Power System Analysis
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Lecture - 10
Transmission Line Steady State Operation
Voltage Control (Contd.)

Welcome to lesson 10, on Power System Analysis. In this lesson, we will be continuing from what we did in lesson 9. That is Transmission Line Steady State Operation. In lesson 9, we talked about the power flow equations on transmission line, under steady state operating conditions. We also discussed how we can compensate for the reactive power flow on the line. And thereby, maintain the voltage profile on the line.

We discussed there static compensation equipment. We also discussed about the rotating compensation equipment. And this lesson, we will talk about the transformer taps and the combination of these equipments. We will also discussed, something about the regulating transformers, how we can control the voltage and power flow on the line, using these regulating transformers. And after this, we will try to solve some problems, which will clarify most of the ideas, that we discussed in lesson 9. And what we will be discussing in lesson 10, today.

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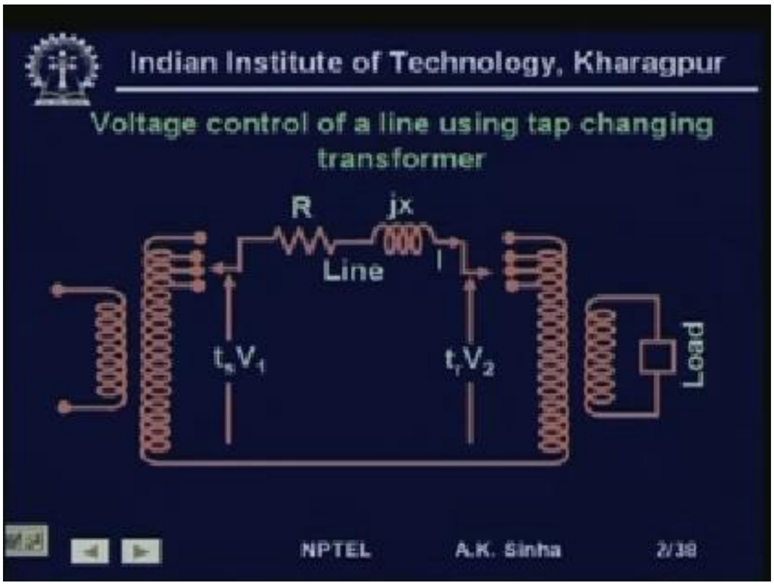

So, we will start with voltage control of a line using tap changing transformers. Here, we have this transmission line, given by it is simple short line model of R plus j x. We have neglected the shunt capacitance for the line in this model. And we have step up transformer, at the sending end. And we are assuming that we have a generator on this side and we have a step up transformer here.

On this transformer, we have a number of taps on the high voltage side. There by, changing the taps we change the turn’s ratio and therefore, the output voltage of the transformer or the voltage of the transformer on the high voltage side. Then, on the receiving end, we again have step down transformer, where we have again taps on the high voltage side. And by changing the tap on this side, we can get the change in voltage at a load.

Therefore, for any given at the voltage at the supply end, we can by managing the taps on the two sides of the transmission line. That is on the two transformers on the two sides of the transmission line, we can control the voltage to the load. Now, these taps are what we call as off nominal tap. That is, if it is placed in a position, where it is the nominal turns ratio of the transformer.

Suppose, this is a 11 kV to 220 kV transformer. Then, when we are putting 11 kV on this side and the low volt this side and if we put the tap at the nominal position, then we will get 220 kV on the high voltage side. And if we place the tap on the upper side of the nominal tap or on the lower side of the nominal tap, we will get different voltage. If you put it on the upper side, we will get higher voltages, if we put it on the lower side, we will get lower voltages.

Normally, the transformers may have taps, which can be in terms of variation of plus minus 5 to 10 percent, with variation at each tap of the order of 2 percent or 2.5 percent or so. Similar thing, we have on the low voltage side. Here, also we can place the taps at the nominal position and then we will get the nominal voltage ratios. If we place the tap above or below, then we will get different voltage is like, if we put it above the nominal position.

Then, the load voltage is going to be somewhat lower than, what it will be, if it is place at the nominal position. Because, high voltage side number of turns will increase, where as the low voltage side the number of turns being same, the ratio will get reduced. So, similarly if we put it on the lower side of the nominal, we will get somewhat higher voltage on the low voltage side.

Now, normally these taps are always placed on the high voltage winding. One reason is, the high voltage winding will be carrying much less current. And therefore, when we are changing this tap especially, if we have on load tap changing transformer, that is OLTC. Then, the current will be much lower here. Also it has been found, that if we place the taps on the high voltage side, we get a much better voltage control, then if we place it on the low voltage side.

So, here, I am showing in this diagram, that we have a voltage t s into V 1, at the sending end, where t s is the off nominal tap ratio. It can be in terms of say, if it is at 100, 10 percent, 10 percent above the normal, then the value of t s is 1.1. If it is say at 5 percent below the nominal, then the value of t s will be 0.95. Similarly, on the receiving end side, we have the off nominal tap ratio as t r. And therefore, the voltage here will be t r into V 2.

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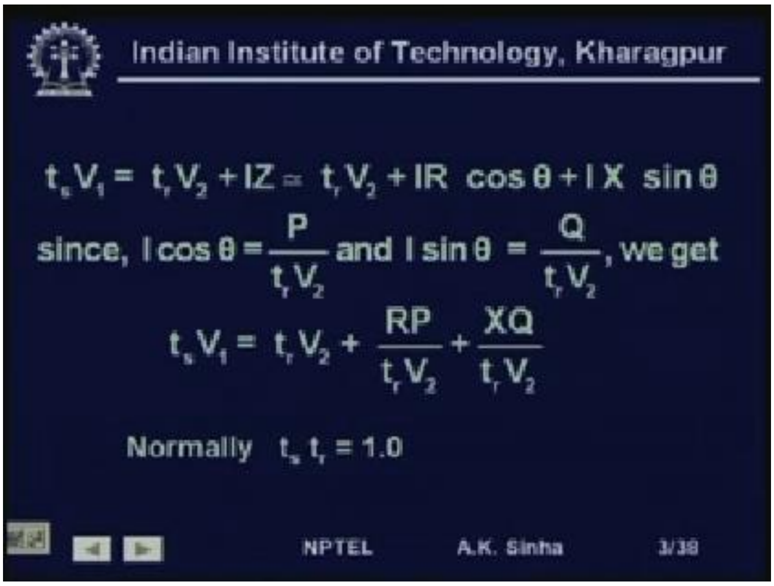

Now, writing the circuit equation for this. We have t s into V 1.

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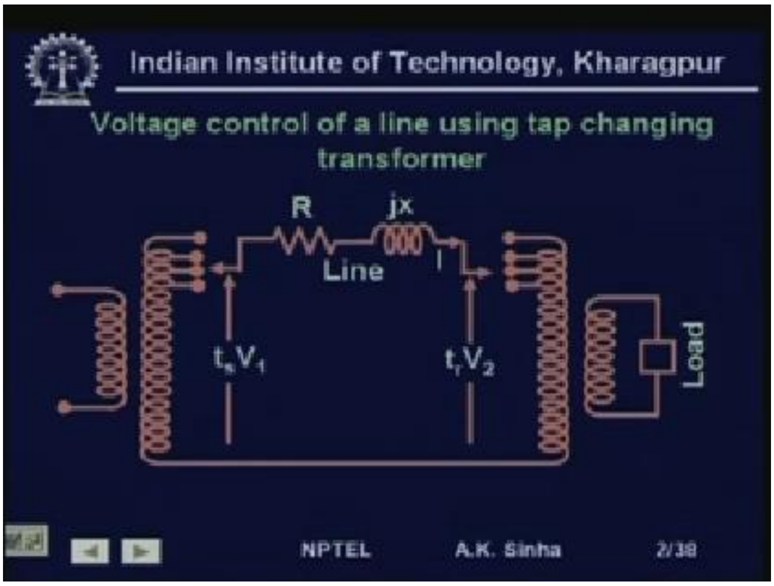

That is, if we go here t s into V 1 will be equal to t r into V 2 plus the drop, which takes place here. If the current flowing in this line is I, then it will be I into Z, Z is equal to R plus j x.

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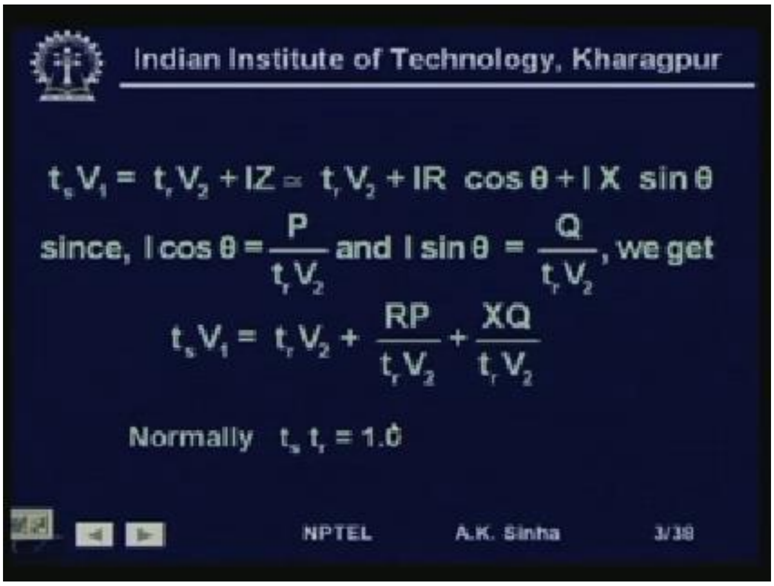

Therefore, we have t s into V 1 is equal to t r, V 2 plus I into Z. Now, this will be approximately equal to t r into V 2 plus I into Z is I into R plus j x, which we can write as approximately equal to I into R cos theta plus I into X sin theta. Now, we also know that, I cos theta will be equal to P by t r into V 2, because t r into V 2 is the voltage. So, V I cos theta is equal to the real power P, therefore I cos theta is equal to P by t r into V 2.

And similarly, we have the reactive power Q is equal to t r into V 2 into I sin theta. This is the voltage into I sin theta is equal to Q. So, I sin theta is equal to Q by t r into V 2. Therefore, substituting these we will get t s into V 1 is equal to t r, V 2 plus this is R into I cos theta. So, R into I cos theta we are replacing by P by t r, V 2. So, R into P by t r, V 2 plus I X into I sin theta. So, X into Q by t r, V 2. This is I sin theta, we have substituted here. Normally, what we do is, we want to keep t s into t r as equal to 1. Because, this is what will make the voltages proper on both sides, so the product t s, t r is generally kept as 1.

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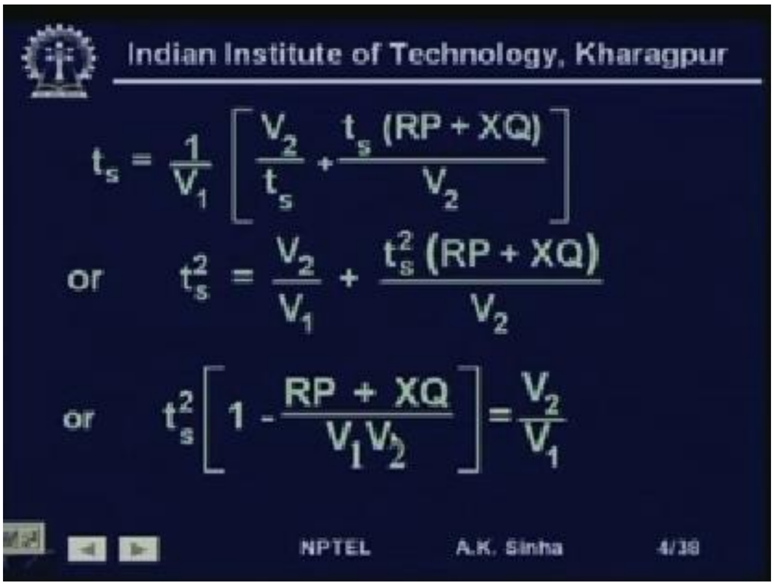

Then, if we do that, then we can write t r is equal to 1 by t s. And therefore, substituting that, we get t s is equal to 1 by V 1. That is V 1 t s is equal to V 2 by t.

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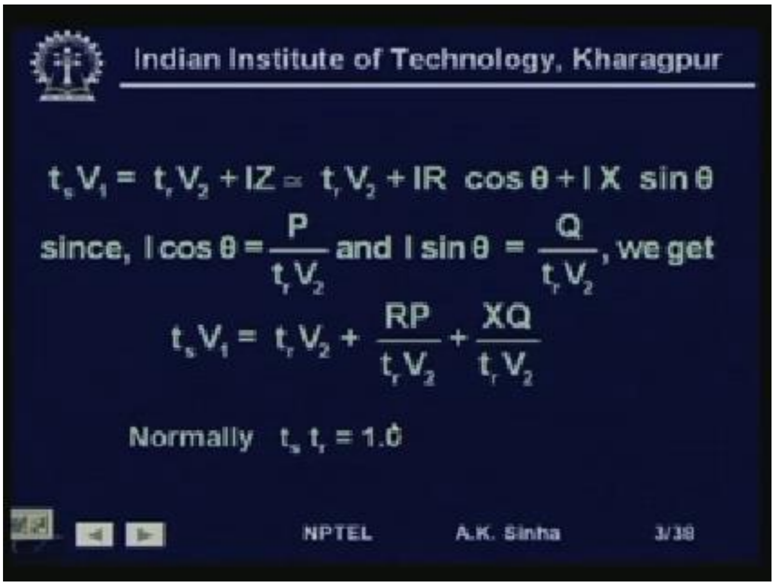

Here t r into V 2. So, t r into V 2, I am writing t r as 1 by t s.

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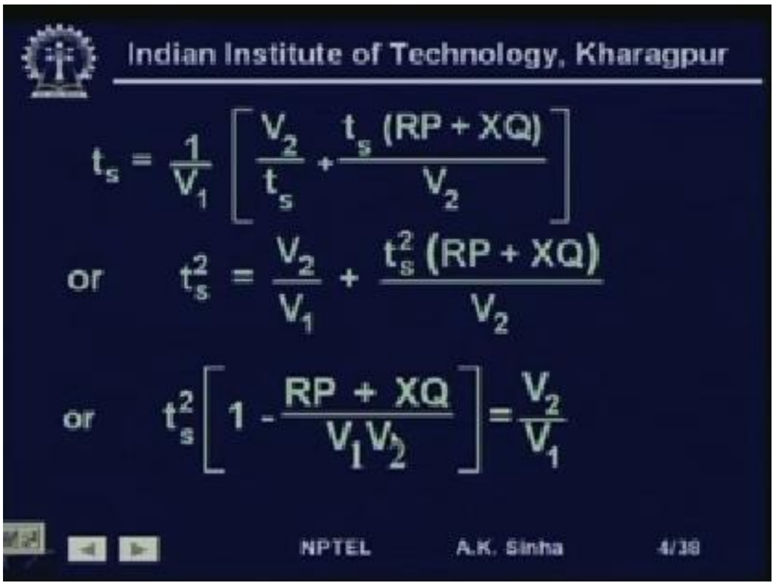

So, this becomes V 2 by t s plus t s into R P plus X Q by V 2, which if we multiply the both sides by t s. Then, we get t s squared is equal to V 2 by V 1, because this t s will cancel out plus t s squared, because it is multiplied by t s. So, t s squared R P plus X Q divided by V 2, I am sorry, this should be V 1, V 2. And therefore, if we take this taking on this side, then we will get t s squared one minus R P plus X Q divide by V 1, V 2.

Because, this here is V 1, V 2, so 1 minus R P plus X Q, V 1 divided by V 1, V 2 is equal to this term V 2 by V 1.

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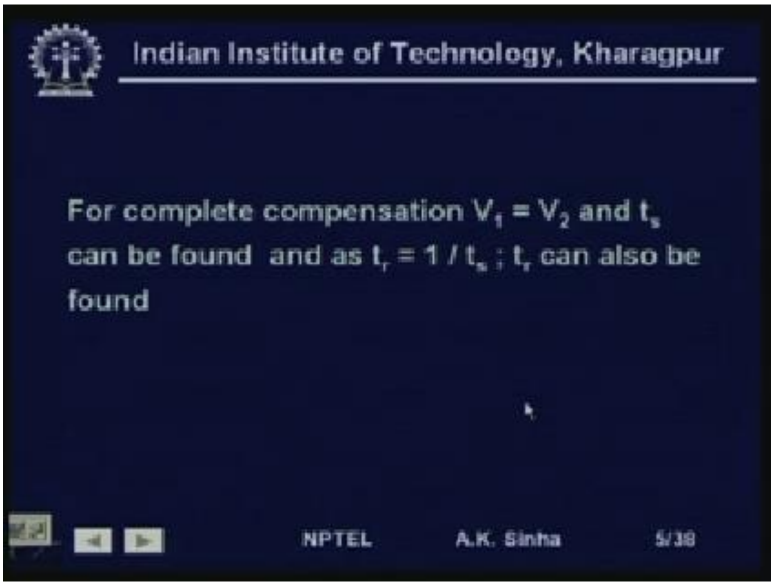

So, from this, we can find out the value of t s for a complete compensation. That is, when V 1 is equal to V 2. Mind it, we are writing all these values V 1, V 2 as per unit values. So, if we want both of them to be 1 per unit, then we can write this as V 1 is equal to V 2 or both side voltages, becoming equal.

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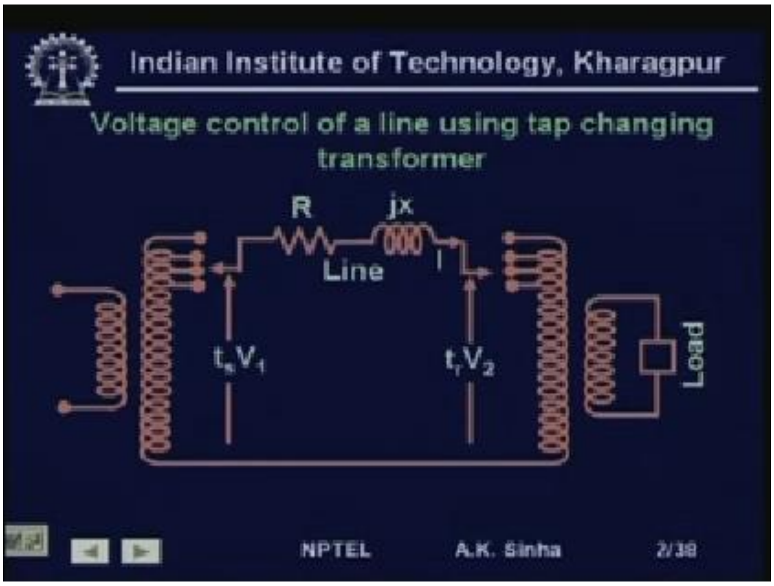

In this case here and here, both the voltages on the transmission line, two ends being equal.

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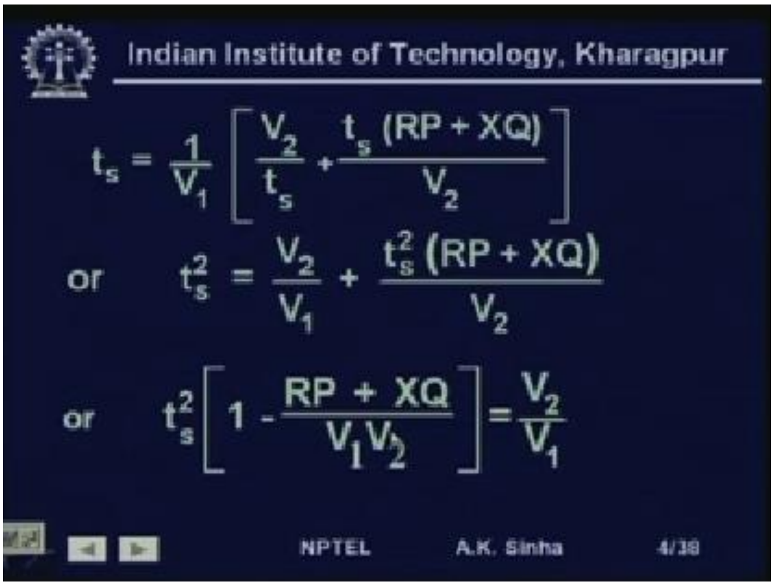

That is the line is fully compensated.

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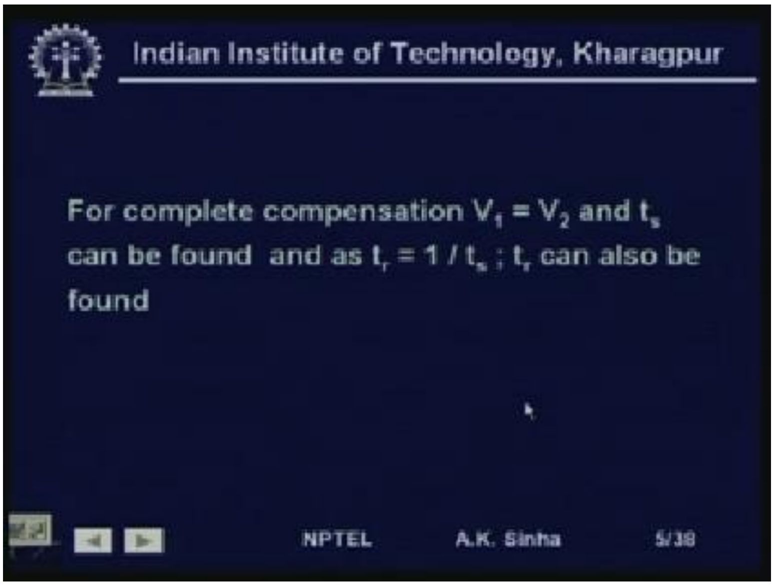

Then, V 1 is equal to V 2 and t s can be found out from this relationship.

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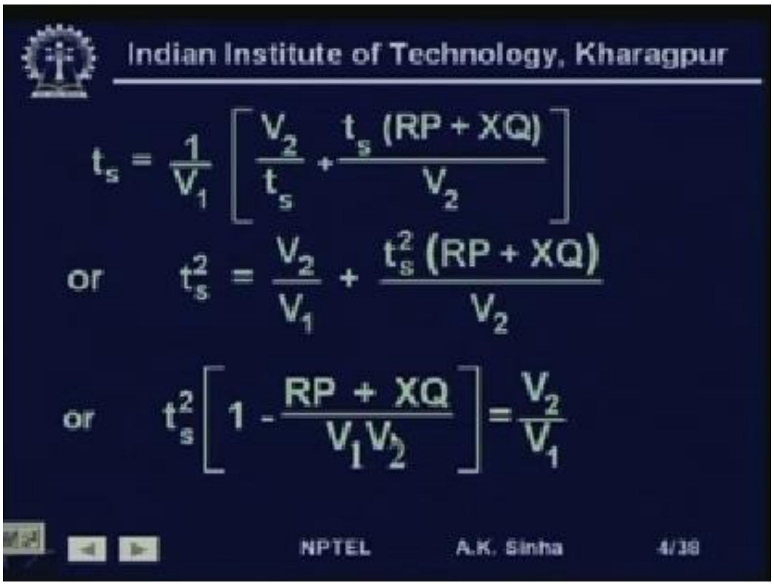

Form here, because V 2 by V 1 will be equal to 1 and solving this, we will get the value of t s.

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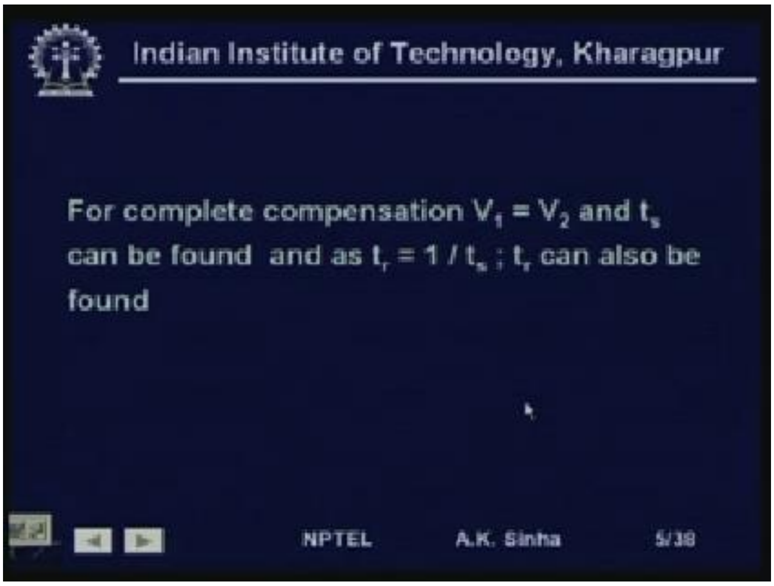

Once, we get t s we know t r is equal to 1 by t s. So, we can also solve for t r. In fact, for any ratio of V 1, V 2 we solve this for t s and then t r.

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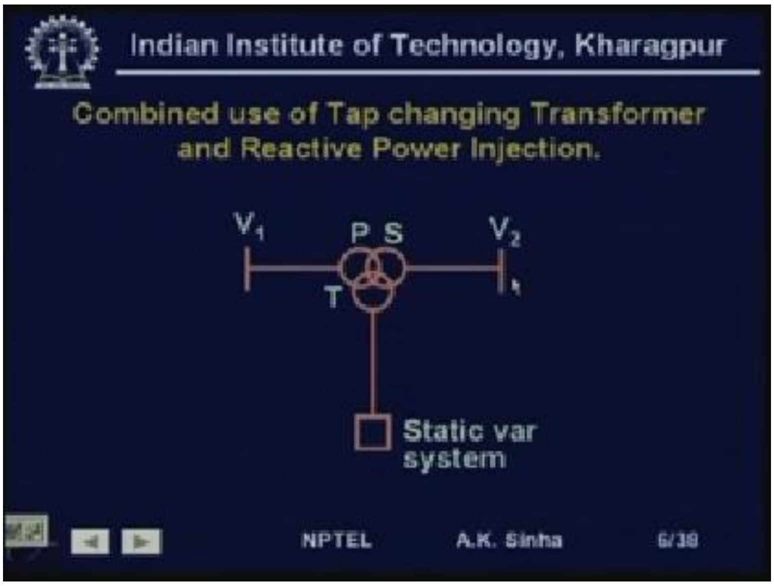

Now, sometimes, we would like to use a combination of the transformer taps as well as the reactive power injection devices. Such as, static power systems or static compensation, any static compensation device, like may be stat com, another devices. So, here I am showing this, there is between these two buses voltage V 1 is at a sending end and voltage V 2 as at the receiving end. We have a transmission line and may be a three winding transformer, which is connected near the receiving end.

And the tertiary of the transformer, we connect the static var system or static compensation device. The primary side we have this transmission line, connected to the sending end. And secondary side, we have the load connected. That is, it is the receiving end bus.

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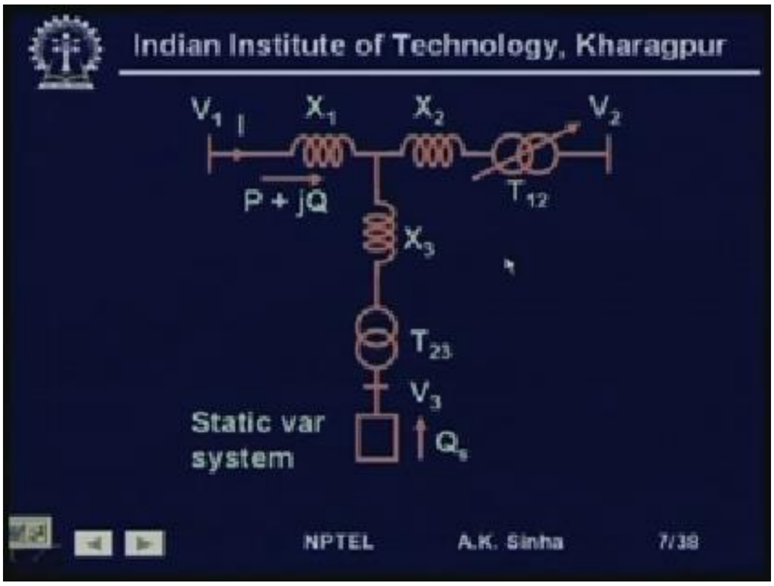

The whole diagram an electrical circuit can be represented by this, where, we have V 1 the sending end, the current I is following through this. X 1 is the reactance of the transmission line, we have neglected the resistance. So, it is the reactance of the transmission line, plus the reactance of the primary side of the transformer winding. X 2 is the reactance of the secondary side of the transformer winding. And X 3 is the reactance of the tertiary winding.

And we have this as the transformation ratio the transformer is shown here. Here, we have the transformation ratio. And we have a variable tap. That is T 12 is showing a variable tap between primary and secondary. So, by changing this T 12, we are basically changing the tap on the secondary side of this. Similarly, we have here on the tertiary; we have connected the static var system or the stat com, which is a static compensation device.

Normally, all these compensating devices, we connect to the tertiary. Also, it is always connected to the low voltage side. For simple reason, because developing or making these devices with low voltage is much cheaper compare to making these devices for very high voltage system. So, therefore, we normally connect these devices at the low voltage end.

So, this is connected on the tertiary. Now, if you see if P plus j Q is the power, which is coming from the sending end. We will have at the receiving end, the power P R plus j Q

R. And if we want that the voltage of the system to be maintained, then what we need is to transfer less amount of reactive power from here.

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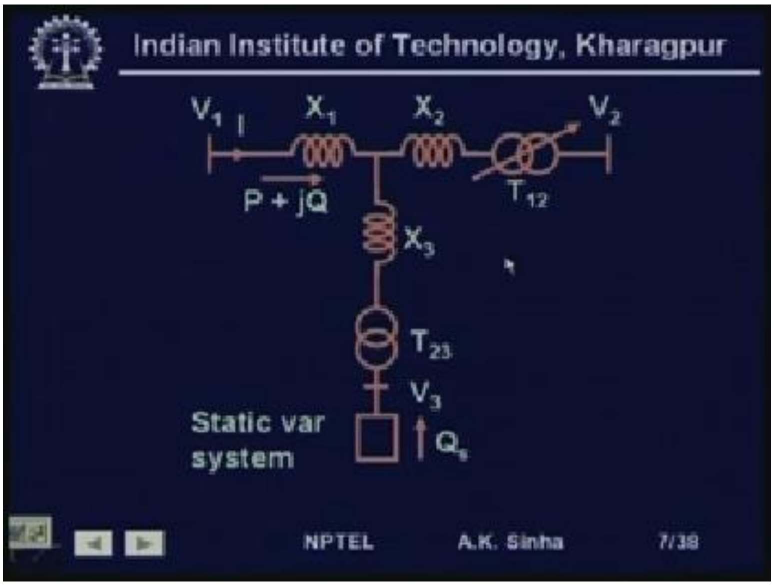

Less amount of reactive power from here, because we know that, if we transfer less amount of reactive power, the voltage at this point will be much higher or much nearer to the voltage here. And therefore, by trying to inject the amount of reactive power, through this compensating device, we can reduce or make this reactive power flow on the line and in the primary of the transformer to very low value or even 0. Sometimes, we can even make it leading and thereby, we can control the voltage here. The other option is by changing that transformer taps; we can again regulate the voltage at V 2. So, a combination of these two, will give me a much larger variation over a larger load variation in the system.

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Now, many times we use regulating transformers. Basically, these transformers are used for injecting voltage into the transmission system. If we inject the voltage in the same phase as the voltage on the transmission system, then what we will be doing is, either we can add the voltage. And therefore, boost the voltage or if we want we can inject the voltage in opposite phase. Then, we will be reducing the voltage or bucking the voltage.

So, we can have a buck transformer or a boost transformer. Normally, in power system, we will be using boost transformers, most of the time, because with the increase in load, it is always the voltage which drops down. So, we try to inject voltage in phase with the voltage on the transmission line. By that way, we can control or the magnitude of the voltage.

If we inject the voltage, in not in phase, with the transmission line voltage, but in quadrature or at some different angle, then we can be making a phase shift of the voltage as well. Because, the final voltage which is coming at the receiving end will be the some of these two voltages, the sending end voltage plus the voltage, which we are adding by this transformer. And since to these two are phases and they are not in same phase. We will get the resultant voltage having some phase difference, from the voltage at the sending end or at the primary side of these transformers.

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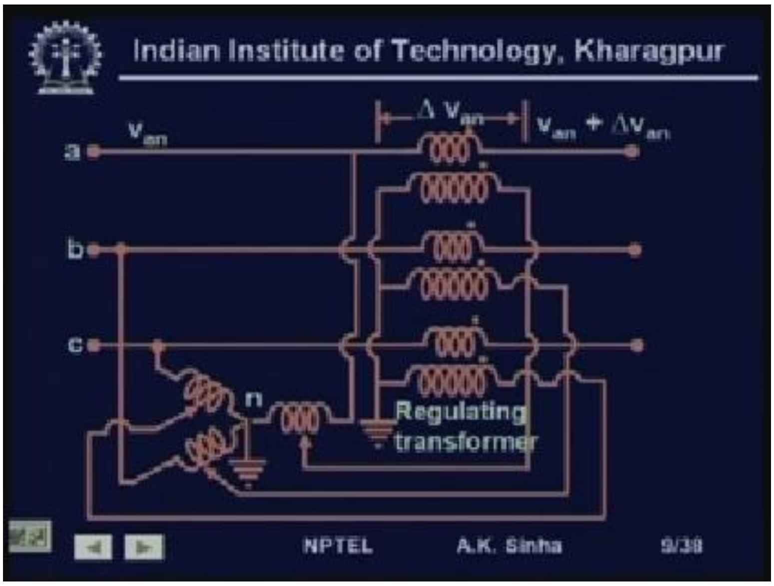

So, here, this is voltage magnitude controller or regulating transformer, which controls the voltage magnitude only. If you look at this, here we have transformer winding, which is a three phase winding, connected to the three phase transformer. And we have taps on this winding. Now, based on all these three taps on the three phases are all ganged. So, they will move together.

So, what we get is, this voltage, whatever voltage we want here, between these two points, will get injected here. So, this voltage can be added to the transmission line voltage in the same phase here. This voltage is in the same phase as this voltage. And therefore, the voltage here is going to be the voltage at this point plus this voltage that we have added.

Because, it is in phase, the same thing happens in all the three phases. And therefore, the secondary voltage gets increased by the amount of the voltage that we have injected. This is the way, how we use the regulating transformer for increasing the magnitude of the voltage at the secondary of this regulating transformer.

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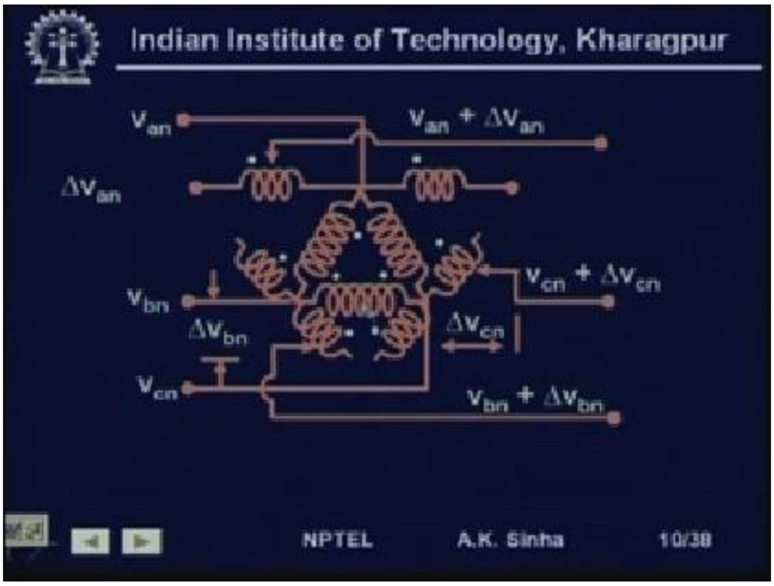

Now, the same thing, if we do by injecting voltage, which is not in phase, but in quadrature. If you look at this transformer, we have a transformer here, like this, which is connected to the primary three phases a n, b n and c n are connected at these points. We have another winding, which has half on this side and half on this side. That is the mid points is connected to this point a and this winding is having the phase of b c.

Similarly, we have a winding here, which is connected at the midpoint to b and this has a phase which is same as a c. Similarly, we have another winding, which is connected at the midpoint to phase c and this has a phase which is same as a b. In this way, what we do is, if you look at the phase a voltage, phase a voltage will be like this. Phase a voltage will be like this, phase b voltage will be like this and phase c voltage, will be like this.

Therefore, we have seen, we are adding or subtracting the voltage or adding any voltage, which is in quadrature, which phase a in this side or in this side. So, if we see, in this present position, the three taps are place like this. Then, we have a voltage V a on which, we have this much voltage added, that is delta Van is added here. Similarly, we have voltage b plus delta b n is added here. We have voltage c plus delta c n is added here.

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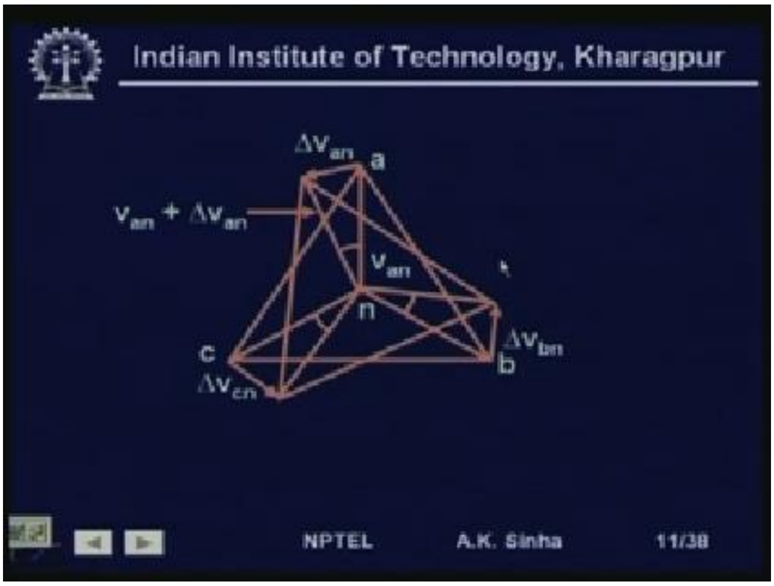

And if we see the phasor, it comes out to be V a is the voltage plus delta V a n is added here. V b is the voltage plus delta V b n is added here. V c is the voltage and delta c n is added here. So, now the new voltage a dash, b dash and c dash will be these points. And we see that, though there may not be large change in the magnitude, the angle of these phases has change. That is a dash is now leading a by this angle theta.

Similarly, c is leading this c by this angle theta and b is leading this b, b dash is leading b by this angle theta. So, this is, what we call as a phase regulating transformer or phase shifting transformer, this is how it works. And we can change the phase angle of the voltage and what is the consequence of changing this phase angle. As we have seen earlier, the real power P is given by V s, V r, by X into sin delta.

Since, V s, V r are regulated to be very near to 1 per unit and X of the transmission line is a constant, therefore to change the real power of flow on the transmission. The only thing that we can do is, change this angle power angle delta, which is the angle by which V s leads V r. And therefore, if you see here by changing this angle, we can change the power flow.

So, by changing the angle of at V r or at V s, we can change the power flow on a transmission line and phase shifting transformers are used for this purpose. Of course, nowadays with power electronic devices coming into picture, we have new kinds of controllers, which we use for power system. Transmission line, voltage and power control. These devices are called flexible ac transmission system devices or facts devices, because they allow you the flexibility of controlling the power flow and the voltage. And thereby, the reactive powers flow on the transmission line. So, both real and reactive power flow in a transmission line can be controlled using these facts devices. Now, we will take up some simple examples, on transmission line operation to understand the concepts. That we learnt in lesson 9 and 10.

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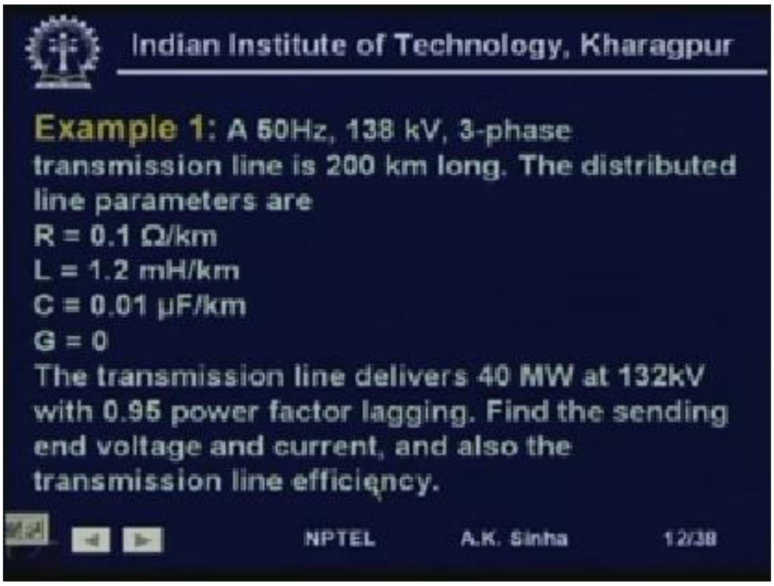

So, first example is a 50 hertz, 132 kV, 138 kV 3 phase transmission line is 200 kilometer long. The distributed line parameters are R is equal to 0.1 ohm per kilometer, L that is the inductance is equal to 1.2 milli Henry per kilometer. The capacitance c is 0.01 micro farad per kilometer the conductance is 0. The transmission line delivers 40 Mega Watt at 132 kV with 0.95 power factor lagging. Find the sending end voltage and current and also the transmission line efficiency.

So, what we are given is the transmission line parameters, it is resistance set in, it is inductance and capacitance per kilometer length. And we have the line length given; we also know that the transmission line has to deliver 40 Mega Watt at 132 kV. Means, the receiving end voltage is 132 kV. And the receiving end power is 40 Mega Watt at 0.95 power factor lagging. We have to find the sending end voltage, that is V s and current that is I s and also the transmission line efficiency. So, let us see how we work it out.

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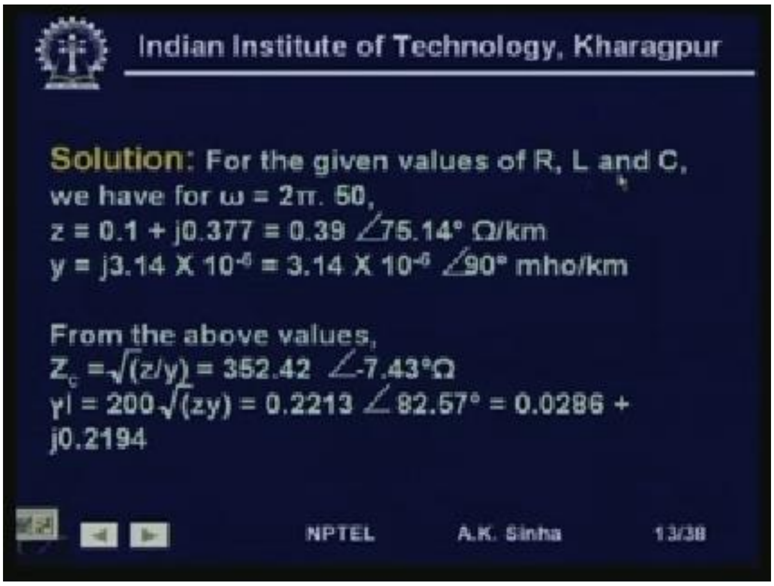

Now, for the given values of R L and C, we have omega. That is the equal to twice pi into f f is 50 hertz, therefore, we can calculate the series impedance per unit length or per kilometer as 0.1, which is the resistance plus j, 0.377. That is twice pi f into L. That is 1.2 milli henry, per kilometers. So, this comes out to be 0.1 plus j 0.377, which is equal to 0.39 with an angle of 75.14 in ohms, per kilometer.

Similarly, the shunt admittance can be computed as j omega c, which comes out to be twice pi into 50 in to 0.1 microfarad per kilometer. So, when we do that multiplication, this is j omega into c and then this comes out to be j 3.14 into 10 to power minus 6. This is equal to 3.14 into 10 to power minus 6, with an angle of 90 degrees; the unit will be mho per kilometer.

Now, using this z and y, we can calculate the characteristic impedance Z c. Z c is given by square root of z by y. So, substituting a value of z and y, we get Z c is equal to 352.42 with an angle of minus 7.43, this will have unit is of ohm, because the length per kilometer, will cancel out and this, will have the unit ohm. Similarly, we can calculate gamma l, this is l is 200 and gamma is given by root z into y.

So, substituting the values, we get this as equal to 0.2213 with an angle of 82.75 degrees, which can be written in rectangular coordinates as 0.0286 plus j 0.2194. So, now that we have calculated gamma l and Z c, we can find out also the values of sin hyperbolic gamma l and cos.

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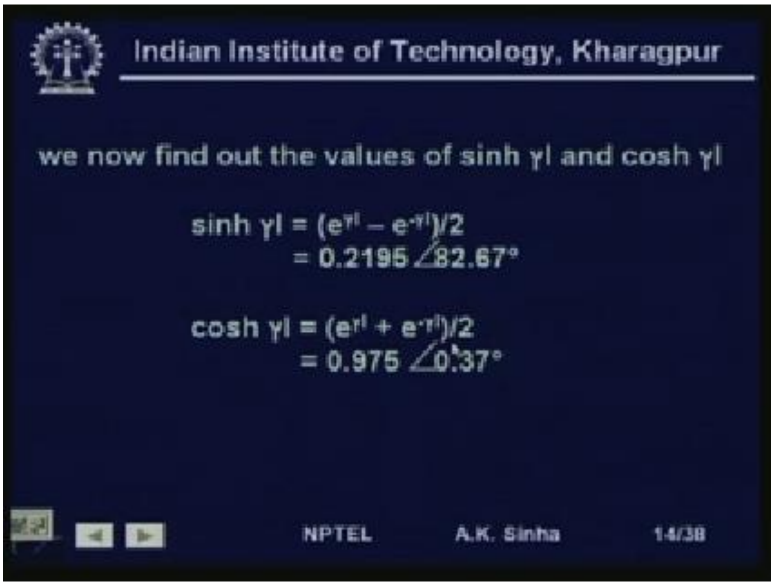

Hyperbolic gamma l sign hyperbolic gamma l is equal to e to the power gamma l minus e to the power of minus gamma l divided by 2, which is after substituting the value of gamma l will come out to be 0.2195 with an angle 82.67. Similarly, cos hyperbolic gamma l will be equal to e to the power gamma l plus e to the power minus gamma l. This whole divided by 2, which will come out to be on substituting the values of gamma l. This comes out to be 0.975 with an angle 0 .37 degrees.

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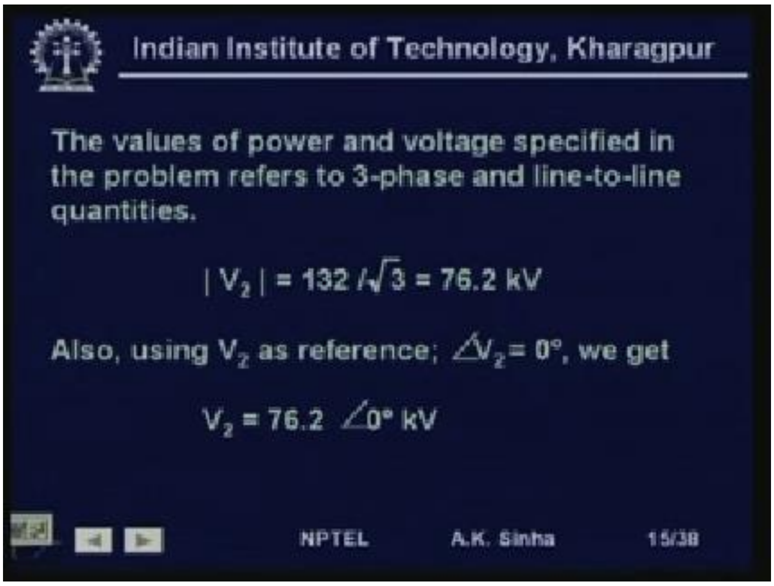

So, knowing sign hyperbolic gamma l cos hyperbolic gamma l and Z c. We can calculate a, b, c, d parameters for the transmission line. Now, the value of power and voltage is specified in the problem refers to three phase and line to line quantities. That is the values, that we are given in the problem is in terms of 132 kV, which is a line to line voltage and 40 Mega Watt, which is a three phase power.

Therefore, the V 2 or the receiving and voltage magnitude is equal to 132 by root 3. We are talking of per phase value or phase to neutral value. So, it is 132 divide by root 3, which come out to be 76.2 kV, because we would like to work on a single phase bases. Therefore, we will convert all the line to line voltages into line to neutral voltages and three phase power into single phase power. That is power per phase. Also we will use V 2, the receiving end voltage as a reference. Therefore, the angle of V 2, we will take as 0 degree. Therefore, the phasor V 2 is equal to 76.2 angle 0 degree in Kilo Volts.

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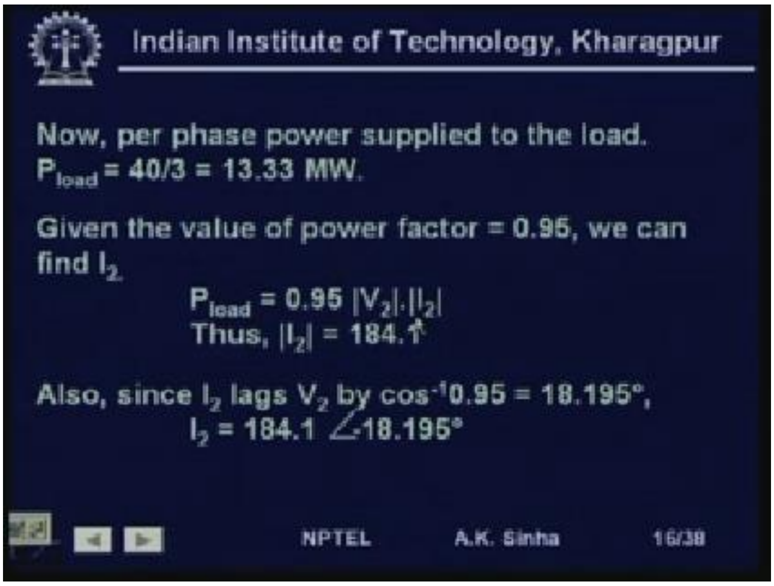

And the per phase power supplied to the load, will be equal to 40, is the three phase powers. So, 40 divided by 3; that is 13.33 Mega Watt. Given the value of power of factor which is 0.95, we can find out the current at the receiving end I 2. Now, we know P is equal to V I cos 5. So, the receiving end power P load will be equal to this is cos 5, 0.95 into V into I. And therefore, substituting the value of P load and V 2 we get I 2, as equal to 1 184.1 amperes.

We also know that, the phase angle between V 2 and I 2, is given by cos inverse 0.95, which is the power factor angle. So, also since I 2 lags V 2 by cos invar 0.95, which is 18.195 degrees. Therefore, we can write the phasor I 2, as I 2 is equal to 184.1 with an angle of minus 18.195. Because, I 2 is going to lags the voltage V 2, because the power factor is 0.95 lagging.

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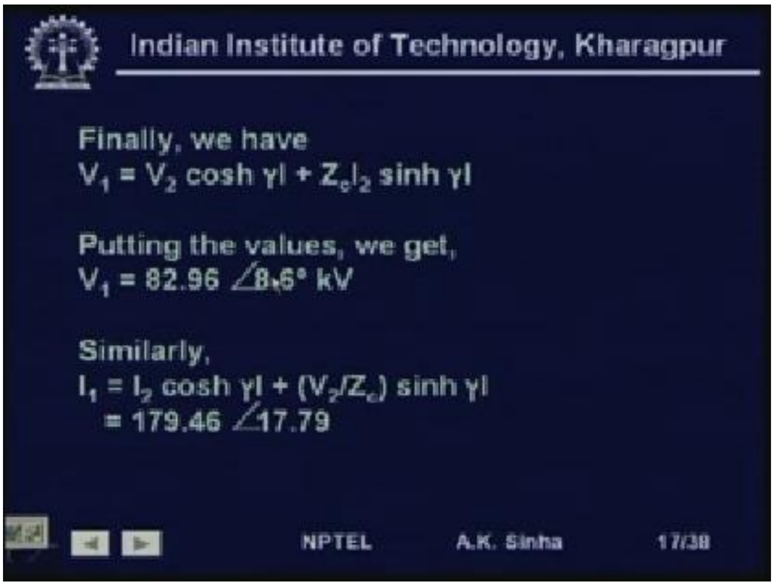

Therefore, now we can calculate the sending end voltage V 1, which will be given by a V 2 plus b, I 2. And a is cos hyperbolic gamma l and V is Z c sin hyperbolic gamma l. Therefore, V 1 is equal to V 2 cos hyperbolic gamma l plus I 2 into Z c sin hyperbolic gamma l. Now, if we substitute the value of cos hyperbolic gamma l, sin hyperbolic gamma l and Z c. Then, we will get the value of V 1 as equal to 82.96 with an angle, 8.6 degrees in Kilo Volts. So, V 1 is 82.96 Kilo Volts with an angle of 8.6 degrees.

Now, this is a line to neutral voltage at the sending end. Similarly, we can calculate the sending end current I 1, which will be equal to c, sorry which will be equal to C V 2 plus D I 2. D is equal to A, which is equal to cos hyperbolic gamma l and C is sin hyperbolic gamma l by Z c. Therefore, I 1 is equal to I 2 cos hyperbolic gamma l plus V 2 by Z c sin hyperbolic gamma l. Substituting, the value of V 2, Z c sin hyperbolic gamma l, cos hyperbolic gamma l and I 2, we will get I 1 as equal to 179.46 with an angle of 17.79 degrees.

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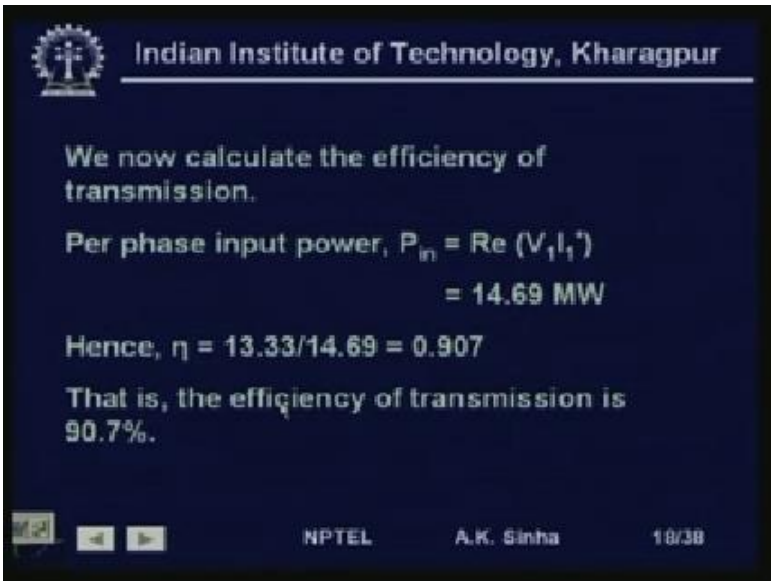

Now, we can calculate the efficiency of the transmission, so per phase, input power will be given by real part of V 1, I 1 conjugate.

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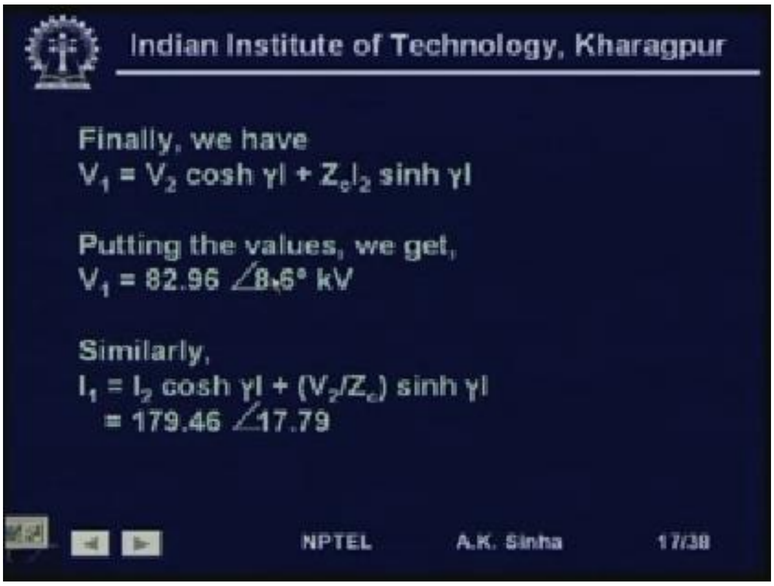

If we do this multiplication, because we know, V 1 is this and I 1 is this. We will take a conjugate, which means, we will put a negative sign to this angle.

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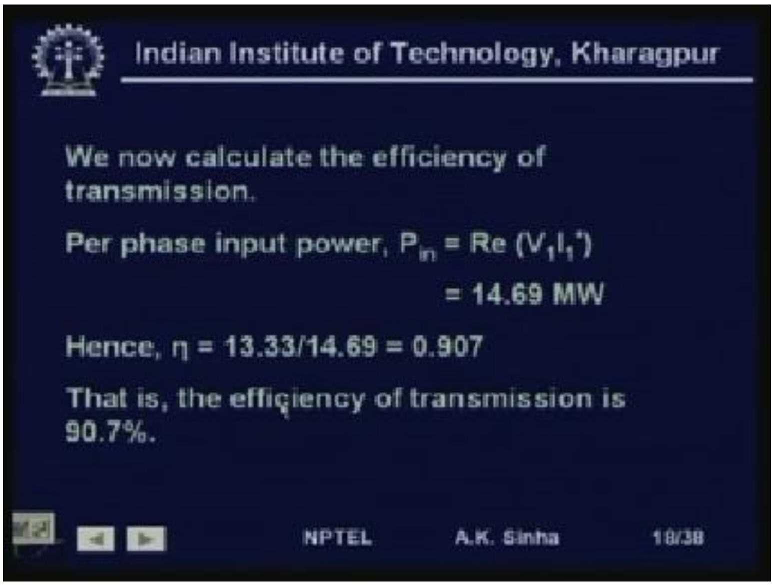

And then we multiply these two, then we are going to get and we take only the real part of that, then we get this as equal to 14.69 Mega Watt. Now, per phase power, which is received, is 40 by 3, which is 13.33. Therefore, efficiency of transmission is output divided by input, which comes out to be 13.33 divided by 14.69. That is 0.907 or the efficiency is 90.7 percent. So, this is one simple problem, that we solved.

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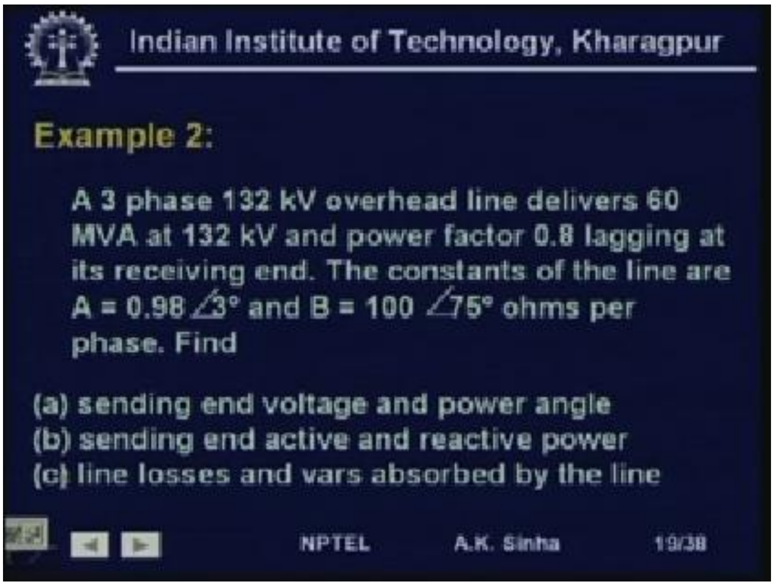

Now, we will take up another problem. Now, this problem states a three phase 132 kV overhead line delivers 60 MVA. Mind it, this is 60 MVA not Mega Watt, 60 MVA at

132 kV and power factor 0.8 lagging at it is receiving end. That is V r or V 2 is given as 132 kV and the P S R is the MVA value is given as 60, MVA at 0.8 power factor lagging. The constants of the line are given as A is equal to 0.98 with an angle 3 degrees and B is equal to 100 with an angle 75 degrees ohms per phase. Now, we need to find for this system, sending end voltage and power angle, B sending and active and reactive power, C line losses and vars absorbed by the line.

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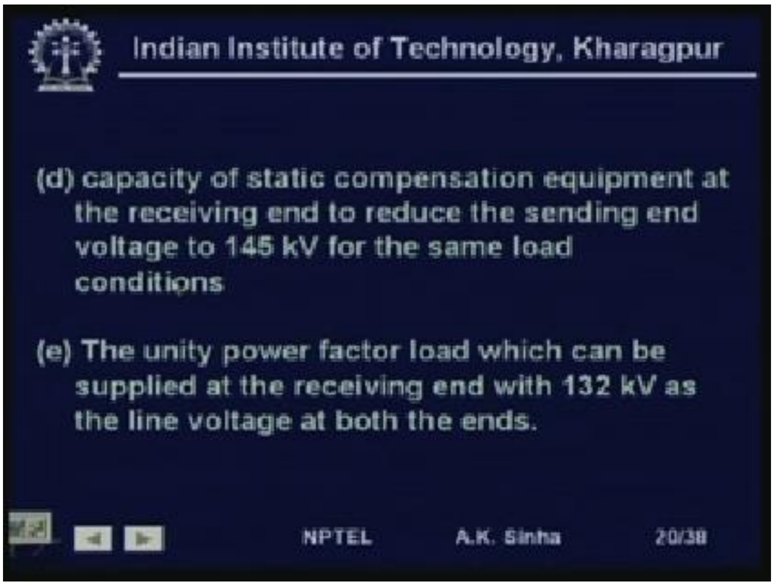
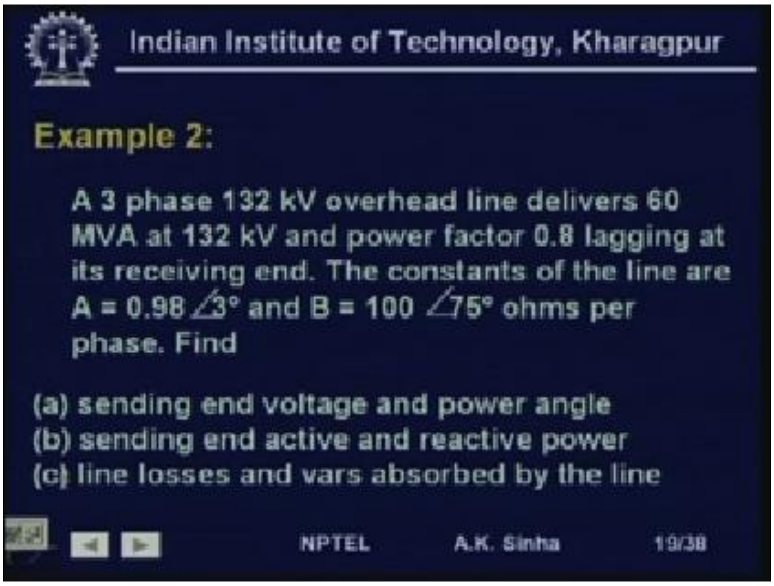


Also we would like to find out the capacity of static compensation equipment at the receiving end to reduce the sending end voltage to 145 kV for the same load conditions. (Refer Slide Time: 38:19)



That is whatever voltage, we have found out in A will be somewhat higher. And if you want to reduce this voltage by keeping the receiving end voltages kept at 132. And now, we want to keep the sending end voltage also at 145 only. That is, we do not want the voltage at the sending end two go beyond 145 kV. And therefore, we will require some compensation, reactive power compensation at the receiving end. So, we need to find out, what is the rating of the compensating equipment for such a condition.

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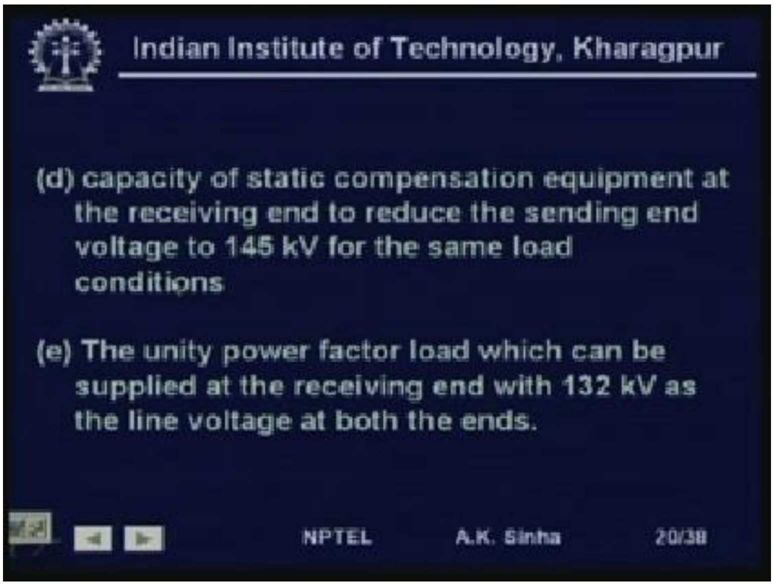

Also we need to find, the unity power factor load, which can be supplied at the receiving end with 132 kV as the line voltage at both the ends. Now, if we want to keep the voltage at both the ends at 132 kV, then what is the amount of unity power factor load?

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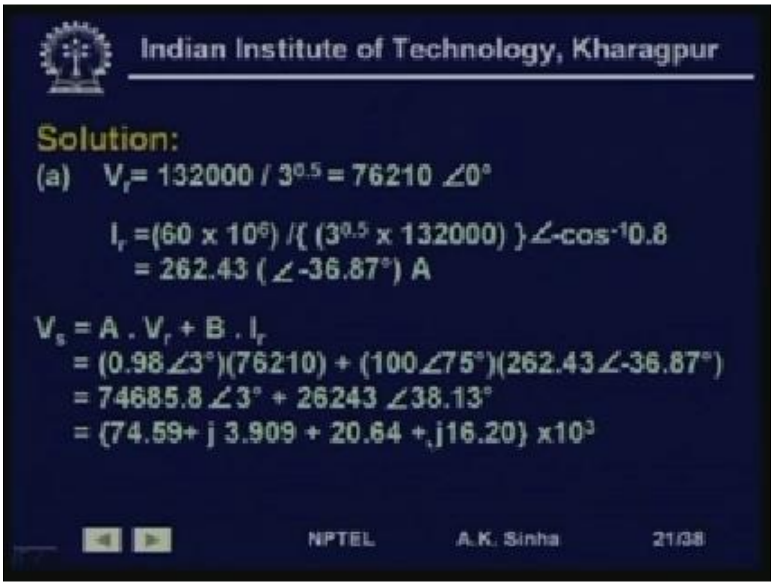

That is purely resistive load, which can be supplied by this transmission line, when we are working with three phase system, especially when we are calculating voltages and current. It is always better to work with the phase to neutral voltages and the currents flowing in each phase. So, what we do is, first we calculate the phase voltage, now for the receiving end, we have been given the voltage as 132 kV line to line.

So, we divided by root 3 to get the phase voltage, which comes out to be 76210, volts. That is 76.21 kV and we are choosing this receiving end voltage as a reference voltage. So, we fix it is angle as 0 degree. Now, next, what we have to do is, we need to find out the current, at the receiving end. We know that the power at the receiving end is given as 60 and the a, at a power factor of 0.8 power lagging.

So, what we do is 60 into 10 to power 6, gives us the 60 MVA with divided by the phase voltage. So, root 3 into, sorry, root 3 into the line voltage. So, this is 3 into 0.5, 3 to the power 0.5. That is root 3 into the line voltage, which is 132 kV. And the angle is given as cos inverse 0.8 with a minus sign to take care of the lagging power factor. When, we do this mathematics, we will get the receiving end current as 262.43 amperes, with an angle of minus 36.87 degrees.

Next is, we need to calculate the sending end voltage V s. We know is equal to A into V r plus B into I r. Since, we have already calculated V r as shown here and I r as shown here. So, we substitute these values. So, A is given as 0.98 angle 3 degrees, V r is 76210 volts plus B is given as 100 angle 75 degrees. And I r is given as 262.43 with an angle of minus 36.87 degrees.

Now, here we have not taken any angle here, because the angle of V r is 0 degree, which is the reference angle, with respect to which we are calculating all angles. So, when we do this calculation, we find this as 74685.8, with an angle of 3 degrees plus 26243, with an angle of 38.13 degrees. And finally, when we calculate this, we get this, out as 74.59 plus j 3.909, which we are this polar coordinate value is converted into rectangular coordinate values.

And this polar coordinate values is put in to rectangular coordinate values, then it comes out to be 20.64 plus j 16.20 and since these are in 1000's. So, we are multiplying this into 10 to the power 3. So, here instead of writing this 1000's, we have taken this 1000's here.

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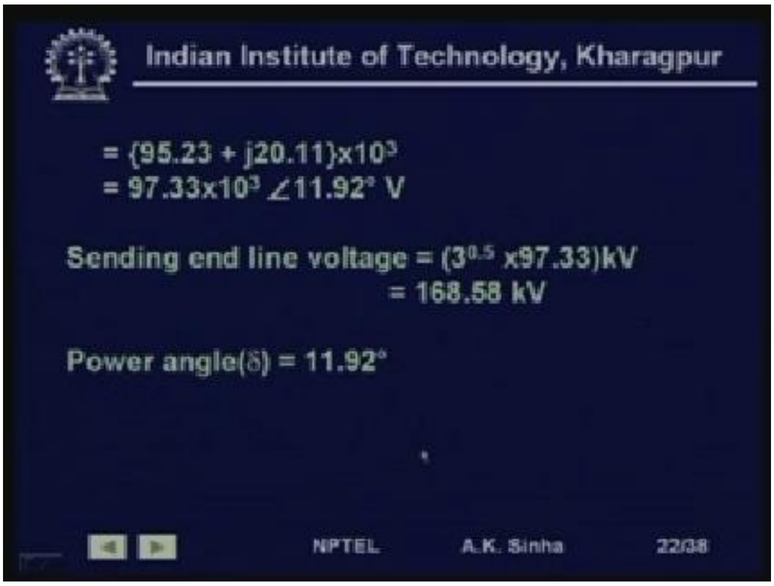

So, when we do this calculation, this comes out to be 95.23 plus j 20.11 into10 to the power 3. That is equal to 97.33 into 10 to the power 3, volts with an angle of 11.92, which tells us that the sending end voltage phase to neutral voltage is 97.33 kV. And the power angle is 11.92 volts, because this is the angle of the sending end with respect to the reference.

If you want to find out the line to line voltage at the sending end, then we multiply this by root 3. So, when we do this, we get this as 168.58 kV and the power angle as we have seen is equal to 11.92 degrees.

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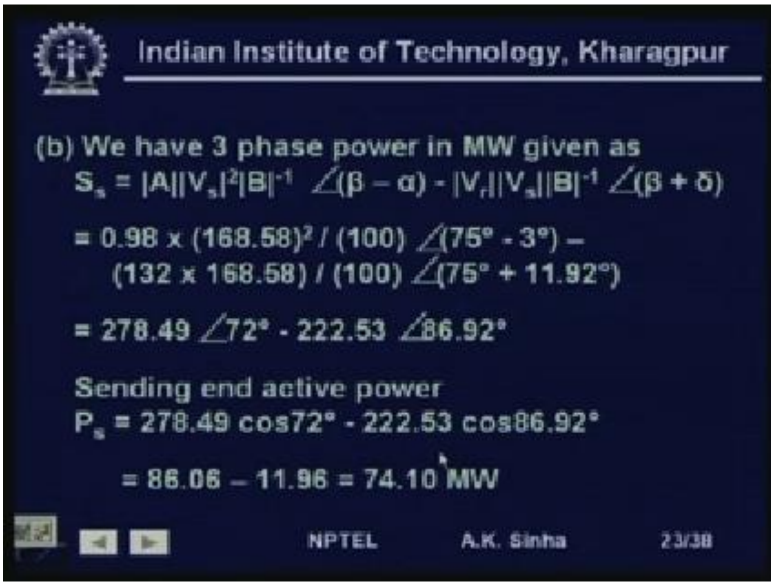

Now, for the b part, where we need to find out the sending end real and reactive power. We have three phase power in Mega Watt given as S s is equal to A V s squared divided by B, with an angle of beta minus alpha for division by B. We are writing B inverse, that is 1 by B minus V r, V s divided by B with an angle beta plus delta. Now, here, mind it, when we are writing this as three phase power, then we are writing V s, V r all as line to line voltages.

Therefore, substituting the values we have A is 0.98, V s is 168.58. So, into 168.58 square divided by B which is 100 at an angle of beta is 75 and alpha is 3 degrees. Minus V r into V s, that is 132 into 168.58 divided by 100, which is B in here. So, with an angle of beta plus deltas, that is 75 degrees is beta plus delta is 11.92, as we have calculated in the previous part.

So, putting all these values and solving, we have got this S s is equal to 278.49 at an angles of 72 degrees minus 222.53 at an angle of 86.92. We do this calculation for calculating the real part, what we need to is, take the cos of these angles. And for reactive power, we take the sin of these angles. So, P s is equal to 278.49 cos 72 minus

222.53 cos 86.92, which comes out to be 86.06 minus 11.96. That is the sending end real power is 74.10 Mega Watt.

Now, since we have used these kilovolt values here, the power will be in Mega Watt, because multiplication of 10 to the power 3 and 10 to the power 3, will give me 10 to the power 6. So, the power here is directly in Mega Watt. When we are using the voltages as Kilo Volts and if we are using line to line voltages, then the power is a three phase power. So, this is a three phase power sending end power is equal to 74.10 Mega Watt.

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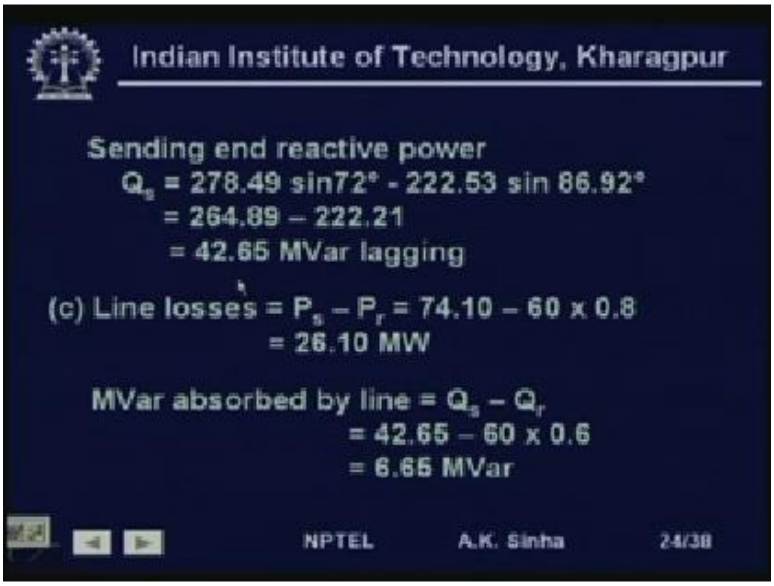

Similarly, we can calculate the sending end reactive power Q s, which will be 278.49 into sin of 72 degrees minus 222.53 into sin of 86.92 degrees. That is, we have to take the sin of the angles, what we had got for S s. Therefore, this comes out to be 264.89 minus 222.21 which is equal to 42.65 Mega Vars lagging. So, this way, we have calculated the sending end real and reactive power.

Now, in part c, we need to calculate the line loses and the Mega Var absorbed by the line. So, line loses will be nothing but, whatever sending end power is there and whatever power is received. If we take the difference of the two, that much amount of real power is lost in the line or lost in the resistance of the line or dissipated by the resistance of the line.

Therefore, line loses is equal to P s minus P r, which is equal to 74.10 minus the receiving end real power will be 60 into 0.8. So, MVA into cos 5, so 60 into 0.8, that is 48. So, therefore, line loses comes out to be 26.10 Mega Watt, which is quite a large amount us loss, almost one-third power is getting lost in the lag. Similarly, MVar absorbed by the line, will be whatever is then we are at the sending end, whatever is being sent on the line and whatever is being received at the receiving end.

So, Q s minus Q r, which is coming out to be 42.65 minus 60 into 0.6, that is sin of the power factor angle. So, this is 60 into 0.6, which comes out to be 6.65, MVar, that is this much 6.65 and MVar is being absorbed by the line itself.

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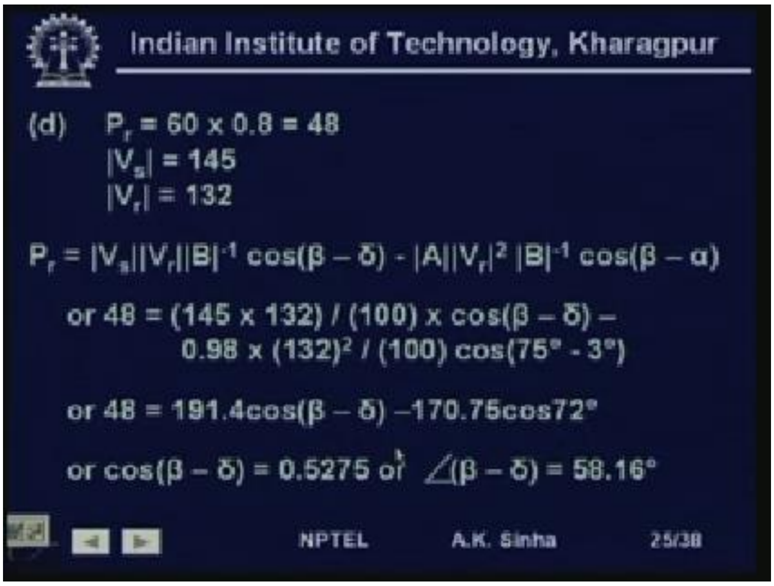

Next, we say that, we want to keep the sending end voltage at 145 kV and the receiving end voltage is kept at 132 kV, then what is the amount of compensation, that is required. Now, the since we are transmitting 60 MVA at 0.8 power factor lagging, which comes out be 48 Mega Watt. Therefore, for this P r is equal to 48 Vs is equal to 145 kV, V r is equal to 132 kV.

Since, this is in Mega Watt and these are in K v. So, we need not write those 10 to power 3 and 10 to power 6. So, P r is equal to V s, V r divide by B into cos beta minus delta minus A into V r square by B into cos beta minus alpha. Now, here we know P r value as 48. So, we substituting all the values we will get 48 is equal to 145 into 132 V s into V r divided by 100 into cos of beta minus delta.

Now, here we do not know, we know beta, but we do not know delta, for this particular operating condition. Therefore, I have not substituted any value here and for these terms A is 0.98 V r is 132. So, A V r square divided by b into cos beta minus alpha, that is 75 minus 3. Now, from this, again if we solve this, we will get cos beta minus delta is equal to 0.5275 or angle beta minus delta is equal to 58.16 degrees. Now, we know beta as 75. So, we can calculate delta very easily, but we do not need the delta value as such, what we need is angle beta minus delta.

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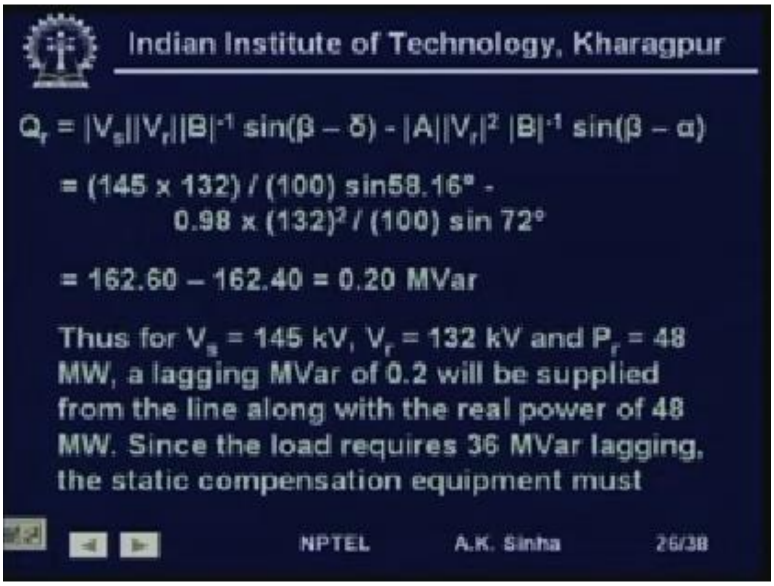

So, we will use this. Now, we know Q r is equal to V s, V r divided by B into sin beta minus delta minus A V r square divided by B into sin beta minus alpha. So, again substituting the values, we will get Q r is equal to 145 into 132 divided by 100 into sin 58.16. This is beta minus delta into A 0.98 into V r square 132 squared divided by 100 into sin 72 degrees. So, after calculating this comes out to 162.60 minus 162.40, which is equal to 0.2 Mega Var.

Thus for a V s of 145 kV V r and V r of 132 kV with P r 48 Mega Watt a lagging, Mega Var of 0.2 will be supplied from the line along with the real power of 48 Mega Watt. Now, since the load requires 60 into 0.6, that is 36 Mega Vars lagging, the static compensation equipment must supply the rest, because the line will supply only 0.2 Mega Var.

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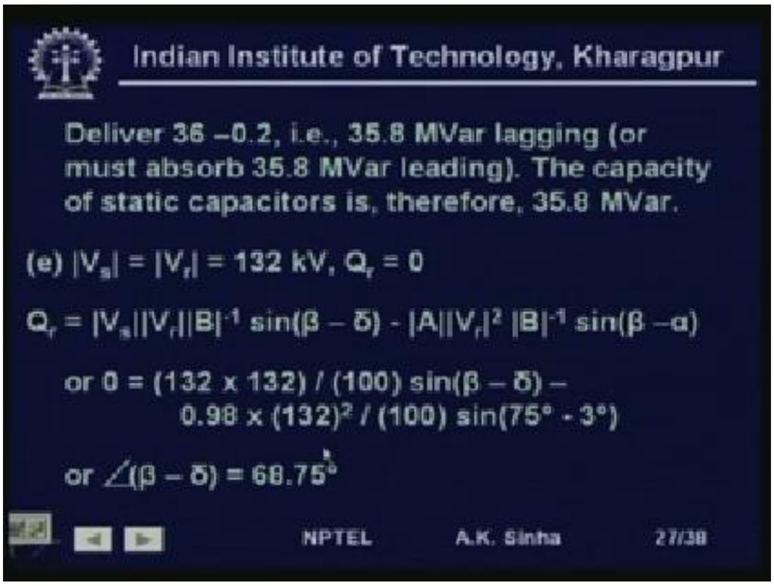

So, the static equipment must deliver 36, minus 0.2, that is 35.8 Mega Var lagging or it we can say it must absorb 35.8 Mega Var leading. That means, the static compensation there has to be capacitive to provide this much Mega Var. The capacity of static capacitor is therefore, 35.8 Mega Var. The third part was if we keep both V s and V r equal to 132 kV and the load is unity power factor, that is Q r is equal to 0, then what will be the power, that we can supply. So, using this identity Q r is equal to 0, we will write Q r relationship as Q r is equal to V s, V r by B into sin beta minus delta, minus A V r square by B the into sin beta minus alpha. And substituting all the values, here we can calculate the angle beta minus delta, which comes out to be 68.75 degrees.

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Now, since we have calculated beta minus delta, we can write down the equation for P r, V s, V r by B into cos beta minus delta minus A V r square by B into cos beta minus alpha substituting all the values, we will get this as 10.36 Mega Watt. That is, if we want to keep the voltage at both ends equal to 132 kV and we want to supply unity power factor load. Then the load that we can supply will be only 10.36 Mega Watt.

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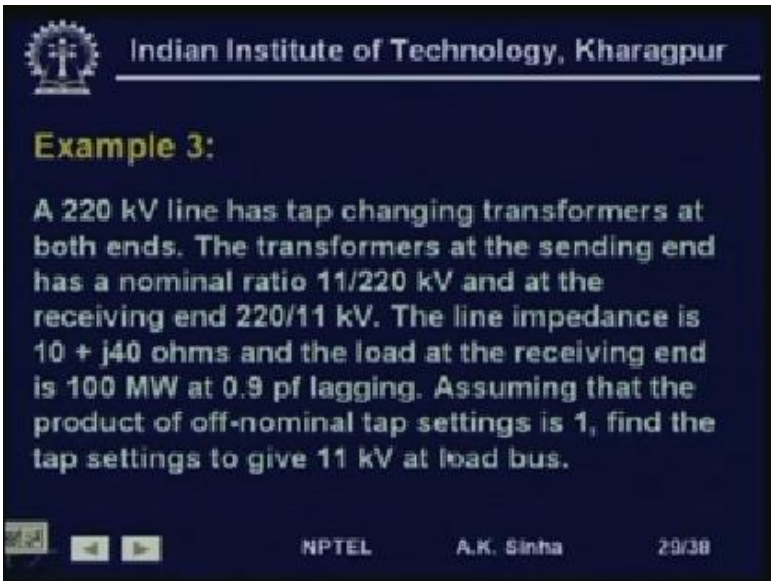

Now, let us take another example, a 220 kV line has tap changing transformers at both ends. The transformers at the sending end has nominal ratio of 11 to 220 kV and at the receiving end 220 to 11 kV. So, step up transformer at the sending end step down transformer at the receiving end the line impedance is ten plus j 40, again we are using a short line model. So, 10 plus j 40 ohms and the load at the receiving end is 100 Mega Watt at 0.9 power factor lagging. Assuming that the product of off nominal tap setting is 1, that is T s into t r is equal to 1, as we said earlier, find the tap settings to give 11 kV at load bus.

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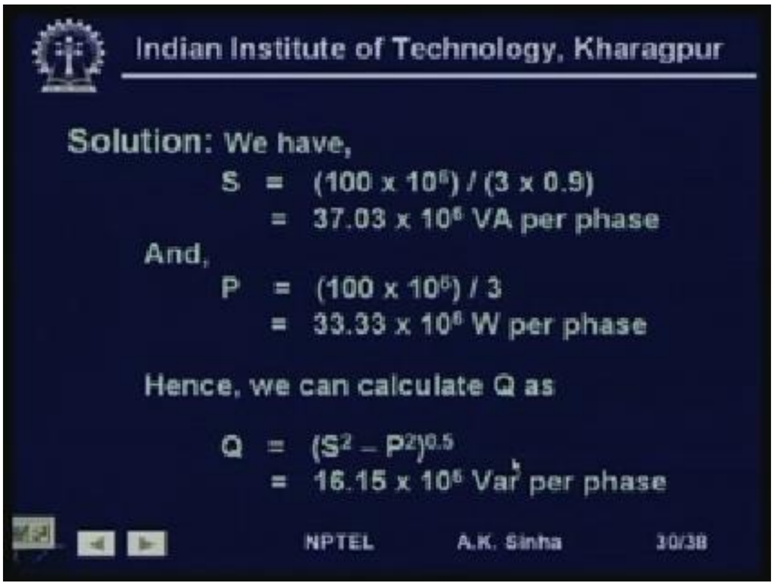

So, this is the example, for what we take for tap changing transformer in today's class. So, now S is equal to 100 MVA, let us 100 Mega Watt is being transmitted at 0.9 power factor lagging. So, S per phase will be 100 into 10 to power 6, this is Mega Watt divided by 3. So, that is Mega Watt per phase divided by 0.9 will give me because 0.9 is the power factor, this will give me the MVA.

So, this is Mega Watt divided by the power factor gives me the MVA. So, this comes out to be 37.03 into 10 power 6 volt ampere 37.06 MVA per phase and P is known as hundred Mega Watt. So, per phase is 33.33 Mega Watt. Therefore, we can calculate what is the value of Q, Q will be S square minus P square root of that. So, this comes out to be 16.16 Mega Var per phase.

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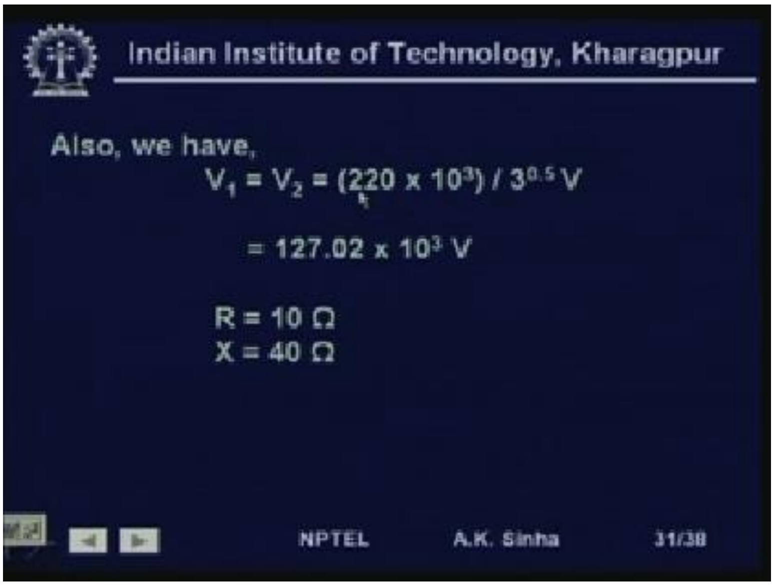

Now, we have V 1 is equal to V 2 is equal to 220 kV and since, we want to work out on a per phase basis. So, we divide it by root 3. So, we will get the line to neutral voltage. So, 220 into 10 to power 3, divide by root 3 volts. This is coming out to 127.02 Kilo Volts.

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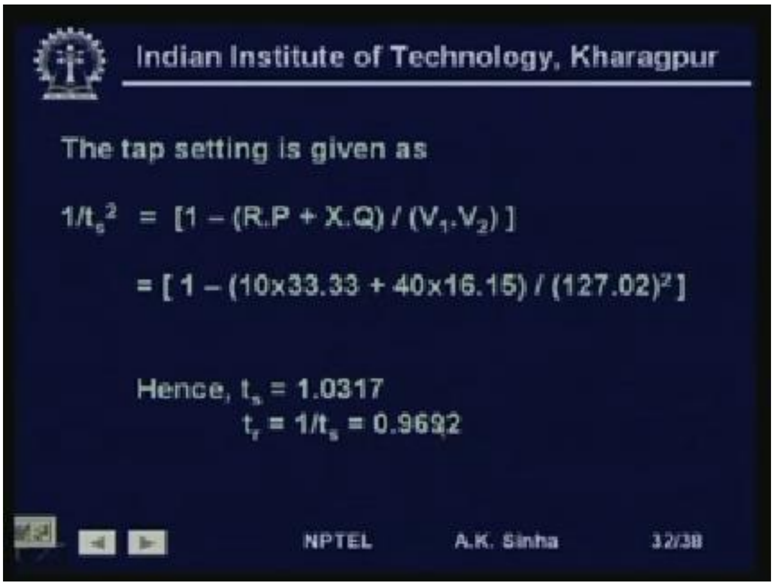

Now, R is given as 10 X is given as 40, therefore substituting this on the relationship for the transformer. That we had derived today, 1 by t s squared is equal to 1 minus R into P plus X into Q divided by V 1, V 2. So, substituting all these values of R, P, X, Q, V 1, V

2. We get t s is equal to 1.0317. And therefore, t r is equal to 1 by t s, which will be 0.9692.

So, if we keep this of nominal taps t s as 1.0317 and t r is equal to 0.9692 both end voltages will be equal to 220 kV line to line. So, with these three examples, we will end today's lesson. And in the next lesson, we will review whatever we have learnt about the transmission line.

So, thank you very much.