A Study on Corrosion Control of Natural Gas Distribution Pipelines at Munshiganj

by

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RECOMMENDATION OF THE BOARD OF EXAMINERS

The project entitled '**A Study on Corrosion Control of Natural Gas Distribution Pipelines at Munshiganj**' submitted by Satyajit Ghosh, Roll No:9613034(P), Session:1995-96-97, has been accepted as satisfactory in partial fulfillment of the requirements for the degree of MASTER OF ENGINEERING (PMR) on 31st December, 2005.

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It is hereby declared that this project or any part of it has not been submitted elsewhere for the award of any degree or diploma.

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ABSTRACT

In Bangladesh, pipe line quality natural gas is the principal source of energy. To ensure proper distribution of it to the end users 16.459 thousand kilometer steel pipe lines have been constructed so far. The market share of Titas Gas Transmission and Distribution Company Limited (TGTDCL) on the basis of pipe line construction among four companies in the country is the highest and about 8.70 thousand kilometers. As these pipelines are growing old, it is becoming more difficult to protect them from the damage caused by corrosion.

Mushiganj town, a distribution network of TGTDCL is the present area of interest, as severe corrosion took place in some portion of pipelines of this area in 1999. An evaluation of existing corrosion control system of the said area has been made. Study shows existing 30 Amp. x 20 volt TR unit based impressed current system of cathodic protection is not adequate to protect all the pipe lines in the area from corrosion. On the other hand impressed current system of cathodic protection is not fully appropriate for the area. Logarithmic mean resistivity of the pipe line environment is 2455 ohm-cm. Most of the pipelines are distributed in two part of the town, one part is called Munshiganj and another part is called Mirkadim. Both of these regions are often flooded by the surge of two adjacent rivers and most of the lines are smaller than 3 inch in diameter. Sacrificial anode method has been suggested as improved design for these areas. The other portion consists of 6 inch to 12 inch diameter distribution mains. This part is 12 km long and laid along highway. For this segment impressed current system has been suggested as improved design.

For implementing the improved design, Tk. 53.21 Lac is required to invest. Financial analysis shows that the investment is viable as compared to the increased operating cost for progressively worn out pipe lines and cost of unaccounted for gas (UFG) for enhanced corrosion in the next 20 years.

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ABBREVIATIONS

A	Ampere
AC	Alternating Current
API	American Petroleum Institute
BAPEX	Bangladesh Petroleum Exploration Company Limited
BCDC	Bulk Customer Development Cell
BCR	Benefit Cost Ratio
BGSL	Bakhrabad Gas System Limited
CP	Cathodic Protection
DC	Direct Current
DRS	District Regulating Station
DTP	Drain Test Point
EMF	Electromotive Force
JGTDCL	Jalalabad Gas Transmission and Distribution Company Limited
IJ	Insulating Joint
IRR	Internal Rate of Return
LC	Local Cost
MMSCF	Million Standard Cubic Feet
NPV	Net Present Value
PGCL	Poschimanchal Gas Company Limited
PSP	Pipe to Soil Potential
PVC	Poly Vinyl Chloride
RSD	Regional Sales Department
SHP	Standard Hydrogen Potential
TGTDCL	Titas Gas Transmission and Distribution Company Limited
TP	Test Point
TR	Transformer- Rectifier
UFG	Unaccounted for Gas

CHAPTER I

INTRODUCTION

Bangladesh is a riverine delta having porous and permeable hydrocarbon bearing sand structures. For the unique condition of traps the country is always considered a gas prone land. The history of natural gas industry in the country started in 1955 when a gas field was discovered at Sylhet, followed by another discovery at Chattak in 1959 Production and distribution were started by supplying gas to the Chattak cement factory through a 4 inch diameter 19 km pipeline form this field. After that, gas supply was provided to Fenchuganj fertilizer factory through a 8 inch diameter 43 kilometer pipeline in 1962 and through a 14 inch diameter 83 kilometer pipeline to Shidhirganj power station in 1967. Since then the industry has gained extensive progress both in terms of extension and volume. Presently four state owned companies viz. Titas Gas Transmission and Distribution Company Limited (TGTDCL), Bakhrabad Gas System Limited (BGSL), Jalalabad Gas Transmission and Distribution Company Limited (JGTDCL) and Poshchimanchal Gas Company Limited (PGCL) are engaged in providing services to about 1.5 million customers.

For supplying natural gas to the customers about 16459.031 Km pipe lines have been constructed so far. 1200 MMSCF gas is being distributed daily through these pipelines. Table-1.1 is extracted from annual report (2003-2004) of TGTDCL and it shows market share of the 4 companies under Petrobangla in the year 2003- 2004 on the basis of Pipe line length and gas sales.

Table-1.1: Pipe line construction up to June'2004 and gas sales in 2003-2004

Company Name	Year of Establishment	Length of Pipelines, km	Yearly gas sales, MMSCM
TGTDCL	1964	8703.11	8480.27
BGSL	1985	5138.91	2418.91
JGTDCL	1959	2379.15	652.52
PGCL	1998	237.86	557.37
TOTAL	-	16459.03	12109.07

The 16,459.03 km pipelines are national resources. To ensure uninterrupted supply to the customers and continuous revenue earning through gas sales, proper conservation and maintenance of the Pipelines is very important. Some of these pipelines are more than forty years old, a major portion have crossed its design life. Gas supply interruptions are increasing with time. Major cause of the supply interruptions is leakage in the pipe line due to corrosion. This problem is most severe for TGTDCL among four companies of Petrobangla. TGTDCL has the largest pipeline network and the leakage and corrosion problems are most acute for this company.

The reasons for increasing leakage in the pipelines are:

(i) Not providing proper attention to corrosion control system. It is neglected by the distribution companies.

(ii) Design of corrosion control is not done during construction of the pipelines. Cathodic protection (CP) system is introduced long after laying of pipelines. During this lag period corrosion in the pipe line initiates and the damage is irreversible.

(iii) Raptures in the PVC coating from overburden stress and removal of PVC tape for welding connection at the time of providing customer connections.

(iv) Ageing of the pipelines.

(v) In most of the areas CP are not functioning properly. But these are not monitored and repaired regularly

(vi) General tendency of replacing pipelines rather than lengthening its life through proper corrosion control.

Country's most of the pipelines are growing old and amount of unaccounted for gas (UFG) through leakage of the pipelines is increasing. Presently UFG of TGTDCL is 7.08% and the company suffers a loss of Tk.200.71 crore per year in terms of sales revenue for this UFG. At least 1% of this loss is caused by emission due to corrosion. This loss is about Tk. 28.35 crore per year. Therefore to curtail this loss existing corrosion control system assessment and improvement of the present system is required.

PVC tape wrapping along with cathodic protection is the usual method adopted for controlling corrosion of pipelines which are laid in moist soil environment. Despite taking such measures for distribution pipelines of TGTDCL at Munshiganj, in the year 1999 severe leakage took place in some portions of the pipelines. At present the loss due to UFG at Munshiganj is 7.18% and it incurs yearly loss of Tk.50.26 lac. So system evaluation from the corrosion control point of view is required.

CHAPTER II

REVIEW OF CORROSION ENGINEERING

Corrosion is the damage to metal caused by reaction with its environment. The common environments that corrode metals are air, water and soil. Corrosion is a natural process for metals that cause them to react with their environment to form more stable compounds. Rusting is a type of corrosion of ferrous metals producing familiar brownish-red corrosion product called rust.

All sorts of chemical and electrochemical processes that are designed to improve the metal are not considered as corrosion even though damage or loss of material can take place by these processes. The location, nature and severity of corrosion depend npon a number of factors which are discussed in the following sections.

2.1 Basic Corrosion Theory

The metals try to lower their energy by spontaneously reacting with environment to form solutions or compounds that have a greater thermodynamic stability. The driving force for metallic corrosion is the Gibbs energy change, ΔG, which is the change in free energy of the metal and environment combination brought about by the corrosion. If a reaction is to be spontaneous as corrosion reactions, ΔG for the process must be negative.

The term ΔG is only the difference between the Gibbs energies of the final and initial stages of the reaction and independent of the intermediate steps. ΔG values are summed up for all the steps to find the true Gibbs energy change for the reaction The units of G are now commonly used in Jouls per mole of metal.

In corrosion measurements, the driving force is more often expressed in volts (V) which can be found from the equation below:

$E = -\Delta G / nF$ ------------- (2.1)

Where,

E = Driving force for the corrosion process, volts.

n = Number of moles of electrons per mole of metal involved in the process,

F = A constant called the 'faraday' which is the electrical charge carried by a mole of electrons (or 96,490 Columb).

With ΔG being negative and with the minus sign in equation 2.1, spontaneous processes always have a positive voltage, E.

Aqueons corrosion is electrochemical in nature. The principles of electrochemistry, established by Michael Faraday in the early nineteenth century, are the key in understanding of corrosion and corrosion prevention.

Every electrochemical corrosion cell must have four components:

(i) The anode, which is the metal that is corroding. It is the positive terminal.

(ii) The cathode which is a metal or other electric conductor whose surface provides sites for the environment to react. It is the negative terminal.

(iii) The electrolyte (the aqueous environment) in contact with both the anode and the cathode to provide a path for ionic conduction.

(iv) The electrical connection between the anode and the cathode to allow electrons to flow between them.

Let us consider the following reaction namely the corrosion of zinc by hydrochloric acid.

$Zn+2HCl=ZnCl_2+H_2$, this equation can be divided into anodic and cathodic reactions.

The anodic reactions:

$Zn=Zn^{+2}+2e$ ....(2.2)

Examining the above reaction shows that the anodic reaction occurring during corrosion can be written in the general form;

$M = M^{+n}+ne$ .... (2.3)

That is, in anode reaction the anode metal M corrodes and goes into solution into the electrolyte as metal ions.

The cathodic reactions:

There are several cathodic reactions encountered during the corrosion of metals. These are listed below

Hydrogen evolution : $2H^{+}+2e=H_2$ ....(2.4)

Oxygen reduction (acid solution) : $O_2+4H^{+}+4e=2H_2O$ ....(2.5)

Oxygen reduction (neutral and alkaline solution) : $O_2+2H_2O+4e = 4OH$ ....(2.6)

Metal ion reduction : $Fe^{+3}+e=Fe^{+2}$ .... (2.7)

Metal deposition : $Cu^{+2}+2e=Cu$.......................(2.8)

2.1.1 Electrode potential

Standard electromotive force series are given by Weast in 1988 and published in the book of Bradford (1989), and shown in Table-2.1 below. These potentials refer to the relative potential of an electrochemical reaction under equilibrium or non-reacting (zero current flow) conditions.

Table- 2.1: Standard electrode potential.

Reaction	**E(v)**
$Au^{3+}+3e=Au$	1.498 Noble (Cathodic)
$Clo_3^- + 3H^+ + 6e = Cl^- + 3H_2O$	1.451
$Cl_2 + 2e = 2Cl^-$	1.358
$Cr_2O_7^{2-} + 14H^+ + 6e^- = 2Cr^{3+} + 7H_2O$	1.232
$O2 + 4H^+ + 4e^- = 2H_20$	1.229
$Pt^{2+} + 2\bar{e} = Pt$	1.118
$No_3^- + 4H^+ + 3\bar{e} = No + 2H_2O$	0.957
$Pd^{2+} + 2\bar{e} = Pd$	0.951
$Ag^+ + e = Ag$	0.80
$Hg_2^{+2} + 2e = 2Hg$	0.797
$Fe^{3+} + \bar{e} = Fe^{2+}$	0.771
$I_2 + 2\bar{e} = 2I^-$	0.536
$O_2 + 2H_2O + 4\bar{e} = 4OH^-$	0.401
$Cu^{2+} + 2\bar{e} = Cu$	0.342
$Cu^{2+}(Sat) + 2e = Cu(cuso4)$	0.316 Reference electrode
$AgCl+e=Ag+Cl^-$ (0.1M- KCl)	0.288 Reference electrode
$Hg_2Cl_2 + 2\bar{e} = 2Hg + 2cl^-(Sat.Kcl)$	0.241 Reference electrode
$2H^+ + 2\bar{e} = H_2$	0.000
$Pb^{2+} + 2e = pb$	-0.126
$Sn^{2+} + 2e = Sn$	-0.138

Table-2.1: (Continued) standard electrode potential

Reaction	**E(v)**
$Mo^{3+}+3\bar{e}=Mo$	-0.200
$N_i^{3+}+3\bar{e}=Ni$	-0.257
$Co+2\bar{e}=Co$	-0.277
$Fe^{2+}+2e=Fe$	-0.447
$Cd^{2+}+2e=Cd$	-0.403
$Cr^{3+}+3e=Cr$	-0.744
$Zn^{+2}+2\bar{e}=Zn$	-0.762
$Nb^{3+}+3\bar{e}=Nb$	-1.009 (Columbium Cb)
$T_i^{2+}+2\bar{e}=Ti$	-1.630
$Al^{3+}+3\bar{e}=Al$	-1.662
$Be^{2+}+2\bar{e}=Be$	-1.847
$Mg^{2+}+2\bar{e}=Mg$	-2.372
$Na^{+}+\bar{e}=Na$	-2.711
$K^{+}+e=K$	-3.040 Reactive (anodic)

Note: ions at 1M concentration, at 25° C (77°F), 1 atm

Sat. = Saturated

The potential of a corroding metal is most useful in corrosion studies and fortunately it can be readily measured in the laboratory under field conditions. The corrosion potential is measured by determining the voltage difference between a metal immersed in a corrosive environment and an appropriate standard reference electrode.

In any electrochemical reaction, the most negative half cell tends to be oxidized and the most positive half cell tends to be reduced. This rule can be applied by considering several examples The corrosion phenomenon of Zinc in acid solutions can be interpreted with the help of Table-2.1. The potential of the Zinc - Zinc ion half cell is more negative than that of the hydrogen ion-hydrogen gas half cell. Thus it indicated that Zinc will tend to be corroded by acid solutions.

It can be pointed out from Table-2.1 that copper will not corrode in hydrochloric acid because copper reduction potential is above (+0.342) hydrogen (0.00) on the standard EMF series. But copper slowly corrode in HCl when oxygen from the air dissolves in the acid making the O_2+H^+ cathode reaction.

$O_2 + 4H^+ + 4\bar{e} = 2H_2O$ has E=1.229V, well above the value of 0.342V for copper.

2.1.2 Galvanic series

The galvanic series is tabulation according to the corrosion potential of various metals and alloys exposed to a specific environment. Such tabulation for metals and alloys exposed to sea water is given by Bradford (1989) and shown in Table-2.2. Metals with positive corrosion potentials are usually called noble or cathodic and those with negative corrosion potentials are usually referred to as active or anodic metals and alloys. Coupling two metals that are using apart in the galvanic series makes a corrosion cell in electrolyte sea water. The more noble metal is cathodic and the active metal corrodes as the anode.

Table- 2.2 Galvanic series in sea water

Graphite	**(Noble End)**
Platinum	
Titanium	
Alloy 20 stainless steel	
316, 317 stainless steel, passive	
Monel Cu-Ni alloys	
302, 304, 321, 347 stainless steel, passive	
Silver	
Nickel	
Silver solder	
Mill scale on steel	
Lead	
430, stainless steel, passive.	
90 Cu-10 Ni	
410, 416 stainless steel, passive	
Bronzes	
Pb-Sn solder	
Copper	
Tin	
Brasses	
316, 317 stainless steel, passive	
Nickel Cast iron	
Low alloy steel	
Mild steel, Cast iron	
Aluminum	
Zinc	
Magnesium	**(Active End)**

2.2 Corrosion Rates

The extent of corrosion is commonly measured either of two ways. In uniform attack the mass of metal corroded on a unit area of surface will satisfactorily describe the damage. However if attack is localized, the amount of metal removed on average over the entire surface is meaningless. The depth of penetration whether by uniform attack, pitting or whatever gives a much better description of almost any type of corrosion except cracking.

2.3 Weight Loss

The corrosion rate in uniform attack (only) can be given as mass per area per time (mass/area.time).The most common unit of weight loss has been milligrams per square decimeter per day (mdd).The international (SI) unit of weight loss is expressed as gram per square meter per day ($g/m^2.d$). To have a very approximate idea of magnitude, it is worth remembering that corrosion rates in the order of 1 $g / m^2.d$ are usually satisfactory.

2.4 Depth of Penetration

The corrosion rate whether for uniform or localized attack, is often given as depth of penetration per unit time. For localized attack such as pitting, the penetration usually refers to the depth of the deepest pit observed, since that one is likely to be the most dangerous. The old traditional unit is mils per year (mpy, where 1000 mils = 1 in). The unit in SI system is millimeter per year (mm/y). Consequently 40 mpy = 1 mm/y, which is quite a severe attack.

For general engineering work the following rules of thumb will prove useful:

(i) When rate of corrosion of a metal is 0.1 mm/y (4mpy) then the metal is considered as good corrosion resistant metal.

(ii) When rate of corrosion of a metal is between 0.1 to 1 mm/y (ie, 4-40mpy) then the metal is considered as satisfactory corrosion resistant metal if greater corrosion can be tolerated.

(iii) When rate of corrosion of a metal is greater than 1 mm/y (40mpy) then the metal is considered as very corrosive metal.

2.5 Calculation of Corrosion Rates

Corrosion rates can not be calculated because it is a function of many variables, and the only way to find Corrosion rate is to measure it. However in cases where the anode and cathode are separated if the current flowing between them can be measured, the corrosion rates can be calculated from the corrosion current.

According to faraday's law,

Corrosion rate = i_{corr}/nF----------------------(2.9)

Where,

i_{corr} = the corrosion current density in amperes per square meter (A/m^2).

F = 96,490 C/mol.$\bar{e}$.

n = number of moles of electrons per mole of metal corroded.

Since coulombs = amperes × seconds , the rate then come out as moles of metal per square meter per second, which converts easily to the usual grams per square meter per day ($g/m^2.d$) by multiplying by the atomic weight of the metal and 86400 s/d. The corrosion rate can be measured when iron corrode in sea water producing corrosion current, I_{corr} = 0.4A. The procedure is as follows:

Corrosion rate,

$= i_{corr}/nF$

$$= \frac{\frac{0.4A}{m^2}(55.85g/mole\,Fe)(86400\,s/d)}{\frac{2\,mole\,\bar{e}}{mole\,Fe}(96490\,A.s/mole)}$$

$= 10\ g/m^2.d$

2.6 Specific Forms of Corrosion

Localized corrosion: Localized corrosion can be defined as selective removal of metal by corrosion at small special areas or Zone on a metal surface in contact with a liquid environment.

The most common type of localized corrosion is pitting in which small volumes of metal are removed by corrosion from certain areas on the surface to produce craters or pits. Pitting corrosion may occur on a metal surface in a stagnant or slow moving liquid. It also may be cased by crevice corrosion, poultice corrosion, deposition corrosion, cavitation, impingement and fretting corrosion. All these are various forms of localized corrosion discussed later.

Another common type is intergranular corrosion (sometimes called "intercrystalline corrosion"). In this form a small volume of metal is preferentially removed along paths that follow the grain boundaries to produce what might appear to be fissures or cracks. the same kind of substance fissures can be produced by transgrannular corrosion (sometimes called 'transcrystalline, corrosion'). In this a small volume of metal is removed in preferential paths that proceed across or through the grains

Pitting, intergranular and transgranular corrosion and selective dissolution are caused by "local elements" or "local cells" which exist at the surface of a metal and have an electrochemical mechanism.

A local cell is a small surface area undergoing corrosion that contains both anode and cathode sites at separate nearby locations. In the case of aluminum in water, for instance:

$Al \rightarrow Al.^{+3} + 3e$ (oxidation)

The aluminum ions are not very soluble in water and combine with hydroxyl ions in the water to form aluminum hydroxide which is not soluble and therefore precipitates as corrosion product;

$$Al^{+3} + 3(OH) \rightarrow Al(OH)_3$$

This reaction lowers the hydroxyl ion concentration in the vicinity of the anode so that the anode areas to become acidic. Negatively charged ions such as chlorides or sulfates tend to migrate toward the anode and may indirectly further increase the acidity. Local cells are produced by differences among small nearly areas on the metal surface. They may result from differences in the metal or the environment or from impressed currents.

A crevice or a local surface deposit may cause one part of the surface to be screened from contact with the bulk of the solution and thus from access to oxygen which the remainder in contact with liquid saturated in oxygen. This cause of local cells is known as "differential aeration" which is the most common form of "concentration cell".

2.6.1 Pitting corrosion

Pitting is a form of localized corrosion that proceeds because of local cell aeration which produces cavities beginning at the surface. These cavities may or may not become filled with corrosion products. Corrosion product may form "cap" over pit cavities which are described as "nodules" or "tubercles" product while the shapes of pits vary widely, they usually are roughly saucer, conical or hemispherical shaped.

Pitting occurs when a film - protected metal is almost but not completely resistant to corrosion. It happens on a metal surface immersed in a solution or moist environment (such as soil). It occur on metals that are covered with a very thin often invisible adherent protection surface film which may be formed during fabrication or be produced by reaction with the environment. Thus pitting occurs on magnesium, aluminum, titanium, stainless steels and copper in cases when surface films develop. It also may occur on iron, steel, lead and other metals. Pits develop at weak spots in the surface film and at sites where the film is damaged mechanically under conditions where self repair will not occur

A pit may go through four separate stages (1) initiation (2) propagation (3) termination and (4) re-initiation. The causes of initiation (i.,e, local cell action) have been discussed. In the propagation stage the rate increases due to change in the anode and cathode environment. A pit may terminate due to increased resistance of the local cell caused by filling with corrosion products, filming of the cathode etc. If a pitted surface is dried out the pits will of course terminate.

Since pitting is electrochemical it can be stopped by cathodic protection. It can also prevented by the use of inhibitions which alter the electrode reactions of the local cell and remove their driving force.

Penetration by pitting often can be prevented by coating the surface of a metal with a sacrificial layer of alloy (e.g, Zinc or aluminum) or by protective coatings. A zinc rich point is sacrificially active and will prevent the pitting of either steel or aluminum.

2.6.2 Crevice corrosion

Crevice corrosion occurs in cracks or crevices formed between mating surfaces of metal assemblies and usually takes the form of pitting or etched patches. Both surfaces may be of the same metal or of dissimilar metals or one surface may be non-metal. It can also occur under scale, surface deposits and under loose fitting metal surface. The crevice may proceed inward from a surface exposed to air. It may exist in an immersed structure.

Crevice corrosion is initiated as the result of the differential aeration mechanism. Oxygen in the liquid deep in the crevice is consumed by reaction with metal. Oxygen content of liquid at the mouth of the crevice exposed to air or of bulk liquid in the case of immersion is greater, so a local cell develops in which the anode or area being attacked is the surface in contact with the oxygen depleted liquid It is also thought that subsequent P^H changes at anode and cathode sites further stimulate local cell action as in the case of pitting corrosion This type of corrosion commonly occurs on film protected metals such as aluminum, magnesium, stainless steels and titanium.

Crevice corrosion often can be prevented at the design stage by avoiding crevices or during construction by filming them with a durable jointing compound that will exclude moistnre and remain resilent. Several synthetic types of compounds are available with much longer lives than vegetable based compounds which have been used for years.

2.6.3 Poultice corrosion

Poultice corrosion is a special case of localized corrosion due to differential aeration, which usually takes the form of pitting when an absorptive material such as paper wood, asbestos, sacking, cloth etc. is in contact with a metal surface that becomes wetted periodically. No action occurs while the entire assembly is dry. Little action occurs while the entire assembly is wet but during the drying period adjacent wet and dry areas develop. Near the edges of the wet zones differential aeration develops and this leads to pitting as in the case of crevice corrosion.

Poultice corrosion is prevented by avoiding the contact of absorptive materials with a metal surface, by painting the surface that will contact such materials, or by designing to see that such materials do not become wet in service.

2.6.4 Deposition corrosion

Deposition corrosion is a form of pitting corrosion that can occur in a liquid environment when a more cathodic metal is platted out of solution onto a metal surface. It generally occurs with the more anodic metals such as magnesium, zinc and aluminum and common cathodic "activators" are mercury and copper ions in solution.

For example soft water passing through a copper water pipe will accumulate some copper ions. If the water is then admitted to a galvanized or aluminum vessel particles of metallic copper will plate out i,e 'deposit' on the surface of the vessel and stimulate pitting by local cell action.

Deposition corrosion can be avoided by preventing the pick-up of cathodic ions that will enter the metal equipment or by scavenging the picked up ions passing the contaminated product through a tower packed with metal turnings that will trap them.

2.6.5 Cavitation

Cavitation damage is a form of localized corrosion combined with mechanical damage that occurs in turbulent or rapidly moving liquids and takes the form of areas or patches of pitted or roughed surface. It has been defined as the "deterioration of surface caused by the sudden formation and collapse of bubbles in a liquid". In some instances cathodic protection has been successful io reducing or preventing cavitation damage. Cavitation damage usually involves physical as well as electrochemical processes, so it cannot always be prevented by this means. In some cases inhibitors have been used successfully to limit cavitation corrosion as in the water side of diesel engine cylinder liners.

2.6.6 Impingement

Impingement attack is a "First cousin" to cavitation damage and has been defined as "localized erosion - corrosion caused by turbulence or impinging flow". Entrained air bubbles tend to accelerate this action as suspended solution. This type of corrosion occurs in pumps, values, orifices or heat exchanger tubes and at elbows and tees in pipelines.

Prevention of impingement attack is the use of more resistant alloys.

2.6.7 Fretting corrosion

The rapid localized corrosion that occurs on closely fitting surfaces in contact under load and subject to small amplitude slip (i.e chafing or vibratory motion) is termed "fretting corrosion".

Fretting corrosion takes the form of local surface discolorations and deep pits. These occur in regions where slight relative movements have occurred between mating highly loaded surfaces. The pits sometimes provide stress raisers for the initiation of corrosion fatigue.

Fretting corrosion can be prevented by eliminating the slipping movement between two surfaces. To prevent the relative motion load can be increased. Lubrication of the contacting surfaces also can be adopted to prevent such corrosion.

2.6.8 Intergranular corrosion

Intergranular corrosion is a form of localized surface attack in which a narrow path is corroded out preferentially along the grain boundaries of a metal. It initiates on the surface and proceeds by local cell action in the immediate vicinity of a grain boundary.

The driving force is a difference in corrosion potential that develops between a thin grain boundary zone and the bulk of the immediately adjacent grains. The difference in potential may be caused by the difference in chemical composition between the two grains. This can develop as a result of migration of impurity or alloying elements in an alloy to the grain boundary.

Intergranular corrosion cause significant loss of ultimate tensile stress of metal. It is prevented by ensuring a metal microstructure which is immune to this type of attack.

2.6.9 Transgranular corrosion

Transgranular corrosion is a form of localized subsurface attack in which a narrow path is corroded at random across the grain structure of a metal disregarding grain boundary. Thus "cracks" appear to develop across grains without any apparent effect on the crack direction by the presence of the grain boundary. It initiates on the surface and proceeds inward, presumably by local cell action. Corrosion fatigue occurs most commonly by transgranular clacking. Transgranular attack is avoided by the use of suitable non-susceptible alloys.

2.7 Factors Affecting Corrosion

Different factors such as metallurgical, mechanical, aqueous environment, atmosphere, soil, biological, stray current etc affects corrosion.

2.7.1 Metallurgical factors

Crystals and grains: Nearly all metals and alloys exhibit a crystalline structure. Crystals have the unique condition in which atoms are automatically and uniformly arranged in all three dimensions. Crystalline nature of metals is difficult to understand because the usual concept of a crystal is a geometrically shaped object. Normally metal grains are so small that they can only be observed well under a microscope.

Metals are frequently plastically deformed in fabricating. In high deformed metals, the grains are deformed and the grain structure is completely disrupted. Normally in this condition the material is somewhat more reactive in electrochemical environment.

Crystal imperfections and defects: In reality there are variations in the crystal structure. These are not perfect three dimensional array caused by crystalline defects. These defect may have vacancies caused by the absence of atoms in the crystal, impurity atoms of different sizes, interstitial atoms etc. Each of the imperfections can produce highly localized differences in electrochemical behavior of metal.

Pure metals and alloys: Metals listed as pure or commercially pure, actually contain a variety of impurities and imperfections. These impurities and imperfections are inherent causes of corrosion in an aggressive environment. High purity metal can be produced by a special technique called zone refining and purity of 99.99999 percent is possible. Such material exhibit corrosion resistance much better than 99 to 99.9 percent pure metals.

Phases in alloys: When an alloying element is added to a base metal it is possible that the crystal structure will remain essentially stable and produce a simple solid solution. When one metal dissolves in another without a change of crystal structure, the result is termed as solid solution or a single "phase".

It is impossible to dissolve a large amount of one metal into another. When this occurs in an alloy, it results in the formation of one or more phases depending on the number and type of components in the alloy. For example the plain carbon steel is a mixture of interstitial solid solution of carbon in body centered cubic iron (ferrite) and an inter-metallic compound called Cementite, (Fe_3 C).

Multiphase materials present a problem from the corrosion point of view because the two phases have wide differences in electrochemical characteristics.

Corrosion prevention by application of metallurgical principles: By applying metallurgical principles it is possible to reduce corrosion. The commonly used principles are:

(i) Selection of high purity material.

(ii) Selection of alloy additions.

(iii) Surface coatings.

(iv) Knowledge of the metallurgical history of the material etc.

2.7.2 Mechanical factors

Stress corrosion cracking: A combination of tensile stresses and a corrosive environment is one of the most important causes of failures of metal structures. When stress exceeds the yield strength of the metal, crack may originate.Table-2.3 shows the environment producing stress corrosion cracking in various alloy systems. The table is found in the training manual prepared by the Directorate of Continuing Education (DCE), BUET (2002).

Table-2.3: Corroding conditions

Alloy system	**Environments**
Aluminum alloys	Chlorides, Humid industrial atmosphere, Marine atmosphere etc.
Copper alloys	Ammonium ion
Brasses etc	Amines
Nickel alloys	Hot concentrated hydroxides
Low carbon steel	Boiling concentrated hydroxides, Boiling concentrated nitrites.
Oil country steels	Hydrogen sulfide and carbon dioxide
High strength low alloy steel	Chlorides
Stainless steel	Boiling chlorides
Austenitic steels (300 series)	Boiling concentrated hydroxides
Ferritic and martensitic steels (400 series)	Chlorides, Reactor cooling water etc.
Titanium alloys	Chlorides, methyl alcohol, solid chlorides at temperatures above 550°F.

Method of preventing stress corrosion cracking: Corrosion stress cracking can be reduced by removing residual stresses present in the material from fabricating process. This stresses can be removed by annealing the structure

If tensile stresses can not be avoided environment can be modified to reduce corrosion stress cracking. The maintenance of oxygen and chloride levels of water to parts per billion in close stainless steel heat exchanger systems operating at high temperatures is one of these.

Corrosion Fatigue: When a material is under repeated mechanical stress in corrosion environment then it is called corrosion fatigue. Corrosion fatigue is a common cause of un-expected cracking of vibrating metal structures So structures are designed to operate safely in air at stress below the fatigue limit.

Corrosion fatigue prevention:

(i) For mild steel through de-aeration of the saline solution restores normal fatigue limit in air.

(ii) Cathodic protection to -0.49 with respect to standard hydrogen electrode (S.H.E) potential also restores normal fatigue limit in air.

(iii) Sacrificial coatings (e.g. zinc or cadmium electro-deposited on steel) are effective because they cathodically protect base metal even at defects in coatings.

2.7.3 Corrosion in aqueous environment

Water is corrosive to metals when it carries dissolved gases (like O_2, Co_2, and So_2). Water with no dissolved gases can not cause corrosion to metals up to boiling point of water. The corrosion behavior of iron in aqueous environment is discussed below:

Anodic reactions:

1. $Fe + \frac{1}{2}O_2(aq) + 2H_2O = Fe(OH)_3 + H^+ + \bar{e}$

2. $Fe = Fe^{++} + 2\bar{e}$

3. $Fe + CO_3 = FeCO_3 + 2\bar{e}$

4. $Fe + 2OH^- = Fe(OH)_2 + 2e^-$

Cathodic reactions:

5. $Fe(OH)_3 = Fe^{++} + \frac{3}{4}O_2(aq) + \frac{3}{2}H_2O + 2e^-$

6. $Fe(OH)_3 + 3Cl^- = Fe^{++} + 3HOCl + 5e^-$

7. $H_2 = 2H^+ + 2e^-$

8. $CaCO_3 + OH^- = Ca^{++} + \frac{1}{2}O_2(aq) + HCO_3 + 2e^-$

9. $H_2O = \frac{1}{2}O_2(aq) + 2H^+ + 2e^-$

10. $H_2O + Cl^- = HOCl + H^+ + 2e^-$

It is evident from above anodic and cathodic reaction is that absence of oxygen or any other oxidizing agent such as chlorine, nitrite and dichromate, a number of reactions may take place in the anode but only one reaction may take place at the cathod. The various factors controlling the corrosion of iron in water are discussed below:

Effect of dissolved oxygen: In nearly neutral water of ordinary temperature dissolve oxygen causes appreciable corrosion (100 mdd). This rate decreases over the period as the iron oxide (rust) film is formed and acts as basics to oxygen diffusion and the steady state corrosion rate may be 10 to 25 mdd. When corrosion is controlled by diffusion of oxygen, the corrosion rate at a given oxygen concentration doubles for every 30°c. As the concentration of oxygen increases it is found that beyond critical concentration corrosion rate drops to a low value.

Effect of dissolved salt: Corrosion rate of iron increases with increase of Nacl concentration. After achieving a maximum, the rate then decreases with increase of Nacl concentration. Oxygen solubility in water decreases continuously with sodium chloride concentration; thus rate of corrosion decreases.

Effect of P^H : Normally when P^H value is less than 4, oxide film is dissolved and iron surface is more or less in direct contact with the aqueous environment increasing corrosion rate. Again when P^H value is more than 10 iron becomes more passive in presence of alkaline and dissolve oxygen, as a result corrosion decreases. The corrosion rate remain unchanged when P^H value between 4 to 10.

Effect of velocity: With the increase of velocity, initially corrosion rate increases because more oxygen comes to the surface. But as the velocity increases enough oxygen reach to the surface to cause passivity and then the rate may decrease. In Presence of chloride ions in water like sea water, passivity is not established and corrosion rate increases with velocity.

2.7.4 Atmosphere and soil corrosion

Moisture content of air, dust content and gaseous impurities affect corrosion of a metal.

Types of atmospheres: Atmospheres vary considerably with the presence of moisture, temperature and contaminants. Thus rate of corrosion vary. Near the sea present of sea salt, near industrial area presence of $So_2, H_2So_4, H_2S, NH_3, No_2$ have direct influence on corrosion of metal.

Thus corrosion rate of metal varies markedly from place to place and thus divide atmosphere into types. Corrosion contaminants form corrosion-product films and accelerate corrosion.

Corrosion - product films: Sometimes corrosion film (rust) accelerates rate of corrosion. For example sulfuric acid absorbed by rust will continue to accelerate corrosion. It can be expressed by the following example:

$$Fe \xrightarrow{H_2So_4 + \frac{1}{2}O_2} FeSO_4 \xrightarrow{\frac{1}{4}O_2 + \frac{1}{2}H_2SO_4} \frac{1}{2}Fe_2(SO_4)_3 \xrightarrow{\frac{3}{2}H_2O} \frac{1}{2}Fe_2O_3 + \frac{3}{2}H_2SO_4$$

Thus rust contaminants accelerate corrosion.

2.7.4.1 Factors influencing corrosivity of the atmosphere

The factors which mostly influence the corrosivity of the atmosphere are dust content, gases in the atmosphere and moisture (critical humidity).

Dust Content: City atmosphere contains dust ranging from 2 mg/m^3 to 100 mg/m^3. Dust free air is less liable to cause corrosion than air heavily liable with dust. Particularly if the dust consists of water soluble particles on which H_2So_4 is absorbed. This was shown by the experiment of Vernon.

Gases in atmosphere: The most important corrosion constituent of industrial atmospheres is sulfur dioxide which originates mainly from burning of coal, oil and gasoline

Moisture (Critical humidity): Vernon discovered first that a critical relative humidity exists below which corrosion is negligible Typical corrosion behavior of iron is a function of relative humidity.

2.7.4.2 Facrors affecting the corrosivity of soils:

Corrosion of soil depends upon:

(i) Porosity

(ii) Electrical conductivity or resistivity

(iii) Dissolved salts

(iv) Moisture.

(v) Acidity or alkalinity.

A porous soil may retain moisture over a period of time or may allow optimum aeration and both factors tend to increase the initial corrosion rate. Corrosion products formed in an aerated soil may be more protective than those formed in an unaerated soil. If soils are not aerated corrosion takes the form of deep pitting. Such type of localized corrosion is more damaging to pipelines than a high uniform corrosion rate. On the other hand poorly aerated soil may contain sulfate reducing bacteria. These may produce high corrosion rates.

A soil containing organic acids is relatively more corrosive to steel, zinc, lead and copper. A soil of poor conductivity that is of high resistivity is less corrosive than a highly conducting soil. But conductivity or resistivity is not the only index of corrosion. Anodic and cathodic polarization characteristic of a soil are also a factor. When cinders present in soil it becomes more corrosive. Corrosion rate of steel and zinc are found about 5 times if they are kept four to five years in cinders.

Remedial measures for corrosion in soil:

(i) Organic and inorganic coatings.

(ii) Metallic coatings

(iii) Alteration of soil

(iv) Cathodic protection.

2.7.5 Biological corrosion

This is the corrosion due to living organisms such as bacteria, algae and barnacles. There organisms live and reproduce in soils and at 0-11 P^H, 30°-180°F temperature and over burden pressure of 15,000 lb/in^2. Thus biological activity affects corrosion in a variety of environments like soil, natural water, sea water and petroleum products etc. These organisms affect corrosion as follows:

(i) By influencing anodic and cathodic reactions.

(ii) By influencing protective surface films.

(iii) By creating corrosive conditions.

(iv) By producing deposits.

2.7.6 Microorganisms

Two types of microorganisms are found:

(i) Aerobic bacteria which requires dissolved oxygen to grow, and

(ii) Anaerobic bacteria which requires little or no oxygen.

Anaerobic bacteria influence corrosion behavior of buried steel structures are the sulfate reducing types (Desulfuricans).These converts sulfate to sulfide according to the following reaction:

$$SO_4^{-2} + 4H_2 \rightarrow S^{-2} + 4H_2O$$

Here H_2 may come from corrosion reaction or from any organic substance present in the soil. Sulfide tends to retard cathodic reactions, particularly hydrogen evolution and accelerate anodic dissolution that is corrosion.

Prevention of Microbiological corrosion:

(i) Coating the buried structure with asphalt, enamel, plastic tape or concrete.

(ii) Cathodic protection is effective when used with coatings.

(iii) To alter the environment.

2.7.7 Stray current corrosion

Electrical currents leaving their intended path and passing through soil, water or other electrolyte will follow any high conductivity metallic paths available. They corrode the metal where leave it and return to the electrolyte. This corrosion is stray current corrosion, sometimes called "electrolysis". It is basically independent of O_2 and P^H. The damage is done because the current leaves the metal as M^{+n} ions and return to the soil. Stray currents are usually termed as "interference". Alternating currents cause much less damage for steel than direct current (1% only).

Figure-2.1 shows corrosion of a steel tank due to stray currents. The best way of preventing stray current corrosion is to eliminate the current at its source (if possible). Good electrical connections, good insulation and proper grounding are essential for preventing stray current corrosion

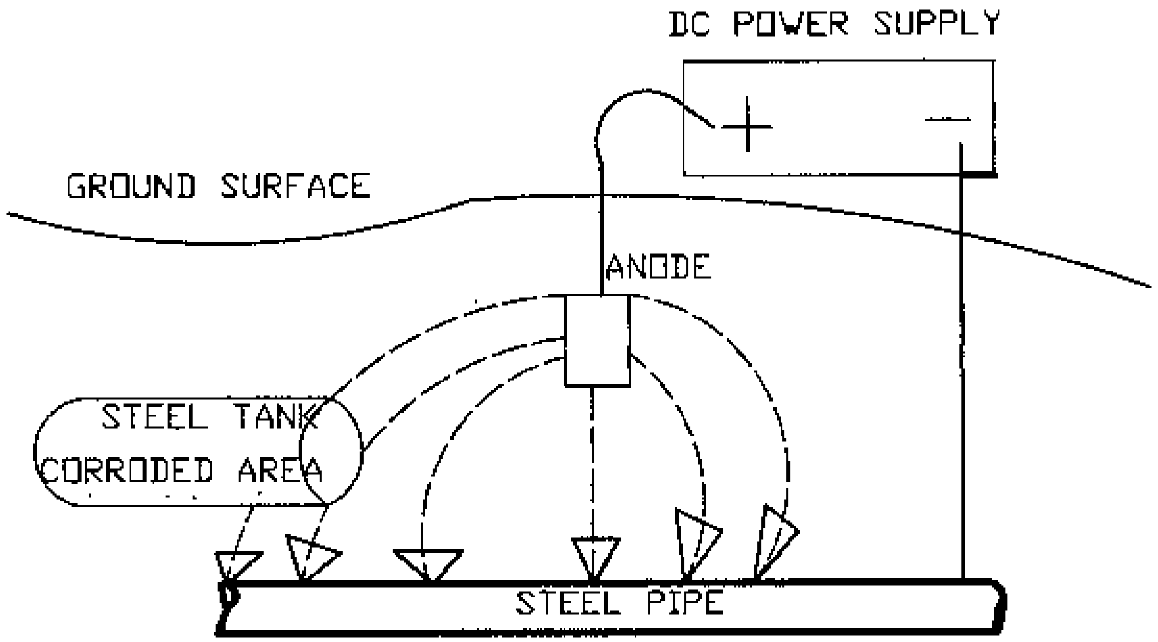


Figure-2.1:Corrosion caused by stray current.

CHAPTER III

METHODOLOGY AND DESIGN CONSIDERATIONS

Natural gas transmission and distribution pipelines are laid below the ground surface. These pipelines are susceptible to corrosion by various subsoil environments. To control corrosion cathodic protection system along with suitable coatings are usual method. Cathodic Protection (CP) converts all anodic areas on a metal to cathods so that corrosion ceases. The protected metal has positive current flowing onto it from the electrolyte so that no current flows off. This result can be achieved in two different ways:

(a) By connecting sacrificial anode to the metal that is to be protected.

(b) By applying an electric current from a separate power source, a technique called impressed current cattodic protection.

General considerations of Cathodic Protection on coated lines: A number of factors are to be considered in designing corrosion protection of pipelines by Cathodic Protection method. Consideration differs to some extent depending on the choice of method. But a number of factors are common for both methods. The factors are discussed in the following sections:

3.1 Soil Resistivity

Resistivity of soil is the resistance of a cube of soil of one centimeter in dimension. Resistivity of a rectangular solid given by,

$$\rho = R\left(\frac{W \times D}{L}\right) \text{--------------} (3.1)$$

Where,

ρ = resistivity, ohm - cm

R = resistance of soil, ohm

W, D and L are dimensions in cm.

Equation (3.1) can be written as $\rho = \text{constant} \times R$,

Or, $\rho = 2\pi aR$,

Where,

a = spacing of electrode of Wenner's four terminal soil resistivity measuring instrument. Constant $2\pi a$ becomes 1000 when a = $5' - 2\frac{1}{2}''$.

Before designing a cathodic protection system, it is very important to conduct soil resistivity survey. The commonly used procedures for resistivity survey are as follows:

(i) Resistivity recording should be taken at least every 400 ft.

(ii) Intermediate readings should be taken where visible changes in soil characteristics are observed

(iii) Two successive reading should not differ by a ratio grater than 2:1

(iv) No two readings should be taken as close as 25'-0".

(v) When a reading is greater than 20,000 ohm-cm, the next reading differ by a ratio of 2:1 is not a problem.

Table-3.1 shows relation of soil resistivity to corrosion rate of steel in soils based on 12 years tests and the table is given by M. Romanoff, National Bureau of Standards, USA and published in Parker (1954).

Table - 3.1: Corrosion of steel in soil.

Soil type	Corrosion rate (mpy)	Type	Soil resistivity (ohm-cm)
Average of 44 soils	61	Moderately corrosive	1000 to 2000
Tidal marsh	100	corrosive	500 to 1000
California clay	137	very corrosive	Below 500
Sandy loam (New England)	21	Mildly corrosive	2000-10,000
Desert sand	5	Progressively less corrosive	Above 10,000

3.2 Pipe to Soil Potential as a Criterion

After installation of cathodic protection system, the efficiency of the system is checked by measuring pipe to soil potential (PSP) at various point along the structure. If the PSP value found above the threshold of 0.85 volt negative referred to standard Copper-Copper sulfate electrode, the structure is fully protected. It is a universally accepted criterion. It is general practice that electrode to be placed in the soil immediately over the line. Figure-3.1 shows a typical Copper-Copper sulfate reference electrode.

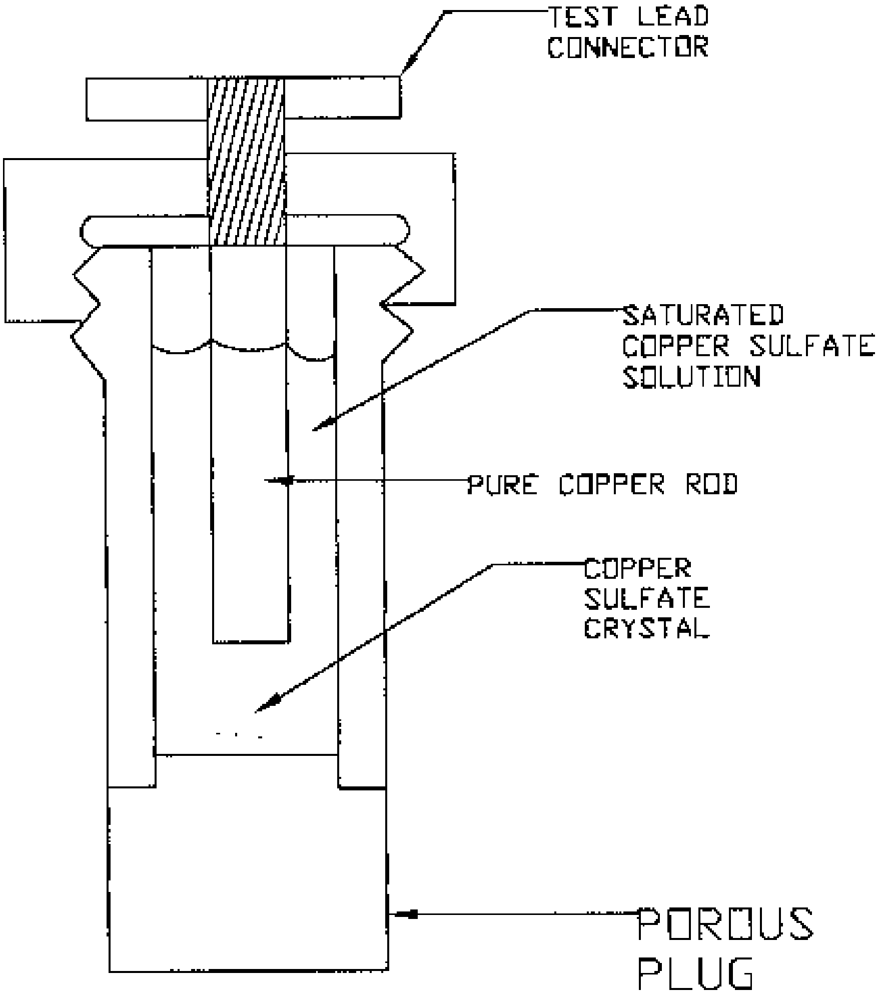


Figure-3.1: Typical Copper-Copper sulfate reference electrode.

Other reference electrodes such as the saturated Calomel, Silver - Silver chloride and pure zinc are available for potential testing. These electrodes can be used by adding or subtracting to the potential readings obtained to covert potentials to a Copper-Copper sulfate reference electrode. Table-3.2 shows the conversion factors given by Peabody, A.W (1973).

Table-3.2: Comparison of other reference electrode potentials with that of the Copper-Copper sulfate reference electrode at 25°C.

Type of reference electrode	Pipe to reference electrode reading equivalent to- 0.85 volt with respect to Copper-Copper sulfate reference electrode.	To correct pipe to reference electrode reading to equivalent readings with respect to Copper-Copper sulfate reference electrode.
Calomel (saturated)	-0.776 volt	Add - 0.074 volt
Silver - Silver chloride (0.1N KCl solution)	-0.822 volt	Add - 0.028 volt
Silver - Silver chloride (Silver screen with deposited Silver chloride)	-0.78 volt	Add - 0.07 volt
Pure Zinc (Special High Oxide)	+0.25 volt	Add -1.10 volt

Note. Based on zinc having an open circuit potential - 1.10 volt with respect to Copper - Copper sulfate reference electrode.

3.3 Coating Effect

It has become common practice to combine cathodic protection with protective PVC coatings. Coated pipeline can be protected for long life at minimum power costs. For this type current distribution is more uniform and current flows to flaws in the coating and thus current requirement is greatly reduce. Generally the cost of cathodic protection of coated pipelines is about 10% of the cost of protecting bare metal. Neither coating nor current can protect a structure alone. So coating is important.

3.4 Current Requirement

The amount of protection current required depends upon corrosivity and it can vary considerably. A well coated pipeline with high resistivity soil may need only 0.5mA/ft^2; on the other hand a bare pipeline in low resistivity soil may need 2mA/ft^2. Field survey is important for determining current requirement precisely.

3.4.1 Current requirement survey

There are two approaches:

(i) Complete protection of the line with temporary installation. This may vary widely to get a satisfactory combination. For most of the cases this method is complicated and generally is not used.

(ii) Determination of electrical characteristics of the line. This method is theoretically possible and an amount of trial and error procedure is required.

3.4.2 Field procedure of current requirement test

Current is drained from the line to a temporary ground bed and its effect is determined at a great distance. The end result provides specification of drainage units and specified quantities of current. A welding machine or storage batteries in series are used as current source for current requirement tests. The following steps are taken:

(i) **Static potential:** Pipeline to soil potential is measured over the entire line, special care is given to road, river and bridge crossings. For good coating, readings can be taken at several miles but for poor coating it can be within few hundred feet. This is the natural potential of the structure in soil.

(ii) **Polarization potential:** A suitable location where rectifier appears to be installed, a temporary drainage point (anode bed) is established and a steady current is drained for a period from one to three hours Pipe to soil potential is then measured of a nearby point during this interval. Value of current to be used should be large enough to cover a long portion of line. PSP near the drain point should not exceed 3 volts.

(iii) **Potential survey:** A current interrupter is used to measure "on" and "off" potential at various points cover the entire line. By the interrupter current is kept on for 40 seconds and kept off for 20 seconds. "On" and "off" potentials are measured at different point just before interruption and just after interruption.

(iv) **Survey of line current:** Line currents are measured on each side of the drainage point and at remote location at each direction. Like the potential values these should consists of "on" - "off" pair.

(v) **New drainage points:** New drainage points should be chosen if the current source is not large enough to cover the whole line and sufficient data are not found for use. Then the process is repeated

3.4.3 Graphical representation of current survey data

After conducting line current survey data are represented in the form of a set of curves:

(i) **Logitudinal distribution curves:** Static potential, 'on' potentials and 'off' potentials at different points along pipelines are plotted against distance from drain point.

(ii) **Attenuation curves:** Polarization potential (difference between 'off' potential and static potential) and driving voltage (difference between 'on' potential and 'off' potential) are plotted against distance from drain point.

(iii) **Polarization chart:** This is a fonctional relationship between polarization potential and driving voltage. It is plotted on log-log paper.

Current survey data are represented by the curves given in Figure-3.2, Figure-3.3 and Figure-3.4.

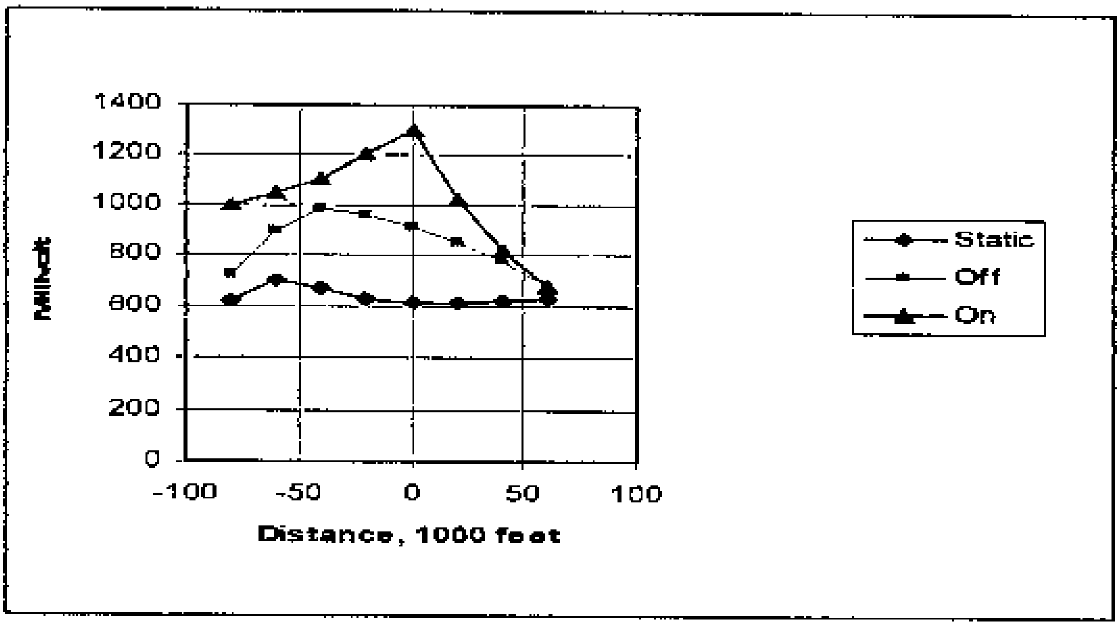


Figure-3.2: Typical longitudinal distribution curves

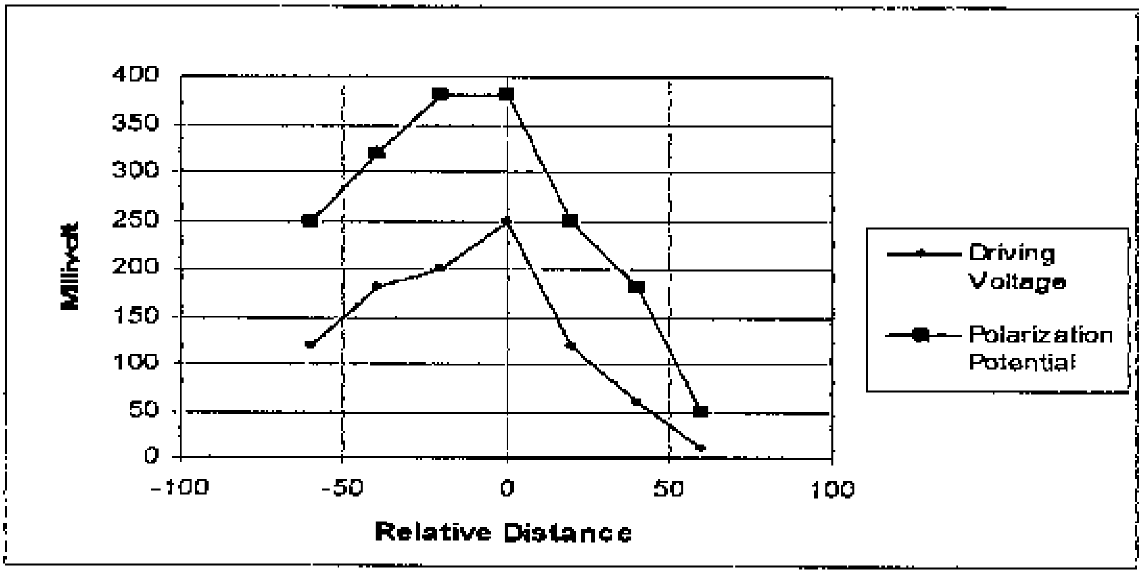


Figure-3.3: Typical attenuation curves.

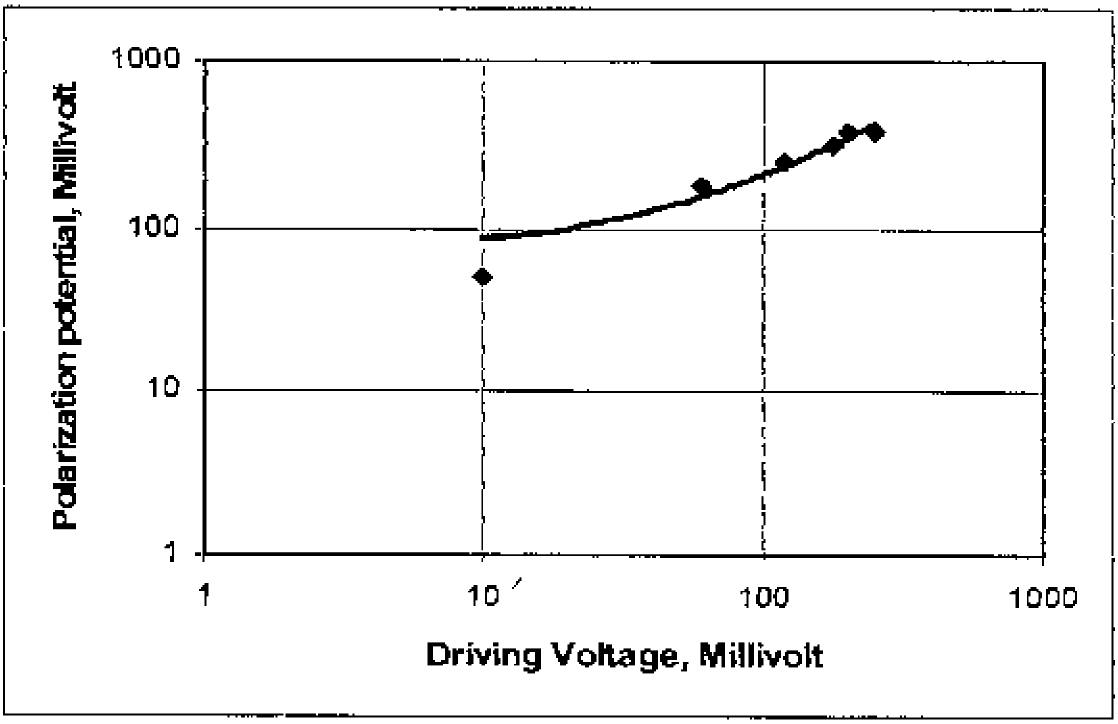


Figure-3.4: Typical polarization chart

3.5 Sacrificial Anode Method

The corrosion control worker should keep informed of the latest catalog information on different alloys available of the various galvanic anode metals. The manufacturer offer many sizes and shapes of anode.

Anode (Al, Mg or Zn) is buried in soil and connected with pipeline is this method, thus a galvanic cell establishes between pipeline (cathod) and anode. In this case the anode will corrode while the steel pipe to which it is attached will tend to be cathodic and free from corrosion. Commonly used materials as anode are described below

3.5.1 Magnesium anodes

Magnesium anodes are used to a greater extent than zinc for earth-burial installations on pipelines and other underground metallic structures. This is because the galvanic cell driving potential is higher permitting practical amounts of cathodic protection current in higher resistivity soils.Table-3.3 extracted from Appalachian underground corrosion short course (1986) shows the composition of different grade of magnesium anode.

Table-3.3: Common alloy specifications – magnesium

Element	Galvomag	Grade I	Grade II	Grade III
Al	0.010% max	5.0 to 7.0%	5.3 to 6.7%	5.3 to 6.7%
Mn	0.50 to 1.30%	0.15% min	0.15% min	0.15% min
Zn	0	2.0 to 4.0%	2.5 to 3.5%	2.5 to 3.5%
Si	0	0.30% max	0.30% max	0.10% max
Cu	0.02% max	0.1% max	0.1% max	0.2% max
Ni	0.001% max	0.003% max	0.003% max	0.002% max
Fe	0.03% max	0.03% max	0.03% max	0.03% max
Other	0.05% each or 0.03% max total	0.03% max	0.03% max	0.03% max
Magnesium	Remainder	Remainder	Remainder	Remainder
solution potential	-1.80v	-1.55v	-1.55v	-1.55v

There are many different sizes and shapes of magnesium anodes available from manufacturers. The corrosion worker should obtain up-to-date catalogs so that correct information will be available to permit matching the optimum anode weight and shape to specific design needs.

Probably the most popular magnesium anode for general use is the 17-pound anode packaged in special chemical backfill. Most of the magnesium weights and shapes can be obtained either bare or packaged in special backfill. Approximately similar weights of magnesium may be available in short chunky shapes or in long slender shapes. There is a reason for this. The resistance to earth of a galvanic anode determines the current output at the fixed galvanic anode cell potential. A long slender anode has a lower resistance to earth in a given earth resistivity than does a short chunky anode. This means that long slender anodes can be the better choice in the higher earth resistivities.

Although either zinc or magnesium installations may be designed for use in any earth resistivity, various considerations tend to dictate that zinc anodes have their best usage in low resistivity earths with lesser advantage as the resistivity increases up to a rule-of-thumb maximum (which may be exceeded in special cases) of about 1,500 ohm-cm. Allowing for some range overlap, a guide for magnesium usage could be between 1,000 and 5,000 ohm-cm. Again, both limits can be exceeded where design conditions warrant

3.5.2 Zinc anodes

Zinc anodes can be obtained in many different weights and shapes. Some may be obtained packaged in special backfill. Again, the corrosion worker should obtain the latest catalog information on currently available zinc anodes.

Zinc anodes work best in very low resistivity environments such as sea water, salt marshes, and similar low resistivity material. In such environments, short chunky zinc anodes work best. As the resistivity gets higher, the long slender anodes would be preferred. This could, for example, be in the general range of 750 to 1500 ohm-cm resistivity. Table-3.4 extractedfrom Appalachian underground corrosion short course (1986) and shows Zinc alloy specification for seawater and underground use.

Table-3.4: Common alloy specification-zinc

Zinc (Mil-A 18001)		Zinc (ASTM B418-67 Type II)	
Seawater Use		Underground	
Element	Percent	Element	Percent
Aluminum	0.1-0.3	Special high grade zinc	99.99%Pure
Cadmium	0.025-0.06		
Iron	0.005 max		
Special high grade zinc	Balance part		
Solution Potential	1.10v	Solution Potential	1.10v

3.5.3 Aluminum anodes

Although investigated extensively in the past, there is not, currently, a type of chemical backfill that is in common usage to permit the practical and economical installation of aluminum anodes in earth burial applications. They do not work well when directly buried in the usual earth environments.

Proprietary aluminum alloy anodes are available which work very well in a sea water environment. Cathodic protection current from anodes so located but connected to buried pipelines or other underground structures can protect such structures effectively. Table-3.5 extracted from Appalachian underground corrosion short course (1986) shows different types of aluminum alloy specification.

Table-3.5: Common alloy specification-Aluminum

Element	Seawater Galvolum-I	Saline Mud Galvolum II	Seawater Brackish Saline Mud Galvolum III
Zinc	0.35% - 0.50%	3.5% - 5.0%	3.0%
Silicon	0.10% Maximum	--	0.1%
Mercury	0.035% - 0.048%	0.035% - 0.048%	--
Indium	--	--	--
Aluminum	Remainder	Remainder	Remainder
Solution Potential	-1.10v	-1.10v	-1.10v

3.6 Comparison between Magnesium Anode and Zinc Anode

Generally two types of anode are used. These are magnesium and zinc. Among these two types which one should be used is a vital consideration.

3.6.1 Characteristics of magnesium anode

(i) Current may be distributed more readily than rectifier by magnesium anode.

(ii) Less amount of current is required for magnesium anode than the case of rectifier. But rectifier current costs less.

(iii) Not economical source of current for high resistivity. Use is limited for resistivity up to 3000 ohm - cm.

(iv) Potential between zinc and steel is much lower than that magnesium and steel. So considering other things being equal, magnesium provides better corrosion resistance than zinc.

(v) As magnesium distributes currents more readily, it corrodes fast. Therefore magnesium can not be used for a design life more than 10 year. Suitable for existing system redesign.

(vi) Cost of magnesium anode is relatively high.

3.6.2 Characteristics of zinc anode

(i) Galvanic potential between zinc and steel is much lower than that of magnesium and steel. Therefore current output is low.

(ii) Works best for soil resistivityis 750-1500 ohm-cm.Can not be used when soil resistivity is over 1500 ohm-cm.

(iii) Because of low current output the efficiency zinc does not fall sharply. It is therefore possible to install zinc for projected life 20, 30 or 40 years. Therefore gas distribution system in congested city area where access is difficult, use of zinc anode is preferable.

(iv) Current output of zinc anodes vary over a wide range and is adjusted with the change of soil resistivity by tidal water. Magnesium can do this adjustment with higher potential and requires much current.

(iv) Cost of zinc anode is less than magnesium anode.

3.7 Galvanic Anode Installation

Galvanic anodes are commercially available bare or with surrounding package of special chemical backfill. Magnesium and zinc anode are available as 8 lb, 12, lb, 17 lb, 32lb size packaged. Longer packaged anodes are installed in auger hole. Anodes may be installed in single or a series of anodes are attached with a header cable. If packaged anode is not used, separate chemical backfill must be used. Chemical backfill provides best performance for long time.

Typical chemical backfills are:

1. A Mixture of gypsum (75%), Bentonite clay (20%) and sodium sulphate (5%).
2. A mixture of Bentonite clay (50%) and plaster of paris (50%).

The size, spacing and number of anode to be installed are result of design and depend upon a number of factors such as soil resistivity, length and diameter of the pipelines to be protected, design life, coating condition, specification of anode etc.

3.8 Design Considerations for Sacrificial Anode Method

In excess to the general considerations of cathodic protection system design, sacrificial method needs consider the following factors:

(i) Selection of anode

(ii) Installation procedure.

(iii) Current output, efficiency and utilization factor of the anode.

Magnesium anodes are usually the first choice. But zinc anode costs less. Again economy can be achieved by using magnesium anode by the application of flexibility which makes it possible to distribute the current where it needed. A Survey of line current requirement and soil resistivity survey data is necessary for such economic design.

3.8.1 Design guidelines

Most of the time, cathodic protection systems are not designed by performing current and conductivity survey. It is rather designed on the basis of some assumptions, empirical values, rules of thumb, data table and design curves. All these are developed from practical experiences. Soil resistivity, coating condition, current requirement and characteristics of anode are strongly considered for developing these standards. Most of the cases the system designed using these guidelines satisfy universally accepted criteria pipe to soil potential (PSP) with respect to Cu-$CuSO_4$ reference electrode -0.85 Volt. Most commonly used guidelines are described below:

(a) Some kind of preliminary estimate is about 2 milliamperes per square foot of equivalent bare steel metal will be required for complete protection. This varies as follows:

(i) For well coated pipe in high resistivity soil : 0.5 mA/ft^2

(ii) For bare pipe in low resistivity soil :2 mA/ft^2

(b) A rule of thumb used for protecting bare steel in soil using standard alloy anodes. When a single anode is not sufficient, two or three anodes can be used.

Table-3.6 is given by Parker (1954) and shows required anode number and anode spacing for different soil resistivity and pipe diameters This table is based on bare pipe. For optimum design a certain percentage of coating defect is considered.

Table-3.6: Design guideline for bare steel in soil.

Soil resistivity (Ohm-cm)	Anodes	Current (milliampere)	Life (years)	Density (milliampere per sq.ft.)	Spacing in feet		
					pipe size		
					2"	3"	4"
360	3-50S	840	10.3	2	675	456	354
380	2-50S	569	10.1	2	457	310	240
400		541	10.6	2	435	295	228
420		516	11.2	2	415	281	218
440		493	11.7	2	396	268	208
460		472	12.2	2	379	258	199
480		453	12.7	2	364	247	192
500		435	13.2	2	350	237	184
520		419	13.7	2	336	228	177
540		404	14.3	2	324	220	170
560	1-50S	285	10.1	2	229	155	120
580		275	10.5	2	221	150	116
600		266	10.8	2	214	145	112
620		258	11.1	2	207	141	109
640		251	11.5	2	201	136	105
660		243	11.8	2	195	132	102
680		236	12.2	2	189	128	99

Table- 3.6 : (Continued) Design guideline for bare steel in soil.

Soil resistivity	Anodes	Current milliampere	Life years	Density milliampere per sq.ft.	Spacing in feet pipe size		
					2"	3"	4"
700	1-32S	229	12.6	2	184	125	97
720		223	12.9	2	179	122	94
740		217	13.2	2	174	118	92
760		211	13.6	2	169	115	89
780		186	10.0	2	148	98	78
800		180	10.2	2	144	95	76
820		176	10.5	2	141	93	74
840		172	10.8	2	138	91	73
860		168	11.0	2	135	89	71
880		164	11.3	2	132	87	69
900		161	11.5	2	129	85	68
920		158	11.8	2	127	83	67
940		154	12.0	2	124	81	65
960		151	12.3	2	121	80	64
980		148	12.5	2	119	78	63
1000		145	12.8	2	116	76	61
1200		121	15.3	2	97	64	51
1400		104	17.8	2	83	55	44

Table- 3.6 : (Continued) Design guideline for bare steel in soil.

Soil resistivity	Anodes	Current milliampere	Life years	Density milliampere per sq.ft.	Spacing in feet pipe size		
					2"	3"	4"
1400		104	17.8	2	83	55	44
1600		91	10.7	2	73	48	38
1800	1-17S	81	12.1	2	65	43	34
2000	1-17H	91	10.8	2	73	49	38
2200		82	11.9	2	66	45	35
2400	1-32S	76	12.9	2	61	41	32
2600		70	14.0	2	56	38	30
2800		65	15.1	2	52	35	27
3000	1-17LH	93	10.5	2	75	51	40
3200		88	11.2	2	71	48	37
3400		83	11.8	2	66	45	35
3600		78	12.5	2	63	42	33
3800		74	13.2	2	60	40	31
4000		70	13.9	2	57	38	30
4200		67	14.6	2	54	36	28
4400		64	15.3	2	51	35	27
4600		61	16.3	2	49	33	26
4800		59	16.7	2	47	32	24
5000		56	17.4	2	45	30	24

Note: 3-50S: 3 numbers 50 pound size Standard alloy. 1-17H: 1 number 17 pound size High standard alloy, and so on.

(c) Rules of thumb which are followed by Titas Gas Transmission and Distribution Co. Ltd. for protecting coated lines. The most commonly used rules of thumb are given in Table-3.7

Table - 3.7: Length of pipelines that can be protected by Magnesium anode.

Soil resitivity, (Ohm-cm)	Pipe size,(inch)	Length of pipe that can be protected by Magnesium anode,(ft)	
		17 pound size	8 pound size
6000-7000	$^{3}/_{4}$	2554	2222
	1	2035	1765
	$1^{1}/_{2}$	1408	1180
	2	1129	968
	3	761	652
	4	593	508
	6	405	353
	8	310	163
	10	249	214
	12	210	-
	14	191	-
	16	167	-
	18	149	-
	20	134	-

3.8.2 Usage of chart in design

Two types of charts are used for coated pipelines:

(i) A selection of anode number and spacing of anode can be done using suitable chart.Figure-3.5 given by Parker (1954) shows anode resistance for number of anodes when placed at certain spacing. This chart is developed using 17-lb package magnesium for coated pipelines in a soil of resistivity 1000 ohm-cm. It can be used for other size of anode such as 32 lb. 50 lb etc., different soil resistivity and for different locations after calculating multiplying factor (M.F).

For soil resistivity:

Multiplying Factor, $M.F = \frac{\rho}{1000}$

For different anode size:

(a) For 9-lb anode :M.F=1.25

(b) For 32-lb anode : M.F=0.9

For location:

(a) For new city area :M.F=1.5

(b) For old City area :M.F=2.0

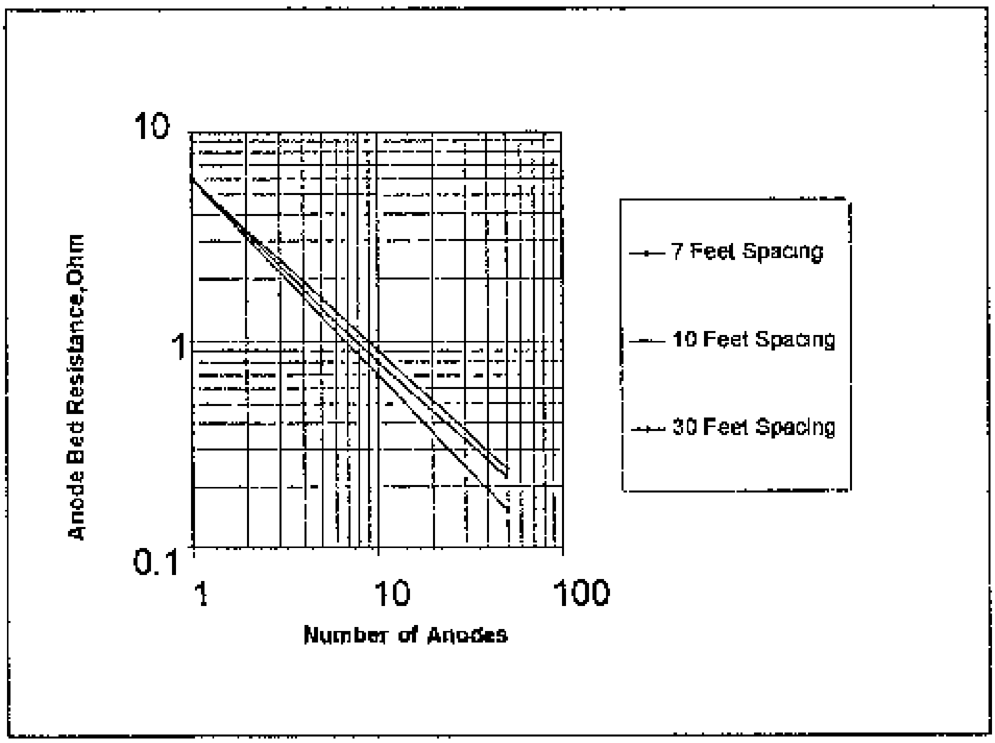


Figure-3.5: Variation of anode bed resistance with number of anode

(ii) There is another chart which is used for designing sacrificial anode size and spacing for protection of coated pipelines. This chart provides number of anode required per 1000 feet of pipe for different coating conductivity and pipe size. Figure-3.6 shows the chart and it is extracted from Parker (1954).

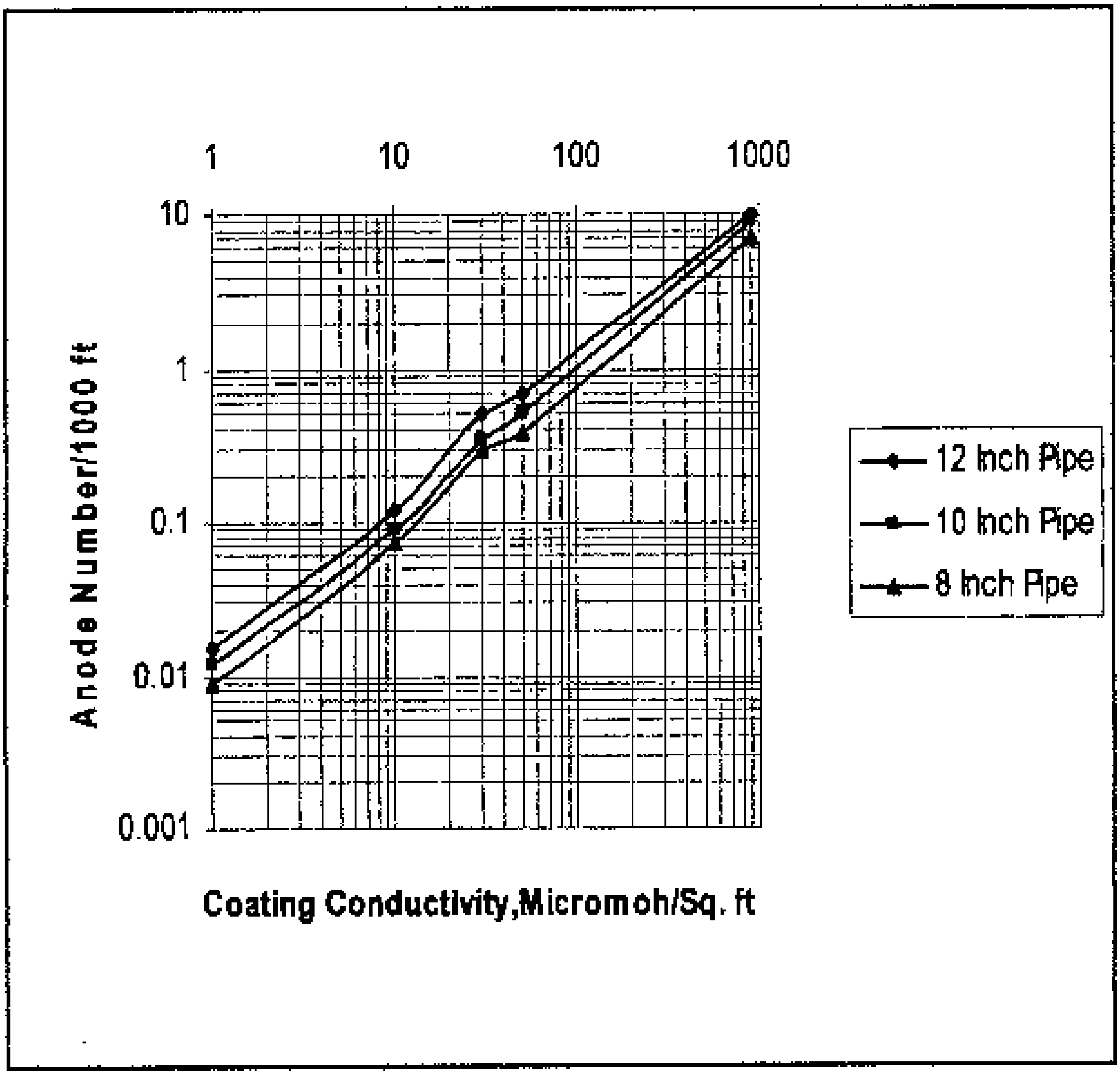


Figure-3.6: Anode number calculation chart for pipe length and coating conductivity.

It is very easy and quick method of finding number of anodes when coating conductivity of pipes is known. Table-3.8 given by Peabody, A.W (1973) shows the value of coating conductivity of pipes in soil of different resistivity.

Table-3.8: Coating conductivity of steel pipe for different soil resistivity.

Steel conductivity micro mhos/sq.ft	Coating condition	Soil resistivity, ohm-cm
0-10	Excellent coating	High>10000
10-50	Good coating	High,2000-10000
50-250	Good Coating	Low,1000-2000
250-500	Average coating	Low,500-1000
500-1000	Poor coating	Low,<500

3.9 Impressed Current System of Cathodic Protection

This is a cathodic protection system for which an external dc power source is required, with the negative wire connected to the protected structure and positive wire connected to the anode lead. Figure-3.7 shows the diagram of an impressed current cathodic protection system for a buried pipeline.

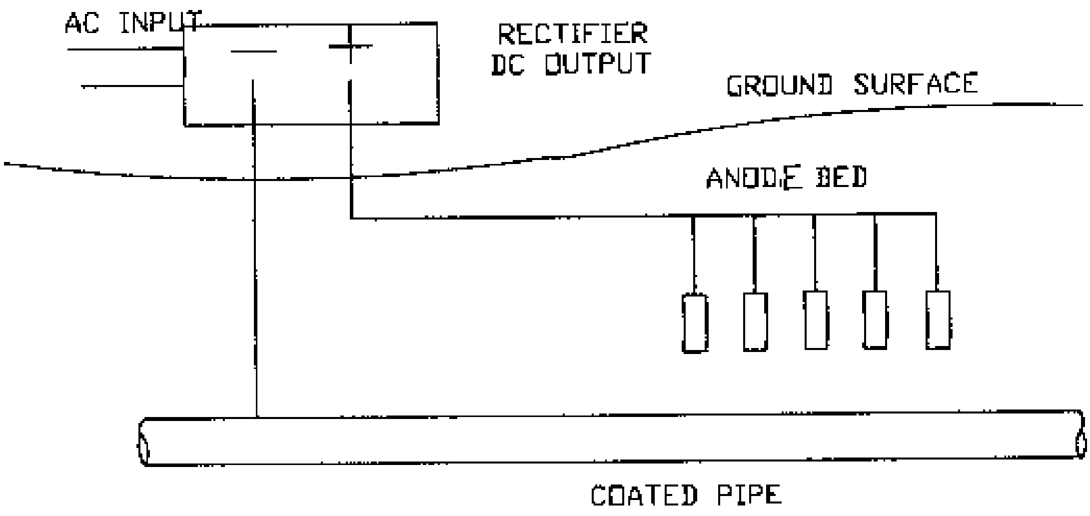


Figure-3.7: Typical diagram of impressed current cathodic protection system.

Impressed current system has the following features:

(i) Impressed current is versatile. A wide range of voltage setting allows the protection current to be adjusted precisely.

(ii) It is effective in high resistance soils, even solid rock with resistivity over 100,000 ohm-cm.

(iii) At the time of maintenance, anode bed can be found easily.

In excess to general considerations of CP, for impressed current system the following factors have to take into account:

(i) There must be a source of electric power.

(ii) A high potential may develop which can cause stray current corrosion to near by structure.

(iii) There must be a suitable location for anode ground bed and rectifier installation.

(iv) By adjusting current from rectifier over protection is possible. But it may cause disbonding to coatings.

(v) Anode bed should be at least 50 meter away from the pipeline.

3.9.1 System design criteria

For complete protection of the structure the following criteria are used:

Criteria 1 : Pipe to soil potential everywhere should be at least - 0.850V with respect to Cu/CuS$_4$ reference electrode. This is the universally accepted criteria.

Criteria 2 : As it is not always possible to maintain pipe to soil potential (PSP) - 0.85V with respect to Cu/Cuso4 reference electrode, a shift of 0.3 volt in the negative direction when cathodic protection is applied. The 0.3 volt potential shift criterion is based on changing the natural potential of the structure in the negative direction. The minimum potential shift for steel, as recognized in the NACE recommended practice and federal pipeline safety regulation issued by the office of pipeline safety is 0.300 volt.

This criterion can be used together with criterion I. This is an assumption used in design to take driving voltage - 0.3 volt. It is not used in sacrificial anode method.

3.9.2 Anode and anode bed

Anodes of impressed current protection are nobler than the metal they are designed to protect, because it should be different from sacrificial anode which corrodes away at a disastrous rate. However scrap iron (such as old pipe line, railroad rails) is sometimes used for temporary anode beds even though it dissolves at the rate of 9.1 kg / A.y.

Other anodes which are used in impressed current system are graphite and duriron(High silicon iron). Graphite is not a good conductor of electricity and therefore corrodes less Consumption of graphte and duriron are 0.5 kg/A.y and 0.1 - 0.2 kg/A.y respectively in most soil.

Anodes are buried in soils at a distance from 50 m to 50 km from the protected structures. The anode bed location should be of low resistance area. A backfill of coke breeze ie, hard coke is commonly used around the anodes to increase their effective size and ensure good contact with the soil

3.9.3 Rectifier

The dc power supply necessary to force current from the anodes is a rectifier. The cathodic protection rectifier consists of two parts (i) an ac step down transference with taps that take off voltages of different amounts to adjust power output and (ii) a rectifier to change ac to dc by means of selenium or silicon plates.

3.10 Design of Impressed Current System

The air of cathodic protection for coated line is to obtain PSP value -0.85 volt with respect to a Cu/$CuSO_4$ reference electrode. Designing an impressed current system includes:

(i) Determination and distribution of the drainage current requirement.

(ii) Sizing the rectifier and finding the number of rectifiers (drain point) required.

(iii) Material selection for anode bed on the basis of design life and low resistance

(iv) Determination of amount of back filling, i,e, hard coke required.

3.10.1 Rectifier design for coated lines

Rectifier system design involves a trial and error method rather than a straight forward mathematical solution. Because attenuation curves for current and potential along a line is somewhat complicated and based on assumptions of uniformity.

(a) The rectifier site is chosen depending upon the following considerations:

(i) Power availability
(ii) Low soil resistivity
(iii) Accessibility
(iv) An assumed value of drainage current at that point.

(b) The distribution of current and potential along the line from the drainage point is projected. The actual pipe to soil potential at any point can be predicted by the following expression.

PSP = Static potential + Driving voltage + polarization potential

Static potential is found from survey. Driving voltage is found from attenuation curve and polarization potential is found from polarization chart.

(c) From the line current survey if all data are available from single drain point then single drain point is chosen otherwise another must be chosen. Then attenuation curve is developed for the second. The expression for PSP is obtained by superposition; PSP=static potential + sum of two driving voltage + polarization potential for this composite driving voltage. Thus by trail and error a combination of drainage points is found which protects the entire line.

These procedures are seldom followed in an industry. General practice is to use readymade curves, assumptions and data table

3.10.2 Rectifier design by using attenuation curves

This method may be used for initial sizing of the rectifier for a planned pipeline. The steps of this method are as follows:

1. Coating conductance, g:

   Coating conductances of steel pipes in different soil are given in Table-3.8. This value can be used.

2. Δ E, driving potential at low point on the pipeline:

   The criterion of shifting potential difference -0.3 volt in the negative direction for design purpose can be used. This is enough to raise static potential -0.55 volt to a $Cu/CuSO_4$ electrode potential -0.85 volt, enough to maintain approved cathodic protection criterion.

3. Δ E at drain point, ΔE_A:

   It is good practice to limit the voltage change at the maximum point to around 1.5 volts. This is to protect disbonding of coating. But for certain circumstances this value may exceed

4. ΔI at drain point, ΔI_A:

   This is the value to be determined. It can be calculated from modified attenuation curves for coated lines given in Figure-3.8.

5. Method of calculation using modified attenuation curves:

   When design data g is assumed in micromhos per square foot, the relationship $\frac{\Delta E_A}{\Delta E_X}$ or $\frac{\Delta E_A}{\Delta E_T}$ is estimated. Then it is possible to calculate both I_A and the distance it will protect for either side of a finite pipe line using Figure-3 8 given by Parker (1954).

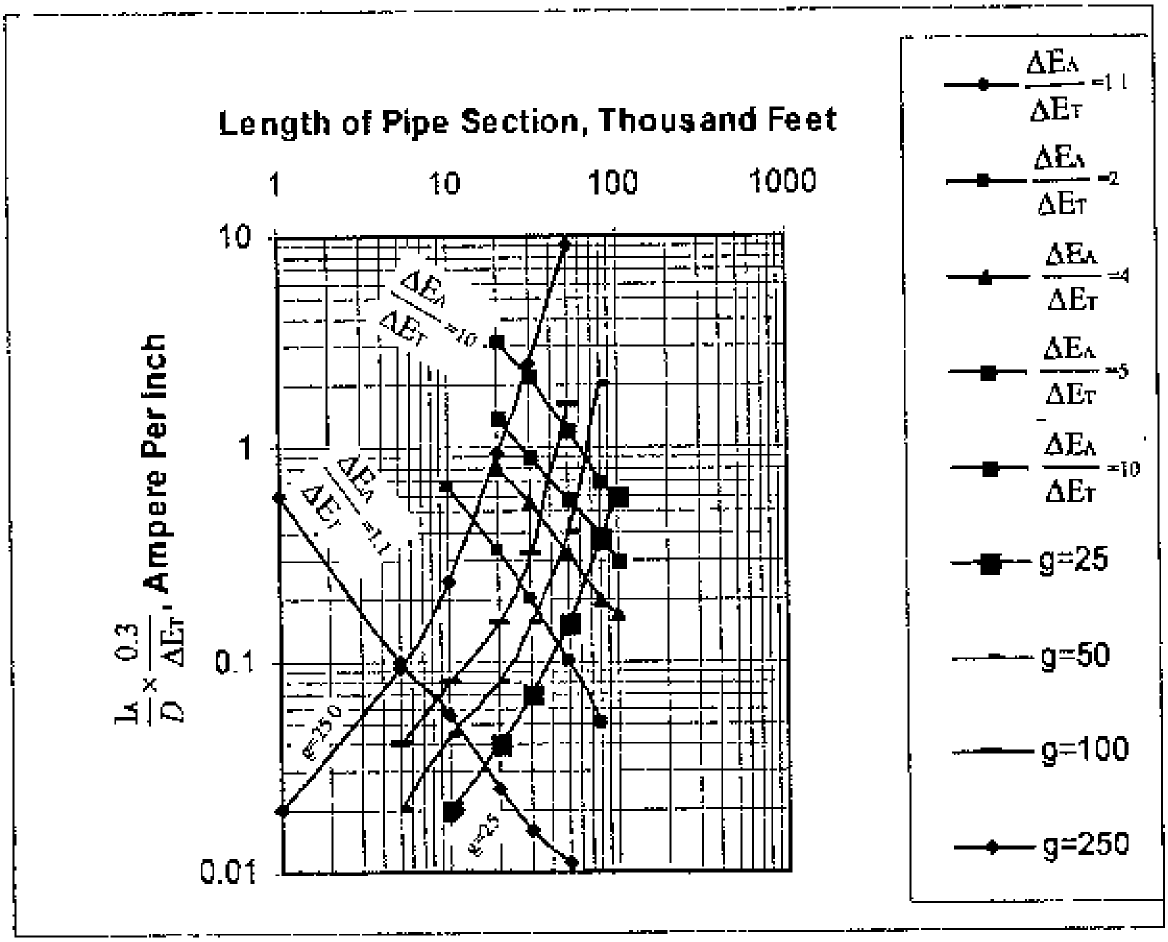


Figure-3.8: Current requirement calculation curves (attenuation curves for coated finite line).

3.10.3 Ground bed design

Vertical anodes: It is necessary to design a ground bed and anode combination to drain a certain amount of current from the line at a certain point. In most cases a row of equally spaced vertical anodes are used. If the row of vertical anodes are selected the items to be determined are the hole diameter and the spacing.

The common types of vertical anode is 3"×60"L graphite single anode. It is placed is a cylindrical column of well tamped coke breeze backfill. The column of coke is the actual anode; graphite anode is merely to establish contact.

The resistance to earth of a single anode is given by Parker (1954);

$$R=0.012\frac{\rho}{2}\log(\frac{35L}{d}) \text{ .... } (3.1)$$

Where,

R=resistance in ohm

ρ = soil resistivity, ohm-cm

L=length of coke breeze column, feet

d =column diameter, inches,

Putting L = 4' and d = 10 inches in equation (3.1)

Then, $R = 0.002$

Or, $R = \frac{\rho}{500}$; this is a good rule of thumb approximation for calculating resistance to earth of a single vertical anode, ie, graphite of 3" Φ× 60"L size.

When several anodes connected in parallel ad with equal spacing, total resistance of the group given by Parker (1954);

$$R_n = \frac{\rho}{\Pi n}\left[\frac{1}{2L}\ln(\frac{4L}{ae}) + \frac{1}{S}(\frac{1}{2}+\frac{1}{3}+\frac{1}{4}+....\frac{1}{n})\right] \text{..........} (3.2)$$

After some algebraic operation the equation can be expressed,

$$R_n = 0.012\ \frac{\rho_1}{L}\log.\frac{35L}{d} + \frac{\rho_2}{S}F_n. \text{ ...., ... } (3.3)$$

Where,

R_n = Resistance of n anodes, ohms

ρ_1 = resistivity at a spacing equal to the depth of the centre of the anode ohm-cm

L= Length of the anode (coke breege column), feet

d = diameter of the coke breeze column, inches

ρ_2 = resistivity at a spacing equal to the anode spacing, ohm-cm.

S = anode spacing, feet

F_n = expression involving the series of fractions, with certain constants. Value of F_n for different value of n is given below:

n	2	3	4	5	6	7	8	9	10	-
F_n	0.00261	0.00290	0.00283	0.00268	0.00252	0.00238	0.00224	0.00212	0.00201	-
n	11	12	13	14	15	16	17	18	19	20
F_n	0.00192	0.00183	0.00175	0.00168	0.00161	0.00155	0.00150	0.00145	0.00140	0.00136

As the number of rod increases, the resistance of the total bed decreases. Thus voltage needed for rectifier to discharge the required current decreases. This voltage may be taken V=IR+2, Here 2 volt added for galvanic difference between graphite in coke breeze and pipe in soil. This value may vary.

Ground bed resistance also can be calculated using chart given Parker, M.F. (1954) and shown in Figure-3.9.

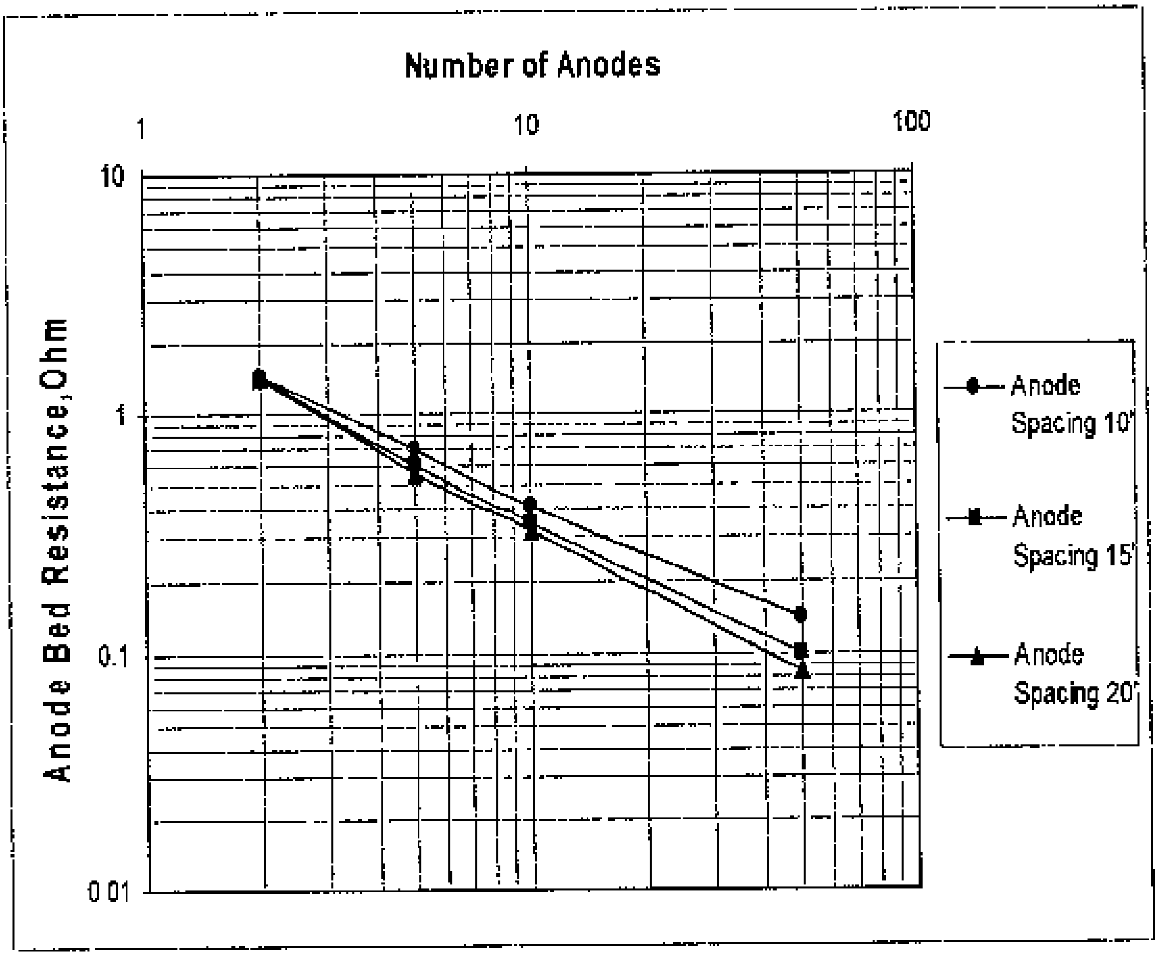


Figure-3.9: Ground bed resistance calculation chart for vertical anode.

A rectifier can be designed more accurately after installing ground bed and pipelines. Thus by loop battery method loop resistance can be determined. Then voltage necessary to deliver the desired current through the ground bed found and according to that rectifier is procured.

Horizontal scrap steel pipe anode: Scrap steel pipe is used as anode when soil resistivity is high and number of anode needed to achieve economically low resistance is impossible. Surface area of such anode is high and makes very low current density at high resistivity soil. Thus economically feasible life found. Such horizontal anode is installed laying a short section of bare pipe line. Necessary electrical connection may provide by welding two or more strap of metal.

The resistance of an anode of this kind is given by Parker (1954);

$$R = \frac{\rho}{192L}\left\{\ln\frac{4L}{D} + \ln\frac{L}{S} - 2 + \frac{2S}{L}\right\} \text{..........} \quad (3.4)$$

Where,

R = total resistance, ohm

ρ = soil resistivity, ohm - cm

L = anode length, feet

D = anode diameter, feet

S = depth to the centre, feet

A backfill of salt and gypsum mixture can reduce this resistance.

CHAPTER IV

EXISTING SYSTEM ASSESSMENT

Natural gas is the main source of commercial energy of Bangladesh. Nearly 70% of country's commercial energy demand is being met by natural gas produced from different gas fields. Presently 1200 MMSCF natural gas is produced and distributed daily to different areas of the country from 9 producing fields. Four natural gas distribution companies are working under the jurisdiction of Bangladesh oil, gas and mineral resources corporation (Petrobangla) to supply natural gas to the end users and collect revenue on behalf of the government of Bangladesh. These gas distribution companies have constructed hundreds of kilometers of pipeline for transportation and distribution of natural gas. Up to June'2004, the total length of pipelines constructed by the distribution companies is about 16,459.03 km Size of the pipelines vary from 3/4" to 30" is diameter. The oldest pipeline of the country is a 4" diameter 19 km pipeline from Chattak gas field to Chattak cement factory constructed in 1959. TGTDCL established in the year 1964 and the gas distribution network was built in 1968. The network of Jalalabad gas and Bakharabad gas are of late 50's (1959) and early 80's (1985) respectively. The other gas distribution company of the country, namely the Paschimanchal gas company Ltd was formed during late 90's (1998).

For uninterrupted supply to the customers and minimizing unaccounted for gas, a safe and leak free pipeline network is essential. Most of the pipelines in the country are growing old. Some pipelines are about 30 to 40 years old. Therefore corrosion attack to these pipelines is a common phenomenon. So an assessment regarding present status of the distribution pipelines is essential for effective corrosion control and monitoring system.

4.1 Statement of the Problem

The interruption of gas supply may occur due to several reasons. Apart from natural aging and deterioration of its section of network, they are often experiencing damage and injuries to pipelines with loss of gas including localized supply interruption. Natural calamities like flash floods, land slides and cyclones create tremendous operational problems too Basically ruptures, line breaks, relief blows, purge-outs and leakages etc. have been causing these supply interruption and resulting fugitive emissions. Leakage in house lines and keeping burners on unnecessarily are most common. Table- 4.1 given by Bakhth (2000) shows emergency call statistics of major distribution companies of Bangladesh.

Table- 4.1: Gas leakage and supply interruption report of major distribution companies.

DESCRIPTION	TGTDCL(Dhaka)			BGSL(Comilla)			JGTDCL(Sylhet)		
	July'98	Aug'98	Oct'99	June'99	July'99	Aug'99	May'99	June'99	July'99
A.Customer No.(On June'99)	667230			175471			57176		
B Call frequency:									
Maximum Call/day	26	27	19	4	6	5	13	15	13
Min. Call/day	4	4	2	0	0	0	4	3	2
Average Calls /day	12.32	12.1	11	1.77	2.48	1.13	7.81	5.67	6.29
C.Calls By Types									
Leakage	312	315	248	37	45	23	187	108	140
No Gas	46	64	59	15	26	11	26	28	18
Low Pressure	11	14	15	0	2	1	15	12	18
Fire/ Condensate & others	9	14	11	0	4	0	14	24	19
Total	378	407	333	52	77	35	242	170	195
D.Leakage Classification:									
Network	13	16	8	2	3	0	5	3	4
Service Line	299	306	241	35	35	23	198	163	187
Others	56	39	84	0	7	0	39	4	4
Total:	368	361	333	37	45	23	242	170	195
E.Cause Of Damage:									
Natural Damage	290	284	257	37	45	23	183	127	160
Un-natural Damage	28	15	22	0	0	0	27	12	15
Other Damages:	30	42	54	0	0	0	32	31	20

The supply interruption and emergency call report illustrates the number of emergency services that are required to provide by the companies everyday. It is clear from the Table-4.1 that most of the complains reported are about leakage of the distribution pipeline and also the highest number of complains were reported to TGTDCL. TGTDCL has the largest distribution network in the country. A major portion of the pipelines of TGTDCL are more than 30 years old The design life of distribution network is normally 20 years. Rehabilitation of these pipelines is increasing significantly. So evaluation of present corrosion status of these pipelines and reinforcing cathodic protection system to save the pipelines from deterioration is important. The improvement of cathodic protection system may increase design life of the network and can contribute more return than expectation.

A comparative study about supply interruption reveals that the cause of negative environmental impacts and extent and duration of supply interruption are different under different circumstances. This is because the frequency and nature of emergency situation at different conditions and times of the year. The general reasons of line leakage and supply interruptions are as follows:

(i) Stray current corrosion and ineffective or disrupted cathodic protection system leading to leakage

(ii) Erosion of sub-grade of roads and river bed/banks leave pipelines in suspended condition. Then leakages take place in pipelines due to corrosion fatigue. Replacements of the sections of network are required.

(iii) External calamities viz. twisting and washing of pipeline during flash flood in pipeline sections leading to a difficult and time consuming replacement operations.

(iv) Metallic water pipes carrying induced currents touching gas line in the urban areas resulting into complex exercise in identifying the exact location leakage and taking remedial action.

(v) Pipeline that was laid 25 years ago or earlier and is naturally corroded particularly in urban areas requires rehabilitations.

(vi) Localized interruptions through leakage in service lines and customer connection manifolds.

(vii) Mains lying in unfriendly and chemically contaminated environment and with fast deteriorating conditions.

(viii) Cover erosion and bending stress due to road slope exposure resulting into cracks and leakages in pipeline sections and fittings.

(ix) Underground high tension electric cables touching gas line in the urban areas calling for replacement of the network section

4.2 Study Area

The present study area is the natural gas network of Munshinganj district town which is a distribution area of TGTDCL. Munshiganj town is situated on the south bank of the river river Dhaleswari and on the east bank of the river Shitalakha. It is adjacent to the Narayanganj district and nearly 20 km. away from metropolitan City of Dhaka

The main mode of transportation from Dhaka to Munshiganj is road. It is also connected to Dhaka with waterways. The highway communication is disrupted at Mukterpur ferryghat where there is no highway bridge. Figur-4.1 Shows the map of Bangladesh indicating the study area of Munshganj. Munshiganj is located in a very low land area and almost every year all parts of the town are flooded and remains under water for several months during the monsoon. Other period of year a major part of the town is submerged by river water, Munshiganj is one of major business centres of the country

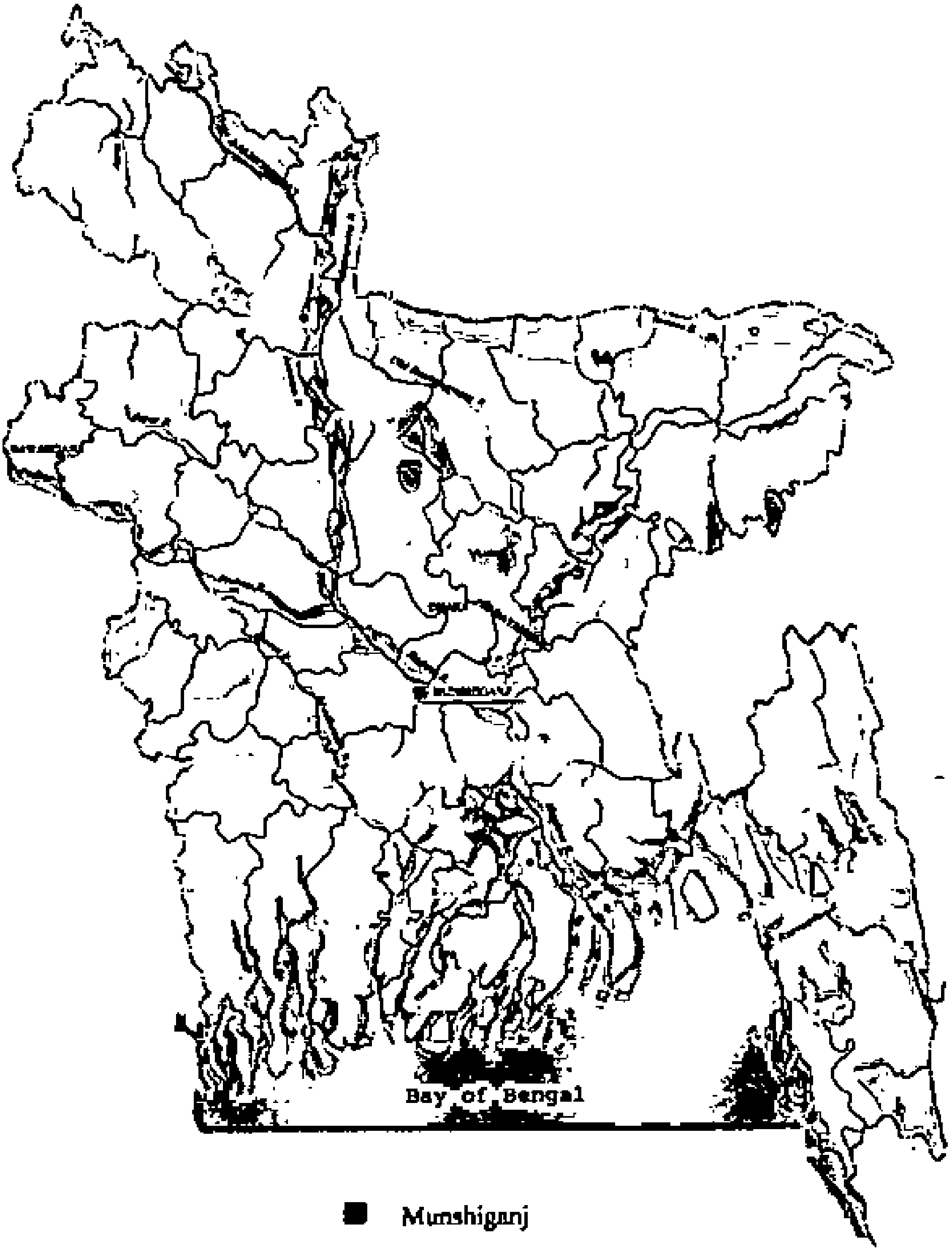


Figure – 4.1: Map of Bangladesh showing the study area

4.2.1 Survey of the area and data collection

The objective of the study is to assess the existing impressed current corrosion control system. For this purpose pipeline survey of the area is important. A detail survey of the distribution area including pipeline, CP station and DRS is done. As built pipeline drawing of the study area is collected from the planning department of TGTDCL. One single map of the whole area was necessary for the study. But that was not available. Four different maps of the different portion were found and scales of these maps were also different. Assimilating these maps into one, a single map of the area has been made and shown in Figure-4.2. For the purpose of the study data related to pipeline, soil analysis, pipe to soil potential, soil resistivity, gas consumption by the customers have been collected. Natural gas distribution network was laid in Munshigonj in 1992. The main source of the distribution line is a 8" diameter pipe from Panchabati Moor, Narayanganj.

Gas supply of Munshiganj was commissioned in March, 1992. Corrosion control of natural gas distribution pipelines of Munshiganj is being done by impressed current method which is a variety of cathodic protection system since July, 1992. All pipes were laid in the trench after PVC tape wrapping. The first significant leakage was detected after three months of pipe lying. Therefore the present status of the pipeline protection system is a matter of interest. Distribution region is divided into two parts of the town. One part is called Munshiganj and other part is named Mirkadim. Figure-4.3 shows typical layout of the two distribution parts including position of district regulation station (DRS).

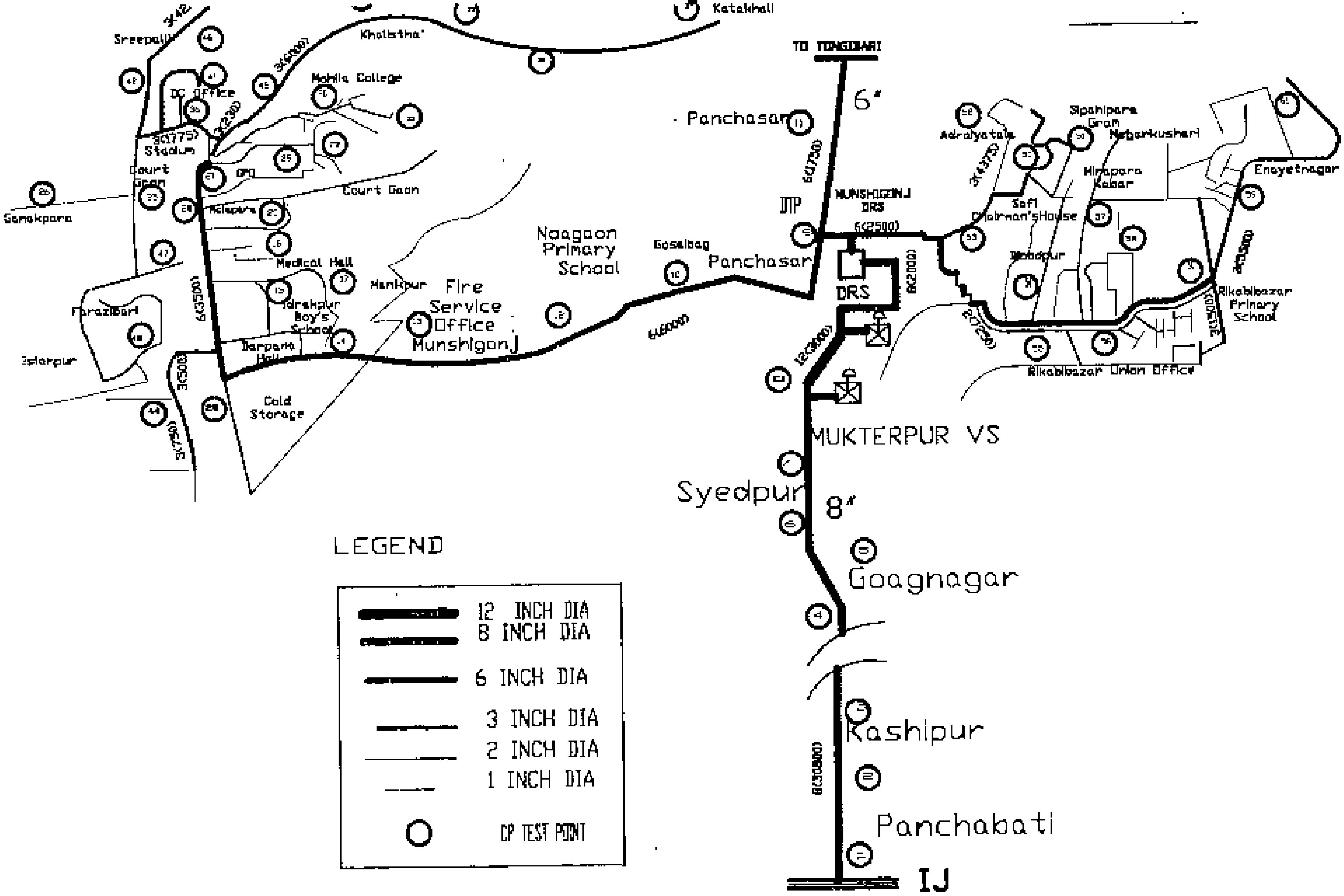
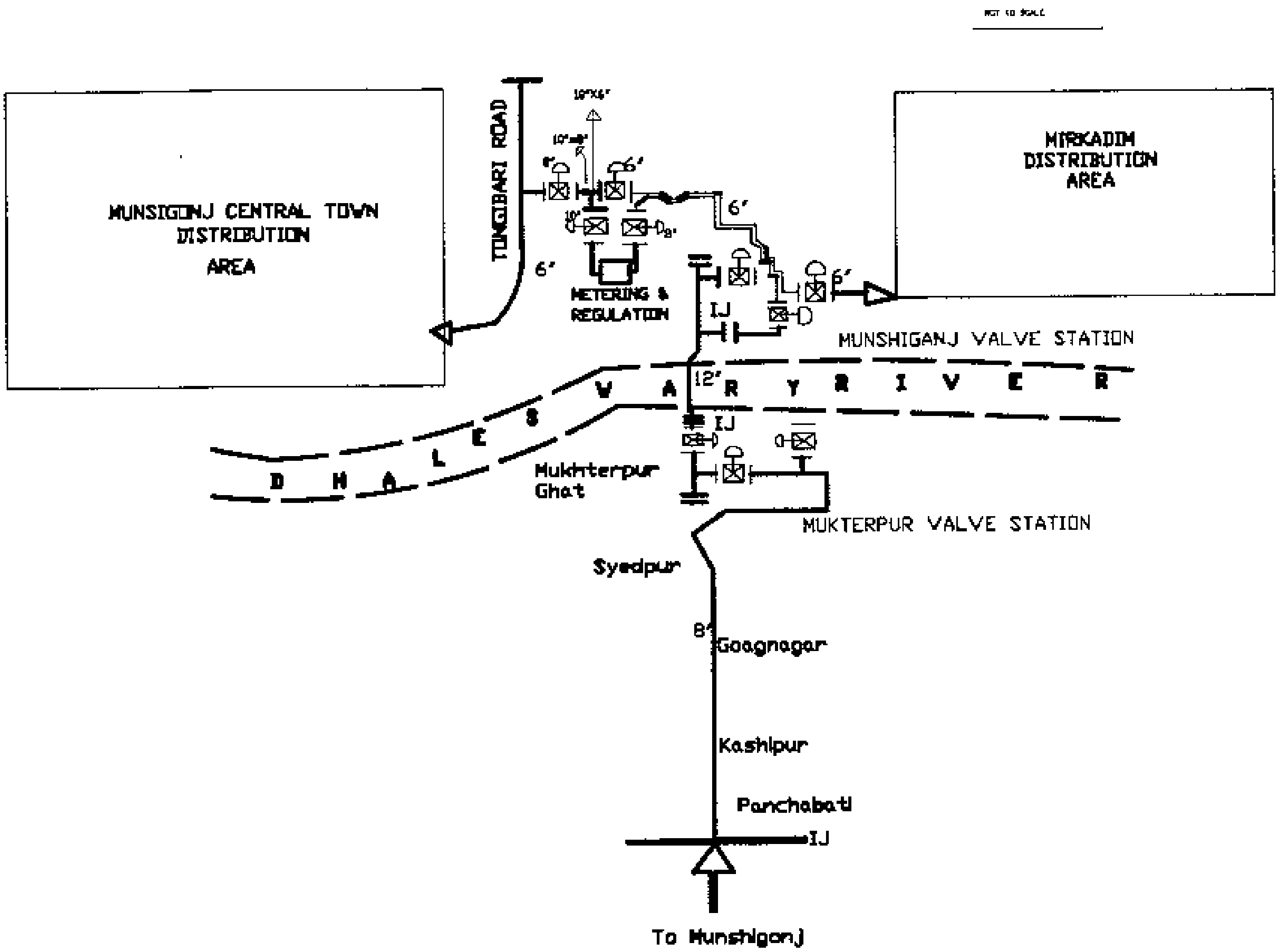


FIGURE-4.2 : STUDY AREA SHOWING PIPELINE NETWORK AND CP TEST POINTS



FIFURE-4.3:Position of Munshiganj Gas Distribution Network

Soil of Munshigonj: Variety of soil found. Clay, ash soil, sandy soil and reddish soil are common. Soil analysis performed by the department of soil science of Dhaka University in 1993 and collected from the investigation report of Ahmed (2000). Soil analysis report shows that,

P^{H} : 7.4 to 8.1

SO_4 : 32 to 41 ppm

Bacteria :(i) Thiobacillus ferro oxidans

(ii) Thiobacillus thio oxidans.

4.2.2 Existing corrosion control system

For corrosion control of Munshiganj gas distribution pipelines impressed current system of cathodic protection was installed in 1992. During that time soil resistivity survey was not performed. The survey was done in 1995. The design considerations and calculation of the existing cathodic protection system are not available today. An assessment of the existing installation is necessary for further development of the system. A short description of the existing system is given below:

Transformer - rectifier:

Cathodic protection (CP) station is installed inside the regional sales office of TGTDCL at Munshigonj. Munshigonj DRS is located besides the CP station. A transformer rectifier is installed at the CP station. The specification of the transformer-rectifier is given below.

(i) Model : Basco

(ii) Origin : England

(iii) Cooling : Oil cooled plinth mounted, Indoor type for continuous operation.

(iv) Minimum output : 30 Amps DC and 20 volt DC

(v) Input : 220 to 240 volt single phase 50 Hz. A.C supply.

(vi) Output control : By multi selector switches or by a percent regulation rule.

(vii) Ambient temperature : 0-50°c

(viii) Humidity : 100%

(ix) Rectifier circuit : Full wave bridge

(x) Rectifying element : Silicon diodes.

(xi) Following instruments and fillings are also installed with transformer rectifier system:

(a) Input voltmeter
(b) Input Ammeter
(c) Output Ammeter
(d) Output Voltmeter
(e) Thermometer
(f) Oil level gauge
(g) Timer
(h)Oil drained value and plug
(i) Rating plate
(j) Earthing for fastening positive cable, negative cable and incoming AC cable.

Output voltage and current of the transformer rectifier can be adjusted by changing tap setting.

<u>Ground bed:</u>

Ground bed of the said CP system is installed at a distance of 250'-0" from the 6" diameter distribution main or Munshigonj- Tongibari road in front of TGTDC office. It was installed in the playground of Panchasar government primary school. But recently the school authority has built a new building over it. 80' long scrap iron pipe of 10" diameter has been used as anode bed. It is laid at a depth of 10'-6" from ground surface. Figure-4.4 shows the position of CP station including ground bed and cable joints.

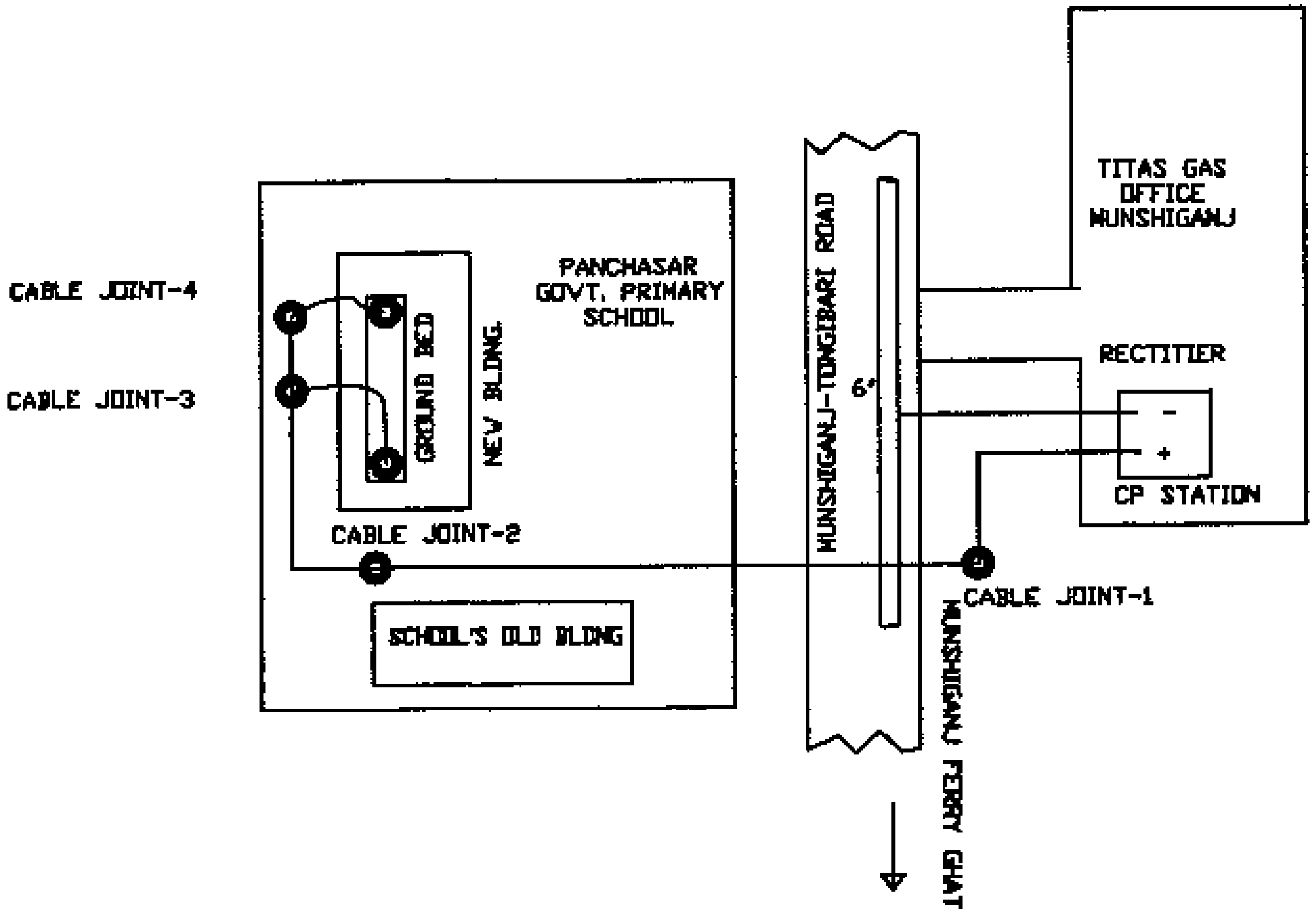


Figure-4.4 Position of Existing CP Station

There is an 8" diameter insulating joint installed at Panchabati moor. The line is electrically isolated here. Thus from Panchabati moor to Munshiganj DRS distribution main pipeline and Munshiganj- Mirkadim distribution network pipelines are covered under the CP station.

4.2.3 Pipeline data

The map constructed for the area shows all the distribution pipelines except $\frac{3}{4}$" diameter pipe. Because at the time of gas commission no customer was connected laying $\frac{3}{4}$" diameter pipeline. The length of $\frac{3}{4}$" diameter pipeline has been considered as 20' per domestic customer. As per general sales procedure of TGTDCL 10 feet $\frac{3}{4}$" diameter pipe is supplied to every domestic customer. No extra cost is charged for that. In practical ten to one hundred feet pipe is required for domestic customer depending upon the distance from the distribution line. After erecting riser of the customer an insulating device named lock wing cock or insulating flange is installed to separate internal line electrically. From 3/4" diameter to 3" diameter locally made steel pipes are used. Pipes of 4" diameter and above that are procured through international tender and quality is as per API 5L grade B specification (2000).

Table-4.2 and Table-4.3 are taken from API 5L grade B specifications (2000), and either of the tables shows pipe diameter, weight per unit length, inside and outside diameter, chemical composition etc. Table-4.4 gives length and diameter of pipelines as laid in 1992.

Table- 4.2: Line pipe specification, Pipe: API 5L Grade B, Seamless

Size (Inch)	Outside Diameter (Inch)	Wall Thickness (Inch)	Calculated Inside Diameter (inch)	Plain End Weight per unit length (kg/m)	Hydro Test pressure (PSI)
1.05	1.05	0.113	0.824	1.13	700
1.9	1.9	0.145	1.61	2.72	1300
$2\frac{3}{8}$	2.375	0.083	2.209	2.03	1470
$2\frac{7}{8}$	2.875	0.083	2.709	2.48	1210
3.5	3.5	0.083	3.334	3.03	1000
4	4	0.083	3.834	3.48	870
4.5	4.5	0.083	4 334	3.92	770
$5\frac{9}{16}$	5.563	0.083	5.397	4.86	630
$6\frac{5}{8}$	6.625	0.125	6.459	5.8	530
$8\frac{5}{8}$	8.625	0.083	8.375	11.36	610
10	10.75	0.188	10.375	21.23	610
$12\frac{3}{4}$	12.75	0.172	12.406	23.13	610

Table-4.3: Chemical composition of pipe: API 5L Grade B pipe

Maximum carbon %	Maximum Manganese%	Phosphorous %		Sulpher Maximum	Columbium,Vanadium& Titanium
		Minimum	Maximum		Maximum%
0.26	1.2	--	0.03	0.03	0.15

Table-4.4: Pipeline data of Munshiganj distribution network as laid in 1992.

Pipe size (Inch)	3/4	1	2	3	6	8	12
Length (Feet)	--	30100	41275	27880	22000	32800	3000
Length (m)	--	9177	12584	8500	6707	10000	915
Surface area (Sq.ft.)	--	8269.96	21600.58	21885.8	34540	68661.3	9420

4.2.4 Soil resistivity data

Soil resistivity is the most important parameter for designing a cathodic protection system of corrosion control. Four pin method resistivity measurement data are given in Table 4.5. These data were collected keeping pin spacing $5' - 2\frac{1}{2}''$. Therefore resistivity is found multiplying resistance by 1000. Resisitivity data were collected around the ground bed of Munshigonj part and some other area of Mirkadim part. Resistivity data have been collected from concerned department of TGTDCL. Soil resistivity data are represented by many different ways. It is useful to prepare a histogram.

Table-4.5: Soil resistivity data of Munshiganj .

Sl No.	Location	Resistance, R (Ohm)	Soil resistivity (Ohm-cm)	Comments
1	Titas Office	2.88	2880	
2	Asia Jhunar Mill,Dighir Par	3.78	3780	
3	Matbar Bari, Dighir Par	2 56	2560	
4	Padma Suta kal,Sarkerpara	1.56	1560	Ash Soil
5	Khurshid Bapery , firingibazar	1.76	1760	Ash Soil
6	Hssain Mistri, Doyalbazar	1.85	1850	Ash Soil
7	Avi rice mill,Binodpur	3.38	3380	
8	Sunmoon Traders, Rice Godawn	1.55	1550	Ash Soil
9	City Bank , Rikaby Bazar	2.6	2600	
10	Bara Masjid,Bhabanpara	1.3	1300	Ash Soil
11	Rogmukti Clinic, north Ramgopalpur	1.35	1350	Ash Soil
12	Ratan Hajibari, north Ramgopalpur	1.2	1200	
13	Meerapara, agriculture Office	1.95	1950	
14	Meerapara, kabarsthan	6.7	6700	Sandy Soil
15	Chali Matbar Bari	2.14	2140	
16	Sayaranjan's House,Ghosh Para	1.55	1550	
17	Gojnabi Master's House, Tengor	1 66	1660	
18	Haji Billal's House	1.15	1150	
19	binodpur primary school	2.1	2100	Ash Soil
20	Kamal Krshna's House,Binodpur	1.77	1770	Ash Soil
21	Binodpur North Panchayet , Masjid	2.65	2650	
22	Situ Madbarbari	1.92	1920	
23	Alam Chan ,South Ramgopalpur	3.09	3090	
24	Mita Cottage(Safi Chairman)Adraaiyatala	3.57	3570	
25	Swapan Chairman, Dingabhanga	2 84	2840	
26	Rikabibazar Girl's High School	1.57	1570	
27	Fulchan Villa, Rikabibazar	1.5	1500	
28	Rikabibazar High School	1.6	1600	
29	Billal Mia's House	1.81	1810	
30	Alim Uddin's House	2.84	2840	
31	Abul Kashem's Shop	1.56	1560	
32	Amjad ali High School,Mirkadim	2.12	2120	
33	Nayabari,Mirkaddddim	1.42	1420	
34	Abul Hossain's House	1.4	1400	
35	Dr. Motalib's House	1.16	1160	
36	Sweetmeat Shop,Mirkadim	2 73	2730	
37	Omar Contactor's House	3.23	3230	
38	Lillah Madrasa, Chandantala	1.44	1440	
39	Islamia Madrasa,Kgozipara	2.54	2540	
40	Kagozipara Primary School	2.04	2040	

Table-4.5:(Continued) Soil resistivity data of Munshiganj .

Sl No	Location	Resistance, R (Ohm)	Soil resistivity (Ohm-cm)	Comments
41	Mr. Safiuddin's House , Meerapara	2.41	2410	
42	Jorapukur Junior Girl's High School	2.93	2930	
43	Jorapukur Mosque	1.39	1390	
44	Mr. Jabbar Khan's House,jorapukur	2.95	2950	
45	Giasuddin's Soap, Jorapukur	4.42	4420	
46	Panchasar Union	2.17	2170	
47	REB Office, Panchasar	2.58	2580	
48	Khalisthan BRAK(RDP), Panchasar	12.3	12300	Sandy Soil
49	SDE Office,HRD,Manikpur	2.19	2190	
50	Hazrat Ali's House,Gonakpara	2.13	2130	
51	Mirhossain's House,Mosque	6.4	6400	Sandy Soil
52	Meereswar Bastuhara(Bridge)	2.36	2360	
53	Anil Bapery's House,Meereswarai	3	3000	
54	Noormia's House, Sarderpara	4.3	4300	
55	Zakir Hossain's House,Jorpukur	4.4	4400	
56	Chanmia Sarder,SP House Road	2.16	2160	
57	Bazlur Rahman House,Cotton Mill,Gosaibag	3.38	3380	
58	ILO,Gosaibag	2.46	2460	
59	BSICIC, Tongibari Road	3.55	3550	
60	BSICIC, Office Ground,Tongibari Road	6.44	6440	Sandy Soil
61	BSICIC ,Office Ground, TongibariRoad	1.7	1700	
62	Doshkani Raster Moor,Tongibari Road	2.88	2880	
63	Sipahipara Bazar	2.39	2390	

A histogram is prepared by plotting the number of readings found in various "classes" or readings of resistivity as ordinate. Resisitivity values are plotted in the abscissa. The classes or ranges should be logarithmic. There is scientific basis for this approach. Because here ratios are more important than differences and normal trend of resistivity data to take form of "Standard distribution" when expressed as logarithms. Mathematical manipulation of the data given in Table - 4.6 are as follows:

Table-4.6: Summary of resistivity data for plotting histogram.

Soil resistivity range, ohm-cm	Number of data, N	Frequency, %	Centre of class
12800			
6400	4	6.35	9600
3200	9	14.28	4800
1600	35	55.5	2400
800	15	23.8	1200

Soil resistivity histogram is prepared by plotting frequency against center of class. Figure-4.5 shows soil resistivity histogram of Munshiganj.

4.2.5 Calculation of logarithmic mean resistivity

It is the logarithmic mean resistivitry by which corrosovity of soils can be compared. Logarithmic mean accurately compare corrosion exposure. The logarithmic mean resistivity of a set of resistivities is the value whose logarithm is the average of all the logarithms of the measured values. Thus resistivity of a soil generally means logarithmic mean resistivity. Calculation procedure of logarithmic mean resistivity of Munshiganj town is shown in Table-4.7.

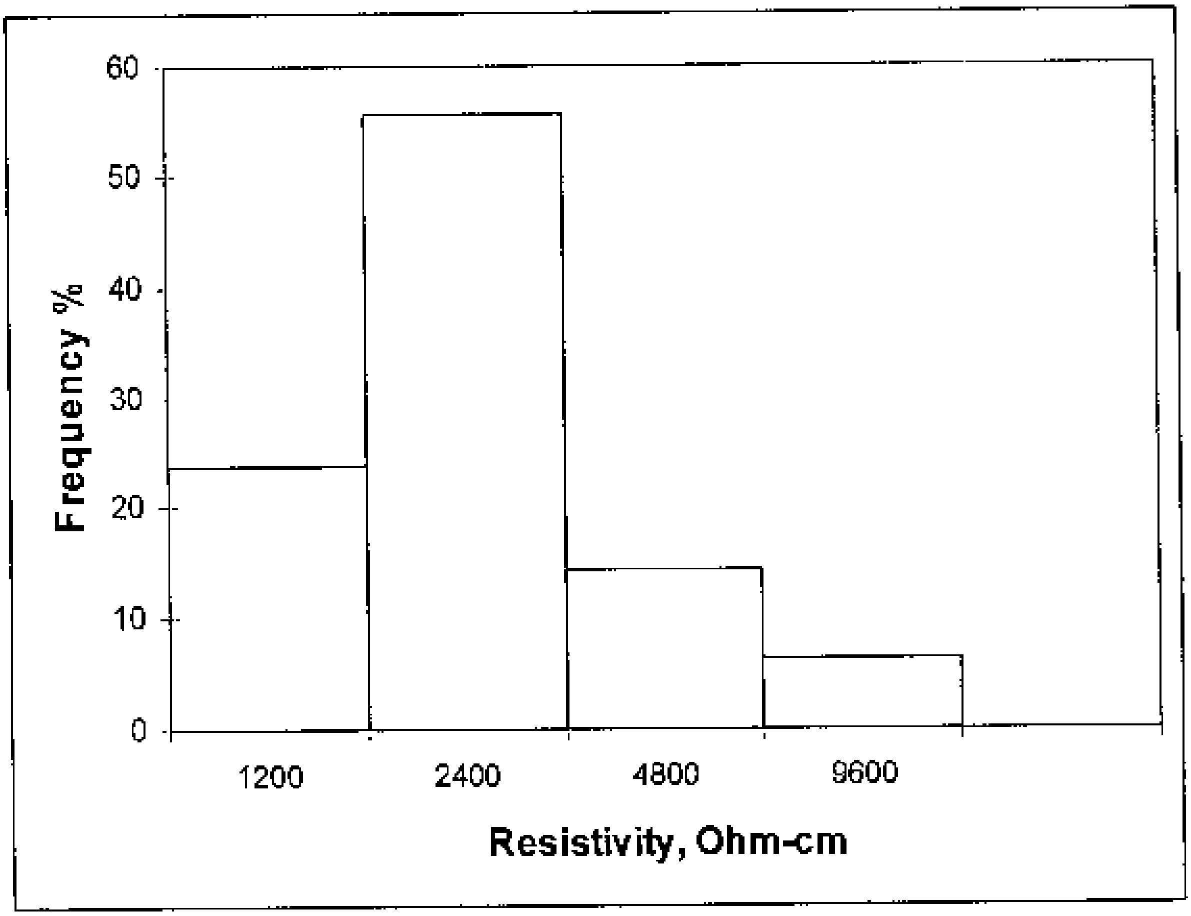


Figure-4.5: Soil resistivity histogram of Munshiganj.

Table- 4.7: Logarithmic mean resisitivity calculation.

Rasistivity range, Ohm-cm	Number of data, N	Log mean of the data, L	N×L
12800			
6400	4	3.98	15.93
3200	9	3.68	33.13
1600	35	3.38	118.31
800	15	3.08	46.19
Total	63	--	263.56

Logarithm of mean : 3.39
Logarithmic mean resistivity : 2454.74 ohm-cm
i,e, Resistivity of the area : 2455 ohm-cm

This calculation has been performed arranging the data range such that ratio of two successive range remains 2.1, which is in widespread use.

4.2.6 Pipe to soil potential data

There are 61 cathodic protection test points set at different location of Munshiganj gas distribution pipelines. Pipe to soil potential (PSP) data are required to measure at each of the stations at regular interval of time. It is general practice to measure the PSP every three months. But in reality, due to some administrative reasons and some unavoidable circumstances it is not possible to take PSP reading once in every three months. PSP data have been collected from concerned department of TGTDCL and represented in Table-4.8. The data table has been represented incorporating the distances and relative distances of test points from drain test point (DTP) The distances from DTP have been measured by surveying of the gas distribution area of Munshiganj and taking help of different maps of the region. PSP data is very much important for monitoring and assessment of cathodic protection system.

Table-4.8: PSP data of Munshiganj CP test points.

T P Location	Station Number	Distance	Relative Distance	Y:Jan'2003	Y:Mar'2002	Y:Sep'2001	Y May'2000
Panchabati Moor	1	34550	1	0.81	0.9	0.92	0.92
Five Star Engineering	2	32630	0.94	0.94	0.92	0.95	1
North Kashipur	3	30400	0.88	-	-	-	1.06
Madhya Kashipur	4	28300	0.82	1	1.8	1.02	1.12
Gupta Nagar	5	26900	0.78	1.05	1.11	1.11	1.2
Syedpur	6	25200	0.73	1.08	1.15	1.2	1.26
7 Km	7	24710	0.72	1.12	1.2	1.25	1.35
Mukterpur DRS	8	18600	0.54	1.15	1.12	1.26	1.4
Mukterpur DPT	9	0	0.00	1.4	1.5	1.75	1.9
Gusalbag	10	3250	0.09	1.5	1.2	1.6	-
Noagaon	11	4750	0.14	1.4	1.15	1.55	1.75
Noagaon West	12	6250	0.18	1.45	1	1.5	1.7
Noagaon East Mosque	13	7750	0.22	1.42	1.8	1.48	1.65
Manikpur	14	8090	0.23	1.4	1.25	1.42	1.45
Idrakpur Primary School	15	7520	0.22	1.32	1.18	1.38	1.6
Manikpur Family Planning	16	7100	0.21	1.34	1.2	1.38	1.6
Manikpur Hospital Road	17	6200	0.18	-	1	-	1.56
Bahga Ali Road	18	10600	0.31	-	1.1	-	1.56
Ishaqpur	19	10000	0.29	1.33	1.12	1.35	1.55
Roushan Radio House	20	10500	0.30	1.33	1.22	1.3	1.6
GPO Munshigonj	21	9200	0.27	1.39	1.3	-	1.52
North Court Road	22	8500	0.25	1.44	1.18	1.22	1.6
Ranjit Master	23	5800	0.17	1.37	1.25	1.3	1.5
Jamiderpara	24	6000	0.17	1.36	1.22	1.35	1.5
Ganakpara	25	14200	0.41	1.35	1.16	1.38	1.48
Munshigonj Girl's School	26	15800	0.46	1.35	1.24	1.35	1.48
Khoka Chairman	27	10300	0.30	1.33	1.1	1.3	1.45
AVM High School	28	10100	0.29	1.26	1.05	1.25	1.4
Ganakpara	29	8300	0.24	1.28	1	1.22	1.4
Deovog woman College	30	6800	0.20	1.32	0.9	1.18	1.45
S M Islam(Deovog Majar)	31	6600	0.19	-	0.95	1.2	-
Zahiruddin HaZi(Deovog)	32	6100	0.18	1.3	1	-	1.4
Fish Farm Office,Deovog	33	6800	0.20	1.34	1.12	1.32	1.45
Hawladerbari,Deovog	34	6300	0.18			1.22	
Abul Kashem, Deovog	35	5900	0.17	1.34	1.39		1.45
D C Residence	36	16600	0.48	1.33	1.4	1.2	1.46
Forest Department, Katakhali	37	15100	0.44	1.3	1.35	1.18	1.42
Kalakhali Bazar	38	13200	0.38	1.35	1.41	1.25	1.5
Old Hospital, Munshigonj	39	13000	0.38	-	-	1.3	1.48
Math Para (Jalal Dewan)	40	13500	0.39	1.44	1.48	1.32	1.55
Munshigonj Stadium	41	17900	0.52	1.43	1.49	-	1.55
Panchghari Govt. Primary	42	16100	0.47	1.38	1.44	1.35	1.5
Munshir Hat Bazar	43	20350	0.59	1.33	1.4	1.36	1.45

Table-4.8: (Continued) PSP data of Munshiganj CP test points.

T P Location	Station Number	Distance	Relative Distance	Y:Jan'2003	Y.Mar'2002	Y:Sep'2001	Y: May'2000
South Islampur	44	20000	0.58	-	-	1.28	-
Khalistha(Sultan Gazi)	45	18300	0.53	1.29	1.35	1.35	1.4
Sekander Ali (Sree Palli)	46	17500	0.51	1.33	1.39	1.36	1.45
PTI Centre (Islampur)	47	11600	0.34	1.34	1.4	1.28	1.45
Islampur Farazi Bari	48	10400	0.30	1.39	1.45	1.3	1.5
Nawapara	49	10400	0.3	1.43	1.49	1.25	1.55
Hat Laxmipur	50	11600	0.37	1.5	1.54	1.15	1.6
Dinga Vanga Matbarbari	51	4700	0.14	1.65	1.72	1.2	1.8
Dinga Vanga ,Ali member	52	3200	0.09	1.69	1.75	1.25	1.85
Adraiyatola, Safi Chairman	53	2500	0.07	1.7	1.77	1.3	1.85
Avi Rice Mill	54	5100	0.15	-	1.61	1.36	1.7
Nandanpur Mosque	55	5500	0.16	1.55	1.66	1.38	1.7
Rikabi Bazar Mosque	56	7750	0.22	1.6	-	1.35	-
Mirapara Majar	57	8000	0.23	-	1.65	1.3	1.72
Kalindipara Kalibari	58	6820	0.20	1.6	1.6	1.36	1.65
Ghoshpara	59	7900	0.23	1.54	1.55	1.25	1.6
Rikabi Bazar East	60	8600	0.25	1.5	1.54	1.3	1.6
Tangor(Raihan Sarif)	61	9600	0.28	1.48		1.2	

Table-4.8: (Continued) PSP data of Munshiganj CP test points.

T.P Location	Y:Mar'1999	Y:Dec'1998	Y.Jan'1997	Y:May'1996	Y:Jan'1995	Y:Jul'1994
Panchabati Moor	0.9	0.95	0.94	0.8	0.75	0.75
Five Star Engineering	0.96	0.98	0.95	0.8	0.8	0.78
North Kashipur	-	-	0.98	0.95	0.85	0.83
Madhya Kashipur	1.1	1.1	1	1	0.85	0.87
Gupta Nagar	-	1.18	1.1	1.05	1.05	1.01
Syedpur	1.15	1.25	1.16	1.1	1.12	1.09
7 Km	1.25	1.4	1.25	1.15	1.21	1.17
Mukterpur DRS	1.3	1.9	1.36	1.2	1.25	1.15
Mukterpur DPT	1.9	1.9	2.1	2	1.98	1.92
Gusarbag	-	-	1.78	1.8	1.75	1.78
Noagaon	1.3	1.35	1.74	1.75	1.67	1.63
Noagaon West	1.36	1.48	1.6	1.7	1.65	1.6
Noagaon East Mosque	1.35	1.4	1.65	1.65	1.6	1.59
Manikpur	1.32	1.32	1.5	1.5	1.45	1.43
Idrakpur Primary School	1.5	1.54	1.5	1.55	1.48	1.46
Manikpur Family Planning	1.5	1.45	1.52	1.55	1.52	1.52
Manikpur Hospital Road	1.4	-	1.52	1.5	1.48	1.44
Bahga Ali Road	-	1.56	1.58	-	1.52	1.46

Table-4.8: (Continued) PSP data of Munshiganj CP test points.

T.P Location	Y:Mar'1999	Y Dec'1998	Y:Jan'1997	Y May'1996	Y:Jan'1995	Y Jul'1994
Ishaqpur	1.55	1.6	1.5	1.48	-	-
Roushan Radio House	-	1.38	1.45	1.45	1.51	1.49
GPO Munshigonj	1.9	1.5	1	1.45	1.45	1.44
North Court Road	1.45	1.45	1.08	1.45	1.45	1.4
Ranjit Master	1.5	1.5	1	1.5	1.45	1.41
Jamiderpara	1.35	1.36		1.5	1.5	1.45
Ganakpara	1.46	1.48	1.02	1.45	1.45	1.37
Munshigonj Girl's School	1.6	1.6	1.04	1.45	1.45	1.41
Khoka Chairman	1.5	1.54	1.04	1.45	1.48	1.39
AVM High School	1.48	1.48	1.05	1.45	1.45	1.38
Ganakpara	1.4	1.4	1.06	1.45	1.43	1.38
Deovog woman College	1.5	1.52	1	1.5	1.45	1.38
S M Islam(Deovog Majar)	-	-	1.02	-	-	1.34
Zahiruddin HaZi(Deovog)	1.43	1.46	0.98	1.5	1.45	1.35
Fish Farm Office,Deovog	-	-	1	1.48	1.43	1.34
Hawladerban,Deovog	-	-	1.36	-	1.42	1.35
Abul Kashem, Deovog	1.4	1.4	1.22	1.4	1.45	1.37
D C Residence	1.35	1.38	1.4	1.5	1.45	1.39
Forest Department, Katakhali	1.3	1.3	1.42	1.4	1.42	1.4
Katakhali Bazar	1.28	1.28	1.44	1.5	1.45	1.41
Old Hospital, Munshigonj	1.4	1.42	1.4	1.5	1.45	1.42
Math Para (Jalal Dewan)	1.45	1.48	1.45	1.45	1.45	1.4
Munshigonj Stadium	1.5	1.52	1.12	1.45	1.35	1.36
Panchghari Govt Primary	1.4	1.45	1.08	1.48	1.4	1.35
Munshir Hat Bazar	1.35	1.38	1	1.5	1.45	1.34
South Islampur	-	-	-	1.5	1.45	1.33
Khalistha(Sultan Gazi)	1.38	1.42	1.03	1.45	1.4	1.35
Sekander Ali (Sree Palli)	1.42	1.46	1.06	1.42	1.42	1.36
PTI Centre (Islampur)	1.3	1.35	1.08	1.45	1.5	1.36
Islampur Farazi Bari	1.4	1.5	0.98	1.5	1.5	1.35
Nawapara	1.42	1.47	1	1.55	1.5	1.5
Hat Laxmipur	1.52	1.56	1.44	1.55	1.75	1.49
Dinga Vanga Matbarbari	1.7	1.75	1.8	1.75	1.75	1.72
Dinga Vanga ,Ali member	1.72	1.78	1.76	1.75	1.8	1.68
Adraiyatola, Safi Chairman		1.82		1.75	0.35	1.7
Avi Rice Mill	-	-	0.85	0.7	1.62	0.63
Nandanpur Mosque	-	1.68	1.36	1.6	1.7	1.54
Rikabi Bazar Mosque	1.6	1.65	1.48	1.6	1.6	1.47
Mirapara Majar	-	-	-	-	1.6	1.49
Kalindipara Kaliban	1.55	1.7	1.52	1.55	1.57	1.51
Ghoshpara	1.52	1.64	1.6	1.55	1.55	1.51
Rikabi Bazar East	1.5	1.55	1.62	1.55	1.57	1.49
Tangor(Raihan Sarif)	1.55	1.58	1.65	1.6	1.6	1.51

4.2.7 Rectifier's tap setting and output data

Impressed current cathodic protection system can be controlled and monitor at tranformer - rectifier station, shortly called CP station. When current consumption at rectifier station increases, voltage setting goes down and PSP value at drain point drops from preset value. It indicates that efficiency of the existing cathodic protection system has been decreased due to some reasons. Then DC voltage and current output from rectifier needs to increase. It is done by changing tap setting of the rectifier. Table-4.9 shows rectifier tap setting of Munshigonj CP station at various times from 1993 to 2003 These data also have been collected from concerned department of TGTDCL and arranged in tabulated from.

Table-4.9: Transformer-Rectifier Tap Setting and Output

Date	Observed Data						Reset Data			
	Tap Setting	AC Input		DC Output		PSP at DPT (Volt)	Tap Setting	DC (Volt)	DC (Ampere)	PSP at DPT (Volt)
		Voltage (Volt)	Current (Ampere)	Voltage (Volt)	Current (Ampere)					
03/08/93	1x1x1	240	0.75	14	10	-1.70	1x2x1	15	11	-2.2
05/08/93	1x2x1	220	1	15	10	-2.1	-	-	-	-
14/10/93	1x1x1	220	1	14	9.5	-1.9	-	-	-	-
30/11/93	1x1x1	220	1	15	9.5	2.0	-	-	-	-
26/12/93	1x1x1	220	1	15	9.5	-2.15	-	-	-	-
20/02/94	1x1x1	220	1	15	9.5	-2.0	-	-	-	-
9/3/94	1x1x1	220	1	15	9.0	-1.9	-	-	-	-

Table-4 9(Continued): Transformer-Rectifier Tap Setting and Output

Date	Observed Data						Reset Data			
	Tap Setting	AC Input		DC Output		PSP at DPT (Volt)	Tap Setting	DC (Volt)	DC (Amp.)	PSP at DPT (Volt)
		Voltage (Volt)	Current (Ampere)	Voltage (Volt)	Current (Ampere)					
6/4/94	1x1x1	230	1	16	9.0	-2	-	-	-	-
17/05/94	1x1x1	230	1	17	9 0	-2.0	-	-	-	-
01/06/94	1x1x1	230	1	16	9.0	-1.95	-	-	-	-
8/06/94	1x1x1	230	1	15	9	1.92	-	-	-	-
30/5/96	2x2x1	-	-	15 V	9 0 A	-2.0 V	-	-	-	-
20/10/96		-	-	15.5	11.0	-2.2	2x2x1	15	10 75	2 05
14/07/97	2x2x12	-	-	14.5	8	-1 9	2x2x1	14.5	8	-1 9
22/09/97	2x2x1	-	-	14.0	9 0	-1 90	-1 90	14 0	9.0	-1.9
03/04/98	2x2x1	-	-	14.0	9.0	-1.82	2x21	14.0	9.0	-1.82
29/06/98	2x2x1	-	-	13.5	9 0	-1.8	2x2x1	13.5	9	-1.80
24/12/98	2x2x1	-	-	12.5	9.0	-1.9	2x1x1	12.5	10.25	-2 15
10/01/2001	2x4x2	-	-	9.5	9.0	-.65	2x4x4	10.25	9.5	--1.75
11/09/2001	2x4x2	-	-	10	8 0	-1.75	2x4x2	10.0	8 0	-1 75
25/01/03	2x2x1	-	-	8.75	8 05	-1.4	2x2x1	8 75	8.05	-1.40

4.3 Data Analysis and System Evaluation

Present cathodic protection installation system described for the said area was constructed 13 years ago. In the mean time length of the distribution pipelines has increased significantly with the increased demand of the customers. From the commissioning of gas supply till today, the numbers of industrial, commercial and domestic gas connections under the distribution system are 15, 23 and 4993 respectively. Distribution network has increased markedly every year by the demand of the local people. TGTDCL also extend distribution line every year as per its own plan and program. At present 1, 00,000 feet 3/4" diameter riser pipe lines have been added to the network. The information about the growth of other sizes of pipe lines such as 1", 2", 3" and 6" diameter pipelines were not available But there were not found. There is a communication gap between local office and planning department. All information regarding the laid pipelines is not sent to planning department. As a result the key map about distribution pipelines is not updated. It is general practice to assume 50% increment of distribution pipe lines for each 20 years period. Deterioration of coating is increasing sharply due to ageing effect, continuous customer connection damaging coating, disbonding of coating for increasing current demand with increasing pipe length etc. Voltage setting at DTP to higher value than recommended value -1.5 volt to satisfy PSP value every where over 0.85 volt (negative) with respect to $Cu/CuSO_4$ electrode causes disbonding of coating Therefore the system installed 13 years back needs to evaluate.

4.3.1 PSP data

Collected PSP data of 10 discrete months of 10 consecutive years (Table-4.8) shows some locations where data are not available. These data could not be collected due to following reasons:

(i) Some times the TP cover was locked and could not be opened at site to collect the data.

(ii) For office administration: when Old technical was transferred then new technician could not trace some locations.

(iii) Test point is sometimes stolen.

(iv) Test point cable is stolen and disconnected by unconscious citizens.

(v) Test points are destroyed or damaged by accident from vehicle.

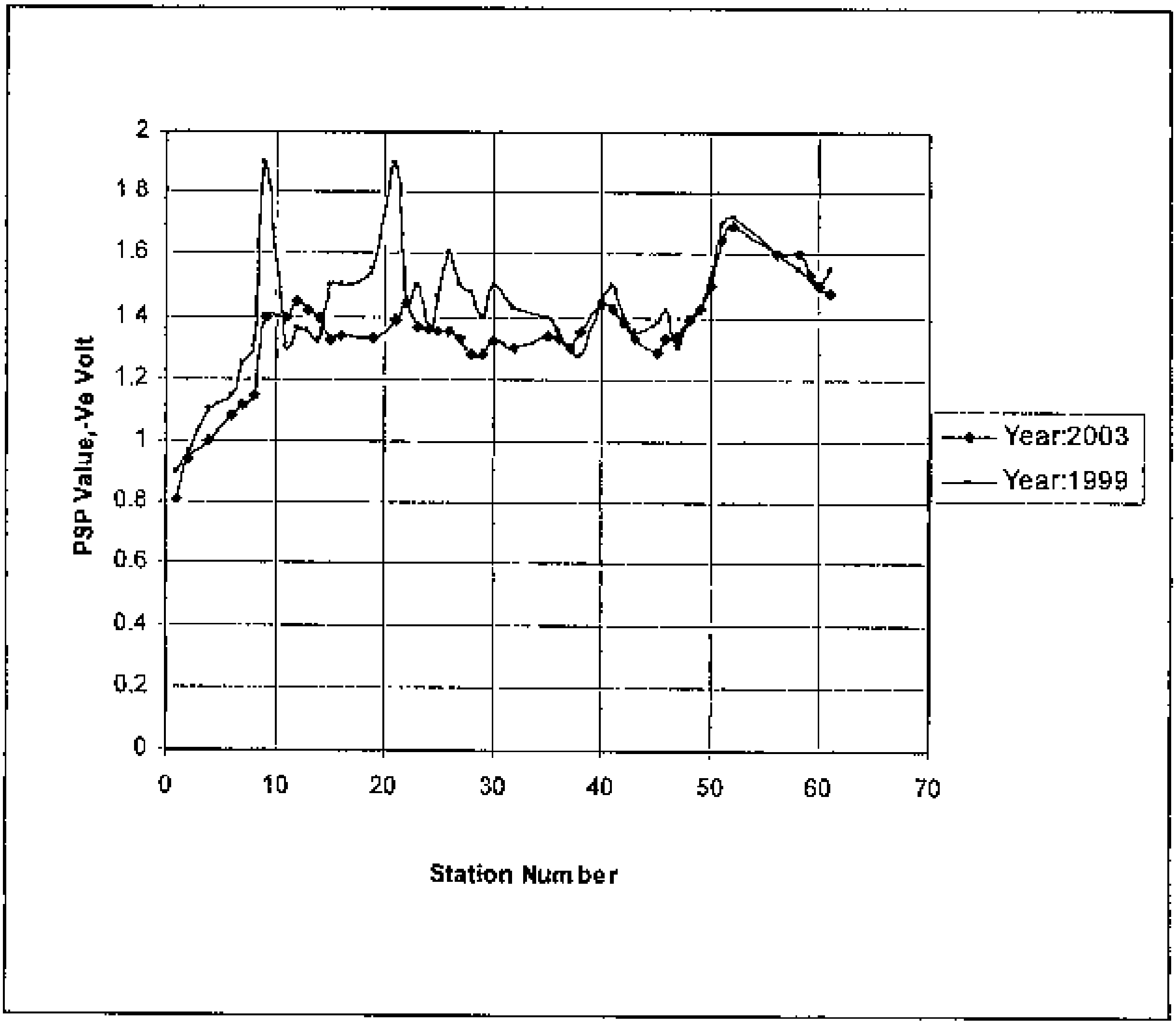


Figure-4.6: Graphical representation of diminishing CP efficiency with time.

At drain point of the line PSP value is set 1.5 volt to 2.5 volt by adjusting rectifier output with tap setting. But it is observed that at DTP, the PSP value always tends to decrease. Graphical representation of diminishing CP efficiency with time is shown in Figure-4.6. Figure-4.7 shows the variation of PSP at DTP with time

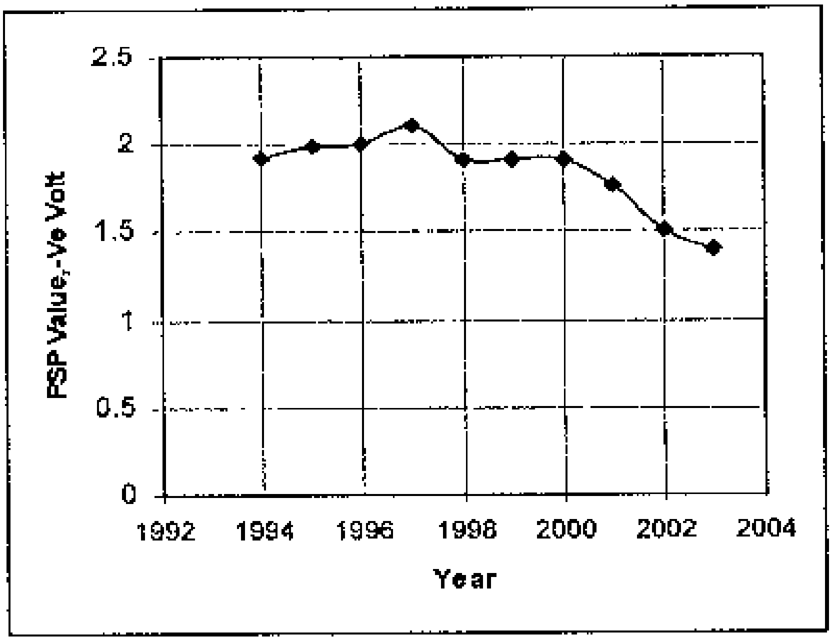


Figure-4.7: Temporal variation of PSP at drain point from setting value.

It is the recommended practice to keep the PSP at feeder or drain point at1.5V. It is not recommended over that because wrapping or coating of pipe becomes loose and ineffective. PSP at DTP is diminishing at Munshiganj and it requires higher tap setting of rectifier For last ten years a large number of times tap setting has done (Table-4.9). But the result is that PSP always falling down. The problem has become acute in recent time. It reveals the fact that the current demand of the distribution lines has increased and existing rectifier is failing to maintain negative PSP over 0.85 volt every where. This may happen due to damage of coating and exposure of pipe connecting with water body.

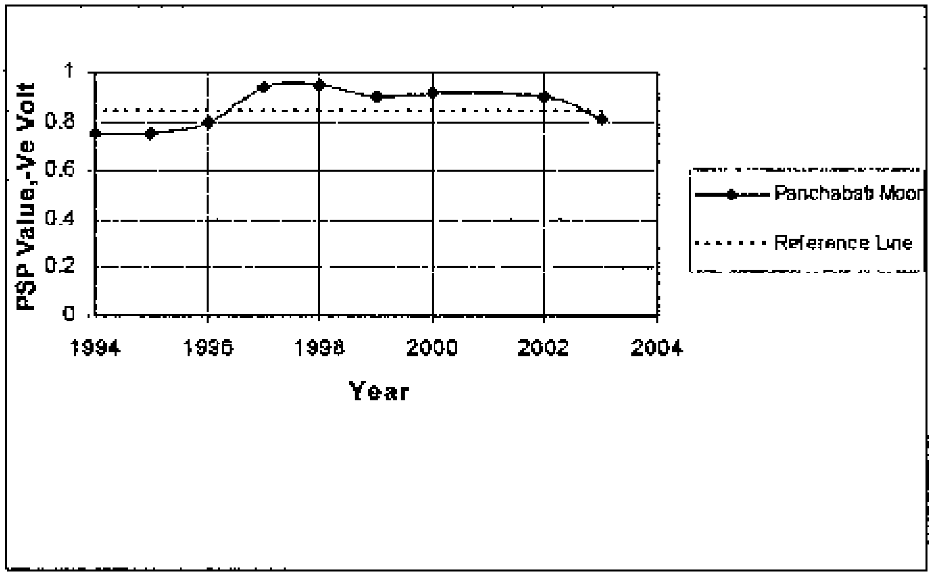


Figure-4.8: Variation of PSP reading at Panchabati moor showing corrosion.

Figure-4.8 shows temporal variation of PSP reading at Panchabati moor which is at maximum distance from DTP. It is evident that from the time of commissioning of CP system at Munshiganj, the capacity of rectifier was not sufficient to protect pipe line at Panchabati moor up to 1997. The curve then goes up and then in the recent years it again falls. Critical PSP value is being maintained. After 1997 because of another CP station commissioned at Sasthapur of Narayanganj which is within 2 km from Panchabati moor Some how there might be established an electrical conductivity with the distribution lines of Narayanganj. It also illustrates a very serious problem to Munshiganj CP station. The problem might be failure of insulating joint at Panchabati moor and drainage of current to a very large distribution network of Narayanganj.

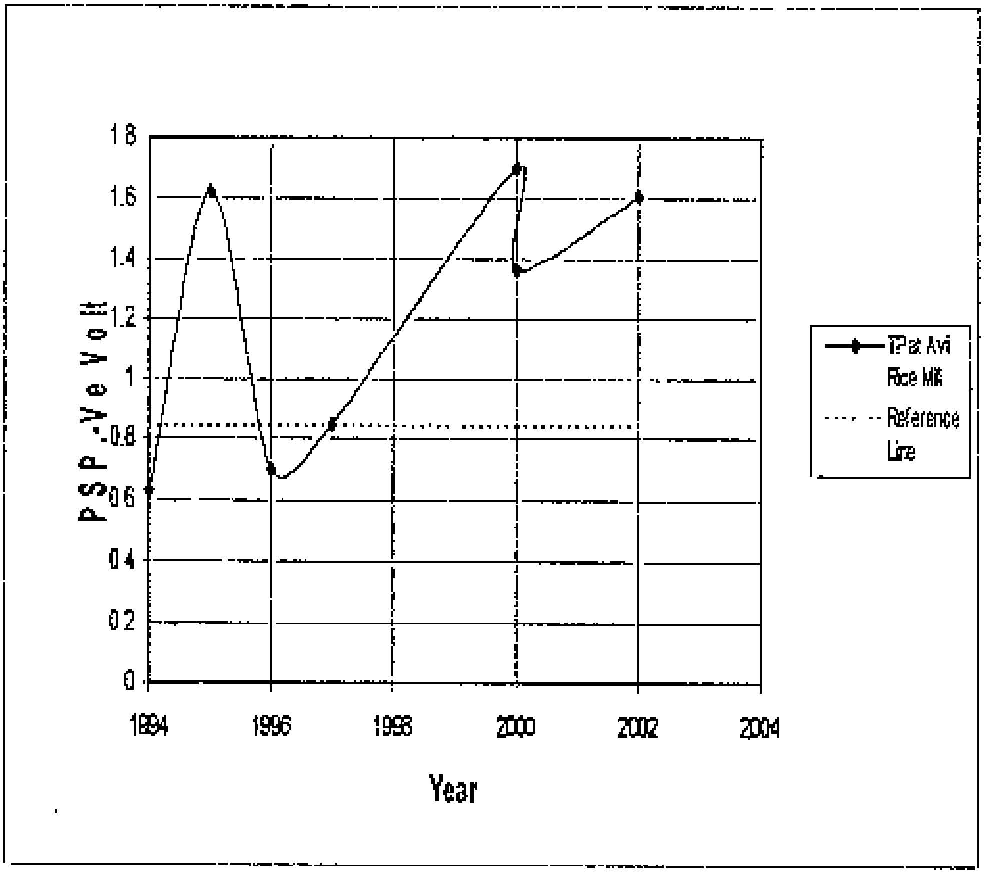


Figure-4.9: Temporal variation of PSP at Avi rice mill area.

Another TP which is at 5100 feet distance from DTP shows PSP values drop below critical line twice in Figure-4.9. Except that PSP value is always well above than critical value PSP at some stations adjacent to this station satisfy critical PSP at the sometime. The reason of going PSP value down than critical is that cable of the test point was disconnected. After maintenance it gave correct PSP value and the structure here is safe from corrosion

Figure-4 10 shows variation of PSP reading with distance from DTP. The plot on semilog paper gives straight line which is identical to typical attenuation curves for finite line.

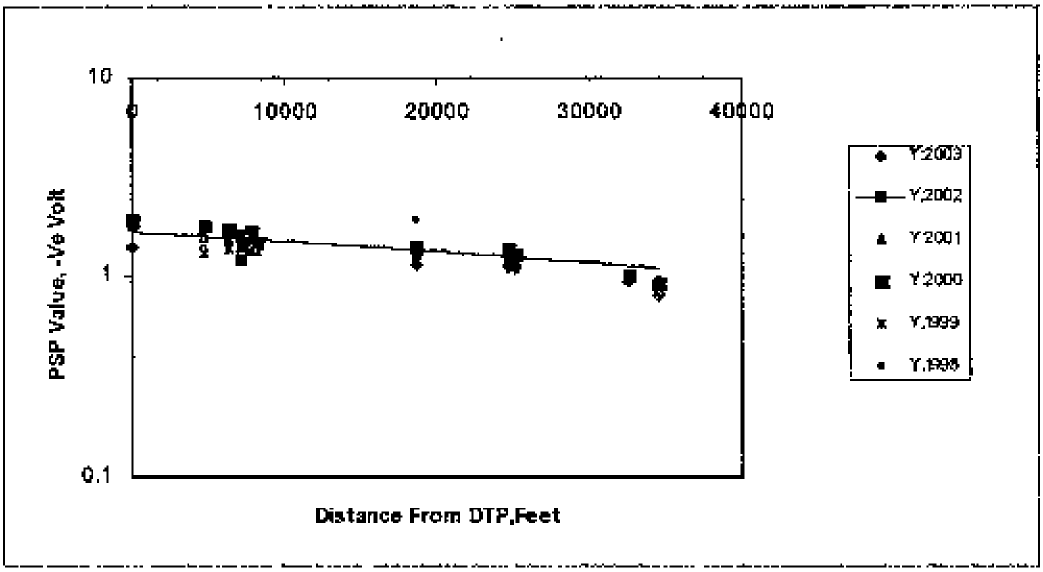


Figure-4.10: Variation of PSP reading with distance from DTP

4.3.2 Pipe line length projection

On the basis of as built drawing of 1992 pipe line data are available (Table-4.4). Assuming 50% growth of pipeline for every 20 years and overall design life up to the year 2025, projected length and surface area of each size of pipe needs to be calculated to assess the existing CP system. Pipelines collected from the map of 1992 do not provide length of 3/4" pipe laid. It has been taken 20' per domestic customer number as on September' 2005. Table-4.10 below gives present and future projection of pipe lines in Munshiganj distribution network up to September, 2005 the distribution mains remain unchanged.

Table-4.10: Pipe length projection

Year	Length of pipe, ft						
	3/4"	1"	2"	3"	6"	8"	12"
1992	-	30100	41275	27880	22000	32800	3000
2005	99860	39882	54689	36941	22000	32800	3000
2025	150790	59823	82033	55441	33000	49200	4500

Note: No actual extension of 6 "Φ, 8 "Φ and 12 "Φ line is made during 1992-2005.

4.3.3 Resistivity data evaluation

Collected resitivity data of Munshiganj gas distribution network area has been analyzed and logarithmic mean resistivity has been calculated. Calculation shows resistivity of the whole area 2455 ohm-cm so the soil is moderately corrosive. The soil consists of ash soil, sand and clay Resistivity of the area is low due to presence of clay and ash soil.

4.3.4 Investigation into rectifier's rating

Whether the existing single drain point rectifier is sufficient to meet present and future current demand to protect the pipe lines from corrosion or not can be investigated by,

(i) Rules of thumb, and
(ii) Using attenuation curve.

For each case it is desired to set design considerations. The considerations available are as following:

(i) Soil resistivity, $\rho = 2455$ ohm-cm.
(ii) Coating conductivity of steel pipes:

For good coating in low resistivity soil: 50-250 micromohs/sq.ft.

Considering deterioration of coating to some extent for the present situation it can be taken as 250 micromohs/sq.ft.

Rules of thumb approach:

Current requirement is calculated using the following assumptions:

For conservative design, current density : 0.5 mA/ft^2

For extreme exposure, current density : 2 mA/ft^2

Current requirement for rectifier's rating investigation considering pipe line data up to September 2005 is given in the Table-4.11.

Table-4.11: Current requirement calculated for Rectifier's rating investigation using pipe length up to September 2005 (Using rules of thumb)

Nominal diameter	outer diameter, inch	Length, ft	Surface area, ft^2	Current requirement, A	
				Considering 0.5mA/ft^2	Considering 2 mA/ft^2
3/4"	0.75	99860	19615	9.8	39
1"	1.05	39882	10988	9.8	22
2"	2.375	54689	34080	5.5	68
3"	3.5	36941	33924	17	67
6"	6.625	22000	38173	19	76.3
8"	8.625	32800	74093	37	148.2
12"	12.75	3000	10036	5.0	20
	Total=	289172	220909	110.3	440.5

Use of attenuation curve for finite coated line:

Data to be used for Munshiganj distribution line:

(i) Soil resistivity : 2455 ohm - cm.

(ii) Coating conductivity :250 micromohs/sq.ft.

(iii) Drainage voltage at DTP, ΔE_A :1.9 volt

(iv) At low point on pipe line driving voltage, ΔE_x : 0 3 volt (Criteria)

(v) Total driving voltage change over the line : ΔE_T =0.3 volt

So, For Munshiganj, $\frac{\Delta E_A}{\Delta E_T} = \frac{1.9}{0.3} = 6.33$

Now from attenuation curve for coated finite line (Figure-3.8), for different sections of pipeline,

$$I = (\text{Chart Value}) \times (\frac{\Delta E_T}{0.3}) \times D$$

$$\therefore \quad I = (\text{Chart Value}) \times D$$

Where, D= diameter of the section of pipe in inch,

And $\Delta E_T = 0.3$ (General assumption)

Table-4.12: Current requirement calculation for rectifier's rating check using pipe line data up to 2005 (Using attenuation curve for coated line)

Pipe size, inch	Outer diameter (D),inch	Sectionalized Length (L), ft	I=Chart value ×D, A
3/4"	0.75	30,000	1.125
		30,000	1.125
		39,860	1.125
	Sub Total	99,860	3.375
1"	1.05	39,882	1.575
	Sub Total	39,882	1.575
2"	2.375	30,000	3.56
		24,689	3.56
	Sub Total	54,689	7.12
3"	3.50	36941	5.25
	Sub Total	36,941	5 25
6"	6 625	22000	9.44
	Sub Total	22,000	9.44
8"	8.625	32,800	12.93
	Sub Total	32,800	12.93
12"	12.75	3000	19.12
	Sub Total	3,000	19 12
Total Current:			59.31 A

Table-4.13: Current requirement calculation for rectifier's rating check using pipeline data up to 2025 (Using attenuation curve for coated line)

Pipe size	Outer diameter (D), inch	Sectionalised Length, ft.	I = Chart value×D, A
3/4"	0.75	30,000 30,000 30,000 30,000 30,790	1.125 1.125 1.125 1.125 1.125
	Sub Total	150.790	5.625
1"	1.05	30,000 24,823	1.575 1.575
	Sub Total	59823	3.15
2"	2.375	30,000 30,000 22033	3.56 3.56 3.56
	Sub Total	82033	10.68
3"	3.50	30,000 25441	5.25 5.25
	Sub Total	55441	10.50
6"	6.625	33000	9.44
	Sub Total	33000	9.94
8"	8.625	30,000 19200	12.93 12.93
	Sub Total	49200	25.86
12"	12.75	4500	19.12
	Sub Total	4500	19.12
Total Current:			84.85 A

The rule of thumb method is estimation and should not be used for design. On the other hand, attenuation curves are useful for design purpose. This was first used by Chevron Oil Co. in 1950's. Calculated current requirement shows that a single TR unit of 30 ampere rating is not sufficient to meet present and future demand of Munshiganj.

4.3.5 Ground bed evaluation

Munshiganj CP station has one 30Ampere × 20 volt transformer rectifier (TR) unit for impressed current cathodic protection system. Some selected voltage drops are considered to occur.

Positive and negative cable : 1.8 volts
(150 m of 35 mm diameter)
Voltage drop in length of ground bed : 0.25 volt.
Back EMF to surrounded ground bed . 1.7 volt
(when coke breege is used)
Change in pipe to soil potential : 2.00 vold
Contingency (around 5%) for TR volts : 1.25 volt

Total . 7 Volts.

Voltage available for the circuit, . (20-1.7) Volt
= 18.3 volt

Minimum circuit resistance, $R_{min} = \frac{18.3}{30} = 0.61$ Ohm

Ground bed of existing Munshiganj CP station is a horizontal scrap iron ground bed consists of:

(i) 2 Nos 40' long 10" diameter scrap pipe
(ii) Depth of placement: 10'-6"

Thus putting,

L = 80',

D = 0.833',

P= 2455 ohm – cm, and

S = 10.5' in the Equation-3.4 given below:

$$R = \frac{P}{192L}\left\{\ln\frac{4L}{D} + \ln\frac{L}{S} - 2 + \frac{2S}{L}\right\}$$

Equation-3.4 gives the value of R = 0.997 ohm. This value is much higher than TR capacity of 0.61 ohm. So the existing 20 volt TR is not enough.

Anode consumption:

Out side diameter of 10" pipe = 10.75"

Weight per meter: 26.5 kg/m

Consumption rate: 9.1 kg/A y

Cathodic protection system was commissioned on July 1992

Time passed: 13 years

Tap setting of rectifier (Table- 4.9) Shows

Maximum current consumption: 11A

Minimum current Consumption: 8A

So, average current output from TR. $\frac{11+8}{2}$=9.5 A

Therefore consumption of anode bed iron:

$C = 9.1 \times 9.5 \times 13$

$= 1123.85$ kg

Weight of installed iron:

$I = \frac{80}{3.28} \times 26.5$

$= 646$ kg

As I < C, existing anode bed requires immediate checking and rehabilitation.

Outcome: Existing system of Cathodic protection for Munshiganj gas distribution network has been analyzed thoroughly. PSP reading collected by the officers and technicians of TGTDCL at different times apparently shows that the system is more or less safe and controlling corrosion of the distribution pipe lines. But evaluating the existing system and considering many other things it can be inferred that:

(i) Existing 30 Amp×20 volt TR set is not sufficient to meet the present and future demand of corrosion control.

(ii) The scrap iron ground bed installed at Panchashar primary school play ground might be consumed totally. It is necessary to conduct loop resistance test and rehabilitation of anode bed .Of course relocation of anode bed is necessary as because a new building has been constructed by the school authority.

(iii) After a certain interval of time TR tap is reset in such a way so that PSP at DTP remains 1.9 volt or more. But it goes down below 1.5 volt (-ve) quickly. On the other hand current consumption at TR site is going down. Voltage setting at TR is also going down .This may happen due to following reasons:

(a) Tapping on the TR set too low.
(b) TR is failing.
(c) Electricity supply is faulty.

As tap setting is done frequently. But the reset high voltage does not sustain even when there is no problem of electricity supply. Calculations shown in the previous sections indicate that an under rated cathodic protection system is installed with respect to present and future pipeline network.

(iv) Number of TP along pipe lines are insufficient and particularly in Mirkadim portion only 11 TP is set. So it is not possible to know the status of every point. No TP is installed after commissioning of CP in 1992. It is not possible to know the status of extended pipe line laid after that time.

(v) Resisitivity (logarithmic mean resistivity) of the area is 2455 ohm-cm which indicate the soil is corrosive generally impressed current method of corrosion control system is suitable for soil of ressitivity more than 10,000 ohm-cm. It works best where soil resistivity is above 100000 ohm-cm, ie, in sandy soil or in ground with high terrain of land where area is not flooded. But a region like Munshiganj which is situated within the grip of two river and entire land is almost flooded every year; impressed current method fails to protect pipelines for a number of reasons.

(vi) For cathodic protection system monitoring measuring PSP at different TP at a interval of time is important. Therefore sincere, dutiful and well trained personnel are required to measure PSP accurately.

(vii) Repairing and maintenance of anode bed cable joints and tap setting of rectifier are most of the time done by unskilled people. Inaccurate connection i.e. wrongly connected cable with opposite polarity cause server damage to the pipe and leakage of the pipe may happen within 3 to 4 days.

(viii) Scrap iron has been selected as anode for ground bed. Rate of consumption of scrap iron is very high (9.1 kg./A.y). Therefore frequent replacement or rehabilitation of anode bed is required. It is necessary to use high silicon iron anode for ground bed. But now the situation has become difficult as the installed anode has been consumed up and the place where it was installed has been occupied by other agency. Station redesigning along with relocation of ground bed is important.

(ix) Draining current at Munshiganj CP Station it is expected to protect the pipeline up to the Panchabati moor which is nearly 11 km away from the CP station. At 1/2 km from CP station the distribution main has crossed river special care is required for this section. Leakage of pipe at this section has become acute these days.

Conclusion: Redesigning of the existing system considering present deficiency in the system is important. The distribution network has already passed 13 years life. Its redesigning life would not be more than 20 years. The system should be redesigned up to the year 2025. Sacrificial anode system is designed for such a short term projection.

The field installation of galvanic anode is simple. Relatively little training is required to attain acceptable construction and maintenance skills. So Sacrificial anode system is more suitable for a country like Bangladesh where general workers are not rightly trained up.

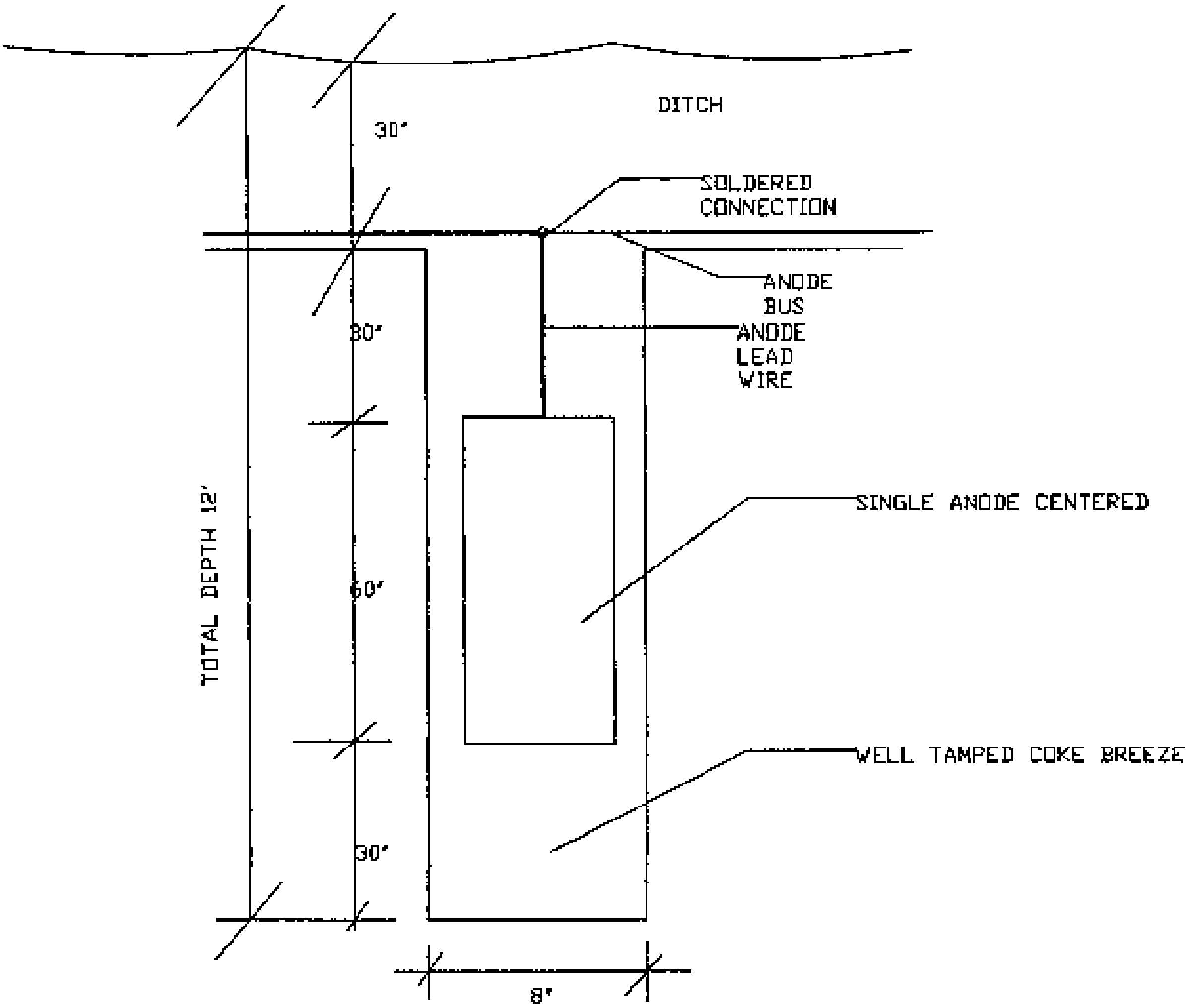
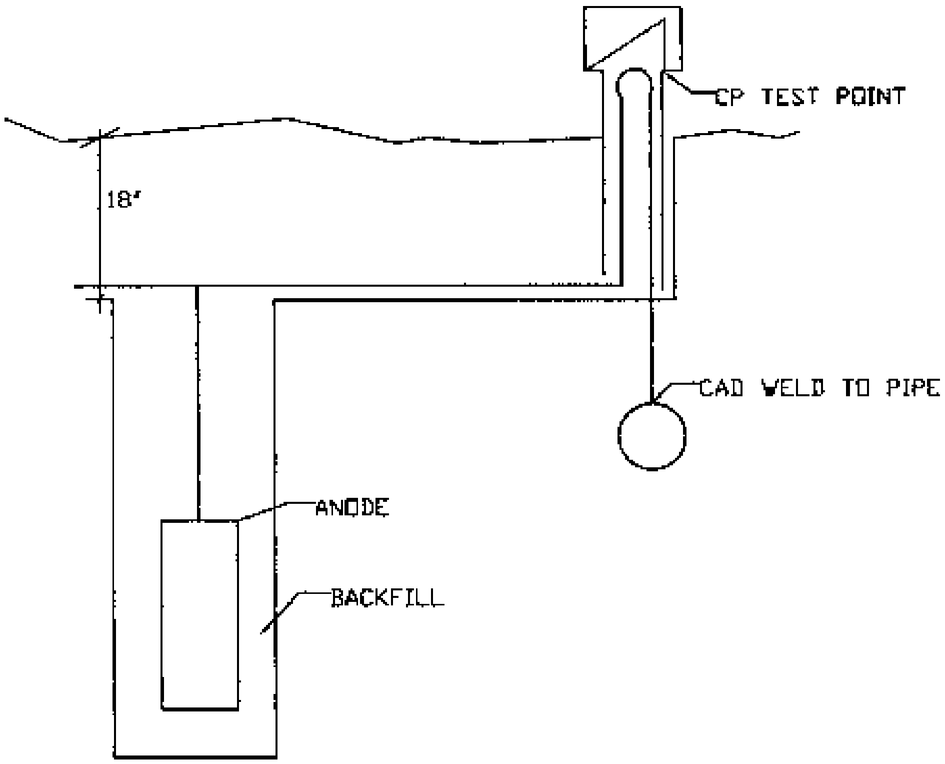


Figure-4.11:Typical vertical anode installation diagram.



Fiure-4.12 :Diagram of a typical CP test Point

CHAPTER V

SYSTEM REDESIGNING

In the preceding sections it is shown that existing cathodic protection system of Munshiganj distribution pipelines is not functioning properly. An improved system design for the said area is essential. The new system should be compatible with the local condition, should cost less and the technology should be such that the local people can operate and maintain it easily. The following discussions support most appropriate method of corrosion control for distribution lines like Munshinganj.

(i) The resistivity of the said area is 2455 ohm-cm. It is a low resistivity soil and sacrificial anode method is suitable for relatively low resisrivity soil, usally under 10,000 ohm-cm.The method is most suitable for resistivity up to 3000 ohm-cm.

(ii) The distribution network has already passed 13 years life. Its redesigning life would not be more than 20 years. The system should be redesigned up to the year 2025. Sacrificial anode system is designed for such a short term projection.

(iii) The field installation of galvanic anode is simple. Relatively little training is required to attain acceptable construction and maintenance skills. Thus this is more suitable for a country like Bangladesh where general workers are not rightly trained up.

(iv) Galvanic anodes tend to be more economical than impressed current installations where small amount of protective current is needed. The distribution area of Munshiganj is relatively small and reqmires less amount of current than that of other large distribution area like Naraqyanganj or Joydevpur. So the sacrificial system would be a good solution for the area

(v) No land acquisition is required for the sacrificial anode method. Ground bed of Munshiganj CP station was installed in the play gromnd of Panchashar government primary school. Now a new building has been constructed over it. At the same time rehabilitation of the ground bed is required. System redesigning adopting sacrificial system would have been a solution here.

(vi) Interference or stray current caused by galvanic anode method is not so severe as caused by impressed current method. Thus to save other useful metallic structure galvanic anode is a l better choice than impressed current method.

(vii) There is no possibility of disbanding of coating caused by the application of excess impressed current method.

(viii) Distribution network of Munshiganj is mostly consists of pipes having diameter $\frac{3}{4}$" to 3". But there is a12 km long section from Panchabati moor to Munshiganj DRS. 11 km of this pipe line is of 8" in diameter, 1 km river crossing of 12" diameter. In excess of these lines, two 6" diameter pipes have come out as distribution main from Munshiganj DRS. 6"diameter prices are giving feed to the Munshiganj central town and Mirkadim. The section consisting of 8", 12" and 6" diameter has more current demand than rest of the distribution lines. This long section of higher diameter line is technically suitable for impressed current method of corrosion control. Other part is technically fit for sacrificial anode method.

(ix) Gas distribution pipe lines of Munshiganj central town and Mirkadim suffer from water surge of the rivers almost through out the year. During the rainy season these two parts remain under water for months together. The resistivity of these parts may go down than calculated resistivity 2455 ohm-cm. So sacrificial anode method is technologically fit for both parts. As most of the pipes of these two part are 3", 2", 1" and $\frac{3}{4}$" in diameter surface area of all the pipes are relatively less and current demand is relatively low compared to the 12 km long section. So cost of sacrificial anode method for central Munsiganj town and Mirkadim business centre would be best method of corrosion control.

5.1 Improved System Design

It is evident from the analysis in the previous chapter that existing single drain point based impressed current method for the composite area like Munshigonj is failing to attain its goal. The possible solutions are as follows:

(a) 3- TR unit based impressed current system. One for long 12 km section including the river crossing, one for Munshiganj central town part and one for Mirkadim part.

(b) Sacrificial anode system for the whole region.

(c) Composite system: Sacrificial anode system for Munsiganj town part and Mirkadim part. Single drain point impressed current method for long 12 km section including the river crossing.

Among these methods serial (b) is not practically and technologically feasible, because distribution of sacrificial Mg anodes are not suitable for the river crossing section as Mg anodes are readily consumed up when resistivity is too low . High standard Zinc or Aluminum alloy can be effective .But such types of anode are not easily available. These are proprietary items and involve administrative complicacy to procure .Length of the total section is 12 km and only 1 km is the river crossing. This part consists of 8" to 12" diameter pipes and has very large amount of surface area. So a large amount of protective current is required. Impressed current method is technologically more suitable and economical for this part. Besides this sacrificial anode method does not provide satisfactory result as there is change of damaging seal of casing, intrusion of water into the casing and corrosion of both casing and original pipe for river crossing part. Thus current requirement may be required to increase. Impressed current method can handle this situation by tap setting. On the other hand sacrificial anode method would not be economical for a 12 km long section. Most of the part of this section is laid close to the highway. The possibility of variation of resistivity is less. So for this section impressed current method is the right choice.

Therefore either the method (a) or method (c) which costs less is the solution. Schematic diagram of method (a) and (c) are given in figure-5.1 and figure-5.2.

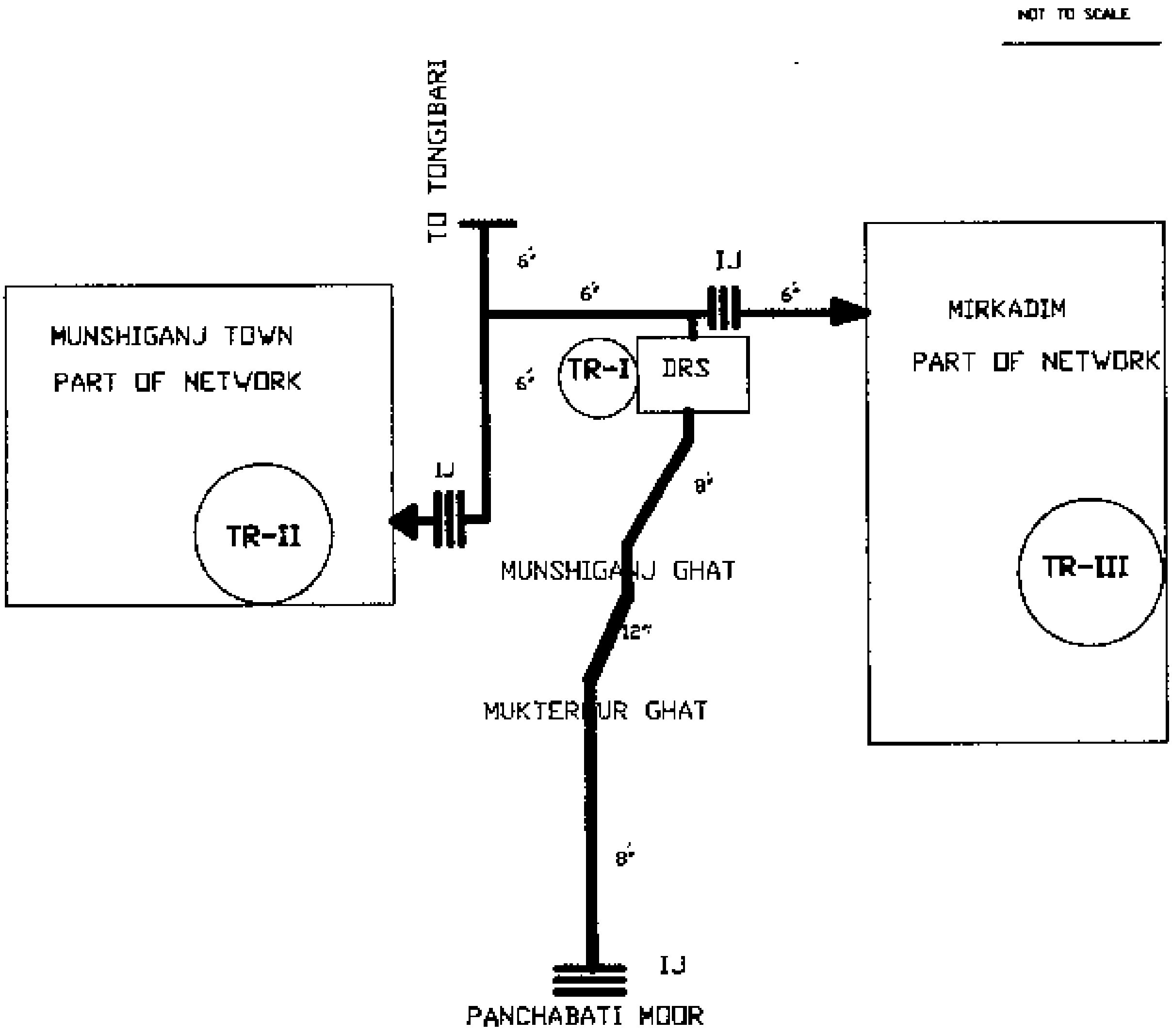


Figure-5.1: Diagram of 3-TR unit system cathodic protection

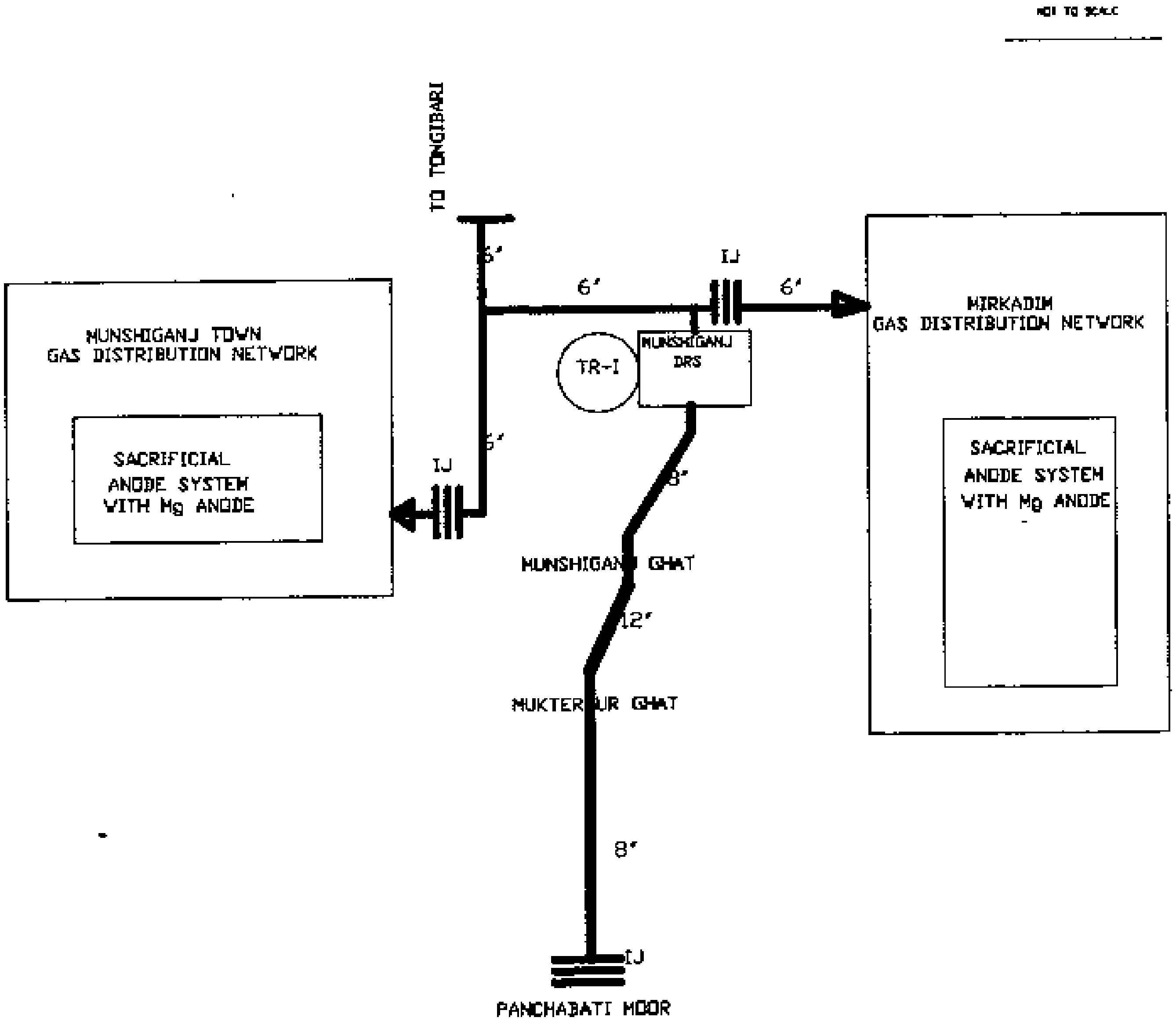


Figure-5.2: Diagram of composite system design , 1-TR unit based impressed current system for the distribution main and sacrificial anode system for other two part of the city.

5.2 3-TR Unit Based Impressed System Design

Current requirement calculations for the area of each of the TR unit, calculation for ground bed and coke breeze requirement have been done separately.

5.2.1Calculation for design of TR- I part

Table-5.1: Pipe line data and current requirement for design TR-I

Nominal diameter ,inch	6"	8"	12"	Comments
Length up to September' 2005, ft	1750	32,800	3,000	Total 33.65 A Current requires.
Projected length up to 2025 considering 50% growth , ft	2625	49,200	4,500	
Outer diameter D, inch	6.625	8.625	12.75	
Surface area, ft^2	4555	1,11,139	15,026	
Current requirement using attenuation curve for coated lines, A	8	10.35	15.3	

<u>Design consideration:</u>

(i) Soil resistivity : 2455 ohm-cm.
(ii) Coating conductance, g : 250 micromoh/sq.ft.
(iii) Driving voltage at DTP : 1.5 volt.
(iv) Driving voltage change at low point of pipe lines, ΔE_X : 0.3 volt.
(v) Total driving voltage change (Assumption), ΔE_T : 0.3 volt

$$\therefore \frac{\Delta E_A}{\Delta E_T} = \frac{1.5}{0.3} = 5.0$$

From curve (Figure-3.8), I_A= (Chart Value) × D Ampere

Where, I_A is drainage current at DTP.

<u>Ground bed design part:</u>

Taking one 50A × 50 volt TR set, minimum resistance, $R = \frac{50-1.7}{50} = 0.966$ ohm

Taking 10 Nos. 10′ x 8″ size vertical borehole with 3″ × 60″ high silicon iron anode and spacing 10′, Equation-(3.3) gives,

$$R_n = 0.012 \times \frac{2455}{100} \log \frac{35 \times 100}{8} + \frac{2455}{10} \times 0.00201$$

$$= 0.2946 \log (437.5)$$

$= 0.2946 \times 2.64 + 0.493$

$= 1.27$ ohm

From chart (Figure-3.9):

$\therefore$ Multiplying factor,

$$M.F = \frac{\rho}{1000} = \frac{2455}{1000} = 2.45$$

$R_n = 0.43 \times 2.45$

$= 1.05$ ohm

With respect to local soil condition the theoretically calculated ground bed resistance is at least 5% less than the minimum circuit resistance.

So, Minimum resistance $R_{min} = 1.05 \times 1.05$

$= 1.10$ ohm, which is so close to minimum circuit resistance required.

So, 10 numbers 10'x8" anodes with 10' spacing is required.

Checking design life with respect to ground bed consumption:

$M = L_T \times f \times I_A$

Where,

M = Weight of anode, Kg

L_T = Design life

f = Consumption rate, Kg/ A.y.

I_A = T-R unit out put current, A

Specification of Silicon- iron anodes that are procured by TGTDCL are as follows:

(a)	Length	:	60" (1500 mm)
(b)	Diameter	:	3" (75 mm)
(c)	Net weight	:	45 kg/ anode

(d) Composition.

- (i) Silicon : 14.5 - 15.25%
- (ii) Carbon : 0.85 - 1.4%
- (iii) Manganese : 0.50 - 0.75%
- (iv) Sulpher : 0.1% Maximum.

(e) Maximum current density : 50 A / m^2

(d) Metal loss : Maximum 0.45 kg/ A.y

(f) Feeder cable : 50m x 10 mm.

(g) Cable protector : Minimum 300 mm sleeve at junctions.

So, M = 20 x 0.45 x 50

= 450 Kg.

Therefore, 10 anodes of 45 kg weight are required.

<u>Calculation of hard coke:</u>

Volume of the bore hole of the ground bed

$V_{GB} = \pi * r^2 * L$

r = Radius of the bore hole in m

L = Length of the bore in m

Using applied length 12 ft and applied diameter 8 inch,

$V_{GB} = 3.14286 * (0.102)^2 (3.65)$

$= 0.119 \ m^3$

Density of hard coke as procured by TGTDCL: 580 Kg/ m^3

So, Weight of hard coke per ground bed,

= 580 x 0.119 = 69 Kg

Hence for 10 ground bed,

= 69 x 10 = 690 Kg required.

5.2.2 Calculation for design of TR- II part (Munshiganj Part)

Table- 5.2: Pipe line data and current requirement for TR-II part

Nominal pipe diameter, inch	$\frac{3}{4}$"	1"	2"	3"	6"
Length up to September 2005, ft	49600	21055	25208	19815	9500
Projected length up to 2025 considering 50% growth, ft	74400	31582	37812	29723	14250
Outer diameter D, inch	0.75	1.05	2.375	3.5	6.625
Surface area, ft^2	14614.29	8685.06	23519.98	27246.11	24725.40
Current requirement using attenuation curve for coated lines, A	0.90+0.90+0.90	1.26	2.86	4.2	7.95
Total Current, A			18.96		

Note: 1. $\frac{3}{4}$" diameter pipe length have been distributed between Munshiganj and Mirkadim by the ratio of the length of distribution mains.

2. $\frac{3}{4}$" diameter pipe has been sectionalized to 30,000 ft.

Total 18.96 ampere current is required at DTP. So, one TR unit of 20 Amp. x 24 volt can be taken

Ground bed design for TR-II part:

Minimum circuit resitance required:

$$R_{min} = \frac{24-1.7}{20} = 1.11 \text{ ohm.}$$

High silicon iron vertical anode bed is selected. 3" x 60" rod available.10 numbers anode of 8" dia x 10' bore hole with spacing 10' provides resistance,

R = 1.27 ohm.

Chart gives; R = 1.05 ohm

So, R_{min} = 1.05 x 1.05 = 1.1 ohm, which is close to minimum circuit resistance.

10 numbers 8 "x 10′ bore hole with spacing 10′ properly tampered coke breezes and one 3″ x 60″ high silicon iron rod in each borehole is required. Each anode's weight is as before 45 Kg.

Coke breege requirement;.

(Calculation as before)

690 Kg. hard cokes required for 20 years design period.

5.2.3 Calculation for design TR-III part (MirkadimPart)

Table-5.3: Pipe line data and current requirement calculation

Nominal pipe diameter, inch	$\frac{3}{4}$″	1″	2″	3″	6″
Pipe length up to September 2005, ft.	50860	18827	29481	17126	10750
Projected length up to 2025, ft.	76290	28240	44221	25689	16125
Outside diameter D, inch	0.75	1.05	2.375	3.5	6.625
Surface area, ft ^{2}	14985.55	7766	27506.54	23548.27	27978.82
Current requirement using attenuation curve , A	0.90+ .90+0.90	1.26	2.85+2.85	4.2	7.95
		Total Current, A	21.81 A		

Total current required: 21.81 Amp.

So, a TR unit of 25 Amp x 20 Volt is required.

Anode bed design:

Minimum circuit resistance required,

$$R_{min} = \frac{20-1.7}{25} = 0.732 \text{ ohm.}$$

Considering 3" x 60" high silicon iron 15'- 0" spacing and well tampered coke breeze, chart shows,

$$\text{Resistance, } R = 0.36 \times \left(\frac{\rho}{1000}\right)$$

$$= 0.36 \times \left(\frac{2455}{1000}\right)$$

$$= 0.88 \text{ ohm}$$

$$\text{So,} \quad R_{min} = 0.88 \times 1.05$$

$= 0.92$ ohm, which is close to minimum circuit resistance 0.732 ohm. So, the design can be used.

Hard coke requirement:

690 Kg as before.

5.3 Composite System Design

Design of this part consists of:

(i) TR-I impressed current system

(ii) Sacrificial anode system for Munshiganj part, and

(iii) Sacrificial anode system for Mirkadim part.

Design output of TR-I has already found. Design of other parts is given below:

5.3.1 Sacrificial anode system design for Munshiganj part

Mg anode would be used rather than Zn anode. Because resistivity of the area is 2455 ohm-cm. Zn anode works better when resistivity up to 1500 ohm -cm.

TGTDCL used method (Thumb rule): Calculation of Mg anode requirement using thumb rule and Table-3.7 is used. This table is generated for resistivity 6000-7000 ohm-cm. But popularly used for other values. Here another assumption is used that for new city area number of anode is increased by multiplying factor 1 5 and for old city multiplying factor 2.0.

Table-5.4: Anode number and spacing calculation for Munshiganj part by using rule of thumb.

Diameter, inch	Design Length, ft	Theoretical Anode Number, (17 lb)	Actual Anodes number.	Actual length	Actual spacing, ft.
$\frac{3}{4}''$	74400	30	60	49600	840
1'	31582	16	32	21055	680
2"	37812	34	68	25208	376
3"	29723	40	80	19815	250
6"	14250	36	72	9500	132
Total Number of 17 lb packaged anodes needed			312		

Note: (i) Theoretical anode uumber $= \frac{Design\,Length}{Length\,to\,be\,protected}$

(ii) Actual number of anodes, n = Therොretical number x M.F

(iii) Actual spacing $= \frac{Actual\,Length}{n-1}$

Based on Mg anode's current out put (used by TGTDCL):

Speciafication of the Mg anode as used by TGTDCL and other design considerations are given below:

(a) Back fill : Packaged anode surrounded by standard back fill 75% gypsum, 20% bentonite and 5% sodium sulphate.

(b) Current out put capacity : 1230 A/hr./Kg.

(c) Voltage out put : 1 55 V with respect to Cu/$CuSO_4$ reference electrode.

(d) Lead cable : 5m insulated lead wire with metal insert of alloy.

(e) Composition of Mg:

(i) Al :5.3%

(ii) Zn :3.0%

(iii) Cu :0.087%

(iv) Si :0.37%

(v) Mn :0.25%

(vi) Fe : 0.005%

(vi) Ni :0.003%

(viii) P :0.03%

(ix) Mg :99.155%

(f) Net weight : 5Kg, 17 lb, 32 lb etc.

(g) Efficiency of Mg anode : 55%

(h) Utilization factor : 0.85

(i) Design life : 20 years

(j) Resistivity of soil . 2455 ohm-cm.

(k) Coating defects or percent of bare pipe measured by holiday defector can be assumed at present : 2%

(l) Coating defects or percent of bare pipe measured by holiday defector can be assumed after 20 years : 6%

(m) Weight of anode : 17 lb (7.7 Kg.)

(n) Current density for bare portion of pipe : 2.0 mA/ft^2 (22 mA/m^2)

So, average % bare part of pipe line in 20 years : $(\frac{2+6}{2}) = 4\%$

From considerations current requirement and number of anodes can be calculated by the following equations:

(i) Current requirement = Design pipe area × % bare pipe × current density

(ii) Number of

$$\text{anodes} = \frac{\textit{Current requirement} \times 20 \times 365 \times 24}{\textit{Anode's current output} \times \textit{Efficiency} \times \textit{Utilization factor} \times \textit{Weight of anode}}$$

Table-5.5: Calculation of anode number and spacing for Munshiganj part by Mg anode's current output

Nominal Pipe diameter, inch	Outside diameter, inch	Design Length, ft.	Surface area , ft^2	Surface area ,m^2	Current requirement, A	Anode number	Anode spacing
$\frac{3}{4}$″	0 75	74400	14614.29	1383.92	1.22	49	1034
1″	1.05	31582	8685.06	822.44	0.73	29	752
2″	2.375	37812	23519.98	2227.27	1 96	78	328
3″	3.5	297723	27246.11	2580.12	2.27	90	223
6″	6.625	14250	24725.46	2363.81	2.08	83	116
Total Number of 17 lb packaged anodes needed					329		

5.3.2 Sacrificial anode design for Mirkadim part:

Design considerations are as before.

Table-5.6: Calculation of anode number and spacing for Mirkadim part by rules of thumb.

Pipe diameter, inch	Design Length, ft	Theoretical anode number	Actual number	Actual length	Actual spacing ,ft.
$\frac{3}{4}$″	76290	30	60	50860	862
1″	28240	14	28	18827	697
2″	44221	40	80	29481	373
3″	25689	34	68	17126	256
6″	16125	40	80	10750	136
Total number of 17 lb packaged anodes needed			316		

Based on Mg anode's current output (used by TGTDCL):

Table-5.7: Anode number and spacing calculation by Mg anode's current output for Mirkadim part

Pipe diameter, inch	Outside diameter, inch	Design length, ft.	Surface area, m^2	Current requirement, A	Anode number	Actual spacing ft.
$\frac{3}{4}''$	0.75	76290	1419.08	1.25	50	1038
1″	1.05	28240	735.41	0.65	26	753
2″	2.375	44221	2604.79	2.29	91	328
3″	3.5	25689	2229.95	1.96	78	225
6″	6.625	16125	2649.51	2.33	93	117
Total Number of 17 lb packaged anodes needed				338		

5.4 Cost Estimation for Proposed 3-TR Unit System Design

A. Foreign material cost:

Table-5.8: Material cost of foreign item (FC) for 3-TR unit system design

Item	Description	Quantity	Unit	Unit price, Tk.	Price ,Tk.
TR unit-I	50 Ampx50 Volt	1	No.	3,00,000	3,00000.00
TR unit-II	20 Ampx24 Volt	1	No.	2,50,000	2,50,000.00
TR unit-III	25 Ampx20 Volt	1	No.	2,50,000	2,50,000.00
High silicon iron anode	3″x60″x45Kg.	30	No.	11000	3,30,000.00
Insulating Joint	6″ IJ	2	No.	12083	24166.00

Total cost (Tk.): 1154166.00

One 30 Amp x 20 volt TR unit is present at Munshiganj CP station. Therefore cost would be reduced.

Reduced cost = (1154166-250000) = Tk. 9, 04,166.00

D. Local Material Cost:

Table-5.9: Cost of local material (LC) for 3-TR unit system design.

Item	Description	Quantity	Unit	Unit price, Tk.	Price, Tk.
Hard coke	$^3/_8$" diameter and resistivity 50 ohm-cm at site	2	Ton	50,000.00	1,00,000.00
PVC cable	16 RM PVC cable	300	m	50.00	15000 00
Anode Junction box	With 30 A and 10 A shunt	3	5000.00	15000.00	15000.00
Gravel	Gravel for filling covering depth.	3	Cu.m	1500.00	4500
PVC pipe	10' diameter, 4 mm perforated conduit	110	m	200.00	22000.00
MS pipe	110	m	135.00	14850	14850
G.I. test points	With concrete base	97	No	3015.00	292455.00
Cad weld charge	To fix cable with pipe	97	No.	90.00	8730.00
PVC cable	For each test points 5m	485	m	36.75	17823.75

Total, Tk. 4,90,358.75

Note. 1. FC: Foreign Currency, LC· Local Currency

2. Number of test points, considering one TP per 3000 feet length

$$= \frac{Total.Length.of.pipeline}{3000}$$

$$= \frac{289172}{3000} = 97$$

C. Construction cost:

Table- 5.10: Construction cost for 3-TR unit system design.

Item	Description	Quantity	Unit	Unit price, Tk.	Price ,Tk.
IJ Instrallation	Includes cutting Welding and fixing	2	Nos.	10,000.00	20,000
Installation and commissioning of TR units	Includes cable Joints and connection to both anode bed and pipe	3	Nos.	20,000	60,000
Borehole construction	includes installation of anodes in borehole	110	m	1500.00	165000.00
Construction of CP Room	10'x10' size 2 room with 3' wide verandah	2	Nos.	2,50,000	500000.00

Total : Tk 7,45,000.00

D.Land cost:

Cost of land for two CP station and 3 ground bed. One CP station exists and existing ground bed relocation is needed.

For two CP stations = 2 Katha
For three ground bed ·4 Katha x 3 = 12 Katha.

………………………… .. …………………………
Total land required = 14 Khata

Cost per katha land = 200000.00 (local cost)

Total land cost (Tk.) = 14x200000.00

= 28, 00000.00

E. Total cost: = A + B + C + D

= 9, 04,166.00 + 490358.75+ 7, 45,000:00+28, 00000.00

= Tk. 4939524.75

+ 10% contingency = 493952 48

Total cost: Tk. 54, 33,477.23

5.5 Cost Estimation for Proposed Composite System Design

A.Foreign material cost (FC):

Table-5 11 · Cost of Foreign material (FC) for composite system design.

Item	Description	Quantity	Unit	Unit price, Tk.	Price, Tk.
TR unit	50 Amp x 50 volt	1	No.	3,00,000.00	3,00,000.00
High silication anode	3"x60"x45Kg.	10	Nos	. 11000.00	1,10.000.00
Mg. anode	17 lb packaged	667	Nos	4500.00	30,01,500 00
Insulating Joint (IJ)	6"	2	Nos	120	24,166.00

Total cost, Tk. 34,11,500.00

B. Local material cost for composite system design:

Table-5.12: Cost of local material composite system design.

Item	Description	Quantity	Unit	Unit price Tk.	Price Tk.
Hard coke	$\frac{3}{4}$"diameter and resitivity 50 ohm-cm at site	1	Ton	50,000	50,000.00
PVC cable	16 RM PVC Cable	100	m	5000	5000.00
Anode Junction box	With 30 A and 10A shunt	1	No.	5000	5000.00
Gravel	For filling covering depth	1	Cu.m	1500	1500.00
PVC pipe	10" dia, 4 mm thick perforated conduit	40	m	200	8000.00
M.S Pipe	1" dia to keep anode in strainght position	40	m	135.00	5400.00
G.I. test points	With concrete base	97	Nos	3015.00	2,92,455.00
Cad weld charge	To fix cable with pipe	97	Nos.	90.00	8730.00
PVC cable	For each test point 5m	458	m	36.75	17823.75

Total, Tk 3, 25,908.75

C. Construction cost:

Table-5.13· construction cost for composite system design.

Item	Description	Quantity	Unit	Unit price, Tk.	Price ,Tk.
IJ installation	Includes cutting, welding and fixing	2	Nos.	10,000	20,000.00
Installation and commissioning of TR unit	Includes cable joints and connection to both anode bed and Pipe	1	Nos.	20,000.00	200000.00
Borehole construction	Including installation of anodes in borehole	40	m	1500.00	60000.00
Installation of Mg anode	Includes excavation of earth, cable connection and fixing of T.P	667	Nos.	300 00	200100.00

Total:Tk 3,00,100.00

D. Cost of land:

No. CP room is required land requires for rehabilitation of present ground bed.

Amount of land needed = 4 Katha.

Cost of land = 4x200000

= Tk. 800000.00

E. Total cost:

A+B+C+D

= 34, 11,500.00+3, 25,908.75 + 3, 00,100.00+8, 00000.00

= 48, 37,508.75

Contigency .10% = Tk. 483750.87

....

Toal cost : Tk. 53, 21,259.62

Conclusion: To meet up the deficiency of existing system two new design systems were proposed. Both of these systems were proposed for protecting the under ground pipelines with better effectiveness. A cost analysis of both installation systems has been made. Analysis does not show any marked difference in installation cost for both systems. Therefore technology, local conditions and operational costs are the major guiding factors of decision making and choice. Proposed Design-I consists of 3 TR units. So operational cost of Design- I would be more than that of design-II which consists of one TR unit and galvanic anodes. It can be simply inferred that operational cost of Design-II would be one-third than that of Design-I as galvanic anodes do not require any maintenance.

In the previous articles it has been discussed about the suitability of sacrificial anode based system for local condition .And technologically for gas distribution network comprises of $\frac{3}{4}$" to 3" diameter pipelines sacrificial anode method is the best. So Design- II is recommended as future cathodic protection of the said area But the question is whether this method should adopt for next 20 years of planning or not. The investment cost of the proposed system is Tk. 53, 21, 259.62, so a further cost-benefit analysis is needed.

CHAPTER VI

COST-BENEFIT ANALYSIS

An improved cathodic protection system has been deigned for the study area. A amount of Tk. 53.21 lac is required for the implementation of the project. The project cost of Tk.53.21 lac includes Tk.34.11 lac foreign currency (FC) and Tk.19.10 lac local currency (LC). An economic investigation should make to justify the proposed investment. The factors which affect project evaluation are (i) investment costs (ii) operating cost and (iii) annual value output. Final output of such analysis are net present value (NPV), benefit cost ratio (BCR) and internal rate of return (IRR).

6.1 Calculation of Cost and Output Values

The system is running at natural pace with a certain trend of operating cost and annual value output. Break up of investment costs are given in chapter V.

6.1.1 Annual value output

It is the total revenue earned per year. It includes customer forecasting for next 20 years, gas consumption of each type of customer, well head price of gas, excise, BAPEX charge and end users price for each year.

Present customer numbers and consumption of the study area are given in Table-6.1.

Table- 6.1: Customer numbers and gas consumption of Munshiganj.

Customer type	Number	Monthly consumption (SCM)	Yearly consumption (MMSCM)
Captive power	04	49,919	0.59
Industry	15	3,38,212	4.05
Commercial	23	32,638	0.39
Domestic (Metered)	08	8,769	0.105
Domestic (Double burner)	3415	2,97,603	3.57
Domestic (Single burner)	1578	1,20,326	1.44
Total =	5043	8,47,467	10.145

Note: Consumption of domestic customers is estimated from revenue earned.

On the basis of present price distribution given in Table-6.2, annual value output has been calculated and presented in Table-6.3

6.1.2 Operating cost calculation

Operating cost has been calculated in two ways:

(i) Considering the proposed investment would be able to stop further deterioration of the CP system, the future operating cost would follow the present trend for improved CP system.

(ii) Considering no further investment for improving present insufficient CP system, the future operating cost would increase progressively for leakage repairing and pipeline rehabilitation. The value of unaccounted for gas (UFG) is included here.

6.1.3 Break up of operating cost

When proposed investment is made for improvement of CP system operating cost are given in Table-6.4. Break up of different heads are given below:

(a) **Payment of long time loan:** TGTDCL has made payment of Tk. 4,690.97 lac during the year 2002-2003, Tk.5,748.24 lac during year the 2003- 2004 and 6,805.51 lac during year 2004-2005 to various money lending agencies. Total gas sales of the company during year 2004-2005 is 9152 MMSCM and gas sales of the study area during year 2004-2005 is 10.145 MMSCM. Therefore contribution of the study area with respect to the long term loan payment is Tk. $\frac{6805.5}{9152.4} \times 10.145$=Tk. 7.54 lac in one year.

(b) **Taxes and duties:** It is considered as 50% of the foreign material procured. So the amount is 34.11 ÷ 2 =11.05 Lac taka.

(c) **Man power:** The man power of the study area and their yearly salary is given in Table-6.4.

Table-6.2: Government of Bangladesh and Private Body's Price Distribution Table (Effect from July'2005)

Sl. No.	Customer Type	Well head (Tk.)	Excise (Tk.)	BAPEX (Tk.)	End User's Price(Tk.)
1	Power	0.22	1.281	0.76	3.73
2	Industry	0.22	2.788	0.76	5.23
3	Commercial	0.22	3.988	0.76	8.23
4	Domestic	0.22	2.222	0.76	4.59

Table-6.3: Annual Value Output (Financial)

	Customer Number						Consumption(MMSCM)				Annual Value(Taka in Lac)		
Year	Power	Industry	Commercial	Domestic	power	Ind	Comm	Dom.	Total	well head	excise	BAPEX	End User's price
1	4	15	23	5001	0.59	4.05	0.39	5.115	10.15	22.32	246 43	0.77	259.43
2	5	17	26	5600	0.65	4.59	0.44	6.50	12 18	26.80	353.50	0.93	374.95
3	6	19	30	5900	0.7	5.13	0.51	8.25	14.59	32.10	504.68	1.11	539.67
4	7	22	35	6250	24.46	5.94	0.59	9 75	40.74	89.63	2850.64	3.10	3416 69
5	7	25	39	6800	24.46	6.75	0.66	10.61	42.48	93.45	3155.35	3.23	3750.95
6	7	28	45	7400	24.46	7.56	0 76	11.54	44 32	97.51	3497.13	3.37	4125.71
7	7	30	49	8200	24.46	8.1	0.83	12 79	46.18	101.60	3847 68	3.51	4520.68
8	7	33	55	9000	24.46	8.91	0.93	14.04	48 34	106.35	4283.48	3 67	5002.26
9	7	36	60	9750	24.46	9.72	1.02	15.21	50.40	110 89	4721.20	3.83	5484 13
10	7	40	66	10450	24.46	10.8	1.12	16.30	52.68	115.89	5233.58	4.00	6038.61
11	7	42	72	11200	24.46	11.34	1.22	17.47	54.49	119.88	5652.66	4.14	6504.39
12	8	45	78	12200	48.92	12 15	1.32	19.03	81.42	179.13	11413.96	6.19	13651.32
13	8	47	85	13225	48.92	12.69	1.44	20.63	83.68	184.09	12180.68	6.36	14525.32
14	8	48	92	14200	48 92	12.96	1.56	22.15	85.59	188.29	12842.06	6 50	15290.66
15	8	52	99	15300	48.92	14.04	1.68	23.86	88.50	194 70	13907.59	6.73	16477.21
16	8	56	108	16400	48.92	15.12	1.83	25.58	91.45	201.19	15032.08	6.95	17725.91
17	8	60	116	17500	48.92	16.2	1.97	27.29	94.38	207.64	16190.10	7.17	19010.27
18	8	65	125	18700	48.92	17.55	2.12	29.17	97.76	215.06	17580.24	7.43	20541.16
19	8	69	135	19900	48.92	18.63	2 29	31.04	100.88	221.93	18911.55	7.67	22016.51
20	8	74	146	21300	48.92	19.98	2.48	33.22	104.60	230.11	20561 37	7.95	23837.89

Table-6.4: present salary of the Man power (As per pay commission'2005)

Employee	Officer				Staff			
	Manager	Deputy Manager	Assistant Engineer	Assistant Manager (Revenue)	Technician	T.C.C	Peon	Guard
Number	01	01	02	02	2	1	2	1x3 (Shift duty)
Monthly Salary (Tk)	20,000	15,000	10,000	1000	12,000	6000	5000	12000
Yearly Salary (Tk)	9,00,000				4,20,000			

Other operating costs are given in Table-6.5 on the basis of actual use in the past.Table-6.6 and Table-6.7 show the calculation of leak repairing cost and pipeline replacement cost along with cost of UFG. These operating costs are included when proposed improved CP system is not undertaken Table- 6.8 shows the increased operating cost.

6.1.4 Cost of leak repairing

Improved CP design and implementation can protect the pipe lines from further deterioration. If it is not done operating cost would increase for increase of repairing and maintenance Leakages of pipe lines are repaired by installing leak repairing clamp on the damaged portion of pipeline. Leak repairing clamps are of two types; (i) Full circle leak repairing clamp and (ii) Half circle leak repairing clamp. Cost of different size of leak clamps are given in Table-6.9and Table-6.10.

Fitting and Fixing Cost of leak clamp: These costs vary according of size of the leak and site condition. Average cost is around Tk. 5000 per leak repair.

Table-5: Operating Cost Considering Investment for Improved CP System

Item Of Works	Year-1	Year-2	Year-3	Year-4	Year-5	Year-6	Year-7	Year-8	Year-9
Cost Of Gas	223.30	267.96	320.98	896.28	934.56	975.04	1015.96	1063.48	1108.8
Duties And Taxes(50% of FC)	17.06	20.00	23.00	27.00	31.00	35	40	45	51
Payment of long term loan	7.54	9.00	11.00	14.00	18.00	22	27	32	37
Manpower:Officer	9.00	10.00	10.00	10.00	12.00	12	13	13	13
Staff:	4.20	5.00	5.00	5.00	6.00	6	6.25	6.25	6.25
Fuel & Ellectricity	3.50	3.50	3.50	3.50	3.50	3.5	3.5	3.5	3.5
Maintenance	3.50	3.50	3.50	3.40	3.50	3.5	3.4	3.5	3.6
Miscellaneous	0.50	0.50	0.50	0.60	0.50	0.4	0.3	0.6	0.7
Total,Tk(in lac)	261.06	310.46	366.48	945.78	991.06	1035.44	1082.41	1135.33	1186.85

Table-6-5 (Continued) Operating Cost Considering Investment for Improved CP System

Item Of Works	Year-10	Year-11	Year-12	Year-13	Year-14	Year-15	Year-16	Year-17	Year-18	Year-19	Year-20
Cost Of Gas	1158.96	1200 96	1791.24	1840.96	1882.98	1947	2011.9	2076.36	2150.72	2219.36	2301.2
Duties And Taxes(50% of FC)	56	62	70	78	85	92	103	125	140	160	180
Payment of long term loan	43	50	58	67	77	87	98	110	122	135	150
Manpower:Officer	16	16	16	20	20	21	21	22	22	25	25
Staff:	7.5	7.5	7.5	9.5	9.5	10	10	11	11	12	12
Fuel & Ellectricity	3 8	3.8	3 8	3.8	3.9	3 9	3.9	3.9	4	4	4
Maintenance	3.7	3.7	3.7	3.9	3.9	3.9	3.6	4	3.8	3.8	4
Miscellaneous	0 7	0.8	0.8	0.8	0.9	0.9	0.8	0 9	0 8	0.9	1
Total,Tk(in lac)	1246 66	1294.78	1893.04	1956.96	2006.18	2078.7	2154.2	2243 16	2332.32	2425.06	2527.2

Table-6.6: Leak Repairing Cost

Year	Number Of Leakage							Cost in Lac. Tk.		
	3/4"	1"	2"	3"	6"	8"	12"	Repairing Clamp Cost	Fitting & Fixing Cost	Total Repairing Cost
1	120	15	12	10	0	0	1	1.84	7.90	9.74
2	133	17	15	12	1	0	0	2.04	8.90	10.94
3	151	22	18	15	0	1	0	2.42	10.35	12.77
4	165	26	22	18	0	0	1	2.75	11.60	14.35
5	180	30	27	22	1	0	0	3.07	13.00	16.07
6	196	35	32	26	0	1	1	3.53	14.55	18.08
7	210	41	37	33	1	0	0	3.88	16.10	19.98
8	228	48	46	38	1	1	1	4.49	18.15	22.64
9	240	57	48	43	2	1	0	4.82	19.55	24.37
10	253	69	56	51	2	2	0	5.43	21.65	27.08
11	270	80	69	66	3	2	1	6.31	24.55	30.86
12	286	92	85	75	4	3	2	7.18	27.35	34.53
13	301	104	98	88	4	3	2	7.94	30.00	37.94
14	318	119	113	99	5	4	2	8.82	33.00	41.82
15	339	132	124	107	5	5	2	9.57	35.70	45.27
16	358	147	135	117	6	5	3	10.40	38.55	48.95
17	379	163	149	129	8	6	3	11.36	41.85	53.21
18	402	180	167	145	10	6	3	12.44	45.65	58.09
19	427	199	188	162	12	7	4	13.74	49.95	63.69
20	453	222	205	180	14	7	4	14.96	54.25	69.21

Table-6.7: Operating Cost for Pipe Replacement and Gas Leakage

Year	Loss for Pipe Replacement		Loss for Gas Leakage	
	% Rehabilitation	Cost,Tk in Lac	Total Cons. MMCM	Cost of UFG,in Lac Tk.
1	1.0	8.85	10.15	36.58
2	1.5	13.28	12.18	50.02
3	2.0	17.70	14.59	63.57
4	2 5	22.13	40.74	187.74
5	3.0	26.55	42.48	206.43
6	3.5	30.98	44.32	226.49
7	4.0	35.40	46.18	247.59
8	4.5	39.83	48 34	271.30
9	5.0	44.25	50.40	295.51
10	5.5	48.68	52.68	322.10
11	6 0	53.10	54.49	346.85
12	6.5	57.53	81.42	538 70
13	7.0	61.95	83.68	574.66
14	7.5	66.38	85.59	609.26
15	8.0	70.80	88 50	652.19
16	8.5	75.23	91.45	696.88
17	9.0	79.65	94.38	742.90
18	9.5	84.08	97.76	794.04
19	10.0	88.50	100.88	844.70
20	10 5	92.93	104.60	902.11

Table-6.8: Increased Operating Cost When Investment for CP Improvement is not made.

Year	Operating Cost(Lac Tk.)	Leak Repairing Cost(Lac Tk.)	Pipeline Rehabilitation Cost(Lac Tk.)	Cost of Unaccounted Gas(Lac Tk.)	Total Operating Cost(Lac Tk.)	Increased Operating Cost(Lac Tk.)
1	261.06	9.74	8.85	36.58	316.23	55.17
2	310.46	10.94	13.77	50.02	385.19	74.73
3	366.48	12.77	17.70	63.57	460.52	94.04
4	945.78	14.35	22.13	187.74	1170.00	224.22
5	991.06	16.07	26.55	206.43	1240.11	249.05
6	1035.44	18.08	30.98	226.49	1310.99	275.55
7	1082.41	19.98	35.40	247.59	1385.38	302.97
8	1135.33	22.98	39.83	271.30	1469.44	334.11
9	1186.85	24.37	44.25	295.51	1550.98	364.13
10	1246.66	27.08	48.68	322.10	1644.52	397.86
11	1294.78	30.86	53.10	346.46	1725.20	430.42
12	1893.04	34.53	57.53	538.70	2523.80	630.76
13	1956.96	37.94	61.95	574.66	2631.51	674.55
14	2006.18	41.82	66.38	609.26	2723.64	717.46
15	2078.7	45.27	70.80	652.19	2846.96	768.26
16	2154.2	48.95	75.23	696.88	2975.26	821.06
17	2243.16	53.21	79.65	742.90	3118.92	875.76
18	2332.32	58.09	84.08	794.04	3268.53	936.21
19	2425.06	63.59	88.50	844.70	3421.85	996.79
20	2527.2	69.21	92.93	902.11	3591.45	1064.25

Table- 6.9: Cost of full circle leak clamp. (Rate from Titas as on 2002).

Size	$\frac{3}{4}$" x6"	$\frac{3}{4}$" x9"	$\frac{3}{4}$" x12"	1' x6"	1"x9"	1"x12"
Working Pressure, psig	100	100	100	100	100	100
Cost, Tk.	660	800	1000	1200	1800	1400

Table -6.9: (Continued) Cost of full circle leak repairing clamp.

Size	2"x9"	2"x2"	2"x15"	3"x12"	4"x12"	6"x12"	8"x12"
Working pressure, psig	100	100	100	10010	100	100	100
Cost, Tk.	1500	1500	1600	1800	1800	2000	2000

Table -6.9: (Continued) Cost of full circule leak reparining clamp.

Size	10" x12"	12"x12"	4" x12"	6" x12"	8"x12"	12"x12"
Working Pressure,psig	100	100	150	150	300	300
Cost, Tk.	2500	2700	2500	3000	5000	-

Table- 6.10: Cost of half circle leak repairing clamp

Size	$\frac{3}{4}$x6"	$\frac{3}{4}$x9"	$\frac{3}{4}$x12"	1"x9"	1"x12"	2"x12"	2"x15"	3"x12"	4"x12"
Working pressue, psig	100	100	100	100	100	100	100	100	100 .
Cost, Tk.	600	600	60	600	600	600	700	1000	1400

Table-6.10: (Continued) Cost of half circle leak repairing clamp.

Size	6"x12"	8"x12"	10"x12"	12"x12"	12"x12"
Working Pressure, Psig	100	100	100	100	150
Cost, Tk.	2000	2000	2000	2400	3500

Table- 6.11: Cost of total pipe line up to 2005.

Pipe cost				Laying cost		
Diameter	Length (m)	Rate/m (Tk)	Cost (Lac Tk.)	Rate/m (Tk)	Cost (Lac Tk)	Total cost. (Lac Tk)
$\frac{3}{4}''$	45973	95	43.67	135	62.06	105.73
1″	18239	135	24.62	250	45.60	70.22
2″	25010	270	67.52	250	62.52	130.04
3″	16903	405	68.45	250	42.25	110.7
6″	10061	1100	110.67	250	25.12	135.79
8″	15000	1550	232.5	250	37.50	270.00
12″	1372	810	11.11	1200	16.92	27.53
						Total = Tk. 850.01 Lac.

6.1.5 Pipe line replacement cost

This cost has been calculated assuming presently 1% pipe line replacement requires and the amount of pipe line replacement increases at the rate of 0 5% per year for the existing CP system. Total cost of pipeline up to the year 2025 is required for calculating increased operating cost for pipe replacement when CP is kept as it is at present. Table- 6.11 gives pipe line cost of the study area.

6.1.6 Cost of unaccounted for gas (UFG)

The study area purchased 0.5765 MMSCM gas and sold 0.53 MMSCM during August' 2005. That is system loss or UFG is 7.18%. Considering increment of 5% UFG of the present rate per year cost has been calculated. The rate of one cubic meter of gas has taken as weighted average selling price of one cubic meter gas.

6.2 Finacial Analyiss

The objective of project evaluation is to observe the influence of investment for implementing the proposed improved calthodic protection system. Another aim is to differentiate between return earned when investment for improved system is made and when it is not made. Computing the desired net present value (NPV), benefit cost ratio (BCR) and internal rate of return (IRR) is important for this assessment.

Net present value (NPV): It is the difference between the present value of cash inflows and the present value of the cash outflows generated by the investment, and discounted at the assumed hurdle rate (Minimum acceptable rate of return).

Benefit cost ratio (BCR) : It is the ratio of total benefit to total cost at a particular discount rate.

Internal rate of return (IRR): IRR of a cash flow is the discount rate at which the present value of the cash flow is zero. The concept IRR determines a discount factor which becomes the 'yard stick'. IRR measures the effective rate of return earned by an investment as though the money had been loaned at that rate.

6.2.1 BCR, NPV and IRR when investment is not made

For calculation of BCR and NPV when investment is not made for CP improvement data have been tabulated in Table- 6.12. Discount factor has been calculated at an allowable discount rate of 15%. From Table - 6.12 discounted total cost is Tk.9092.61 lac and discounted total benefit is Tk. 36423.30 lac.

$$\text{Benefit cost Ratio (BCR)} = \frac{TotalBenefit}{TotalCost} = \frac{36423.30}{9092.61} = 4.005$$

And net present value (NPV)= Total benefit- Total cost

$$= 36423.30-9092.61$$

$$= \text{Tk. } 27330.69 \text{ Lac.}$$

Data is tabutated in Table- 6.13 for calculating IRR.

$$\text{IRR:} \quad LDF + \frac{[NPVatLDF]-[HDF-LDF]}{[NPVatLDF - NPVatHDF]}$$

$$= 13 + \frac{33469.38[14-13]}{33469.38-30205.74}$$

$$=23.25$$

Where,

LDF = Lower discount factor

HDF = Higher discount factor.

6.2.2 BCR, NPV and IRR when investment is made for CP improvement

For calculation data are tabulated in Table- 6.14 .Cost and benefit are discounted at 15% as before total discounted cost is Tk.7008.99 Lac and total discount benefit is Tk.36423.30 Lac. Therefore,

$$\text{BCR} = \frac{Total\,Benefit}{Total\,Cost} = \frac{36423.30}{7008.99} = 5.19$$

$$\text{NPV} = 36423.3\text{-}7008.99 = \text{Tk. } 29414.31 \text{ Lac.}$$

IRR has been calculated from data Table- 6.15.

$$\text{IRR: LDF} + \frac{[NPV\,at\,LDF]-[HDF-LDF]}{[NPV\,at\,LDF-NPV\,at\,HDF\}} = 13+\frac{35945.27[14-13\}}{35945.27-32473.91} = 23.35$$

6.3 Comparison

Financial analysis shows that the proposed investment of Tk. 53.21 Lac for improvement of CP system brings more return than keeping the system unchanged. If improvement is not made operating cost would increase for deterioration of the system. BCR, NPV and IRR for improved system are higher than existing system. The net cash payment curve in Figure-6.1 shows the return of improved system is much higher which markedly supersedes the investment cost. On the other hand due to increased operational cost cash payout of existing system has dropped initially. But future sales planning has balanced it in the latter years. In the net cash payout curve two sudden jnmps are seen. These jumps indicate a large amount of return for a large volume of gas sales, which is a prediction assuming establishment of two separate power plants at Munshiganj within next 20 years. Though it is hard to sale as planned, but in reality socio-economic condition of a region is developed when such a kind of planning is materialized. On the other hand enforcing care on CP system would ensure smooth and trouble free supply to the customers. Therefore investment for improvement of the existing CP system of Munshiganj gas distribution network is justified.

Table-6.12:Financial analysis (NPV, BCR) when investment is not made for CP improvement.

Year	Investment Cost	Operating Cost	Total Cost	Total Benefit	Discount Factor @ 15%	Total Discounted Cost	Total Discouted Benefit
1	0	316.23	316.23	259.43	1	316.23	259.43
2	0	385.19	385.19	374.95	0.8696	334.96	326.06
3	0	460.52	460.52	539.67	0.7561	348.20	408.04
4	0	1170.00	1170.00	3416.692	0.6575	769.28	2246.47
5	0	1240.11	1240.11	3750.95	0.5718	709.09	2144.79
6	0	1310.99	1310.99	4125.71	0.4972	651.82	2051.30
7	0	1385.38	1385.38	4520.68	0.4323	598.90	1954.29
8	0	1469.44	1469.44	5002.26	0.3759	552.36	1880.35
9	0	1550.98	1550.98	5484.13	0.3269	507.02	1792.76
10	0	1644.52	1644.52	6038.61	0.2843	467.54	1716.78
11	0	1725.20	1725.20	6504.39	0.2472	426.47	1607.89
12	0	2523.80	2523.80	13651.32	0.2149	542.36	2933.67
13	0	2631.51	2631.51	14525.32	0.1869	491.83	2714.78
14	0	2723.64	2723.64	15290.66	0.1625	442.59	2484.73
15	0	2846.96	2846.96	16477.21	0.1413	402.28	2328.23
16	0	2975.26	2975.26	17725.91	0.1229	365.66	2178.51
17	0	3118.92	3118.92	19010.27	0.1069	333.41	2032.20
18	0	3268.53	3268.53	20541.16	0.0929	303.65	1908.27
19	0	3421.85	3421.85	22016.51	0.0808	276.49	1778.93
20	0	3591.45	3591.45	23837.89	0.0703	252.48	1675.80
					Total	9092.61	36423.30

Table-6.13: Financial Analysis (IRR) When Investment is not made for CP Improvement.

Year	Investment Cost	Operating Cost	Total Cost	Total Benefit	Net Benefit	NVP at Higher Discount Factor of 14%		NVP at Lower Discount Factor of 13%	
						Discount Factor	NVP	Discount Factor	NVP
1	0	316.23	316.23	259.43	-56.80	1	-56.80	1	-56.80
2	0	385 19	385.19	374 95	-10.24	0.8772	-8.98	0.885	-9 06
3	0	460.52	460.52	539.67	79.15	0 7695	60.91	0.7831	61.98
4	0	1170 00	1170 00	3416.692	2246.69	0 675	1516 52	0.6931	1557 18
5	0	1240.11	1240.11	3750.95	2510.84	0.5921	1486.67	0 6133	1539.90
6	0	1310.99	1310.99	4125.71	2814.72	0.5194	1461.97	0 5428	1527.83
7	0	1385.38	1385.38	4520.68	3135.30	0.4556	1428.44	0.4803	1505.88
8	0	1469.44	1469.44	5002.26	3532 82	0 3996	1411.71	0.4251	1501.80
9	0	1550.98	1550.98	5484 13	3933.15	0.3506	1378.96	0.3762	1479 65
10	0	1644 52	1644.52	6038.61	4394.09	0 3075	1351.18	0 3329	1462.79
11	0	1725.20	1725.20	6504.39	4779.19	0.2697	1288 95	0.2946	1407.95
12	0	2523 80	2523.80	13651.32	11127.52	0.2366	2632.77	0 2607	2900.94
13	0	2631.51	2631.51	14525.32	11893.81	0.2076	2469.15	0 2307	2743 90
14	0	2723.64	2723 64	15290.66	12567.02	0.1821	2288.45	0.2042	2566.19
15	0	2846.96	2846.96	16477.21	13630.25	0.1597	2176.75	0.1807	2462.99
16	0	2975.26	2975.26	17725.91	14750.65	0.1401	2066.57	0.1599	2358 63
17	0	3118.92	3118.92	19010.27	15891.35	0.1229	1953 05	0.1415	2248.63
18	0	3268 53	3268.53	20541.16	17272 63	0.1078	1861.99	0.1252	2162.53
19	0	3421.85	3421.85	22016 51	18594.66	0.0946	1759 05	0 1108	2060.29
20	0	3591.45	3591.45	23837.89	20246.44	0.0829	1678.43	0.0981	1986.18
Total Tk. In lac							30205. 74		33469.38

Table-6.14: Financial analysis (NPV,BCR) when investment is made for CP improvement.

Year	Investment Cost	Operating Cost	Total Cost	Total Benefit	Discount Factor @ 15%	Total Discounted Cost	Total Discounted Benefit
1	53.21	261 06	314.27	259.43	1	314.27	259 43
2	0	310 46	310.46	374.95	0.8696	269.98	326.06
3	0	366 48	366.48	539.67	0.7561	277.10	408.04
4	0	945.78	945.78	3416 692	0.6575	621.85	2246.47
5	0	991.06	991.06	3750 95	0.5718	566.69	2144.79
6	0	1035.44	1035.44	4125 71	0.4972	514.82	2051.30
7	0	1082.41	1082.41	4520.68	0.4323	467.93	1954.29
8	0	1135 33	1135.33	5002.26	0.3759	426.77	1880.35
9	0	1186.85	1186.85	5484 13	0 3269	387 98	1792.76
10	0	1246.66	1246.66	6038 61	0.2843	354.43	1716.78
11	0	1294.78	1294 78	6504 39	0.2472	320.07	1607.89
12	0	1893.04	1893.04	13651.32	0.2149	406.81	2933.67
13	0	1956.96	1956.96	14525.32	0.1869	365 76	2714.78
14	0	2006.18	2006.18	15290.66	0 1625	326 00	2484.73
15	0	2078.7	2078.7	16477.21	0 1413	293.72	2328.23
16	0	2154.2	2154.2	17725.91	0.1229	264.75	2178 51
17	0	2243.16	2243.16	19010.27	0.1069	239.79	2032.20
18	0	2332.32	2332.32	20541.16	0 0929	216 67	1908.27
19	0	2425.06	2425.06	22016.51	0 0808	195.94	1778.93
20	0	2527.2	2527.2	23837.89	0.0703	177.66	1675 80
Total, Tk in lac						7008.99	36423.30

Table-6.15:Financial analysis (IRR) when investment is made for CP improvement.

Year	Investment Cost	Operating Cost	Total Cost	Total Benefit	Net Benefit	NPV At Higher Discount Rate of 14%		NPV at Lower Discount Rate of 13%	
						Discount Factor	NPV	Discount Factor	NPV
1	53.21	261.06	314 27	259.43	-54.84	1	-54 84	1	-54 84
2	0	310 46	310 46	374.95	64 49	0.8772	56.57	0 885	57.07
3	0	366 48	366.48	539 67	173.19	0 7695	133 27	0.7831	135.63
4	0	945.78	945.78	3416.692	2470.912	0 675	1667 87	0.6931	1712.59
5	0	991.06	991.06	3750.95	2759 89	0.5921	1634.13	0.6133	1692 64
6	0	1035.44	1035.44	4125 71	3090.27	0 5194	1605 09	0.5428	1677.40
7	0	1082.41	1082 41	4520.68	3438.27	0.4556	1566.48	0.4803	1651.40
8	0	1135.33	1135.33	5002 26	3866.93	0 3996	1545.23	0 4251	1643 83
9	0	1186.85	1186.85	5484.13	4297.28	0.3506	1506.63	0.3762	1616.64
10	0	1246 66	1246 66	6038.61	4791.95	0.3075	1473.52	0 3329	1595 24
11	0	1294 78	1294.78	6504.39	5209 61	0.2697	1405.03	0 2946	1534.75
12	0	1893.04	1893.04	13651.32	11758.28	0.2366	2782 01	0.2607	3065.38
13	0	1956 96	1956.96	14525.32	12568 36	0.2076	2609.19	0 2307	2899.52
14	0	2006.18	2006.18	15290.66	13284.48	0 1821	2419 10	0.2042	2712.69
15	0	2078 7	2078 7	16477.21	14398 51	0.1597	2299.44	0.1807	2601 81
16	0	2154.2	2154.2	17725.91	15571 71	0 1401	2181.60	0.1599	2489 92
17	0	2243.16	2243.16	19010 27	16767.11	0.1229	2060.68	0.1415	2372.55
18	0	2332.32	2332.32	20541.16	18208.84	0.1078	1962.91	0 1252	2279 75
19	0	2425.06	2425.06	22016 51	19591.45	0 0946	1853.35	0.1108	2170.73
20	0	2527.2	2527.2	23837.89	21310.69	0.0829	1766.66	0 0981	2090 58
						Total	32473.91		35945 27

Net Present Value Curve

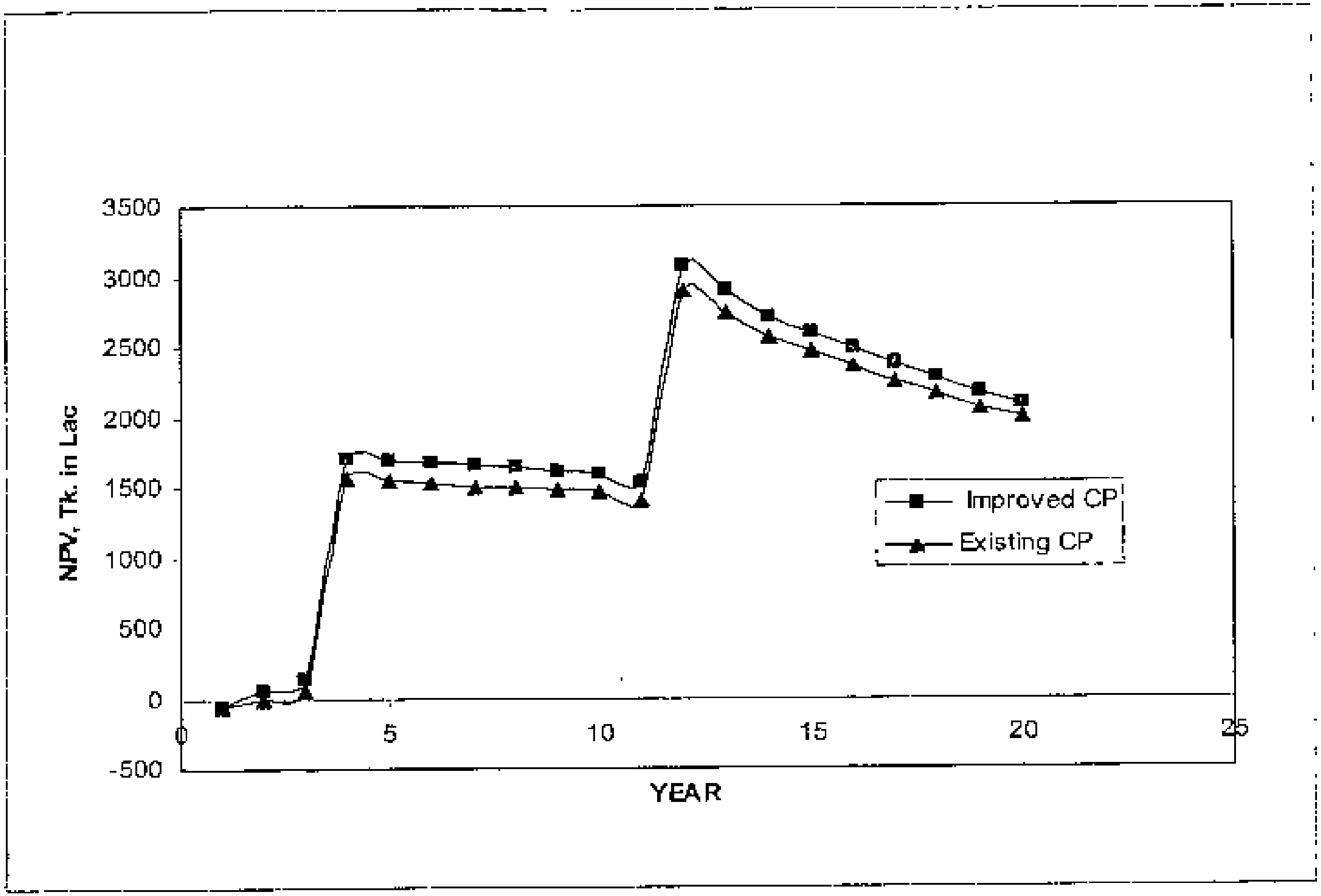


Figure-6.1: Comparison between net cash payout of existing CP and improved CP.

CHAPTER VII

CONCLUSIONS AND RECOMMENDATIONS

The study shows that the existing corrosion control system is insufficient and not working properly. The rectifier of the existing impressed current cathodic protection system is under sized and ground bed is almost consumed up. Therefore corrosion in some places have initiated, which is causing leakage and supply interruption. Disruption of supply due to corrosion not only causes inconvenience to the customers but also affects the image of the operating company. For the operating company operational safety and profitability are very important. Environmental considerations are also no less important. The gas emission increases loss to the operating company.

An improved corrosion control system has been designed for reducing supply interruption, money loss due to leakage caused by corrosion and accident. The improved system is a composite one, which includes both impressed current system and sacrificial anode system. The impressed current system of corrosion control has been adopted for the region where soil resistivity is high, pipes are of large diameters and areas are not flooded. The sacrificial anode method has been used for congested town region where soil resistivity is relatively low, pipes are of smaller diameters and areas are flooded very frequently.

Determination of current requirement is very important for optimum design of cathodic protection. There is a substantial difference between current requirement of bare pipe and coated pipe. Usage of coating has reduced current requirement to a minimum value and has made corrosion control cost effective. In this study current requirements have been determined in various ways. Comparing output of each method with others, current requirement was finalized.

For implementing the improved cathodic protection system an investment of Tk. 53.21 Lac is required. Financial analysis shows that BCR and IRR of the improved project are 5.19

and 23.35 and respectively. Whereas BCR and IRR of the existing system are 4.005 and 23.25 respectively. Net present value of the improved system and existing system are Tk. 35941.31 Lac and Tk.27330.69 Lac. So the investment is viable.

Recommendations: For designing a more effective corrosion control system the following factors are recommended:-

1 Before designing the system field survey for current requirement and potential survey must be conducted.
2. For corrosion control system design, coating defects must be determined.
3. Horizontal and vertical resistivity of the soil should be measured at certain interval.
4. Measurements of effective electrical resistance of coating on the pipeline should be done.
5. Bell hole examinations for evidence of corrosion activity should be done.
6. Use of recording instruments for study of stray current or any other unstable condition.
7. Acidity or alkalinity of the soil environment must be determined.
8. Determination of conditions suitable for anaerobic bacterial corrosion is required.
9. Considerations of logistical and technological adequacy and effectiveness of existing re-active maintenance system should be done.
10. Introduction of computerized maintenance system and execution of cost effective pro-active maintenance including safest and promptest customer service should be done.
11. Evaluation of socio-cultural awareness level and launching of an awareness program about gas safety and network damage should be conducted.
12. The leakage loss due to corrosion is required to quantify accurately.
13. The study can be performed for the whole gas distribution network of Bangladesh.
14. A more detail economic analysis should be conducted.

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