Cathodic Protection Engineering
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Lecture – 04
Cathodic protection engineering: Criteria

Hi today, we shall discuss an important topic of Cathodic Protection Engineering, that is Cathodic protection Criteria.

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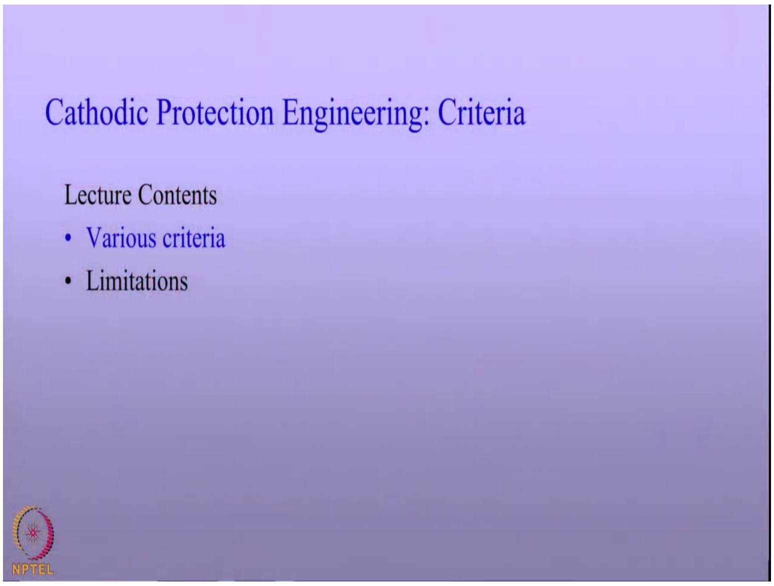

Cathodic Protection Engineering: Criteria

Lecture Contents

- Various criteria
- Limitations

In this lecture, we will discuss various types of criteria that are available for cathodic protection, what are the limitations of these criteria.

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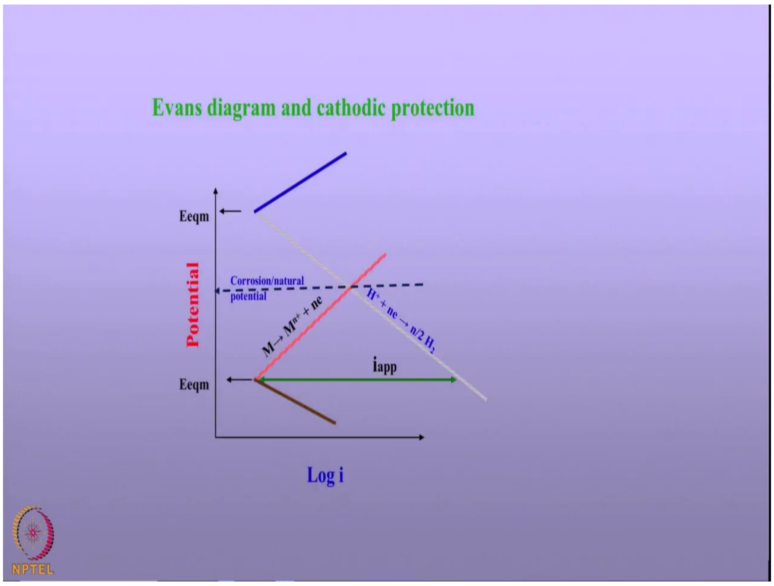
Evans diagram and cathodic protection

Let us start with the well known diagram, the Evans diagram and how it is related to cathodic protection. We have seen this in the last couple of lectures. Now, the cathodic protection criteria will be discussed in relation to this diagram. What is shown here is, when you have a structure buried in a electrolyte or maybe in the soil; it exhibits a potential which is called as the natural potentials or corrosion potentials.

And corresponding to these particular potentials, the metal dissolves given by this current, the corrosion current density. Now, in cathodic protection criteria, we bring down this potential from the natural potentials to as low as possible; ideally you should bring down to the equilibrium potential as shown in the diagram.

Below the equilibrium potential, the metal is completely immune to corrosion. Any potential that you hold the metal, there is a corresponding current, corrosion current. If you want to completely prevent the metal from corrosion, you need to bring down the potential to a value which is equivalent to equilibrium potentials.

But that also means, we need to supply a large amount of current in order to enforce the cathodic protection of the structures. In addition to that, you also see there is a significant increase in the cathodic reaction occurring on the metal surface; this is quite damaging, if it leads to hydrogen evolution on the metal surface.

So, on the one hand, you want to minimize the corrosion rate where bringing down these potentials as close as possible to equilibrium potentials; on the other hand, you need to supply large amount of current density and also there is a likelihood of the metal getting damaged, because of hydrogen evolution.

If the pipeline is coated, there will be damage to the coating. So, in this diagram one thing is very clear that, if you are going to bring down the potential from the open circuit potentials, the corrosion rate decreases. And as you bring down the metal is getting polarized in relation to the corrosion potentials.

The polarization concept here in cathodic protection engineering is used in reference to corrosion potential; it is used in reference to corrosion potentials, it is not used in reference to equilibrium potential as you normally do. So, as we polarize the metal towards more negative potentials; then the metal tends to become lower and lower in terms of corrosion rate.

So, from the engineering point of view, we are not looking at totally you know immunizing the metal from corrosion; you want to bring down a to a corrosion rate to an extent that you have a desired life for the structures. And so, there are different criteria which describes the adequacy of cathodic protection of the metals.

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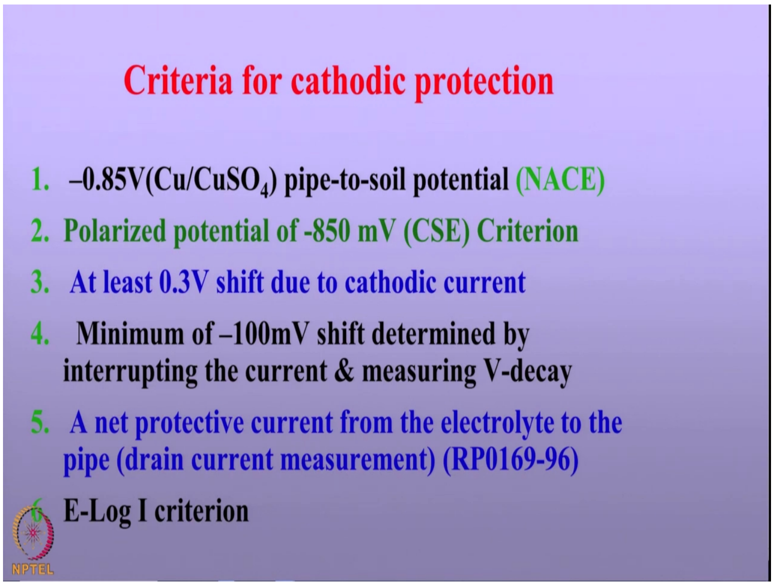

Criteria for cathodic protection

1. –0.85V($Cu/CuSO_4$) pipe-to-soil potential (NACE)
2. Polarized potential of -850 mV (CSE) Criterion
3. At least 0.3V shift due to cathodic current
4. Minimum of –100mV shift determined by interrupting the current & measuring V-decay
5. A net protective current from the electrolyte to the pipe (drain current measurement) (RP0169-96)
6. E-Log I criterion

We shall see one after another, what are the criteria for cathodic protection. The first and foremost criteria that have been widely used, the simple one is -0.85 volt with respect to copper saturated copper sulphate electrode, which is the pipe to soil potential for the metal.

If you can hold the metal at this particular potential, then it is adequately said to be protected from corrosion. There is yet another criteria which is based on the polarized potential of the metal, which is a true polarized potential of the metal, which is again is 0.85 volt with respect to copper saturated copper sulphate electrode is measured.

This is a another very simple criteria which is 0.3 volt shift from the corrosion potentials or the natural potential of the metal. So, this shift is made towards the negative direction. The fourth criteria is about shifting the potential to 100 millivolt and that 100 millivolt is determined by interrupting the current, the cathodic protection current and measuring the voltage decay.

There is another simple method criteria, a net protective current from the electrolyte to the pipe; this is also called as a drain current measurement, is another criteria for ensuring that the metal is protected adequately. As another last criteria I would say, is based on potential versus log I curve that you determine for a given structure. Now, we shall look at in detail, what are the merits and demerits of these six criteria.

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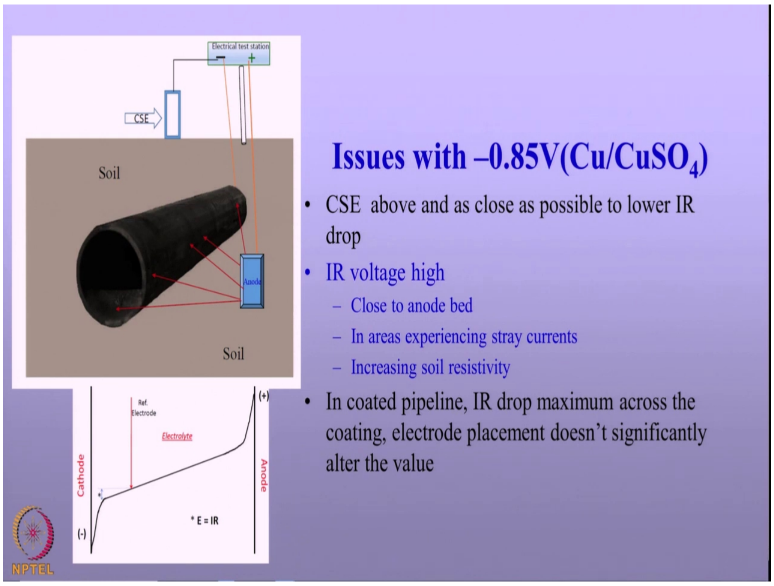

Issues with –0.85V(Cu/CuSO$_4$)

- CSE above and as close as possible to lower IR drop
- IR voltage high
  - Close to anode bed
  - In areas experiencing stray currents
  - Increasing soil resistivity
- In coated pipeline, IR drop maximum across the coating, electrode placement doesn't significantly alter the value

Now, let us look at various merits and demerits of each of these criteria. Let us start with the first criteria, which is -0.85 volt that is pipe to soil potential measured with respect to copper saturated copper sulphate electrode. This criteria is a simple method, is very versatile and you can measure the potential anytime; in fact it can be measured as online.

But however, the main problem arises by the fact that, the measured potential may not be actually corresponding to the polarized potential of the pipeline. Now, what I shown in this left side diagram is a cathodic protection system or a pipeline using sacrificial anode. The potential of the pipeline is measured using copper saturated copper sulphate electrode.

As you notice that, the electrode is normally not kept just over the pipeline; it is normally kept little away from the pipeline. In such a case, we are not measuring the true potential of the pipeline; instead we measure the potential of the soil at the location, where the reference electrode is kept.

What is shown below in this diagram is the potential variation between the sacrificial anode and the pipeline which is cathodically protected. You can see that the potential drop happens within the soil; and this potential drop happens within the soil, because of the resistance offered by the soil.

So, if you are going to keep the reference sector somewhere here; between these two points, there is a voltage drop. And this drop is related to the resistance of the soil and the extent of current that is passed in the cathodic protection of the pipeline. So, this requires to be discounted in order to measure the true potential of the pipeline, so that is not possible in this criteria.

It is possible to minimize this IR drop by keeping the reference electrode as close as possible to the pipeline. It is also you can see that as I stated before, when the soil resistivity is more; the issue becomes very high and you have stray currents again, it interferes with the measurements of the true potential of the pipelines.

If the pipeline is well coated you would notice that, because of the resistance offered by the coating; the IR drop lies very steeply between the coating on the metal surface, compared to that drop, the soil resistance is significantly less. So, the row of IR drop becomes less in a well coated pipelines.

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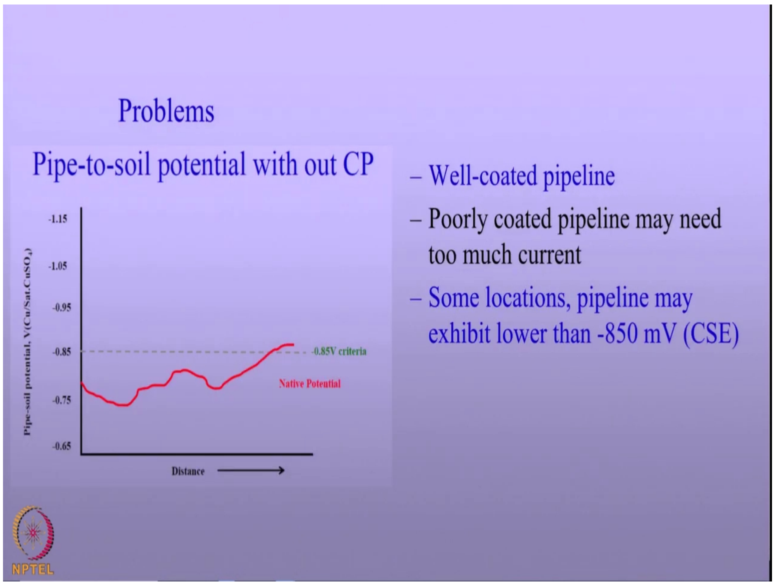

Problems

Pipe-to-soil potential with out CP

- Well-coated pipeline
- Poorly coated pipeline may need too much current
- Some locations, pipeline may exhibit lower than -850 mV (CSE)

So, in order to overcome this particular problem, we go to the next technique. Before you go to next technique, I would like to discuss with you the other important problem that one faces if one follows the 0.85 volt criteria. The plot shown on the left side is a schematic of the potential measured over a pipeline, over a some distance; you will notice that for a long distance, the native potential of the pipeline is well below the criteria which is 0.85 volt criteria.

However, at some locations, you do notice the natural potential or the native potential of the pipeline is above the 0.85 volt criteria. This gives one a feeling that, the pipeline over here is cathodically protected, even though no external current is applied over this location.

That means, simply measuring the pipeline potentials with the reference electrode, obtaining a value lower than 0.85 volt, does not guarantee that the pipeline is protected due to cathodic protection. The other problems associated with this criteria is, if the pipelines are poorly coated or the coatings deteriorated over a time period and you want to maintain a pipeline at a potential which is below 0.85 volt, which is the criteria; then the pipeline may need lot of current to cathodically protect.

So, in such cases, this criteria becomes very difficult to apply. We will see later what other criteria can be applied, if the coating is severely damaged in pipelines. Of course, in the well coated pipelines or the newly laid pipelines, where the coatings are very good, this criteria works very well.

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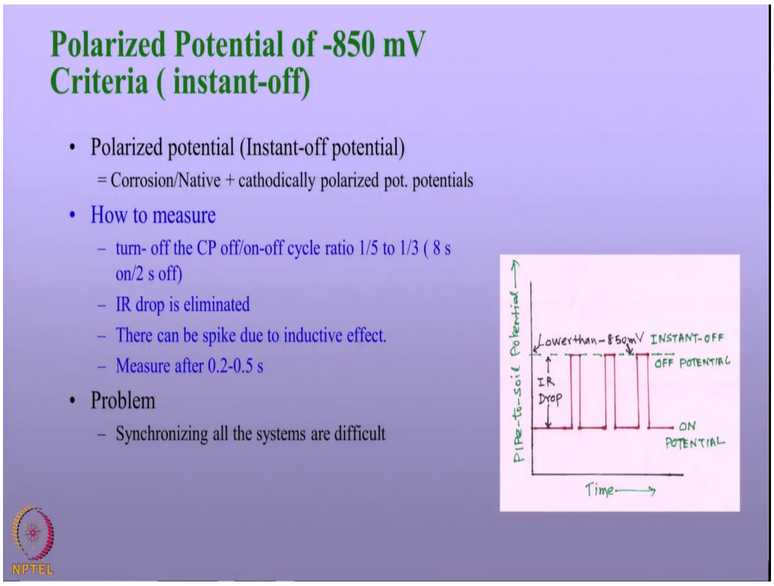

Polarized Potential of -850 mV Criteria (instant-off)

- Polarized potential (Instant-off potential)
  = Corrosion/Native + cathodically polarized pot. potentials
- How to measure
  - turn- off the CP off/on-off cycle ratio 1/5 to 1/3 (8 s on/2 s off)
  - IR drop is eliminated
  - There can be spike due to inductive effect.
  - Measure after 0.2-0.5 s
- Problem
  - Synchronizing all the systems are difficult

In order to overcome the IR drop offered by the soil between the pipeline or the structure on the reference electrode, the another criteria has been devised and that this criteria is called as instant off criteria. The principle of this criteria is as follows, if a current is passed across a resistor and if you turn off the current; the phase lag between the current and the potential is 0; that means if you turn off the current, instantaneously the potential drops, that corresponding to the resistance offered by the circuit.

So, what is done in this case is you know in a pipeline, where the structures are cathodically protected and in which case we call them as on potentials; the potential measured with respect to a reference electrode; when the cathodic protection is on is called as on potentials.

Then you turn off the rectifier and then you follow the voltage change; instantly you will see the potential drops and in the off conditions, you hold it for some time and again you turn it on. So, this can be cycled a couple of times in order to ensure that, the potential so measured is consistent with that.

The instant off potential is considered as the true potential of the pipeline; because we eliminate the potential drop due to the soil. So, the polarized potential or instant off potential is equivalent to the native potential of the pipeline plus the cathodically polarized potentials that occur due to passing the current.

Now, how do you really measure it? We have seen now, you have on-off cycles and the ratio between the off time and on time is one fifth to one third ratios. Typically the on time is 8 seconds and the off time is 2 seconds right. Notably there can be some spike seen some cases, because of inductive effect, that can be ignored.

Typically the potential is measured after about 0.2 to 0.5 seconds, after you turn off the rectifiers. This is for superior technique compared to the 0.85 volt criteria. The difficulty lies here is synchronizing all the systems are very difficult.

For examples, if there are nearby areas, there are pipelines; we need to turn it off and we need to turn off all the cathodic protection stations, so that the pipeline does not receive any current. So, that is one of the major disadvantage of this particular technique.

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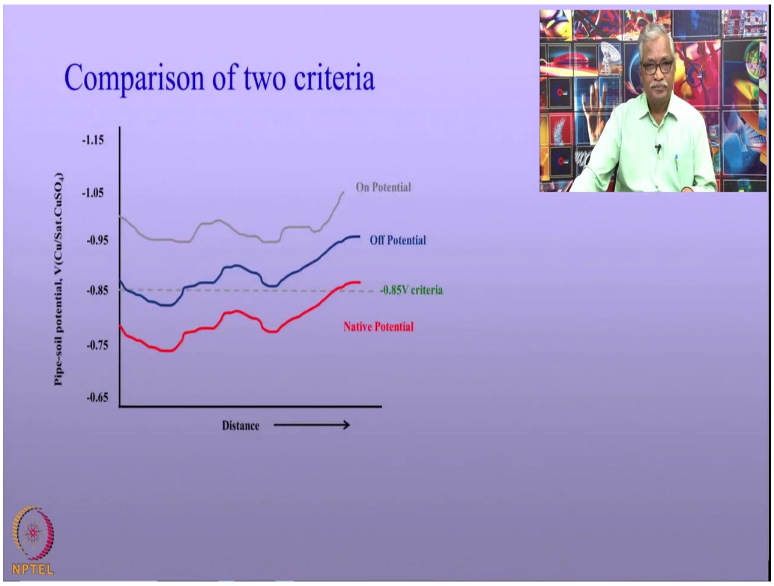

Comparison of two criteria

The schematic graph shown here illustrates how important is to use the off potential measurements over the on potential measurements. What you notice in the top line here, the top curve corresponds to the potential measured with respect to a reference electrode over a distance.

You notice that across the distance over the pipeline, the potentials are well above the criteria which is -0.85 volt criteria. But you compare that with the off potentials; there are few locations, you notice that the pipeline is not adequately cathodically protected.

In this case is barely protected; that means the higher voltage that you notice in the on potential, it is essentially due to IR drop offered by the soil. So this means that on potentials sometimes can be problematic; it may not exactly give the true potential of the pipeline.

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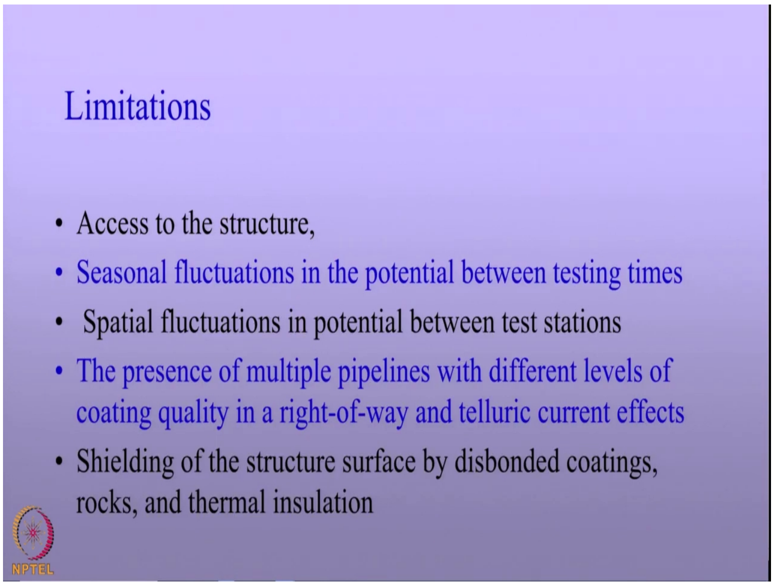

Limitations

- Access to the structure,
- Seasonal fluctuations in the potential between testing times
- Spatial fluctuations in potential between test stations
- The presence of multiple pipelines with different levels of coating quality in a right-of-way and telluric current effects
- Shielding of the structure surface by disbonded coatings, rocks, and thermal insulation

Well there are some other disadvantages apart from synchronizing the various you know stations. The access to structures; sometimes the seasonal fluctuations in the potential between the testing times; spatial fluctuations in potential between test stations; the presence of multiple pipelines as I told you, I mean you need to disengage them during cathodic protection.

And sometimes you may be having problems with the disbonded coatings; they shield the current so the pipeline does not receive the current and so there can be problems.

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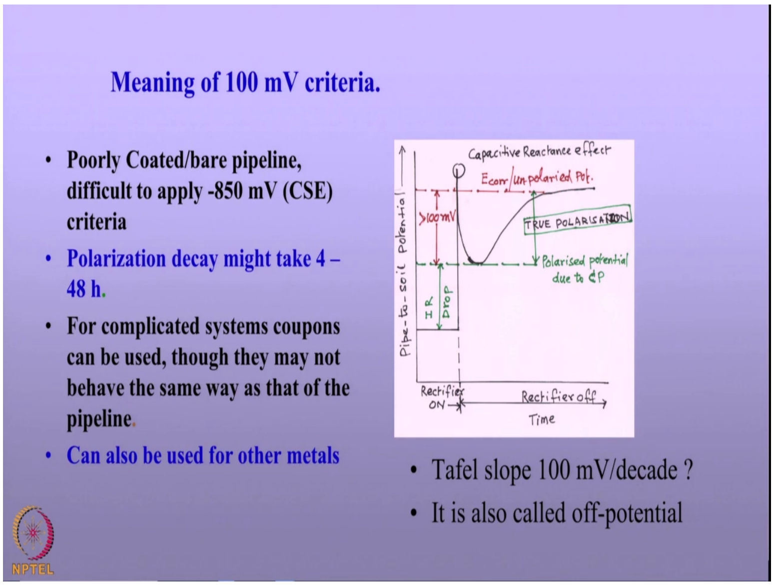

Meaning of 100 mV criteria.

- Poorly Coated/bare pipeline, difficult to apply -850 mV (CSE) criteria
- Polarization decay might take 4 – 48 h.
- For complicated systems coupons can be used, though they may not behave the same way as that of the pipeline.
- Can also be used for other metals

- Tafel slope 100 mV/decade ?
- It is also called off-potential

There is yet another criteria, which is 100 millivolt criteria here. And this criteria in fact becomes very important when the pipelines are poorly coated or when you talk about bare pipelines. As we discussed, when you are going to talk about the bare pipelines, if you use 0.85 volt criteria, you need to apply much more current and that becomes unviable.

In this criteria, the following way you make the measurement; you turn off the rectifier and then follow the potentials, that can be spike in the potential you see here and maybe because of capacitive reactance or inductance can happen. And then there is a drop in the potential taking place and this drop in potential to this place, the difference between this point on the on potential is due to IR drop.

But you allow the pipeline not to receive current, that means you keep the rectifier off for longer time, the pipeline starts depolarizing, because the pipeline does not receive any current, the potential tends to become that of the corrosion potential or the natural potentials.

So, depending upon the locations, this decay may take about 4 to 48 hours and ultimately it reaches the potential which is the true potential of the pipeline or the native potential of the pipeline. The potential difference so measured after about 4 or 48 hours and the instantaneous off as noted here is the true polarization the pipeline is experiencing.

And if this value is greater than 100 millivolts, and the pipeline is considered to be adequately protected. When you say adequately protected, we will consider them as required lifetime. If you want to make some calculations, if you assume that the Tafel slope for the anodic reaction is 100 millivolt per decade; you see that this change in 100 millivolt will lead to a reduction of corrosion current density by 10 times and which means the life of the structure can be increased by 10 times.

If the pipeline is supposed to last for 5 years without a cathodic potential and applying cathodic potential, it can become 50 years. So, that is the engineering requirements. So, we are not completely stopping from corrosion, but the cathodic potential is adequate for the desired a life of the component.

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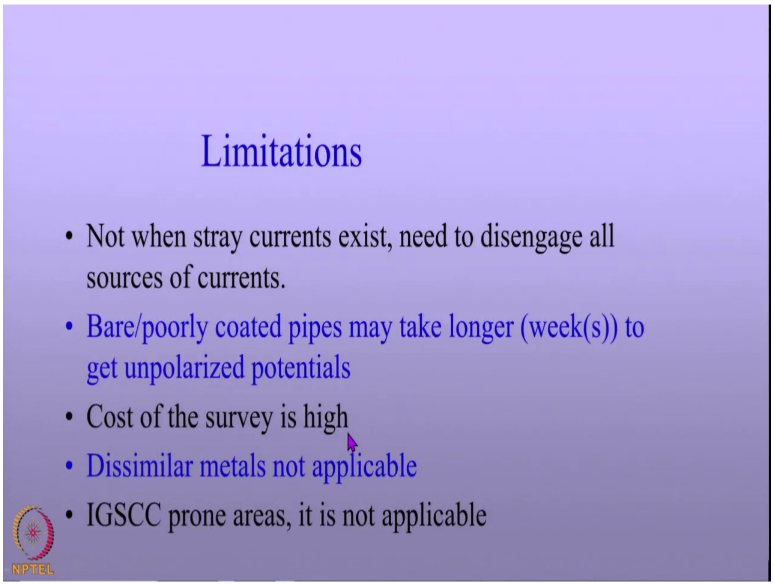

Limitations

- Not when stray currents exist, need to disengage all sources of currents.
- Bare/poorly coated pipes may take longer (week(s)) to get unpolarized potentials
- Cost of the survey is high
- Dissimilar metals not applicable
- IGSCC prone areas, it is not applicable

Some of the problems associated with this technique is, you need to disengage all the sources of current, as you do in the case of off potentials as well. And since you need to allow the pipeline to reach its natural potentials, which is called as unpolarized potentials; you need to, it may take sometimes a week maybe longer that may not be practical in many situations.

You might turn off your own structures; but if there are surrounding structures which are cathodically protected, it is hard to switch off cathodic protection for all the structures. Moreover the cost of the survey is quite higher; this technique again is not applicable when you are going to talk about dissimilar metals.

And in the areas where the structures are prone to intergranular stress corrosion cracking, this 100 millivolt criteria is not applicable; because the IGSCC occurs because of the anodic dissolution, we need to protect little bit more than what the 100 millivolt criteria can offer.

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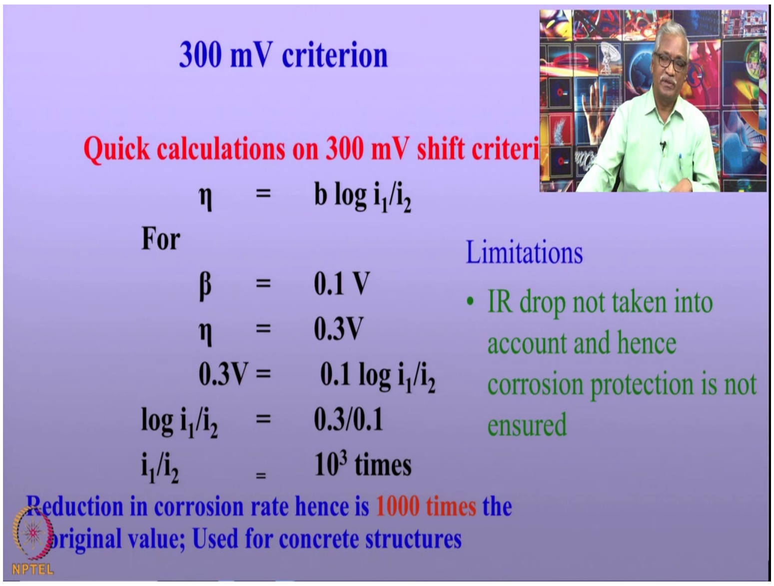

300 mV criterion

Quick calculations on 300 mV shift criteri

$\eta = b \log i_1/i_2$

For

$\beta = 0.1$ V

$\eta = 0.3$V

$0.3\text{V} = 0.1 \log i_1/i_2$

$\log i_1/i_2 = 0.3/0.1$

$i_1/i_2 = 10^3$ times

Limitations

- IR drop not taken into account and hence corrosion protection is not ensured

Reduction in corrosion rate hence is 1000 times the original value; Used for concrete structures

There is yet another criteria which is a 300 millivolt criteria and this criteria is based on polarization; you move the natural potential by 300 millivolts towards the negative direction. So, you increase the current, until the pipeline potential shifts 300 millivolts more negative from its corrosion potentials or the natural potential. Now, it is possible for one to calculate what will be the change in the corrosion current density if one applies 300 millivolt criteria.

Now, it is similar to what we done for 100 milli volt criterion, right. We all know that, the overvoltage is related to beta, the Tafel slope and the current between the two potentials, when it was not applied, when the cathodic potential was applied. So, if you assume that the Tafel slope is about 100 millivolts and the over voltage; that is the change in voltage from the natural potential to the polarized potential is considered as 0.3 volts.

Then you can able to calculate and show that the current ratios between the cathodic protected structure and freely corroding structures, the current ratios is about 10 power the 3 times. That means, you can bring down the corrosion rate by 1000 times, if you shift the potential by 300 millivolt due to cathodic protection.

However, there is a limitation; the limitation is very much similar to the first criteria of cathodic protection that is -0.85 volt. Here too there is a voltage drop, is called as IR drop due to soil; that cannot be accounted in the 300 millivolt criteria. In fact for that reason, this criteria has been now taken off from the normal standards. But this criteria is still being used for structures such as concrete structures; because there we do not know the true potential of the steel rebar.

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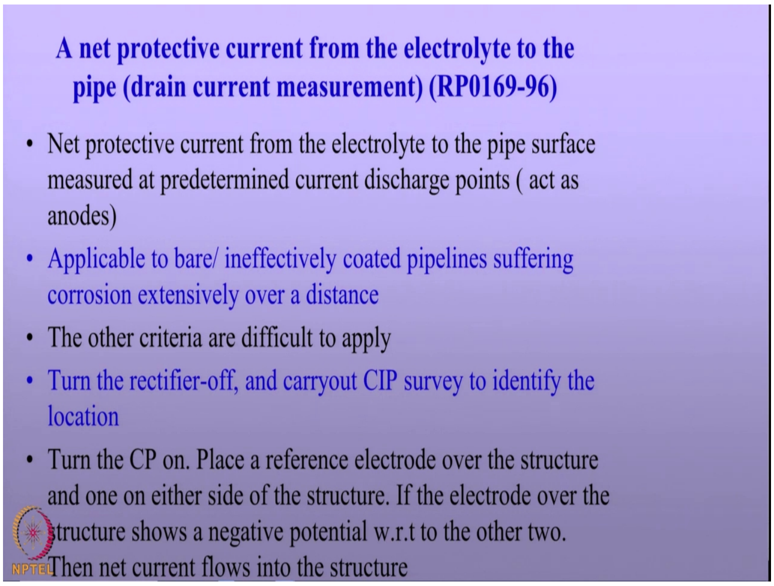

A net protective current from the electrolyte to the pipe (drain current measurement) (RP0169-96)

- Net protective current from the electrolyte to the pipe surface measured at predetermined current discharge points (act as anodes)
- Applicable to bare/ ineffectively coated pipelines suffering corrosion extensively over a distance
- The other criteria are difficult to apply
- Turn the rectifier-off, and carryout CIP survey to identify the location
- Turn the CP on. Place a reference electrode over the structure and one on either side of the structure. If the electrode over the structure shows a negative potential w.r.t to the other two. Then net current flows into the structure

The other criteria is a net protective current from the electrolyte to the pipe. This criteria is used mainly on locations where selectively the metals are getting corroded. The pipeline, you know we have seen in earlier case, when we discuss about the external corrosion of the buried structures; we said that there are certain locations, there are anodes and some location that becomes a cathode, the localized corrosion they do occur may be like, because of soil variations, microbial corrosion and such kind of factors.

So, this criteria can be successfully applied to locally prevent the corrosion of the structures. And the structures which are bare or ineffectively coated, they suffer extensively corrosion over a distance even in normal pipelines. And in such cases it’s very difficult to apply the other criteria; because it requires lot of current in order to meet the -0.85 volt criteria. And so, one uses a net protective current from the electrolyte to the pipeline, that is the criteria.

So, the current can enter the pipeline, you assume that the pipeline corrosion is getting reduced. How do you ensure that the net current enters the pipeline? For that, this procedure is applied, one turns on the CP cathodic protection systems, places a reference electrode just over a structure and two reference electrodes on either side of the structures.

If the electrode over the structure shows negative potential with respect to the other two reference electrodes; then it’s assumed that the current enters from the soil on to the pipeline. So, this is used in a limited areas so that you can achieve localized cathodic protection of the structures.

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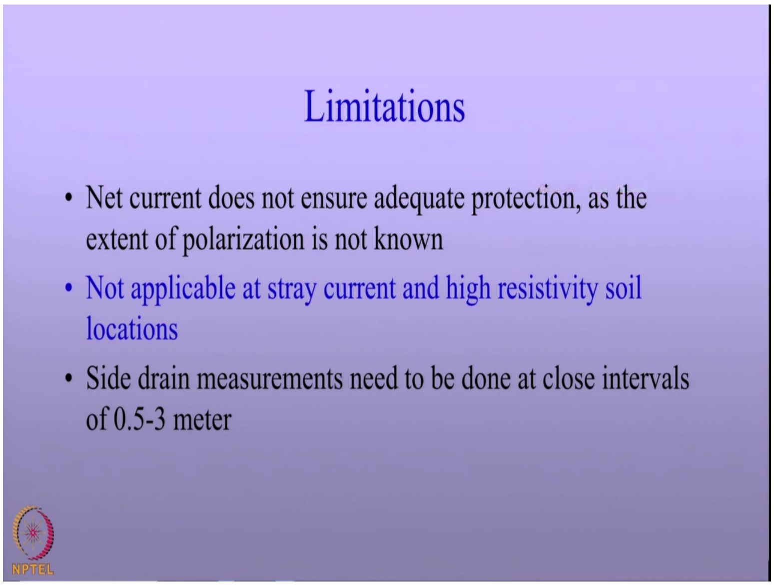

Limitations

- Net current does not ensure adequate protection, as the extent of polarization is not known
- Not applicable at stray current and high resistivity soil locations
- Side drain measurements need to be done at close intervals of 0.5-3 meter

Limitations again, you know that current enters the pipeline, but we are not sure whether how much of a current is entered; whether there is adequate polarization that is causing the pipeline to avoid corrosion to the desirable extent. It is also not applicable where there is a stray current corrosion and where the soil has got high resistivity.

And in such a kind of criteria, one has to measure potentials at the close intervals as close as 0.5 meters in order to ensure that the narrow region which you are interested in protecting the structure, a net current enters the pipeline.

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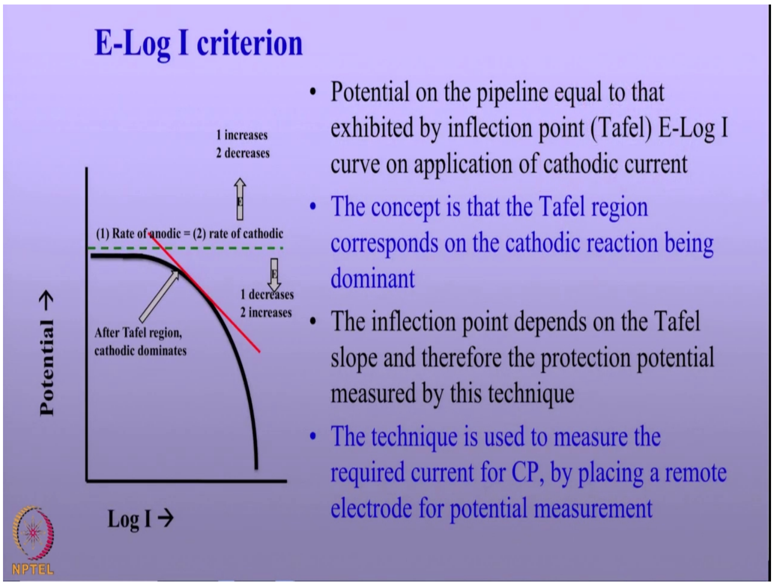

E-Log I criterion

- Potential on the pipeline equal to that exhibited by inflection point (Tafel) E-Log I curve on application of cathodic current
- The concept is that the Tafel region corresponds on the cathodic reaction being dominant
- The inflection point depends on the Tafel slope and therefore the protection potential measured by this technique
- The technique is used to measure the required current for CP, by placing a remote electrode for potential measurement

The last criteria that you like to discuss is based on potential versus log I plots. This actually is a polarization plot of the structures. What I shown here is the line that corresponds to the natural potential of the structure. At the natural potentials, you know that rate of the anodic reaction is equal to rate of cathode reaction taking place.

If one polarizes the structure towards more positive value, positive potentials; then what happens? The reaction 1 increases, the reaction rate 2 decreases. On the other hand, if one polarizes the structure towards the negative potentials, then the reaction 1 that is the metal resolution decreases and the cathodic reaction such as H^+ reduction or oxygen reduction increases.

As you polarize more and more, you increase the potential; you see that the rate of the cathodic reaction is increasing. Now, there is an inflection point and this inflection point is important point. What you see here is a tangent drawn across narrow zone wherein the potential and the log current are linearly related to this and this is called the Tafel region.

Above this inflection point, the potential and the current follows the Tafel kinetics and when it follows the Tafel kinetics, it means that one of the reaction is dominant. See, in this case the cathodic reaction is dominant, the anodic reaction becomes very weaker; that means the pipeline you have net cathodic reaction, the cathodic reaction is much higher here and anodic reaction is virtually suppressed.

So, Tafel region means the relationship is hold valid only when in this case the cathodic reaction rate is much higher than the anodic reaction rates. And so, the inflection point indicates that, at that particular potentials the pipeline is adequately protected.

So, this is again a criteria; for this, normally people install a temporary ground bed and apply the current and obtain this potential versus the current plot. And by identifying this inflection point, you identify the potential required to protect cathodically the pipelines.

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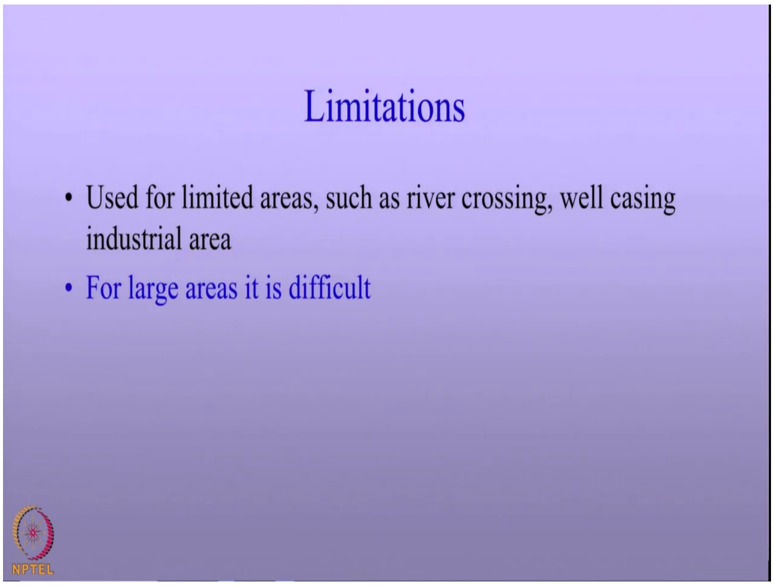

Limitations

- Used for limited areas, such as river crossing, well casing industrial area
- For large areas it is difficult

The limitations again used for limited areas, such as river crossings, well crossing industrial areas. For large areas it is difficult; because you cannot polarize the structure, if it is too large.

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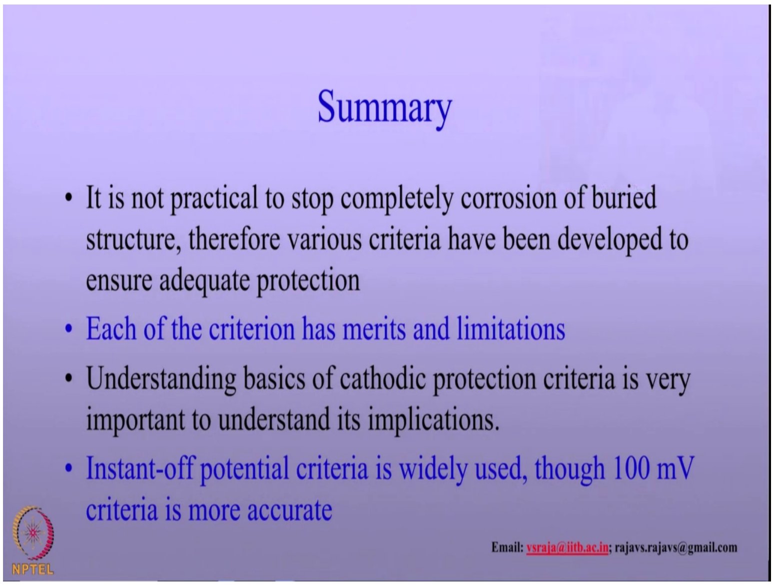

Summary

- It is not practical to stop completely corrosion of buried structure, therefore various criteria have been developed to ensure adequate protection
- Each of the criterion has merits and limitations
- Understanding basics of cathodic protection criteria is very important to understand its implications.
- Instant-off potential criteria is widely used, though 100 mV criteria is more accurate

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To summarize what you have seen so far; we have seen from the Evans diagram, we can in principle completely stop the metal from corrosion, but that is not practical. What is practically is, to protect the structure, so that it serves the desired life. For that we have various type of criteria and these criterion, they have some merits and demerits we have seen.

But in order to appreciate, you need to understand the basics of the cathodic protection criteria in each case. If you look at all these criteria, instant off potential criteria is very widely used and it is more reliable than -0.85 volt criteria; though the 100 millivolt criteria is more accurate, it gives you to what extent the pipeline is polarized.

Thank you.