8 K=0.0165

Anode paralleling factors (F) for various numbers of anodes (N) installed in parallel [14]
N =4 P=0.00283

(5) Calculate the number of anodes required to meet maximum anode groundbed resistance requirements:

$$Ra = \frac{\rho K}{LN} + \frac{\rho P}{S} \quad (19)$$

Where
Ra: the anodes' resistance
ρ: soil resistivity in ohm-centimeters
K: the anode shape
N: the number of anodes
L: length of the anode backfill column in feet
P: the paralleling factor
S: the center-to-center spacing between anode backfill columns in feet. [14]

$$N = \frac{\rho K}{L\left(Ra - \frac{\rho}{S} P\right)} \quad (20)$$

N= 2000*0.0165/ [7ft (20 – (2000*0.00283/20))] =3 anodes
(6) Determine the total circuit resistance.
(a) Calculate the anode groundbed resistance

$$Ra = \frac{2000 * 0.0165}{4 * 7} + \frac{2000 * 0.00283}{20} = 1.46\ ohm$$

(b) Calculate the groundbed resistance for a 500foot header cable. The resistance specified by the manufacturer is 0.0159 ohm per 100 ft of AWG cable:

$$Rw = \frac{ohm\ (L)}{100\ ft} \quad (21)$$

Where
L: the structure's length in feet. [14]

$$Rw = \frac{0.0159\ ohm * 500\ ft}{100\ ft} = 0.0795\ ohm$$

(c) Calculate structure-to-electrolyte resistance

$$Rc = \frac{R}{N} \quad (22)$$

Where
R_C: the structure-to-electrolyte resistance.
R: the coating resistance in ohms per square feet.
N: the coated pipe area in square feet. [14]

$$Rc = \frac{2500\ \text{ohm/sq ft}}{11800\ \text{sq ft}} = 0.212\ ohm$$

(d) Calculate the total resistance Rt

$$Rt = Ra + Rw + Rc \quad (23)$$

Where
Ra : the anodes' resistance
Rw: the groundbed resistance
Rc : the structure-to-electrolyte resistance. [14]
Rt= 1.46+0.0795+0.212=1.75 ohms
(7) Calculate rectifier voltage

$$Vrec = (I)(Rt)(150\%) \quad (24)$$

Where
I: total protection current in amperes
R_t: total circuit resistance [14]

$$Vrec = (2.36\ A)(1.75\ ohms)(150\%) = 6.2\ V$$

Case 3: immerged tank in water.
Design data.
(1) Tank capacity will be 500,000 gallons.
(2) Tank height (from ground to bottom of bowl) will be 115 feet.
(3) Tank diameter will be 56 feet.
(4) The tank's high water level will be 35 feet.
(5) Overall tank depth will be 39 feet.
(6) Vertical shell height will be 11 feet.
(7) Riser pipe diameter will be 5 feet.
(8) Tank will be ellipsoidal on both top and bottom.
(9) All inner surfaces will be uncoated.

(10) Design for a maximum current density of 2 milliamperes per square foot.
(11) Electric power available will be 120/240-volt a.c., single phase.
(12) String-type HSCBCI anodes will be used.
(13) Design for a 10-year life.
(14) Water resistivity is 4000 ohm-centimeters.
(15) The tank water must not be subjected to freezing.
(16) An assumed deterioration rate is 1.0 pound per ampere-year. [14]
Computations.
(1) Find the area of wetted surface or tank bowl

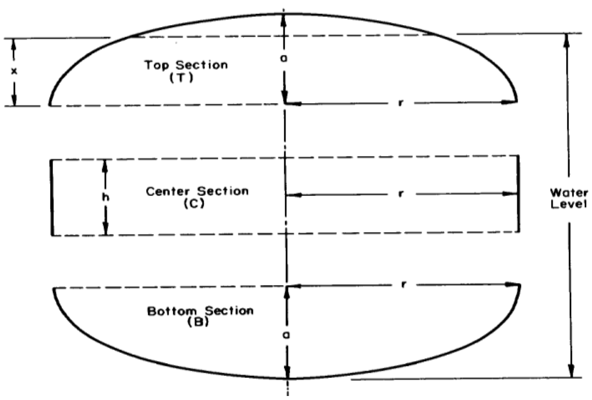

Fig 3.segmented elevated Tank for area calculations.
(a) For the top section (T)

$$A_T = 2\Pi rx \text{ ,(approximately),} \quad (25)$$

where r = 28 feet (tank radius), x = 10 feet. Thus,
A =2 x 3.1416 x 28 ft x 10 ft =1759 sq ft.
(b) For the center section (C)

$$A_T = 2\Pi rh \quad (26)$$

Where
r = 28 feet (tank radius) and h = 11 feet. Thus,
` A = 2 x 3.1415 x 28 ft x 11 ft =1935 sq ft.
(c) For the bottom section (b)

$$A_B = \sqrt{2}\sqrt{ra^2 + r^2} \quad (27)$$

Where r = 28 feet (tank radius) and a 14 feet. Thus,

$$A_B = \sqrt{2} x 3.1416 \ x 28 \ ftx \sqrt{14 + 28} \text{ =3894 sq ft.}$$

(d) Therefore, A the total wetted area of the tank bowl is
$A_T + A_C + A_B$ = 7588 sq ft.
(3) Find the maximum design current for the tank:

$$I_T = IA \quad (28)$$

I: Max Current Density
A: Total Wetted Of Tank Bowel [14]
I_T = 2.0 mA/sq ft x 7588 sq ft =15.2 Amp.
(4) Find the minimum weight of tank anode material

$$W = \frac{YSI}{E} \quad (29)$$

Where:
W: Weight of anode material.
Y: design life.
S: anode deterioration rate.
I: Maximum design current.
E: anode efficiency. [14]
Y = 10 years, S = 1.0 pound per ampere-year, E = 0.50, and I = 15.2 amperes. Thus,

$$W = \frac{(10 \ yr)(1.0 \ Ib/A - yr)(15.2 \ A)}{0.50} = 304 \ Ib$$

(5) Find the rectifier voltage rating.
(a) The electrical conductor to the main anode is wire size No.2 AWG, rated at 0.159 ohm per 1000 feet, and has length of 200 feet. Thus, the resistance of the wire, R, is:

$$R = \frac{\text{length}}{ft} * ohm \quad (30)$$

$$R = \frac{200 \ \text{ft}}{1000 \ ft} * 0.159 \ ohm = 0.032 \ ohm$$

(b) For the voltage drop in the main anode feeder

$$E = IR \quad (31)$$

Where:
E: the voltage drop in the main anode feeder
I : Maximum design current.
R: the resistance of the wire. [14]
I = 15.2 amperes and R = 0.032 ohm. Thus,
E = 15.2 A x 0.032 ohm = 0.49 V.
(c) For the voltage drop through the main anodes

$$E = IR \quad (32)$$

Where I = 15.2 amperes and R = 3.03 ohms. Thus,
E = 15.2 A x 3.03 ohms= 46.0 V
(d) The total voltage drop in main anode circuit is thus
E = 0.49 + 46.0 =47 V
Use a multiplying factor (safety factor) of 1.5 to get 75 volts.

6 ECONOMIC CONSIDERATIONS

Batteries are changed every 3 years; diesel generator is exchanged ever 12 year and PV modules fixed this duration overall 25 year.

Tab 2. *Average lifetime*

Item	Average lifetime
PV module	25 years
Batteries	3 years
Diesel generator	12 years

According to present market pierces, these studies consider the following costs in dollar $.

Tab 3. *Economics of systems items*

Type of energy system	Cost
PV energy source	
Solar Modules cost per 200wp	140$
Mounting cost per 200wp	17$
Cables and others	23$
Battery	
Battery and Mounting cost /Kwh	110 $
Installation cost	5 $
Diesel generator	
Tank 1 L of fuel cost	250 $
Fuel cost per litter	0.2 $/L

7 ECONOMIC CALCULATIONS

Financing the system is assumed to be done by a bank suppose that system cost is P ($) paid at t=0, and this amount is borrowed from a bank. This borrowed is paid back by N equal annual payments each A per year. Eq.(33) shows the relation between P,A,N and interest rate [15] .

$$P = \frac{A}{1+i} + \frac{A}{(1+i)^2} + \dots + \frac{A}{(1+i)^N} \quad (33)$$

$$P(1+i) = A + \frac{A}{1+i} + \frac{A}{(1+i)^2} + \dots + \frac{A}{(1+i)^{N-1}} \quad (34)$$

From (6)-(5) we get the following equation

$$P = A * \left[\frac{1-(1+i)^{-N}}{i} \right] \quad (35)$$

Where:
P=Initial payment at starting moment.
A=Installment of payment.
i=annual interest rate.
N= number of Installments.

$$P_t = E * C_o \left[\frac{1 - \left(\frac{1-L_s}{1+i_y} \right)^N}{i_y - L_s} \right] \quad (36)$$

Where:
Pt=Total system cost over 25 year.
E=Average yearly generated energy (Kwh).
Co= Selling price per Kwh.
Ls= yearly loss in system efficiency.
Iy= yearly interest rate.
N=Total number of year.
If Ls = Iy

$$P_t = \left[\frac{\text{Eo Co N}}{1 + \text{iy}} \right] \quad (37)$$

Where:
Pt=Total system cost over 25 year.
E_O =Average yearly generated energy (Kwh).
C_o= Selling price per Kwh.
iy= yearly interest rate.
<u>Remote area solution</u>
1-PV +batteries (stand alone)
2-PV + Two Diesel generators
3-PV+Small batteries + 1 Diesel generator
4-PV +Small batteries + 2 Diesel generators
<u>PV Grid</u>:
Solar module = number of module * cost each module
Mounting cost per n*200 WP=0.083* number of module*200WP
Cables and others =
Number of module*200WP*(11628/100000)
PV modules and its supports =
Solar module + Mounting+ Cables and others
<u>Batteries:</u>
Storage capacity = V* AH
Where:
V: value of volt
AH: array hour
Cost of batteries= Storage capacity*110
<u>1 diesel generator:</u>
Initial diesel generator cost including mounting and Installation =250$
Fuel and Filters every month cost = 11.5 (average diesel generator running hours per day)* 30 (month)*1 (average diesel consumption per hour) +100$ (transportation) + 173 $ (filters air and gas and small maintenance required) = 618$
Total Diesel generator = Initial diesel generator cost including mounting and Installation+ Fuel and Filters every month cost=250+618=868$.

8 COMPUTATIONS OF PV ARRAY SIZE AND STORAGE BATTERIES SIZE

Simulation program is based on:
1- Climatic condition of Cairo
2- Array tilt angle equal to latitude angle (30).
3- Constant load 24 hours
4- Three consecutive cloudy days

Tab 4. *The monthly average values of Ta, HB, and KT*

Cairo			
Jan	Ta	HB	KT
Feb	18	3.3	0.6
Mar	22	4.5	0.61
Apr	23	5.7	0.62
May	28	6.6	0.63
June	30	7.5	0.65
July	35	7.8	0.7
Aug	36	7.7	0.7
Sep	34	7.2	0.7
Oct	32	6.2	0.65
Nov	30	5.0	0.65

Case 1: pipelines require CP on the surface of soil:
VB=25V & I Load=1.8 Amp
Load Power: 45 W
PV array Size: 400 W_P
Eo (yearly generated energy):394 Kwh/yr
1-PV +batteries (stand alone):
In this system is simulated by using MATLAB for 10 inch x 2100 m long pipeline, VB=25V & I_{Load}=1.8 Amp. This simulation is pointed per year as average energy per year .the energy generated by solar cell ,energy to operating the load , SOC of batteries string during the year shown in Fig4.

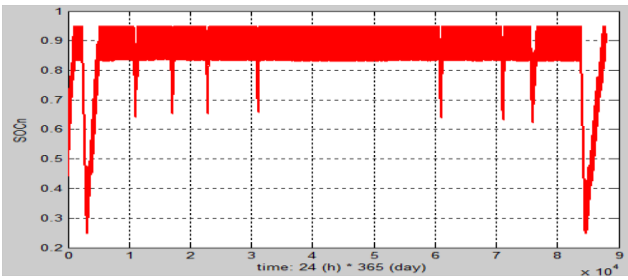

Fig 4. *.SOC per year for Stand-Alone system for*

10 inch x 2100 m long pipeline A, VB=25V & I_{Load}=1.8Amp
1-PV +battery (stand alone)
Battery size: 5.750 Kwh
Co (Cost):0.443 ($/Kwh)

2-PV + Two Diesel generators
Co (Cost): 0.249 ($/Kwh)
3-PV + small battery (stand alone) and one diesel generator running on the cloudy days
Battery size: 0.36 Kwh
Co (Cost):0.125 ($/Kwh)
4-PV + small battery+ 2 Diesel generator.
Battery size: 5.750 Kwh
Co (Cost):0. 26 ($/Kwh)

Case 2: pipelines require CP totally buried in the soil:
VB=6.2V & I Load=2.136 Amp
Load Power: 13.24 W
PV array Size: 106 Wp
Eo (yearly generated energy): 116 Kwh/yr
1-PV +batteries (stand alone)
In this system is simulated by using MATLAB for 10 inch x 6800 ft long pipeline, VB=6.2V & ILoad=2.136 Amp. This simulation is pointed per year as average energy per year .the energy generated by solar cell, energy to operating the load, SOC of batteries string during the year shown in Fig5.

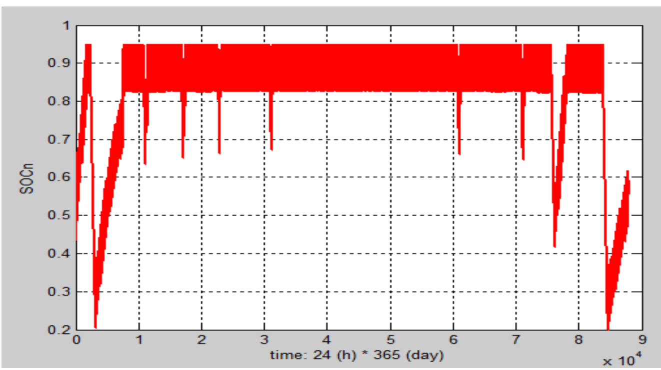

Fig 5. *SOC per year for Stand-Alone system for*

10 inch x 6800 ft long pipeline ,VB=6.2V & I Load= 2.136Amp

1-PV +battery (stand alone)
Battery size : 620 wh
Co (Cost):0.251 ($/Kwh)

2-PV + Two Diesel generators
Co (Cost): 0.23 ($/Kwh)

3-PV + small battery (stand alone) and one diesel generator running on the cloudy day's
Battery size : 0.39 Kwh
Co (Cost):0.21 ($/Kwh)

4-PV +small battery+ 2 Diesel generator.
Battery size : 5.750 Kwh
Co (Cost):0. 34 ($/Kwh)

Case 3:immerged tank in water :
VB=75V & I Load=15.2 Amp
Load Power: 1140W
PV array Size : 9Kwp
Eo (yearly generated energy) : 9986 Kwh/yr

1-PV +batteries (stand alone)
In this system is simulated by using MATLAB for Elevated Steel water tank VB=75V & I Load=15.2 Amp. This simulation is pointed per year as average energy per year .the energy generated by solar cell ,energy to operating the load , SOC of batteries string during the year shown in Fig6

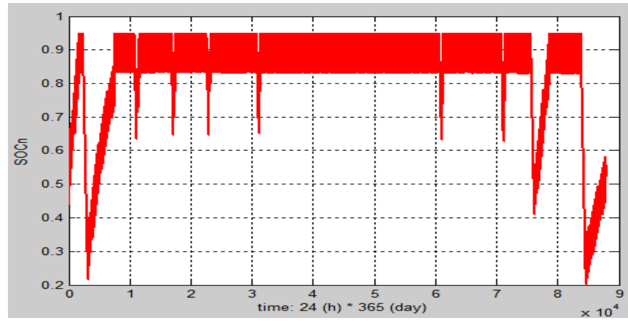

Fig 6. *SOC per year for Stand-Alone system for*

VB=75V & I Load=15.2Amp
1-PV +battery (stand alone)
Battery size : 142.5 Kwh
Co (Cost):0.43 ($/Kwh)

2-PV + Two Diesel generators
Co (Cost): 0.21 ($/Kwh)

3-PV + small battery (stand alone) and one diesel generator running on the cloudy day's
Battery size : 0.36 Kwh
Co (Cost):0.158 ($/Kwh)

4-PV + small battery+ 2 Diesel generator.
Battery size : 5.750 Kwh
Co (Cost):0. 235 ($/Kwh)

9 CONCLUSION.
The proposed regulated CP system avoids the difficulties associated with conventional CP system. The regulated CP system has the following advantages over the conventional one:
(1) It saves the effort and time of the technician
(2) it saves the energy because the volt age is automatically adjusted so the DC voltage is never more than the required value and there is no dissipation in a potentiometer
(3) corrosion is essentially stopped since the metallic structure will always receive the exact required DC current
(4) Coating destruction is almost entirely stopped since overprotection is eliminated. Accordingly, both human power and transport cost to adjust the system voltage are saved. Hence the proposed system provides economic advantages over the conventional one. The proposed system adds only a minor cost the conventional system-the cost of the electronic circuits added to the system control.

10 REFERENCES
[1]. W. Anis and M. Nom-. Performance analvsis of PV system for maximum utilization of solar radiation, AMSE international conference on signal and data. Moscow, June 30-July 2 (1993).

[2]. J.H. Morgan 'Cathodic Protection' National Association of Corrosion Engineers (NACE) 1987 2nd Edition.

[3]. S. Ewing, Committee report .American gas association, p,10 (1939).

[4]. O'M. Bockris and A. Reddy. Modern electrochemistry, Plenum Press, New York (1970).

[5]. M. Berde. "Thyistor engineering" 6th. ed. chap. 10. Khanna Publishers. Delhi. India (1990).

[6]. S. Dewan and A. Straughen. Power Semiconductor Circuits. chap. 6. Wiley Interscience publications, John Wiley &Sons. New York (1975).

[7]. W. Anis. Design of novel battery voltage regulator for photovoltaic systems. Solar Cell 28, 19-29 (1990).

[8]. K. G. Davies, The Corrosion Handbook (incorporating Corrosion Prevention Directory), 1999.

[9]. H. H. Uhlig Corrosion and corrosion control. Wiley, New York, 1985 (3rd edition).

[10]. J. Newman, Electrochemical systems. Prentice Hall. Engle wood Cliffs, NJ (1973).

[11]. K.R .Trethewey, and Chamberlain J., Corrosion for Science and Engineering, Longman Publishing Ltd, UK, 1995, p.375

[12]. W. R. ANIS and H. A. ALFONS, "Photovoltaic powered regulated cathodic protection system", Vol. 53, No. 2. pp. 211-214, 1994.

[13]. C. BASALO, ' Gas and Water pipelines, corrosio Degradation and protection ', Technique and Documentatio Lavoisier, Paris, 1987.

[14]. A .JOHN. J.R. WICKHAM, "ELECTRICAL DESIGI CATHODIC PROTECTION" Technical Manual TM 5-811- Aerospace Corp., Washington, Calif., April. 1985.

[15]. J.i. Heineke, "Microeconomics for business decision Theory and applications", Prentice Hall, Inc. Engle woc cliffs, New Jersey, 1976.