Cathodic Protection Engineering
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Lecture – 11
Cathodic protection engineering: Stray current corrosion and its control

Welcome back to this lecture series on Cathodic Protection Engineering offered by NPTEL online.

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In this lecture on stray current corrosion and mitigation; we will be looking at the following aspects, that is what is stray current corrosion in buried structures? We have seen in the beginning when we talked about the external corrosion of buried structures. Stray current corrosion is one of the main problems that affects, the structural integrity of these pipelines and storage tanks etcetera.

The stray current corrosion also is an important problems in offshore structures especially the ship hulls. So, we look at what do you mean by the stray current corrosion in details. Then, we will also look at how to detect stray current corrosion in the structures. So, remember that these structures are buried they are not visible to the naked eyes. So, how do you really detect the stray current corrosion occurring in these immersed or buried structures?

Once we know that this stray current corrosion is operating and their principles of stray current corrosion. We should be looking at how to mitigate the stray current corrosion occurring in these structures. Lastly we will be covering the topic AC interference and mitigation. We will notice that AC interference is a major problem in terms of safety hazards, but it can also lead to corrosion issues.

So, in this lecture we will be focusing more on AC interference in as related to corrosion of the structures. Before, we discuss stray current corrosion; let us go back to the cathodic protection in general.

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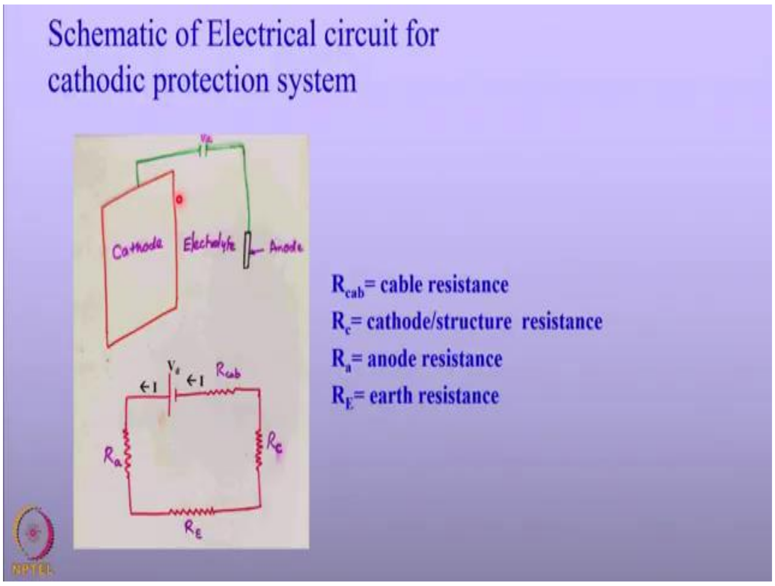

What is shown in this diagram is a schematic of cathodic protection of a structure involving anode and a cathode, and of course, a source which is a DC source a rectifier. I have used this here rectifier, because the stray current corrosion is mostly occurring when the structures are protected using impressed current cathodic protection system. We will see the reason also very shortly.

So, coming back to this cathodic protection of the structures, you notice that the source the current source, the anode, dissipates current in the soil. And, then the current travels to the cathode and again goes back to the rectifier. Now, this is the path of the current flow in a normally cathodically protected structures.

So, this current flow can be given in terms of a simple equivalent circuit given below here. It consists of several resistors, resistance is offered by let us say the cable here, the resistance offered by the cathode, the resistance offered by the electrolyte, and then the resistance offered by the anode. If, you notice that all these resistances are in series. So, they offer resistance for the flow over current in the cathodic protection of engineering structures.

So, what happens, if there is a foreign structure close to this cathodically protected structures. So, that is see that we shall now see what happens if there is going to be a foreign structure lying very close to this cathodically protected structures.

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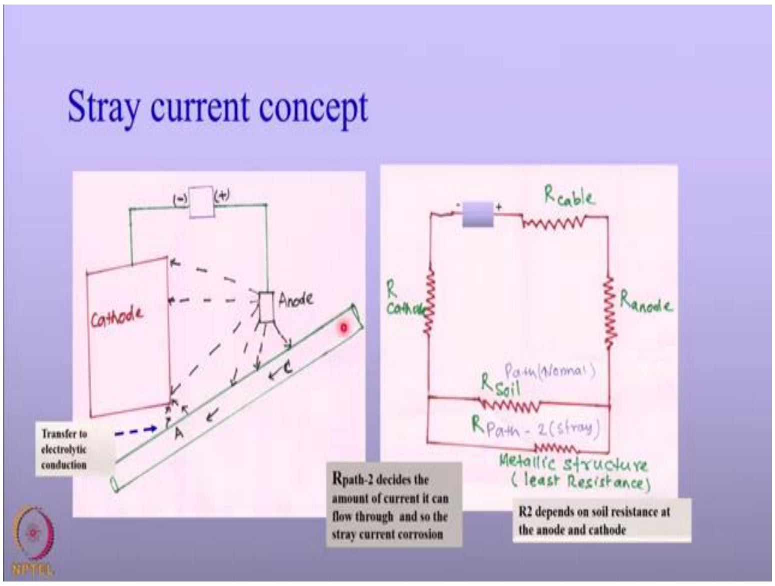

In this slide on the left side a schematic of the cathodically protected structure and the foreign line, that is passing through the structure is given on the right side an electrically equivalent circuit of the same is provided. Let us look at the schematic of so, let us look at the schematic given on the left hand side of the diagram here. So, let us examine what is happening in a system where stray current corrosion occurs. That is illustrated schematically, that is illustrated schematically using this diagram here.

We have seen in the previous slide, that the cathodic protection system typically consist of an anode, a cathode and a rectifier. And, the current in this such a case completely travels from this anode to the cathode that is cathodically protected structures. In the case of foreign structure like a pipeline which is passing by in this vicinity, then a part of the current that leaves this anode enters the foreign pipeline. When the current enters from the soil onto the pipeline, you know that this location becomes a cathode.

It is very much similar to the structure, which is intended for cathodic protection. So, the current enters this pipeline, it travels along the pipeline now you notice that the metallic structure has the least resistance compared to the resistance offered by the soil. So, the current easily flows along this metallic structures. And, this current flow is through electronic conduction.

Now, this current flow cannot continue forever, because the current has to go back to the circuit and to rectifier. And, so, where the current goes or the wherein when the or when the current travels very close to the when the current travels very close to the vicinity of the buried structures, the current tries to leave the structure. And, enters the soil and from there it enters the intended cathodically protected structure and then goes back to the rectifier.

So, you notice that a major part of the current; however, goes to the structure which you wanted to protect, but a part of the current again enters into the foreign structures. As we discussed earlier, the when the current enters a pipeline that becomes a cathode it does not lead to any corrosion; however, when the; however, when the current leaves a pipeline into the soil, there is a transformation from electronic conduction to electrolytic conduction here.

And, as a consequence there is going to be electrochemical reaction and so there is going to be corrosion taking place. As we notice that this place acts as an anode much in similar way the anode that is intended in the cathodic protection systems. So, there is a corrosion occurring in the foreign line, in this vicinity leading to corrosion damage.

And, this is called as stray current corrosion, because a part of the current that has intended to go into the protected structures, strays into this the foreign structures, and then goes back to the circuit. When it goes back to the circuit the corrosion occurs at the location where the current leaves the structure.

So, this is the concept of the stray current corrosion occurring in the foreign structures. Now, the same thing is now given in terms of, the same thing is given in terms of electrical equivalent on the right hand side here. You have a current source which is rectifier; this current source faces the resistance of the cable resistance. The anode resistance and the soil resistance, and the cathode in a normal cathodically protected systems, where there exists no external pipelines.

Should there be an external pipeline as you seen here, the current again stays from this anode and goes into the structures. And, there is a resistance offered by the soil ok, that is indicated over here. You can see that the resistance, this is the resistance offered by the soil.

So, what fraction of the current or what fraction of the total current, enters into this structure, depends upon the resistance offered by the soil over here and over here ok. So, that is the total resistance offered by the soil for the stray current to enter the metallic structures. Notice again the metallic structures are highly electronically conducting, it actually does not provide any resistance for the flow of current.

So, this is the concept of stray current corrosion. To summarize what the stray current corrosion is that whenever you have a foreign pipeline or foreign structure, they lie in the vicinity of the already cathodically protected structures, a part of the current from the anode enters the foreign structures. The place of entry for this structure becomes a cathode and where the current leaves back to the circuit and that becomes anode here.

The place where it becomes the anode the pipeline suffers severe corrosion. And, the extent of corrosion that enters the pipeline, it depends upon the resistance offered by the soil over here, that is between the anode and the on the foreign pipeline and the pipeline on the buried structures. So, that is the principle of stray current corrosion.

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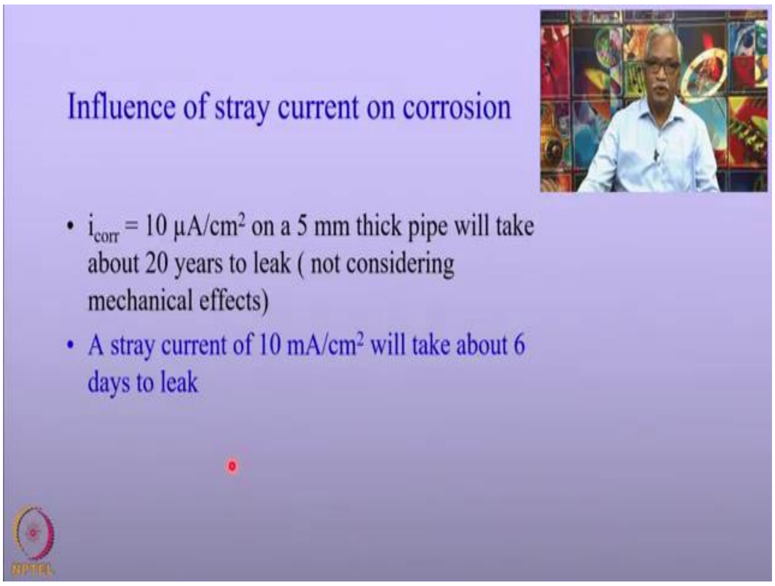

Now, why we should be worried about stray current corrosion? Let us look at this data given here. It is an indication right it is an approximate indication of what will be the effect of stray current corrosion on a pipeline or a buried structures.

Normally, the pipelines will have a corrosion current density in the order of 10 micro ampere per centimeter square. And, if the structure happens to be of 5 millimeter thick and it is allowed to corrode, the structure will last 20 years for the leak to commence, not of course, considering any mechanical effect.

Because, when you reduce the thickness of the structures and there are internal pressure like hoop stress there can be early failures. Assuming that the mechanical effects are not come in to play it takes about 20 years for the structure to leak. On the other hand for a stray current corrosion if it is of the order of let us say 10 milli ampere per centimeter square, it will just take about 6 days to leak. So, that is the effect of stray current corrosion we should be worried about.

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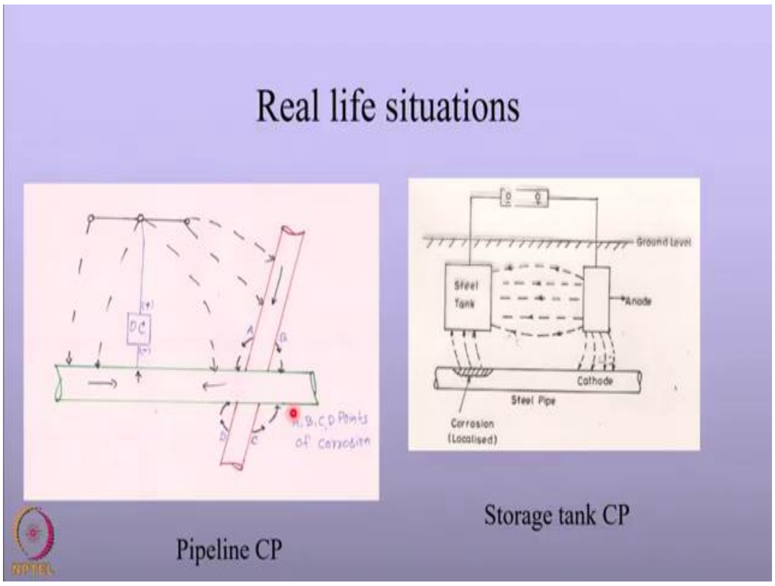

Now, let us go to the real life situations, let me describe the two cases or three cases to make you understand, how the stray current corrosion occurs in practice. What is shown on the left side is corresponding to the pipeline. And, what is shown on the right side is between a tank and the pipeline here.

In the left side the pipeline given in the green color corresponding to the one which is cathodically protected using a rectifier and the anode bed anode ground bed here. As you notice that the current is intend to go into protecting the structure here right.

But, a part of the current can travel into the soil and enter a pipeline which is foreign to this particular pipeline. And, this pipeline may be protected cathodically or may not be protected cathodically, it is possible right. So, as you notice that this pipeline, where it receives the current it becomes a cathode, and it the current in this travels along the pipeline, when the current reaches close to the intended pipeline. It jumps from the pipeline and to the soil and you see that, there is going to be dissolution over here.

And, of course, the internal pipeline here does not corrode because the internal pipeline receives the current it is cathodically protected right. And, as you see the point A, and point B, they suffer the corrosion problems. So, as the point D and points point C. Because, it is still possible that some of the current travels over the pipeline here and again tries to return back to the circuit.

What is shown on the left on the right side, what is shown on the right side is a cathodic protection system of a tank using the impressed current cathodic protection systems, and anode. And, there is a foreign pipeline going very close to the steel tank right.

And, again a part of the current leaves this anode and enters this pipeline and again, when the pipeline nears the steel tank. It is you know when the pipeline nears this tank you would expect the current that travels in the pipeline jumps into the soil and leading to the corrosion.

So, this normally occurs in the plants, because the storage tanks are all located in the plants. Whereas, the one which show on the left side are all for the cross country pipelines or other pipeline networks not necessarily belonging to any plants.

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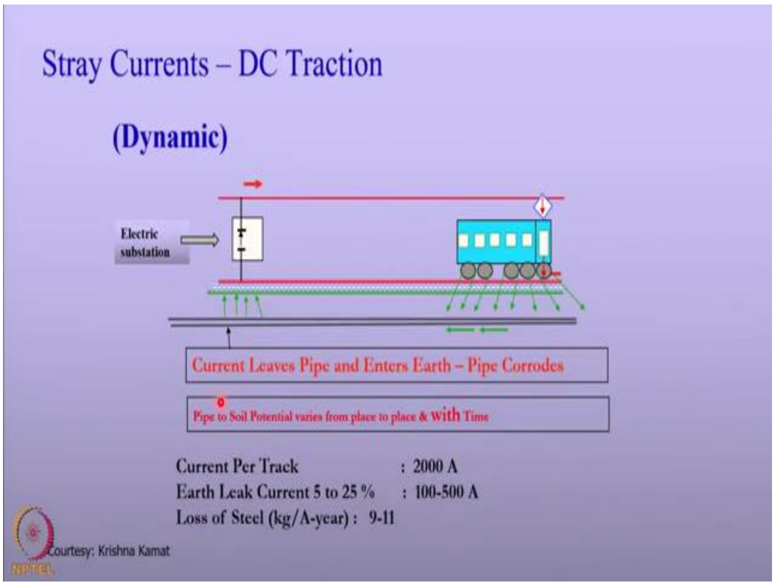

Let us look at the another example which in fact, is a very important example, that happens in the metros where there are electric DC traction systems. Now, what is shown in this diagram is locomotive driven by a DC current right? And, you have a substation a current leaves the substation here and goes through the over line cable. And, it does work in this DC engine. And, the current now from this engine leaves the railway tracks.

And, along the railway track the current is supposed to travel, because it is a steel one right, it is offers least resistance for the flow of current. It offers least resistance for the flow of current; it should go back to substation. So, the current in a normal course of time is expected to travel from the electric substation to the locomotive right.

And, then it is supposed to return back through this railway tracks, this rails because it is electrically conducting. However, there is leakage current, that leaves this rails and enters the soil and from there it enters the pipeline.

Now, the pipeline is electrically a good conductor. It allows the flow of current much easier and then it travels along the pipeline. But, here again that the current cannot travel indefinitely it has to return back to the electric substation. So, when the pipeline nears the substation at that location, you see that the current leaves the pipeline and enters the substation.

So, there is going to be corrosion at this location, because the current leaves the pipeline. We define the anode is the one where the current is leaving. We define cathode is the one where the current is entering and so, there is going to be severe corrosion.

Let us look at the same numbers. Assume that the current per track is about 2000 amperes is required for to drive this electric vehicle right. And, even if you consider that about 5 to 25 percent of the current is leakage current, that enters the soil and then to this pipeline you notice that about 100 to 500 amperes of current enters this pipeline. As a consequence you notice that at this location a large amount of current is leaving the pipeline and so, it suffers a severe amount of corrosion.

Now, with this kind of current you notice that, we have about 9 to 11 kg per ampere year is the kind of dissolution that can happen on to this place. And, so, you can have very quick leak happening on these pipelines. This kind of corrosion is a dynamic in nature, because this occurs only when the rail passes through this. And, then other times you do not have this happening this is different from what you seen earlier ok where you have a static stray current corrosion because here the stray current corrosion occurs all through the day. As opposed to this you have stray current corrosion which is dynamic in natures.

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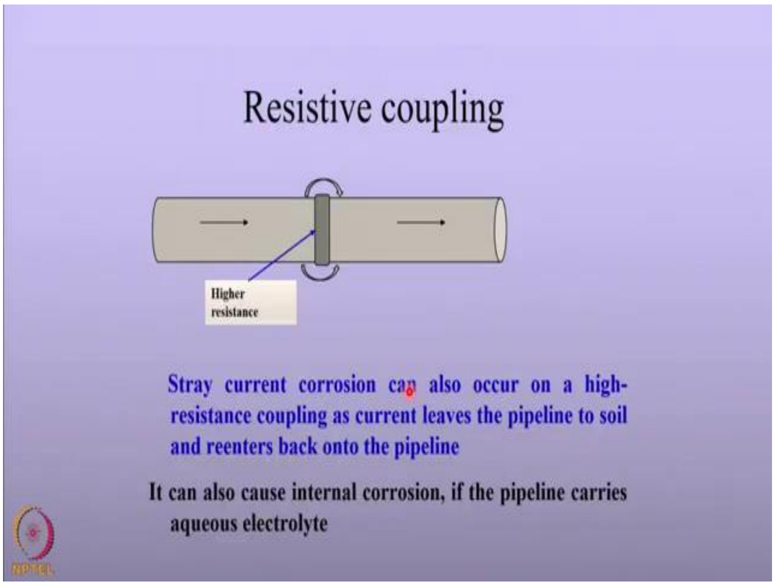

There is another kind of stray current corrosion which is different from what you have seen so far. Assume that there is a coupling here, that joins two segment of the pipelines and if this happens to be offering higher resistance, then what happens is it abstracts the normal flow of the current. So, as a consequence a current leaves this pipeline into the soil and again re-enters the pipeline at other end.

Where the current leaves the pipeline suffers corrosion of course, here there is not a problem because it becomes a cathode. It is also important to notice that, when you have such a resistive coupling you can also have internal corrosion because the current also can jump within the pipeline. So, the internal corrosion can occur when you have a resistive coupling in the pipeline due to stray current corrosion.

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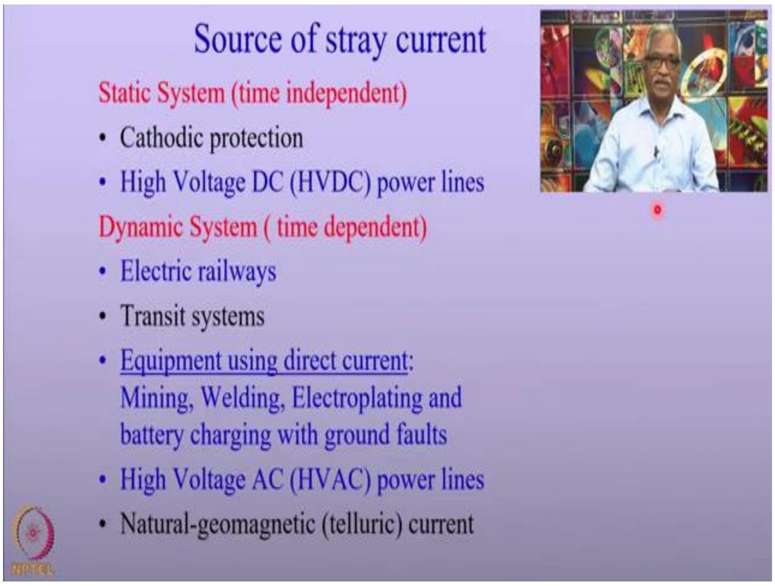

It is important for us to know what the sources that causes the stray current corrosion. Because by knowing that, we can easily mitigate the stray current corrosion. The stray current corrosion can occur for two types of systems; one which is static in natures and other one which is a dynamic in natures.

When you say dynamic, it is a time dependent. And, the static systems are like between the cathodically protected systems. And, a foreign line that we talk about or we also have high voltage, DC, power lines, that is which are traveling along the intended structures.

In the dynamic systems there are several of them actually some of them are quite obvious like electrical railways the transit systems, other electric transit systems. You also have some equipments using direct current they involve mining, welding, electroplating, battery charging with ground faults, and we also can have high voltage AC power lines.

We see later that in a separate topic. High voltage power lines they do cause stray current corrosion, but the extent of stray current corrosion due to high voltage AC power lines are minimal as compared to high voltage DC power lines. We also have natural geomagnetic are called as telluric currents, which cause stray current corrosion problems.

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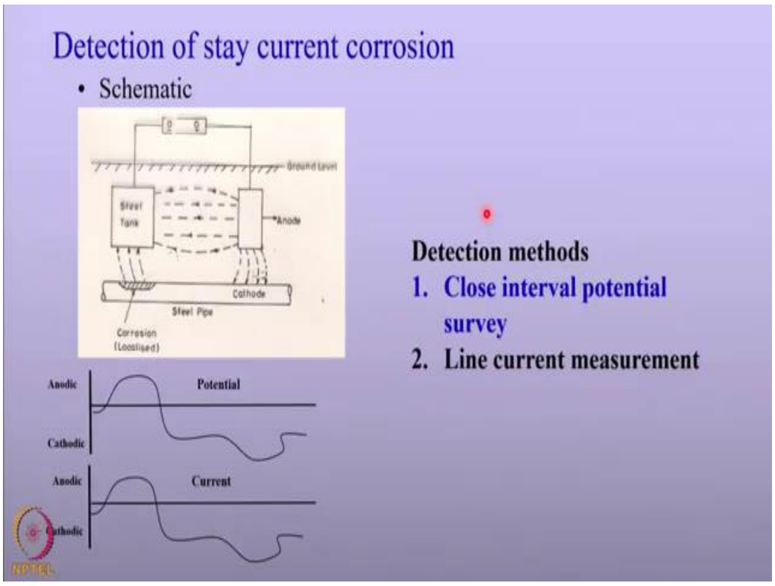

We have just now discussed the source of stray current corrosion. Let us move on to the next important topic that deals with stray current corrosion, that is detection of stray current corrosion. I hope you will recollect one of the lectures we talked about surveys. To find out how the underground pipelines suffer corrosion, how do we detect the location where underground pipe lines are suffering corrosion?

We use two techniques; one is called close interval potential survey, the other one is line current measurements. We will see that how these two techniques can be used to determine the location, or to detect the location where the buried structures suffer the stray current corrosion. Please notice that these are buried structures, its not possible to inspect by visual means in order to understand how stray current corrosion is detected, let us look at this diagram.

Wherein the steel tank is protected cathodically using impressed current systems, there is an anode here. And, there is a foreign pipeline which is in the close proximity of this tank and there is stray current corrosion over here. And, of course, the current where it enters the pipeline it is the pipeline is rendered cathode right.

Obviously, you will notice that when the current enters the pipeline here, it causes a shift in the potential of the pipeline. Because, there is going to be an electrochemical reaction as a response to the current, that is flowing onto the pipeline.

So, there is a change in the potential here. Also as a consequence more current is flowing in the pipeline between this segment and this segment. When the current leaves and this location act as anode, so, the pipe to soil potential over here is going to change. So, the pipe to soil potential at this location corresponds to a cathode and the pipe to soil potential at this location corresponds to the anode. So, that is what is given schematically in the diagram here ok.

And, you notice that this in this axis the top corresponds to the anodic potentials and the bottom corresponding to the cathodic potentials. You notice that in this location the potential is more negative right. And, the potential remains same, because no additional current enters here, it remains almost the same. As you notice as we approach the tank, the potential tends to become anode right and then again the potential drops.

So, close interval potential survey can detect the stray current corrosion where it enters and where it leaves a structure. It is also possible to measure the line current and what is given here below in this schematic is a line current between these two segments of the pipelines. As you notice that at this location there is more cathodic current right, because the current is collected by the pipeline, because of the stray current here. And, then the current turns anodic because the current leaves the structure here.

So, it is possible to detect the stray current corrosion using the two techniques, simple techniques, which is close interval potential survey and the line current measurements. Of course, between these two techniques the close interval potential survey is simpler.

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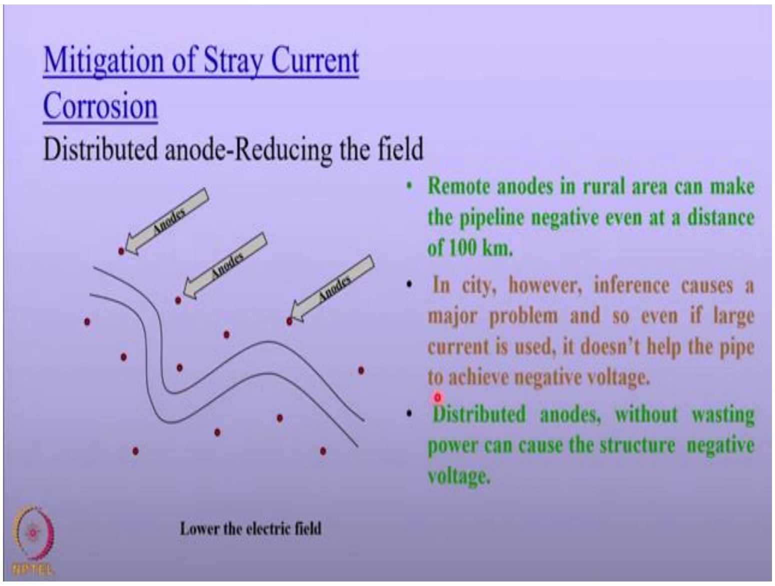

Let us now move on to mitigation of the stray current corrosion. One of the ways to mitigate stray current corrosion is you have a distributed anodes. So, that the field around the anode is decreased ok. So, instead of you know a single anode to cover large area of the cathodic protection of the pipelines. We can have multiple anodes distributed over a distance right. And, this reduces the stray current corrosion to a large extent, because they can lower the electric field, in the soil around the anodes.

This is required because in a typical rural areas you know even a single anode ground bed can protect pipeline over a distance of 100 kilometers long distance. We can keep the pipeline negative enough to protect cathodically. In the city; however, the pipelines are congested, there are other foreign structures interfering with the flow of current, as a consequence stray current corrosion becomes very predominant.

So, the distributed anode system lowers the stray current corrosion very significantly. Without wasting much of a power therefore, the use of distributed anode ground bed systems minimizes stray current corrosion and also reduces the power wastage to effectively cathodically protect the given structures.

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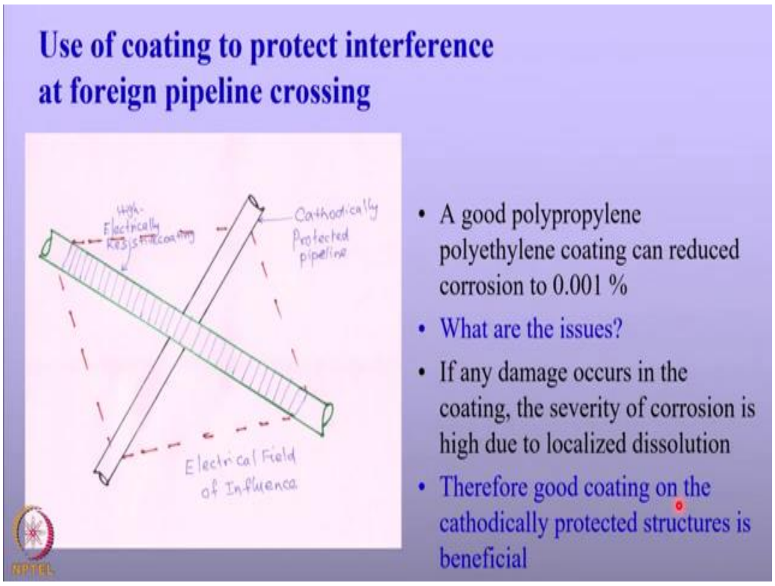

There is another method of controlling the stray current corrosion is to offer resistance. We have seen that, using the electrically equivalent circuit that, the resistance offered by the soil between the anode and the foreign pipeline. And, the foreign pipeline and the intended structures, decides the extent of stray current that enters the foreign lines. Therefore, one of the ways to minimize stray current corrosion is to provide high resistance path for the flow of current.

So, what is shown here in this diagram is a pipeline which is cathodically protected right. And, there is a foreign pipeline which crisscrosses the cathodically protected pipeline. And, so, you would expect that the stray current that entered this pipeline will leave the pipeline here causing corrosion of this foreign pipeline. So, in order to minimize this in high resistance polymeric coating, such as polypropylene coatings can be applied on this pipeline.

Now, to what distance we would apply this coating it depends upon the electrical field of influence between these two pipelines. So, that is to be determined. So, as to decide to what length or what segment of the pipeline requires to be coated with the organic coatings or paint coatings. As we notice here a good polypropylene coating can reduce the stray current corrosion to about 0.001 percent. So, that is a significant drop in the corrosion of the pipeline due to stray current corrosion.

But, how are what are the issues? However, there are some issues when you use this coating to prevent stray current corrosion. In the case of small defect occurring any of these locations you would expect that the current will be localized and so, there will be severe corrosion occurring at that location. So, in order to reduce this it is essential to coat the other pipeline as well, if it is not been applied with any coatings.

So, that the resistance offered by the other pipeline also detects the current from leaving the pipeline. We have shown earlier that stray current corrosion occurs, because of change over from electronic conduction to the electronic conduction right. That is where the current leaves the pipeline and enters the soil, the corrosion occurs.

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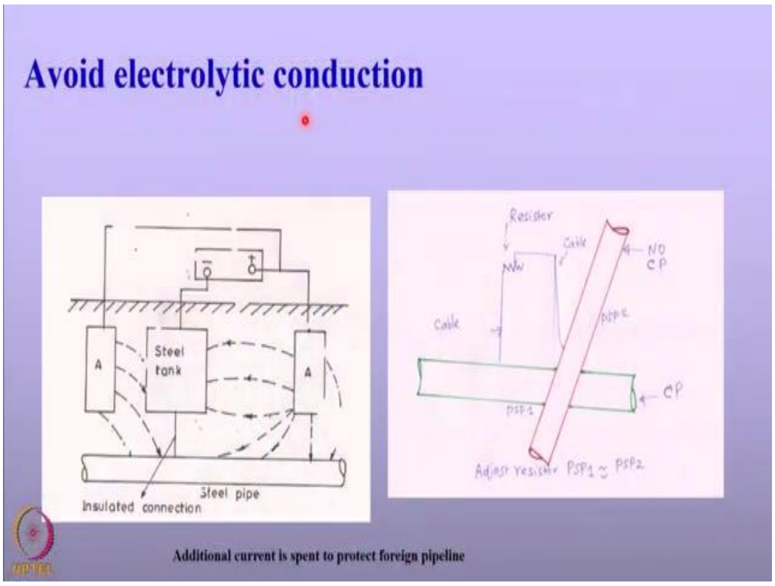

If, you can avoid this electrolytic conduction, then the stray current corrosion can be avoided. That is shown in this diagram here; you see there is a tank which is cathodically protected using two anodes here schematically shown. And, there is a rectifier to supply the current. As you notice that the part of the current from the anode enters this pipeline and travels through. And, we expect the stray current corrosion to occur over here.

So, instead of allowing the current to transform from electronic into electrolytic conduction right, you can use an insulated connection electrical cable, between steel tank on the pipeline. The current leaves the pipeline through the cable and thereby avoids the corrosion of the foreign pipelines.

So, it is very simple. So, what is the problem here? The only problem that one would encounter is that in such a case, this segment of the pipeline that you notice here. Will be cathodically protected at the expense of the current provided by this rectifier, and so one spends the power to protect the foreign pipeline.

So, in order to minimize this power consumption to protect cathodically the other pipeline, one uses a resistor. So, that is shown in this diagram here on the right side wherein the bonding between the electrical bonding between the pipe 1 and pipe 2 is done through a resistor. So, this resistor can minimize the flow of current; however, it is important to ensure that the value of the resistance introduced here is not so high. That it prevents the flow of current through this electrical bond.

And, encourage the flow of current from the pipeline onto the soil directly. So, in order to do this the resistor is adjusted such that the pipe to soil potential of the foreign pipeline. And, the pipe to soil potential of the cathodically protected pipeline are very much closer to each other.

So, by using a reference electrode and a voltmeter, you can measure the pipe to soil potentials at both these locations and ensure that they are almost close to each other. So, that the driving force for the flow of current through this critical bond is minimized.

We have so far seen three types of mitigating the stray current corrosion. One was using the distributed anodes so, that the electrical field around the anode is very minimal. The second case we used coatings in order to offer very high resistance for the flow of current. In the third case, in the third case the electrical bonding was done in order to avoid electrolytic conduction. And, transfer the current from the pipeline and to the intended structures directly.

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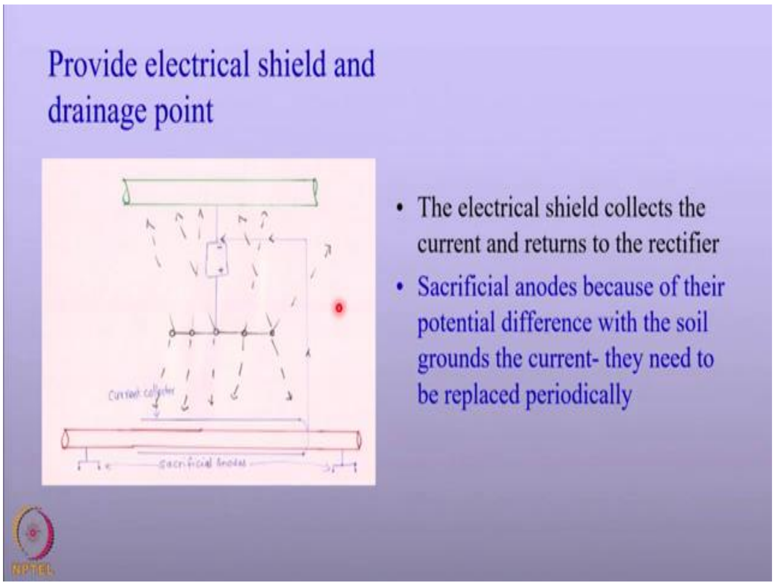

The stray current corrosion can also be minimized using another concept called as electrical shield. That is schematically, that is schematically shown in the diagram. As you notice this pipeline is cathodically protected using a rectifier and the anode over here. And, in a normal circumstances the current will leave these anodes and stay into this pipeline, and somewhere else it will return back to the pipeline causing the stray current corrosion.

Now, surrounding this anode the field is so large. So, if you can use a metallic collector it could be a another metallic pipe, surrounding this the foreign pipeline. And, electrically connect this pipeline with rectifier. The current that travels from the anode gets collected by these collected and returns back to the rectifier. So, major part of the current is not going to enter the pipeline stray current corrosion is significantly avoided at the source of current itself.

There is one more way of minimizing the stray current flowing into the pipeline is by installing sacrificial anodes at a distance from the collector. You notice that, the sacrificial anodes have much more negative potential as compared to the pipeline. So, the current drains into the soil here and returns back to the circuit.

Thereby you can minimize the stray current corrosion travelling in the pipelines. The stray current corrosion of the foreign line can be controlled by installing a separate cathodic protection system, for that particular pipeline.

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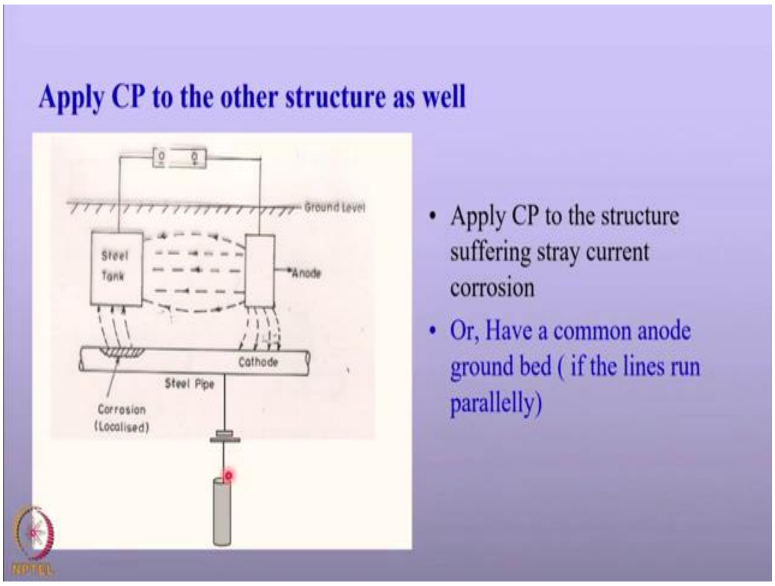

One can use a sacrificial anode installed onto the pipeline and the so, the corrosion at this location can be very much minimized. There are other effective ways of controlling the stray current corrosion is to relocate the anode ground bed.

Suppose you have pipelines which are travelling parallel to each other's. And, if it is possible to relocate the anode ground bed such that, the anode ground bed is shifted far away from the intended pipelines, then the stray current corrosion entering the foreign line becomes minimal.

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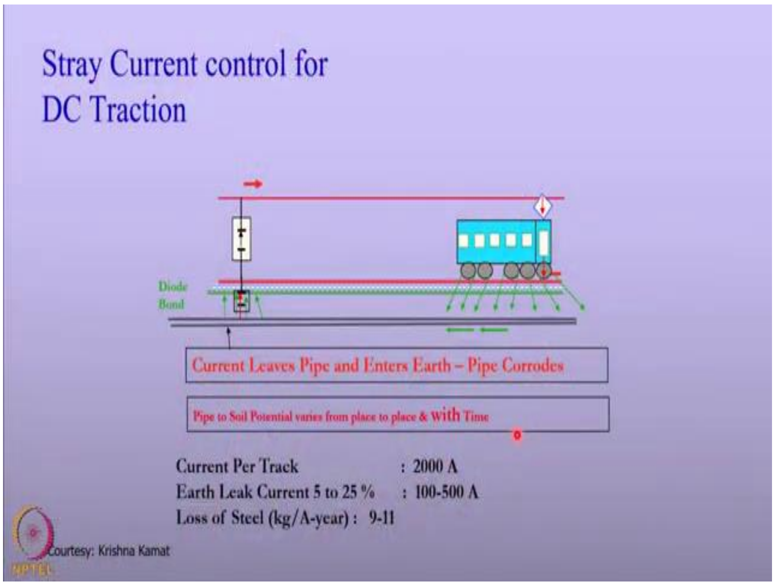

We have seen earlier the stray current corrosion in the DC traction system is very severe and it requires to be controlled, without which the pipeline can corrode very quickly. And, this is done by using almost all the principles we discussed so far, we see that now one after another.

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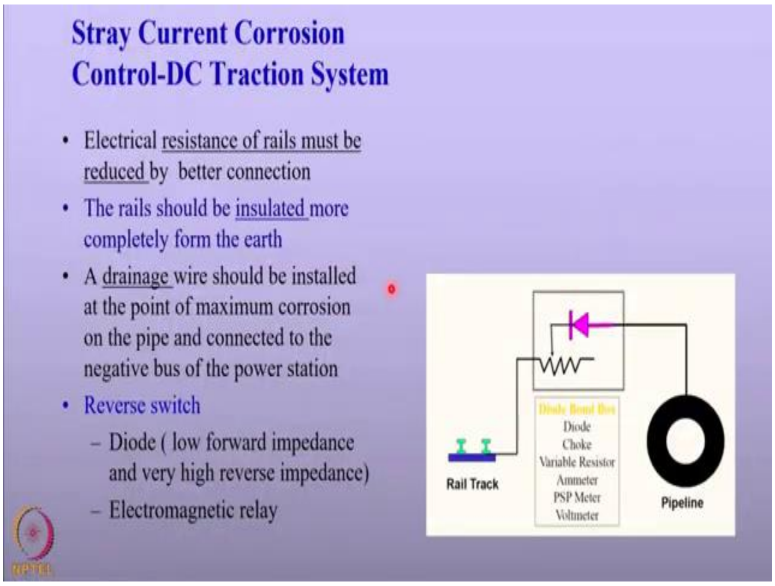

First of all we understand that the current that returns to substation, they travel through the rails. As a first attempt to minimize stray current corrosion the electrical resistance of the rails must be reduced, wherever there are mechanical joints. There has to be electrical shorting has to be done using the cables and when this is welded it is less of a problem.

The other attempt to the second method is insulate the rail, from the earth, using very good insulators may be a concrete better than the wood. So, that the amount of current that strays from the rail into the soil into the ground becomes very minimal.

After attempting these two to minimize the stray current corrosion, it is necessary to control the stray current corrosion at the drainage point, where the current is returning back to the substation. Over here we use the electrical bonds, short the pipeline with the with the rail.

So, that no electrolytic conduction happens, there is going to be electronic conduction the current enters into the rail and then to the substation and do not cause any stray current corrosion. However, there is a problem we notice that the DC traction systems is dynamic in natures.

So, when the rail is not there the current may start flowing. We have seen earlier the stray current corrosion in DC traction system is dynamic in nature; that means, the stray current corrosion at the location occurs only when the train passes through that location.

The remaining time it is likely that the DC current from the pipeline can enter the rails. So, the disturbing the cathodic protection systems of the intended structures, that requires to be avoided. That is done by having what is called as a reverse switch the constituents of the reverse switch is shown schematically in the diagram here. As you see here that the reverse switch consists of a diode that is in series with the electrical bond that you connect between the pipeline and the railway track.

And, this diode does not allow the DC current to flow from the pipeline and to railway track. So, that way it reduces the flow of DC current from the pipeline on to the railway track. It is also possible to have an electromagnetic relay so, that you can break the circuit whenever the train does not pass through this segment of the pipeline.

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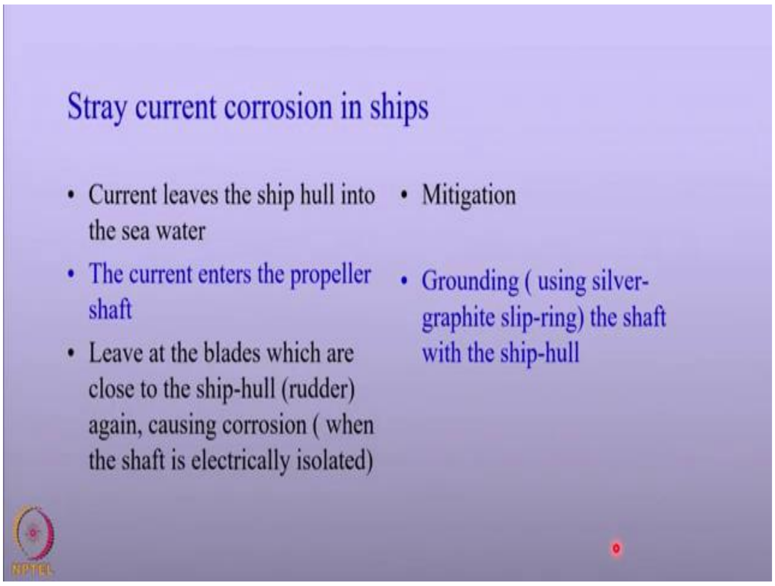

So, far we discussed stray current corrosion occurring in buried structures, buried in the soil. Stray current corrosion can also occur in off shore structures. We will use ship as an example to see, how stray current corrosion can occur in off shore structures.

So, stray current corrosion always occurs, because some part of current leaves the structures into the electrolyte be it soil or be it water. As we know that current cannot travel in the electrolyte, in the soil indefinitely. And, can enter a nearby structures, nearby metallic structures.

And, the metallic structures again is a good conductor of current, the current travels along the metallic structure and when it encounters the main body then the current leaves the metallic structure, gets into the electrolyte or the soil. And, again enters the main body metallic structures, which is cathodically protected. In the case of ships we know that the ships are driven by the propellers.

The current that leaves from the ship hull enters the electrolyte and from there it enters the propeller shaft, which is very close to the ship hull. Because, the propeller is metallic and highly conducting, the current travels along the propeller shaft.

And, then it goes till the end where you have the blades. These blades are in the close vicinity of the radar and so, at that location the current leaves the propeller system. And, then tries to enter radar and through radar it goes back to the source. As we notice that, the current leaves the blades and that location becomes anode and causes the corrosion. This happens because in a normal circumstances the shaft is electrically isolated right.

So, in order to minimize the stray current corrosion these propeller shafts are grounded using silver graphite slip ring, which makes an electrical contact with the main body. And, so, the current travels through the slip ring and back to the systems. The stray current corrosion is mitigated. We shall now summarize various mitigation technique to control stray current corrosion.

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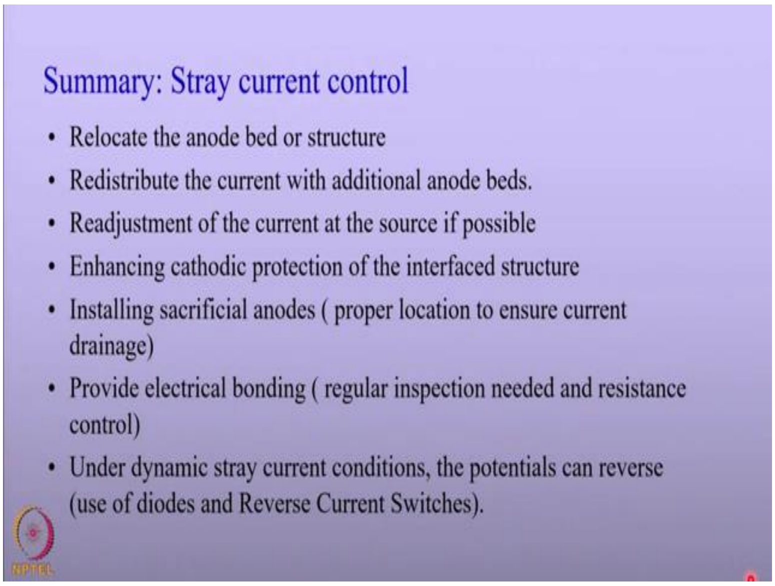

We can relocate the anode bed or structures to minimize the current that enters into the foreign lines. You can have distributed anode systems. We can also readjust the current at the source if possible. You can enhance the cathodic protection of the interface structures, install additional cathodic protection for that.

You can also have sacrificial anode installed in the pipeline, in the foreign pipeline, which will act as a drainage points. Providing electrical bonding we also seen that, providing electrical bonding can lead to excess current drainage from the main source. So, you can also have a resistance installed in the systems.

And, again when you have electrical bonding a regular inspection is needed, because in the event of electrical bonding snapped, then there will be stray current corrosion. Under dynamics stray current conditions; we install diodes in order to minimize the current travelling from the pipeline on to the structures. Let us go to the last topic of this lecture AC interference.

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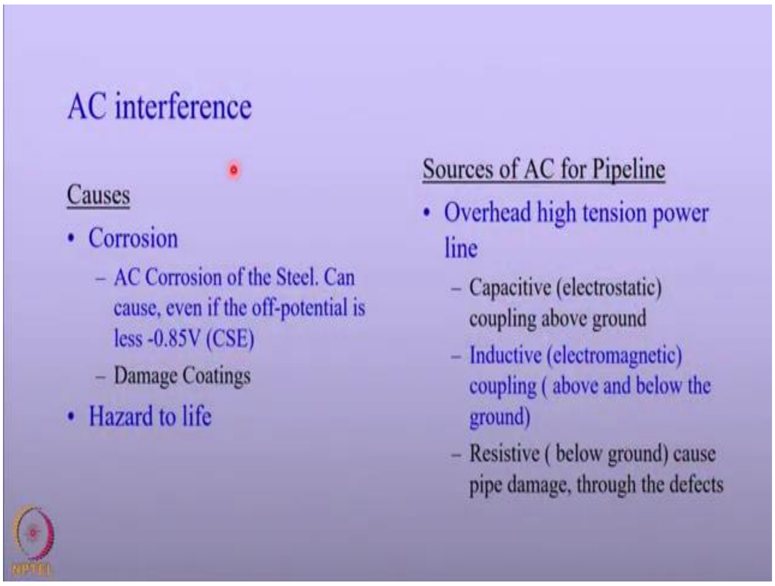

The AC interference with the intended pipelines structures can have two consequences. One, it can affect the corrosion of the pipeline or the structures; it can be hazardous to life. The very interestingly the AC corrosion of the steels can occur even if the off potential is less than minus 0.85 volt.

What does it mean? One may measure structure to soil potential, let us say even minus 0.951 would expect that the pipeline is free from corrosion or the corrosion of the pipeline is significantly reduced, but that does not happen if there is AC interference.

The presence of AC current can also damage the coatings. From the corrosion point of view these two are very important. From the point of view of hazard, there is another issue. Let us now look at the source of AC for pipelines. The AC current is due to overhead high tension power lines.

Now, we have a buried structure or above ground structures, over which you have high tension power lines AC power lines are transport conduct the current. There are three means over which the current is induced in the pipeline.

One, it can be capacitive between the high tension power lines and the above ground pipeline, there is a capacitive effect, if the voltage is very high at a certain circumstances. It can and build up electrostatic charges and the AC current can enter the pipelines. The AC current can also enter a pipeline through electromagnetic coupling. And, this can happen if the pipeline is above ground or below the ground. As opposed to the capacitive coupling it happens only when the pipeline is above the ground.

Now, the current that, so, entered the pipeline will go into the ground and that is due to resistive, the resistance offered by the pipeline. And, in this case the current flows mainly through the defects, the coating defects in the pipelines.

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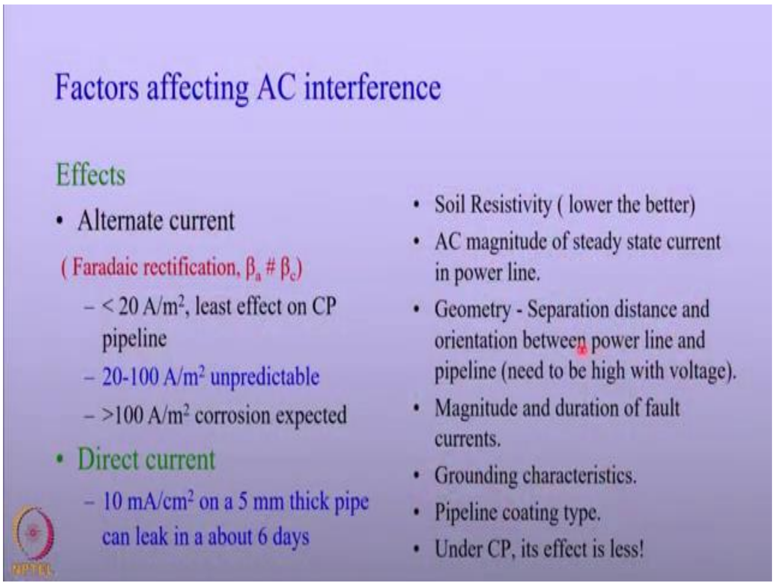

So, what are the factors that affect AC interference? From the point of view of corrosion you notice that the AC is generally not lead to any electrochemical reactions, we know that the current is alternating. And, so, AC does not lead to any electro chemical reactions in general. However, there is a concept called faradaic rectification, that is asymmetry in the beta A, beta C values, leads to some kind of rectification occurring at the interface. That leads to partial conversion of AC current into DC current.

Very interestingly, if the current the AC current is lower than 20 ampere per meter square. It does not lead to any corrosion; that means, the rectification does not occur, you do not get large amount of DC current or any significant amount of DC current to cause any corrosion of the pipeline. Between 2, between 20, and 100 ampere per meter square, it is little unpredictable, that would depend upon the other conditions that you see shortly.

If, the AC current exceeds 100 ampere per meter square the corrosion is really expected. You compare this current, AC current versus the DC current. Around 100 ampere per meter square you do not expect significant amount of corrosion. On the other hand if you have 10 milli ampere per centimeter square DC current on a pipeline. We note we saw earlier that, the pipeline will suffer leak in 6 days, if the thickness of the pipe is about 5 millimeter.

So, you need a large amount of AC current in order to for the pipeline or steel structure to suffer corrosion, because only a fraction of the AC current is converted into DC current. What are the factors that affect AC interference they are listed here? As we notice that AC interference has two components; one is corrosion, other is the safety involved to the personnel who come in contact with these structures, when there is presence of AC current in the structures.

Now, the AC interference would depend upon the factors listed here. The first is the soil resistivity, you know that lower the soil resistivity the current can drain off much easier. So, higher soil resistivity can lead to more AC interference. Of course, the AC magnitude of the current that is flowing in the pipeline in the normal circumstances. The separation between the pipeline and the power line is important, we have seen earlier that the AC interference comes because of both electromagnetic and as well as the capacitive natures.

And, so, the distance between the pipeline and the power lines are very important. As the distance increases, the extent of AC current entering the pipeline decreases. And, the magnitude and duration of the fault current sometime the current also increases right. So, the extent of increase in current momentarily how much time the current is at high value, decides the extent of AC interference with the pipeline the grounding characteristics a well grounded structures will drain the current much easier.

The nature of the pipeline coatings and also whether the pipeline that we talk about is cathodically protected or not very interestingly, the interference corrosion is less when the pipeline is cathodically protected.

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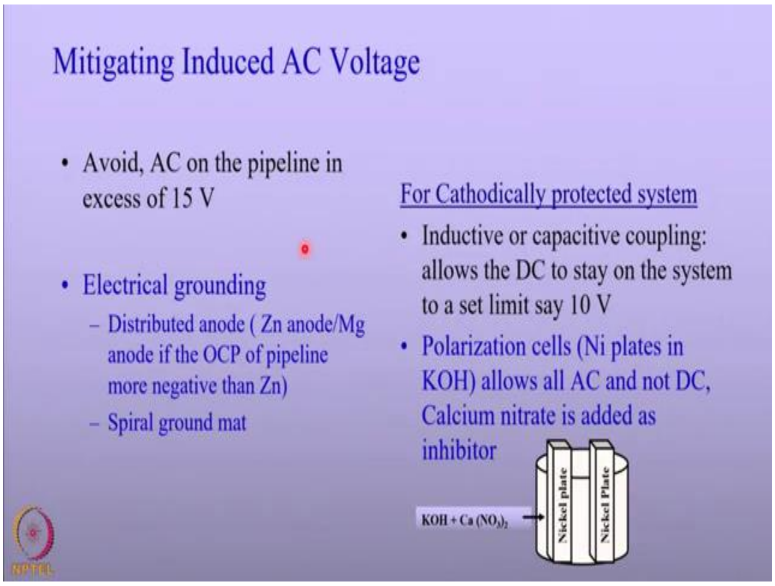

So, let us look at the last important aspect of AC interference, that is mitigating the AC induced voltage and thereby AC induced corrosion. It is important to know that the AC interference is not a problem.

So, long as it does not cause a voltage greater than 15 volt, less than that is not safety hazard. In order to reduce the AC interference a good electrical grounding is very important. In this case the grounding is done by zinc anode and the magnesium anodes.

Notice that, zinc anode and magnesium anodes have OCP that is open circuit potentials or the natural potential is much lower than that of the steel pipeline and so; they become easy drainage point for draining the AC current right. Now, zinc anodes are used normally, but if zinc anodes are passivating in certain conditions, the magnesium anode is used, we know that magnesium has much higher negative potential as compared to zinc and so, is more effective.

However, the dissolution rate of magnesium is higher. So, when we use zinc anode and magnesium anode, it is necessary to replace them as and when they get consumed. There are various ways to ground very effectively; I am not going to details about that the spiral ground mat is another way of increasing the effectiveness of grounding.

When you ground these structures ok, there is going to be a likely problem that these points will act as drainage point for the current to flow from the cathodically protected structures. While we talk about electrical grounding to minimize the AC interference, we should look at their effect on cathodically protected structures.

We know that, the cathodically protected structures carry the DC current. And, the these drainage points also can drain the DC current to minimize the effectiveness of the cathodic protection of the structures.

So, in order to reduce the current drainage, the DC current drainage, one can use inductive or capacitive coupling, which allows only the AC current to flow out of the pipeline and does not allow the DC current to flow out of the pipelines. And, this inductive and capacity couplings are normally set a limit of 10 volts.

One can use the polarization cells that allows the AC current and not the DC current. The polarization cells are a typical electrochemical cell that consists of two nickel plates ok; one end is connected to the pipeline, other end is grounded actually.

Now, we know that, through this AC current can pass through much easier, because this system does not offer any resistance for the flow of current, but DC it offers resistance for the flow of current here. So, the polarization cells are utilized in order to minimize, the flow of current from the pipeline onto the earth, when I say flow of current, I mean the DC current which we do not want to entrain from the pipeline.

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To summarize today's lecture, we saw that stray current corrosion arises out of the presence of a nearby current source or telluric current. The stray current corrosion can be detected using two techniques; one is close interval potential measurement and other is the line current measurement. The stray current corrosion can mitigate it, if you can eliminate the electrolytic current.

You can increase the resistance for the flow of stray current, decreasing the resistance for the primary current. Provide electrical shielding and you can install the drain points, and where possible can have common anode beds; that means, the two structures can have common cathodic protection systems. Where it is not possible you can relocate the ground bed.

In this lecture we briefly discussed AC interference; we saw that AC interference in general does not affect corrosion. But; however, if the AC current exceeds 100 amperes per meter square, it can cause corrosion. There are various means you can mitigate the AC interference and so, that we can avoid AC corrosion as well.