Cathodic Protection Engineering
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Lecture – 12
Cathodic protection engineering: Coatings and rectifier selection

Welcome back to the online course on Cathodic Protection Engineering. In today's lecture I shall be discussing on two different topics and it related to Cathodic protection engineering. This lecture covers protective coatings and transformer rectifier unit. I shall orient this lecture however, from the perspective of their importance with respect to Cathodic protection engineering and not going into details the science and technology of coating and transformer rectifier unit.

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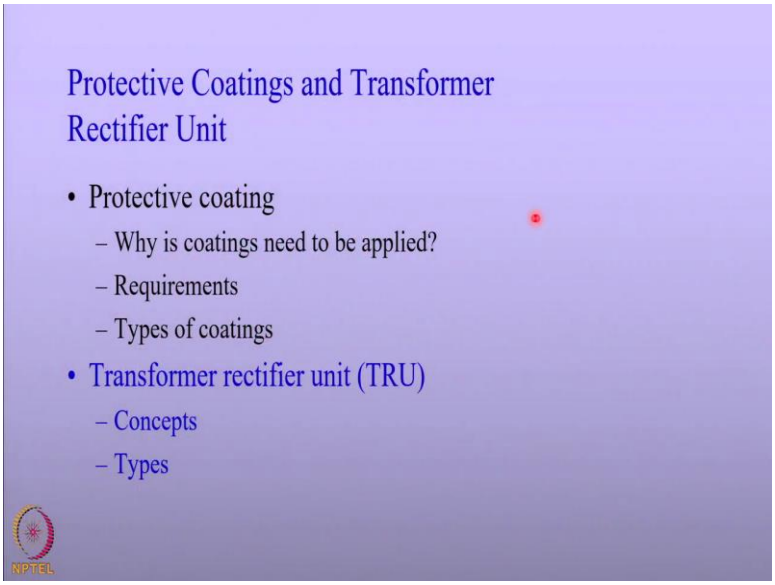

In today's lecture we shall cover the following topics. In protective coatings we shall first address why at all a protective coating is required when the pipelines or the structures are cathodically protected. Once we are convinced that the coatings are required, then it is necessary to understand what are the requirements of these coatings then we should look at the typical coatings applied for pipeline applications.

Then, we will move on to the next topic the transformer rectifier unit, in that we look at the concepts involved in selection of the transformer rectifier unit and then the types of transformer rectifier unit that are employed for cathodic protection of structures.

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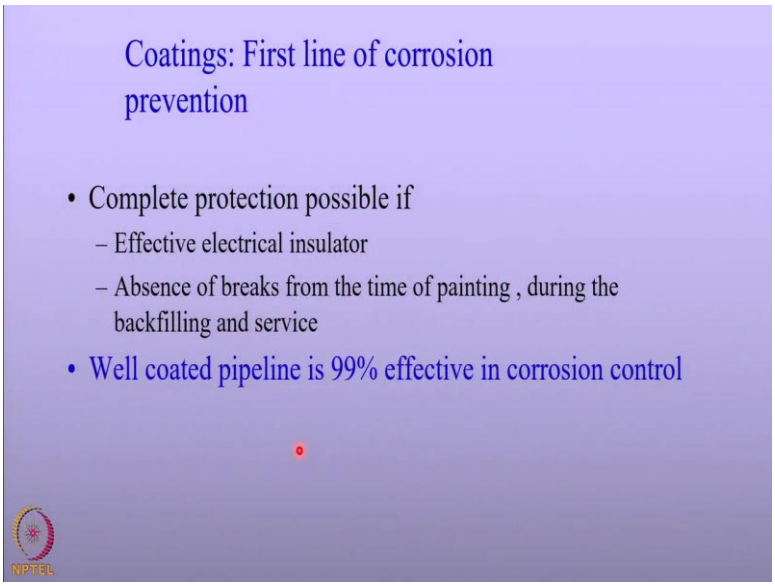

First one would ask the question, why would someone to coat a pipeline or a structure if these are cathodically protected? On the other hand, if someone coats in the structure with a protective coating, why would one would go for cathodic protection?

Indeed, you will see that the application of coatings are mandatory or in fact, complementary to cathodic protection of structures. Suppose, if one chooses only the coating a protective coating, then the coating should offer complete electrical isolation because corrosion is electrochemical nature, it should not allow the transfer of charges between the metal and the corrosive medium.

It should be a completely electrically insulating and since these coated structures are being transported in service or being commissioned at the locations, these coatings should be free from any damages during transportation and commissioning. Both are not really possibles there is no perfect protective coatings there is no perfect paint coatings and it is also not possible that these coatings can be free from any damages during commissioning and transport.

So, that is the reason why these coatings are not very ideal and they cannot protect the structures completely from the corrosion. However, it should be recognized that a well coated pipeline requires only about a less than 1 percent of the current required for cathodic protection.

However, it is known that well coated pipeline is 99 percent effective in corrosion control. So, you will see that the coating and cathodic protection are complementary to each other there is yet another reason why the pipelines are coated that can be seen here very clearly in this diagram.

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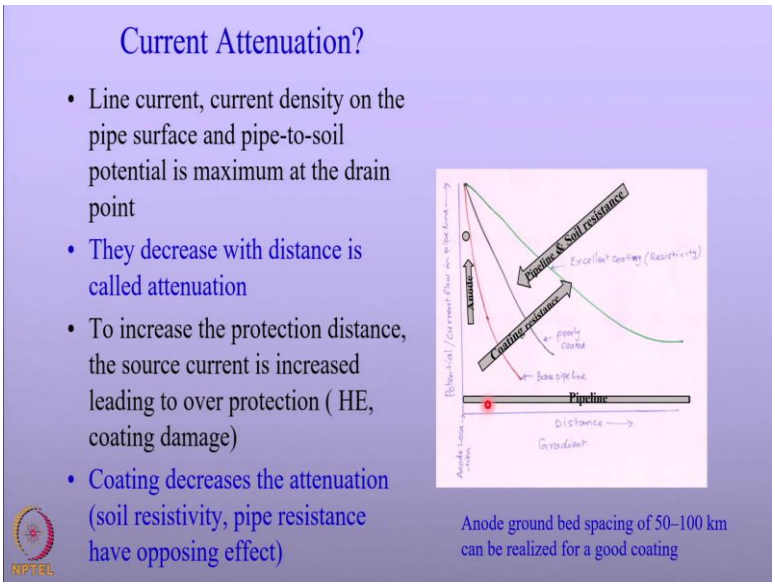

This is related to current attenuation that occurs in the pipeline. Let me now describe what is current attenuation. What is shown in this diagram on the right side of the slide is the variation of the potential and the current with respect to the distance across the pipeline from an anode location. Now, what you notice here is that the both the current and the potential is maximum at the pipeline in the vicinity of the anode location.

But as one moves from this anode location you find that the current and the potential drops very significantly with the distance and this happens if the pipeline is bare in nature. And in order to increase this coverage of cathodic protection in pipelines; that means, in order to extend the length over which the pipeline can be cathodically protected sufficiently using this anode this necessary that this drop in the potential and the current should be minimized.

And this drop in potential and current is called as attenuation. So, we need to minimize the attenuation in order to make this cathodic protection very effective. So, one way to improve the attenuation or reduce the attenuation is to apply coatings on the pipelines.

So, what you see here this black curve here on the green curve here is how the attenuation can change depending upon the natural coatings.

The coating is really excellent you will find that the current drop and the potential drop is quite really minimum they are minimum It is also to be noted that the attenuation also depends upon the pipeline resistance and the soil resistance. Higher the soil resistance and higher the pipeline resistance there is sharp attenuation taking place and so, it makes the cathodic protection least effective.

So, these two factors counter the effect of the coating resistance. So, in order to improve the attenuation, it is necessary to apply better coatings so, that a single anode can effectively protect cathodically pipeline over a long distance. In fact, an ideal system can give rise to protection over a distance of 50 to 100 kilometers if the coating is really good.

There is one more reason why the coating requires to be applied and this to be applied very effectively is that when you increase the distance of cathodic protection over which the pipeline is effectively protected, it means that the current in the closed vicinity of the pipeline or the pipeline receives large amount of current at the location where the anode is located and also as a consequence the pipeline has a higher pipe to soil potentials that is the pipeline is over protected in this case if the attenuation is very poor.

When you want to extend the region of cathodic protections as a consequence of over protection the pipeline can undergo hydrogen embrittlement because hydrogen start evolving on the metal surface if the potential is sufficiently negative in natures also when you see later that if you rise the potential beyond certain levels with respect to piped soil then the coating also get damaged. So, these are the reasons why coatings are mandatory for many applications whenever cathodic protection is done.

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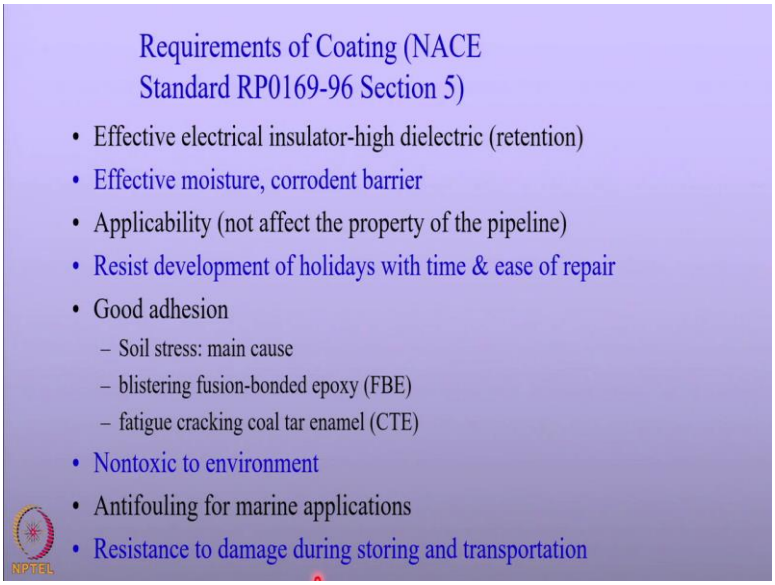

So, now we understand that coating is very important and it indeed is complementary to cathodic protection of structures, then we should look at what are the requirements of a coating that will make the cathodic protection very effective.

The NACE Standard RP0169-96 Section 5 describes the various requirements I am not going to go into details, I give here only salient features of the requirements and those who are really interested in this they can refer this standard to get much more information.

Let us start with the first and foremost requirement. The first and foremost requirement is it should be electrically insulating. So, that is possible if you have very high dielectric it should able to retain the current, it should not leak the current in the system. So, that is one of the most important characteristics of the pipeline coatings.

The second important characteristics of the coating is, it should be resistance against corrosion how is it possible? It should resist the transfer of moisture, it should resist the transfer of any corroding species such as chlorides so, that the pipeline is not affected by the corrosion process.

Now, the other important thing is it should be compatible with the pipeline ok. So, it should not affect the pipeline property because sometimes when you apply a coating you might apply to higher temperatures ok. So, you should not interfere with the property of the pipeline. As we as the pipelines are used in service and over a time period the

pipelines get damaged the defects appear and these defects are called as holidays actually.

So, a good coating must resist the development of holidays with respect to time; that means, have longevity so, that the cathodic protection becomes very effective over a long period. More importantly that when the coating is damaged it is should be possible to repair them very easily because that is another property for a versatile coating.

There is something very inherent about the coating is coating adhesion. The coating adhesion is indication of the resistance of the coating towards corrosion. In fact, those who have gone through the course on coatings they will understand that the adhesion and the corrosion resistance are directly related to each others.

Better adhesion means less permeation of the corrosive species and so, the coating does not get damaged and so, coating give you better resistance towards corrosion. In addition to in addition to this good adhesion properties because these coatings are applied on buried structures, it should resist the soil stress it should not get damaged when there is slight movement taking place in the soil.

Another important property is resistance against blistering. And blistering is common it can happen when cathodically protected structures or blistering becomes very common when the structures are cathodically protected using ICCP that is Impressed Current Cathodic Protection systems because the potential can shoot and so, so there is going to be a hydrogen evolution and so, on so, forth.

We will see this a little more detail in the next slide. And there are certain coatings like a coal tar could be little more brittle, it should resist a fatigue and many of these pipelines are under fatigue loading conditions because of the transport of the products and you know the pressure keeps fluctuating as a consequence the coating must resist the fatigue cracking.

There is no need to have less emphasis on toxicity because environment compatibility is very important these coating should be less toxic to the environment. Living organisms we have seen earlier causes microbial corrosion of the pipelines, but these organisms can also damage these coatings ok. So, there should be resistance against the microbial attack

on the ground that is on the onshore in the marine applications there is going to be fouling it should be resistance against fouling.

In a typical ship when the coating is applied if it is not resistance against fouling and any fouling will increase the drag and so, it is not going to be good for the ship. So, antifouling is very important especially for transportation in the sea water applications.

And it is vital that these coatings resist any damages due to storing and transportation. Let me try to spend some time on a very important property of the coatings especially for cathodic protection that is cathodic dis-bondement resistance.

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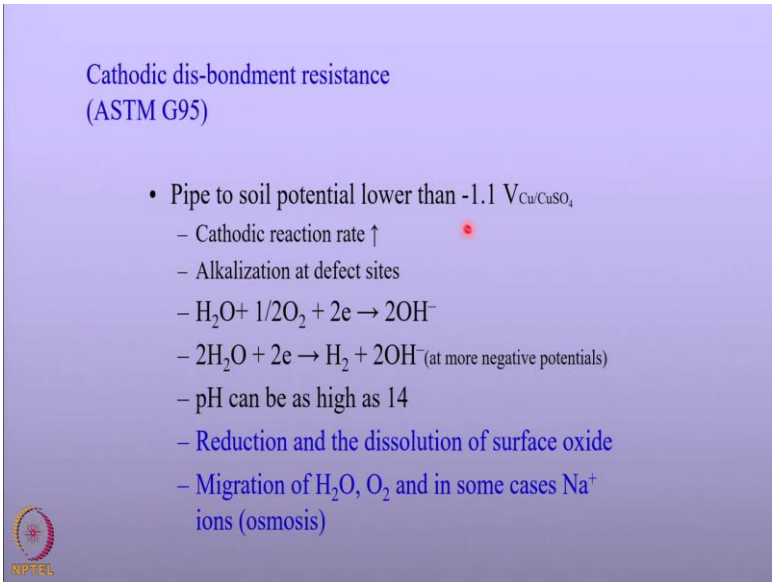

As we have seen earlier in few of the lectures that when the pipelines or the structures are protected using ICCP that is Impressed Current Cathodic Protection systems and its very likely that at some regions of the structures the potentials go well above the required potential criteria that is - 0.85 volts with respect to copper copper sulfate.

In fact, for a long pipelines in order to protect the pipeline at a at a longer distance, it is necessary that the potential is to be increased. As a consequence the pipeline very close to the anode receives higher current and so, the potential of the pipeline or the structure with respect to soil increases much lower than - 1.1 volt with respect to copper copper sulfate. When I say much lower it means it becomes more negative than - 1.1 volt with respect to copper saturated copper sulfate electrode.

As you know that when the potential becomes more negative then the cathodic reaction increases because the over voltage for the cathodic reaction increases as a consequence the cathodic reaction kinetics is accelerated and in aqueous conditions the cathodic reaction is it could be either the reduction of water giving rise to hydrogen evolution on surfaces or if you have water and water as a dissolved oxygen content it can get reduced to form hydroxide in either case hydroxide is formed on the surface.

You notice that if the hydroxide is formed little less then it is good for the pipeline corrosion resistance because it can form nice oxide film which is very protective. However, if the cathodic reaction is very high rate; however if the cathodic reaction occurs at a high rate, the accumulation of hydroxide at the interface leads to rise in pH beyond 14.

As a consequence the so, called protective oxides that we want to have they also start dissolving if somebody looks at the pourbaix diagram of iron water system, they will know that at ph values beyond 14 the iron iron hydroxide iron oxide they are not stable. So, dissolve as a consequence the metal start corroding at a higher rate.

It is also to be noticed that when the hydroxide concentration at the metal surface such as pipeline or the tanks increases beyond certain level, then there is going to be migration of water, the oxygen content in some cases even sodium ions because of the osmosis taking place.

As the water starts accumulating at the interface, interface between interface between the metal and the coating then the blistering really occurs because the accumulation of water means it applied the pores and as a consequence the coating delaminates are dis bonds. So, this is called as cathodic dis bondment resistance.

So, when a ideal coating should resist against over potentials. So, the ASTM G95 describes a technique to evaluate the metal against cathodic dis bondment resistance I am not going to go into details and we have seen the concepts and anybody can look at this standard and see how this test can be really conducted.

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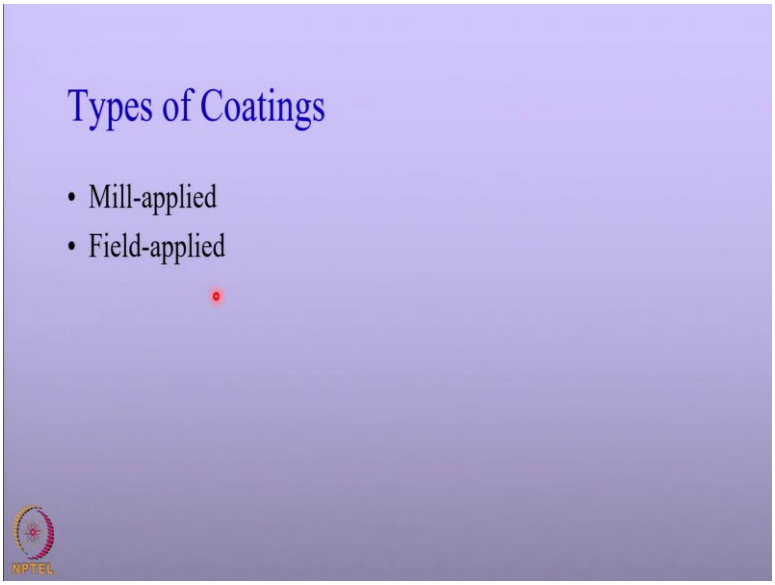

Let us come to the coatings, we have two types of coatings depending upon the applications one is mill applied that is applied in the shop floor and the pipelines are pre coated actually and then transported to the site, the other kind of coatings is the field applied coatings because even the mill applied coatings or pre coated pipelines there are certain edges of the pipeline, it is not being coated because they need to be welded.

So, these locations required to be coated on the field and so, you have special type of coatings called field applied coatings. So, we shall briefly look at these two types of coatings as applicable to cathodic protection of pipelines. What I have listed in this slide are the different kinds of coatings which are applied typically to the pipeline systems.

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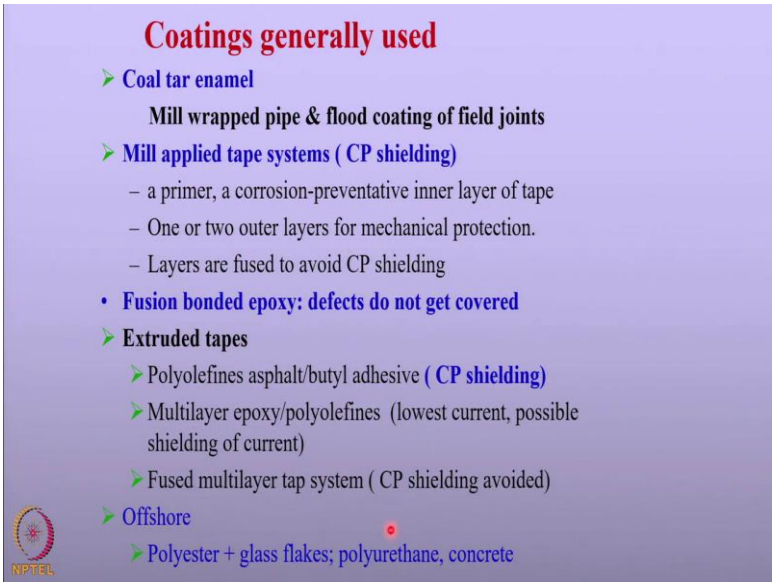

The listed one on the top the coal tar enamel is one of the oldest coatings applied on the pipeline. Nowadays, it is being reduced or in some countries they are they are almost eliminated and these coatings are applied using mill wrapped the pipe on the on the shop floor or on the field you use a flood coatings the molten coal tar enamel is applied over the field joints.

And the other means of applying coating is using mill applied tape coatings ok. So, the various polymeric tapes are being produced and applied onto the pipelines and these pipelines first applied with the primer and primer is an important part of applying protective coatings to structures and we all know that the primer not only resists the migration of the corrosive species, but acts as a inhibitor as a second defense against corrosion.

The primer consists of some kind of pigments they avoid or they minimize the corrosion to a larger extent. Primarily we know that the coatings the polymeric coatings the corrosion prevention mechanism is mainly as a physical barrier for the transport of the corrosive species. However, as you seen before that these coatings are not free from defects the corrosive agents permeate through this coatings.

So, should this corrosives permeate to the coatings, there should be second line of corrosion protection mechanisms the primers containing pigments, they offer resistance against corrosion of the structures. The primer also enables a good adhesion of the coating to the substrate that is the structure.

So, the primer is in fact, very valuable for corrosion prevention of structures whenever the coatings are applied in addition to this primer which is primary concerned with corrosion prevention and adhesion there are other layers are applied over the pipelines over the primer and they mainly take care of the mechanical protection mechanical damage.

In fact, they also take care of barrier action that is they offer resistance against the permeation of the corrosive agents and so, that they will not reach the metallic surfaces. You can have one or two layers are applied on the pipelines.

It is also important to notice to know that in case these layers disbond they come out of the surface they shield the current from flowing to the metal surface because they are not

sticking to the metal surface. As a consequence, they are lying in the soil and there is no potential driving force for the current to permeate through the coatings.

Should the coating lie on the metal surface the driving force applied because of the cathodic protection enables the current to reach the metal surface. In case of the layers getting debonded and moving away from the metallic surface they in fact, act as a shielding against the current flow to the metal surface so; that means, they become detrimental in fact, the shielding has led to the other kind of problems called stress corrosion cracking in some pipelines.

So, in order to avoid this these layers are fused so, that the disbondment the removal of the of the top layers do not. So, that the removal of the coating does not really takes place. We also have the fusion bonded epoxy coatings it gives a good adhesion to the surfaces actually and the only problem with the fusion bonded epoxy is that it does not cover all the defects the defects are still exposed and so, the current requirement is little more than the mill wrapped coatings.

Of late the extruded tapes of polyolefin's are being used to coat the pipeline structures, the polyolefin's could be polypropylene or polyethylene and both of them they give very effective resistance against corrosion and in fact, we see later that they reduce the current requirement for cathodic protection very significantly.

So, in order to apply these tapes you know the adhesives are required. So, let us say asphalt or butyl adhesives are applied on the surfaces in order to promote bonding between the tapes. As you seen earlier that the tapes can also lead to CP shielding in the event of these layers you know top layers they debond and then they detach from the surface and so, they shield the cathodic protection they shield the current from flowing to the structures.

So, again in order to prevent that fused multilayer tap systems are used. In fact, the problem of CP shielding is now completely eliminated because of the use of fused multilayer tap systems that enables the resistance against any kind of debonding of these layers from the surface.

What you seen so, far they are mainly applicable to the offshore structures of course, the fusion bonded epoxies and other kinds of coatings are also used in the offshore

structures, but offshore structures because the structures are immersed in the water all the time, the coating must be resistance to immersion to various kinds of salt solutions actually.

So, far we have seen coatings that are normally applied for onshore structures. As opposed to onshore structures offshore structures are submersible in water. So, the property of the coating should be resistance to water over a time period not only that some of these offshore structures are subjected to tidal waves requiring high mechanical integrity against impact.

So, the kind of coatings used for offshore structures are different as compared to what is being used in the onshores. So, I given here some examples one is a polyester glass flakes that mainly used when there are against the tidal waves. It gives you high resistance against impact damage and also good corrosion resistance.

Polyurethane coating has another good coating against impact it has got good toughness and of course, you can also apply concrete that concrete is more resistance to impact and so, it can be ineffective coating from in fact, it can be very effective coating against corrosion and offer.

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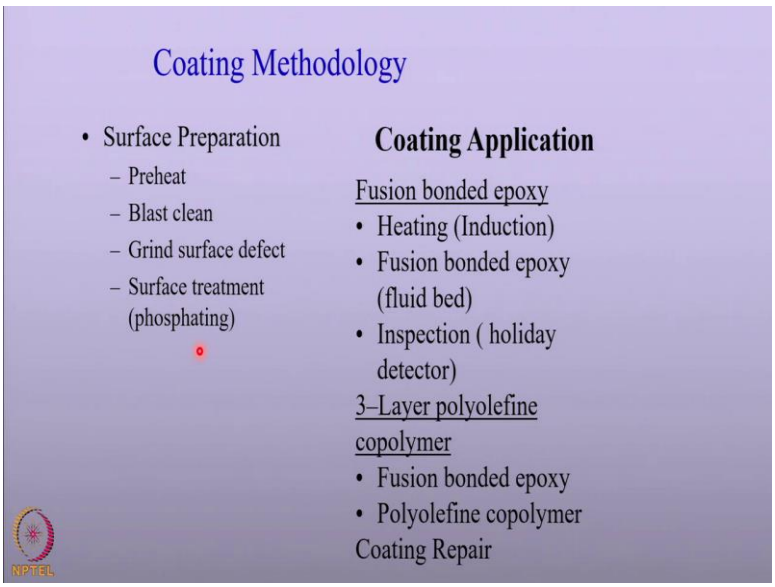

Let us move on to the coating methodology how these coatings are applied. We all know that the performance of the coatings against corrosion depends upon the quality of the

coatings. We talked about you should have high electrical resistance high dielectric constant, but it is not sufficient to have a good coating, it is also important to apply this coatings properly an improper application of the coating does not give better performance. So, that starts with surface preparation.

I listed here few things in a typical pipeline coatings, the following steps are followed. We preheat the pipelines blast clean all this descaling of this oxides, then grind the surface defects any on the surface of the pipelines, then they go for phosphating.

The phosphating is the phosphating helps good adhesion it also improves the corrosion resistance of this of the coatings so, applied on the surface. We shall now move on to the coating applications and we have two types of coatings which is fusion bonded epoxy and three layer polyolefin copolymer coatings.

Fusion bonded epoxy coating is still used and what I given here are the steps involved in applying the fusion bonded epoxy coatings, it starts we eating the pipelines to require temperatures so, that the epoxy powders when they fall on the surface they melt and form bond and cure. And the fusion bonded epoxy is done in a fluidized bed reactor and after coating is done, it is necessary to inspect for any holidays or that is a defects in the coatings.

When it comes to three layer polyolefin coatings a fusion bonded epoxy coating as a first step is still very useful because you know the among all these coatings the epoxy provides a unique property of high adhesion against the substrate. So, start with the epoxy coating and then go for polyolefin layers maybe two layers of that it gives you better performance from the point of view of cathodic protection.

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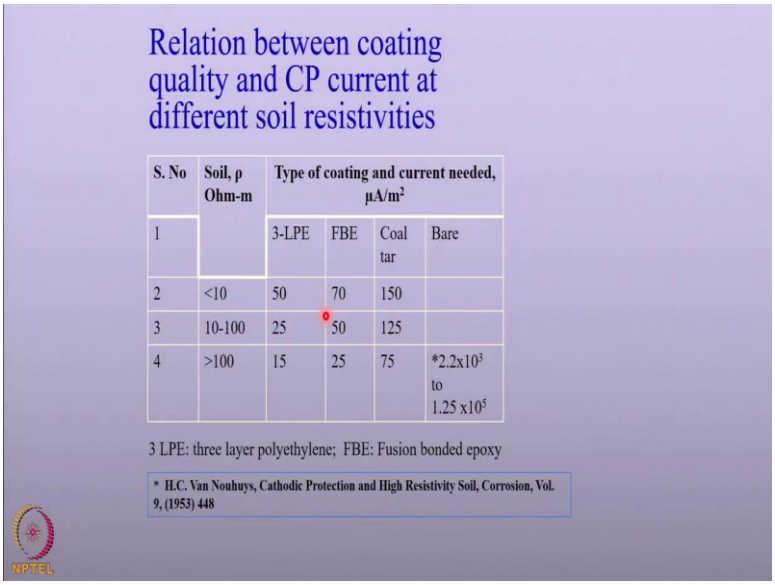

I have shown this table here to get an idea about the relation between the coating quality and the current requirement on one hand and the role of soil in terms of the effectiveness of the coatings.

So, as you notice now what I shown in this column is the resistivity of the soil starting say less than 10 Ohms meter and then to up beyond 100-Ohm meter right and corresponding to these resistivities if you use three the three different types of three different types of coatings namely three-layer polyethylene fusion bonded epoxies coal tar and you see the variation in the current requirement among these coatings.

The coal tar requires the largest amount of current you can see here in terms of micro ampere meter square, the fusion bonded epoxy is little better the best among three is three-layer polyethylene coatings. As you notice that the resistivity of the soil increases as it increases now the current requirement for any kind of coating decreases. So, there is a relation between soil resistivity and the nature of the coating to the current requirement for cathodic protection.

What you notice here is the coating significantly reduces the current requirement for cathodic protection that you seen also earlier in this lecture, I have shown here the current required for a bare pipe ranges between 2.2 into 10^3 micro amperes to 1.25 into 10^5 micro. yeah 10^5 micro amperes right.

Now, compare this with the current requirement for a three layer polyethylene coatings, they are about 3 orders of magnitude and 5 orders of magnitude reduction in the current

is achieved, but this not only saves the power requirement for cathodic protection if you notice we see earlier that current attenuation that occurs in the pipeline is one of the major factors and with this better coatings right you can cathodically protect a longer segment of the pipelines. So, that is an important part of application of coatings for the pipelines.

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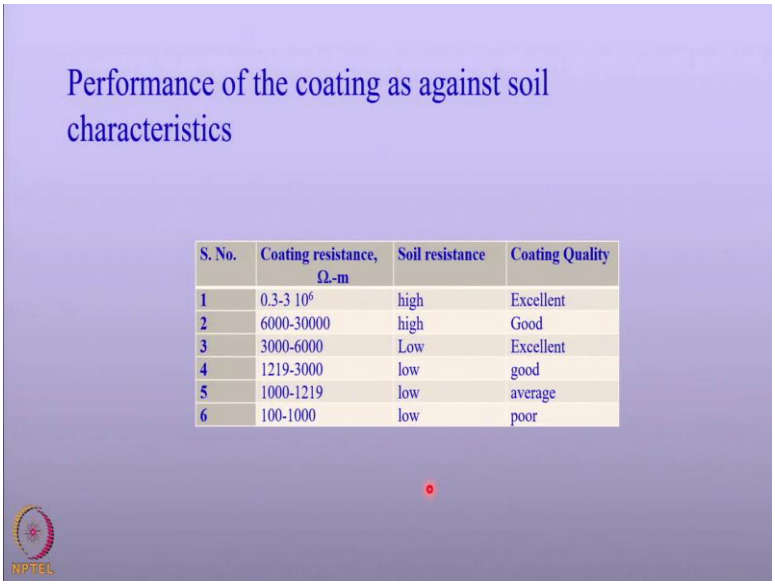

Let us look at the other characteristics related to the performance of the coating against the soil characteristics. Now, we know that the soil can have different type of resistivity right it can be very high to very low value.

Depending upon the nature of the soil, the character of the coating is ranked for a high resistivity soil the coating resistance has to be higher, then we call them as coating of high quality. As the soil resistivity decreases right and you will see that even the coating resistance in the order of 3,000 to 6,000 Ohm meter is still called as an excellent coating. However, poor resistance in the range of 1000 or 100 is not cannot be considered for cathodic protection applications.

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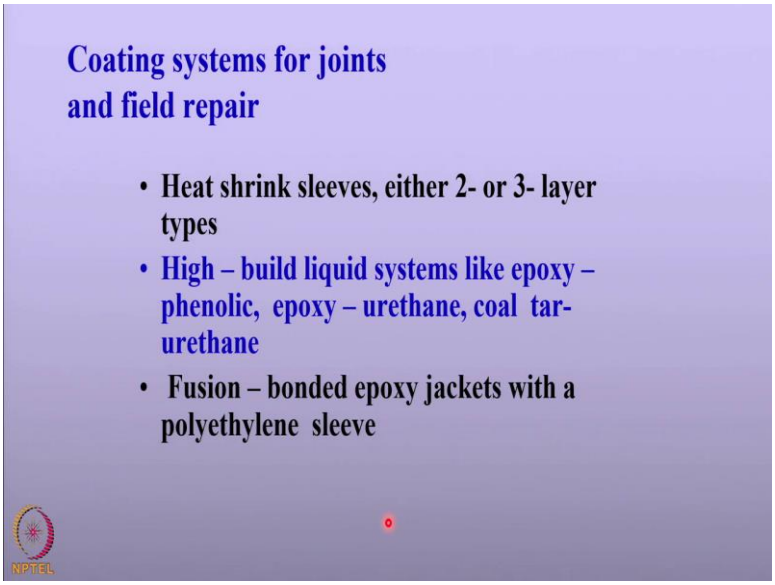

We have seen so, far coatings applied at the mill the coatings are also applied on the field one is for the joint joints and other whenever the coating is damaged. The three types of coatings are applied in the field it could be heat shrink sleeves either of 3 or 2 layer types like what is in polyethylene the polypropylene type or it could be epoxy phenolic epoxy urethane coal tar urethane and so, on so, forth.

In this case, this is applied in the liquid state and allowed to cure you can also use a fusion bonded epoxy jackets with the polyethylene sleeve in order to improve the coating performance.

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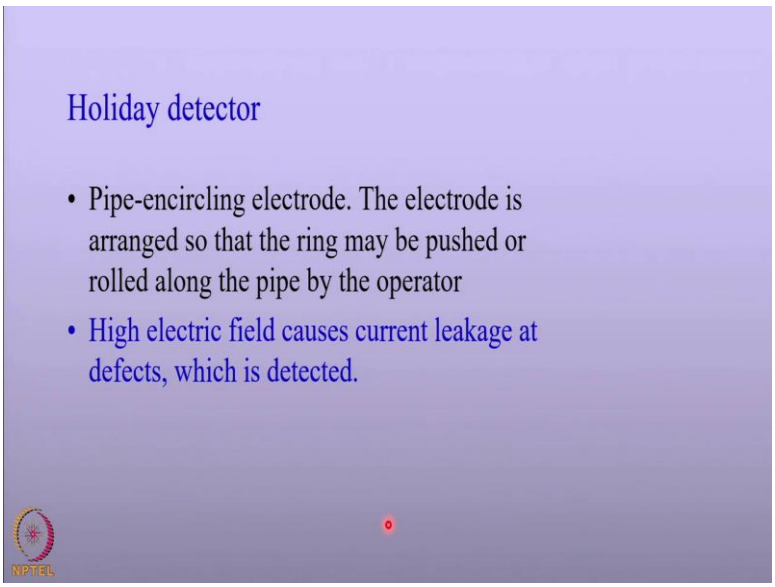

We know that the holidays in the coatings could be detrimental, it can lead to cathodic disbondment, it can lead to higher current demand. So, it is important to inspect the pipeline against the presence of holidays.

The technique is using applying higher voltage between a circling electrode on the pipeline and this electrode is moved from one end to another end and as the ring is pushed or rolled over the pipeline whenever this ring encounters a defect because of high electric field a current leakage occurs and which is detected and repaired.

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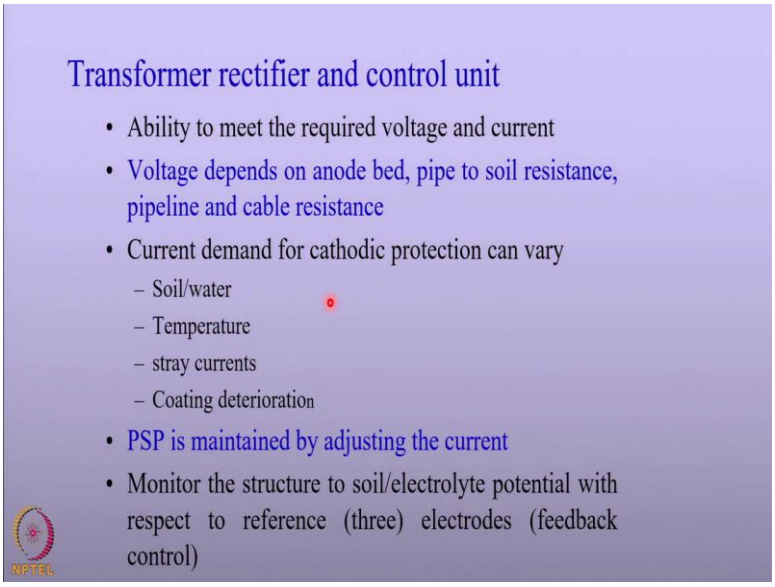

We shall now move on to the next topic of discussion today that is Transformer Rectifier and Control unit this is called as TRU in the cathodic protection parlance. The rectifier must able to meet the required voltage and the current for cathodic protection of the intended structures.

Now, we also know that the voltage the required voltage to protect cathodically a structure also depends upon the anode bed resistance pipe to soil resistance, pipeline resistance and cable resistances. So, when you know all these values then it is possible to calculate the voltage required to maintain for cathodic protection of structures.

We also know that what is the current required per unit area. So, accordingly the current capacity can be calculated. However, the demand for current could change over a time period when there is a change in soil chemistry or the water or if the temperature of the

pipeline or the structure changes because you change the process fluids or in case there are stray current corrosion coming into pitches and coating can also deteriorate over a time period.

So, the current requirement can change with the time. So, when deciding the capacity of the rectifier one should take this into account. In typically one should maintain the required pipe to soil potentials and for that the required current is adjusted in the rectifier system.

And one can monitor the potential of the pipeline with respect to a copper copper sulfate electrode may be located at few locations and so, that the current can be varied to meet the requirement.

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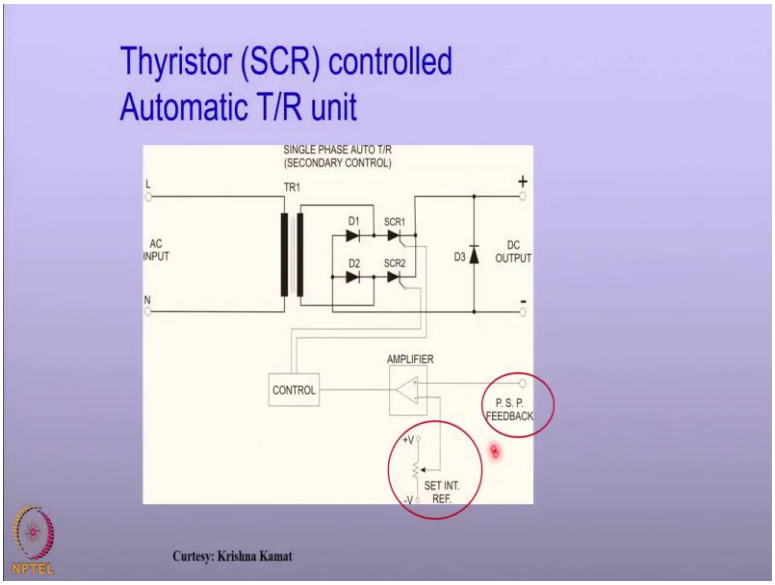

What I shown here is a schematic of a thyristor control automatic TR unit. The two important things that you look at it one is pipe to soil potentials this is measured using a reference set reference here right. So, if the pipe to soil potential is changing because of various conditions as we talked about before say stray current or coating defect has happened or because of the climatic conditions you know wet conditions happening.

If the pipe to soil potential changes and that is measured with respect to set internal reference, it feeds to an amplifier and then the current is adjusted so, that the pipe to soil

potential is maintained to require values. So, this is normally done in a automatic TR unit.

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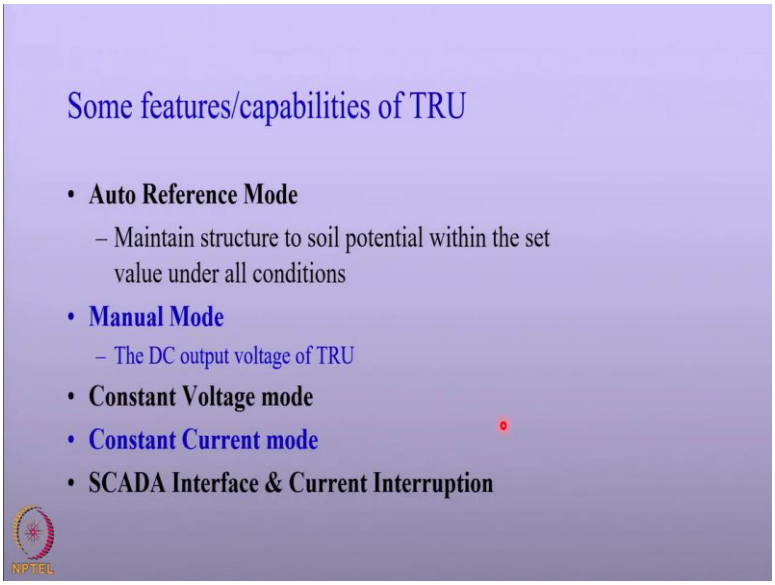

Some other features and capabilities of TRU as you seen before it is auto referencing mode it maintains the pipe to soil potentials all through the rectifier must also have the capacity to operate using a manual mode to change the dc output in terms of voltage or maybe in terms of current also.

In addition to these the control unit should have a SCADA interface in order to remotely monitor and control the cathodic protection the TR unit can also have a current interrupter whenever you want to do a survey and should be synchronized so, that you can able to measure the off potential of the pipeline or the structure with respect to soils. So, we have almost come to the end of this lecture. So, before I close this lecture I like to summarize what you seen so, far.

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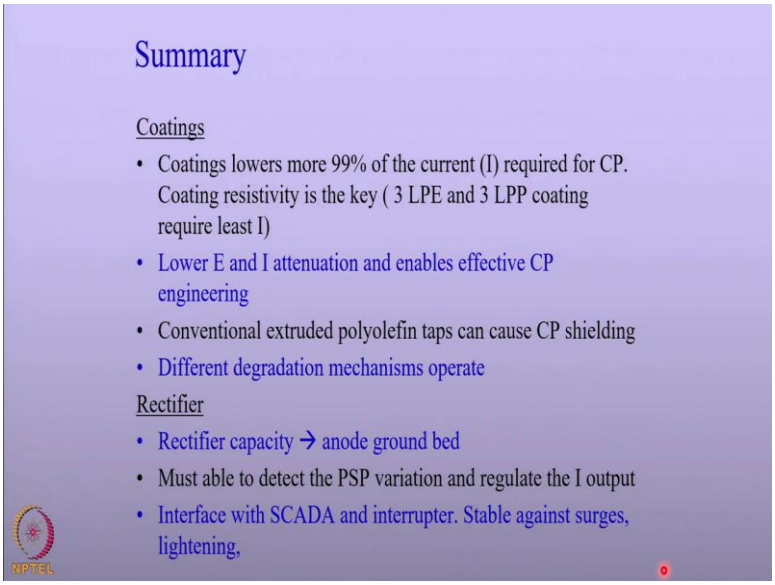

We looked at the two important topics of cathodic protection one is coatings other is rectifier. We saw that coatings and cathodic protections are complementary. Coatings make the cathodic protection very efficient it also reduces the current demand for cathodic protection and there are different types of coatings among them three-layer polyethylene coatings, three layer polypropylene coatings are considered to be most effective in reducing the current requirement for cathodic protection.

As we have seen earlier the coating not only lowers the current demand, it also lowers the potential and current attenuation occurs along the long pipelines and it makes the cathodic protection very effective. In fact, the reducing the attenuation also increases the resistance of the coating against cathodic disbondement, it also lowers the tendency of the pipeline towards hydrogen embrittlement.

We also saw that the conventional extruded polyolefin taps can cause CP shielding and that is now avoided by fusing these layers the next aspect is rectifier. In rectifier we look at the capacity of the rectifier in terms of voltage and current in addition to the capacity of the rectifier the ability of the rectifier to maintain the pipe to soil potentials or the pipe to structure potentials under various changes occurring in the soil or due to sticker and corrosion etcetera.

So, that is done by regulating the current output. The rectifier control unit should also have ability to interface with SCADA and also have interrupted. It should be stable

against surges and lightning so, that it is not damaged in service. I hope you had a reasonable overview of the coatings and rectifiers in this lecture.

Thank you.