Power System Analysis

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Lecture - 9
Transmission Line Steady State Operation

Welcome to lesson 9, in Power System Analysis. In this lesson, we will discuss about Transmission Line Steady State Operation. Well, when we talk about the steady state operation on transmission line. What we really mean is, how the line is going to perform, when we want to transmit certain amount of power through it. So, here what we will do is, we will discuss and derive the relationship between the voltage currents and the power, which is transmitted over the transmission line.

In the earlier lessons, we had derived the models for the transmission line. Mostly, we had used the A, B, C, D parameter model and the pi equivalent circuit module. Here, we will try to take help of the A, B, C, D model and develop the power transfer relationship on the transmission line, using these A, B, C, D parameters. First, we will consider two bus power systems, the simplest one, a generating station supplying power to a load, through a transmission line.

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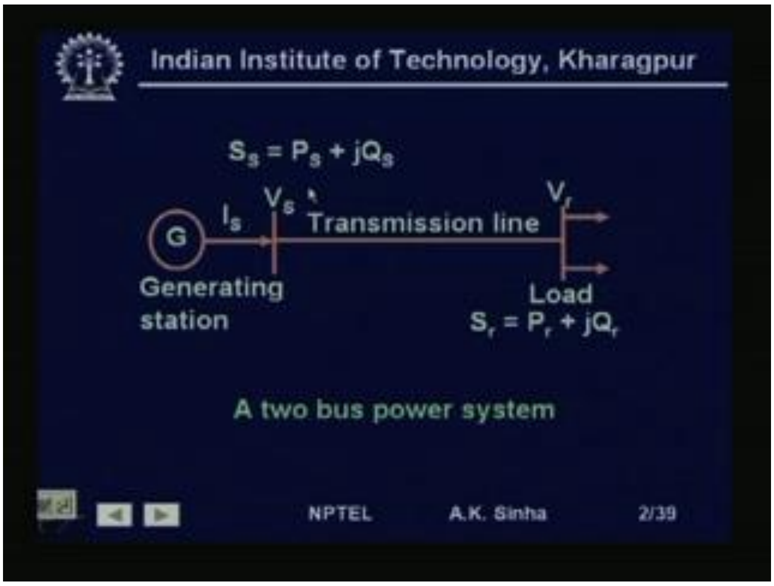

The system as shown in this figure has this generating station, which is connected to a bus power the voltage of this bus. Bus power is V s, because we call this bus as the sending end bus. The current flowing from the generator into this bus is I s. And then this bus sending end bus is connected to the receiving end bus at which the loads are connected, this by means of a transmission line.

The transmission line as we are said earlier is characterized by the A, B, C, D parameters. So, for this system V r is the voltage at the receiving end. And normally, what we assume is that, we take this receiving end voltage phase angle as 0 degrees, whereas the sending end voltage phase angle as angle delta. The sending end power, the complex power at the sending end S s is equal to P s plus j Q s. Where, P s is the real power and Q s is the reactive power at the sending end. Similarly, S r is the complex power at the receiving end, where P r is the real power at the receiving end and Q r is the reactive power at the receiving end.

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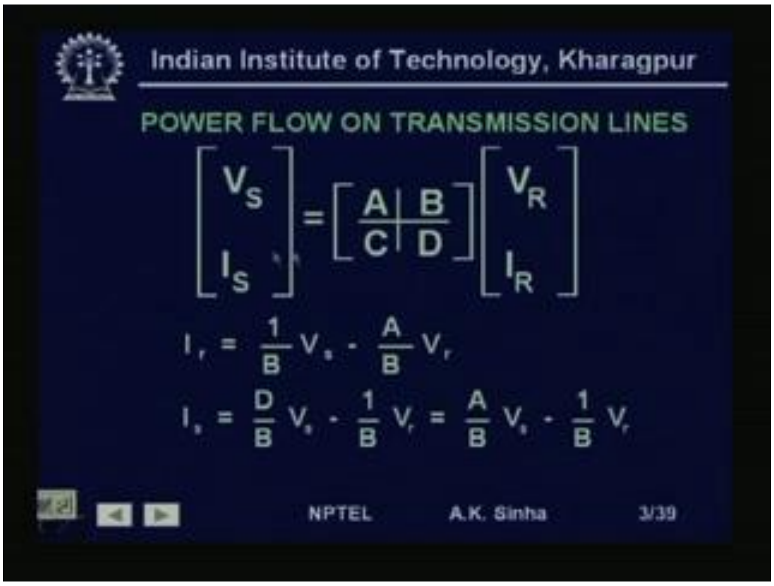

Now, we will try to develop the power flow relationship for this system. We have already develop the relationship using the A, B, C, D. The parameters for the transmission line as V s, I s is equal to A, B, C, D, V R, I R. That is the resending end voltage and current, in terms of receiving end voltage and current, with A, B, C, D parameters for the transmission line.

If we solve these equations, then in terms of the sending end and receiving end currents. Then, we will get the receiving end current I r is equal to 1 by B, V s minus A by B, V r and I s is equal to D by B, V s minus 1 by B, V r. We have already seen, that A is equal to D. Therefore, we will replace this D by A and we will have I s is equal to A by B into V s minus 1 by B into V r. So, once we have found out these currents, the receiving end and sending end currents, we can write down the relationship for power.

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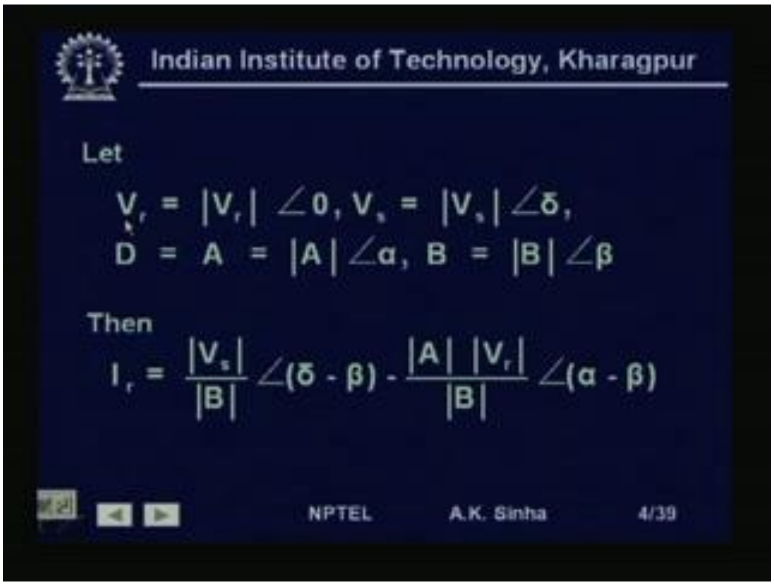

Now, here, as I said earlier, the receiving end voltage V r, we are assuming it to have a magnitude V r and the angle 0. That is, we are making this receiving end voltage as a reference phase. And V s is equal to magnitude of V s and an angle of delta, which is the angle by which the sending end voltage leads the receiving end voltage. Also, we have D is equal to A. And A, since we know is a complex number.

We are writing this A as a magnitude of A with a phase angle alpha. And B, as we know is comes out to be equal to Z for a pi equivalent circuit. So, this is also a complex number and we writing B as magnitude of B with an angle beta. So, once we substitute these values for I s and I r. then we have I r is equal to V s, magnitude of V s by magnitude of B, with an angle delta minus beta. And minus magnitude of A into magnitude of V r divided by magnitude of B, with an angle alpha minus beta.

We are just substituting the phasar values for A, B, C, D and V s, V r in this relationship. Similarly, we can get the value of I s as A V s by B, all these magnitudes with an angle alpha plus delta minus beta minus V r by B with an angle of minus beta. Now, you try to find out the conjugates for these currents. Because, we know that the complex power s is given by V I conjugate.

So, we will get the conjugates of these currents as I r conjugate will be equal to V s by B with an angle beta minus delta. This angle, what we had earlier is now replaced by the negative of it, when we take the conjugate. So, instead of delta minus beta, we have now beta minus delta here. Similarly, this other term is minus A V r by B and the angle instead of alpha minus beta as we had for I r. For I r conjugate, this angle becomes beta minus alpha.

Similarly, we find out the conjugate for the sending end current I s. This is equal to A V s by B, angle beta minus alpha minus delta. Again, we take the negative of the angle that we had for I s minus V r by B, with an angle beta.

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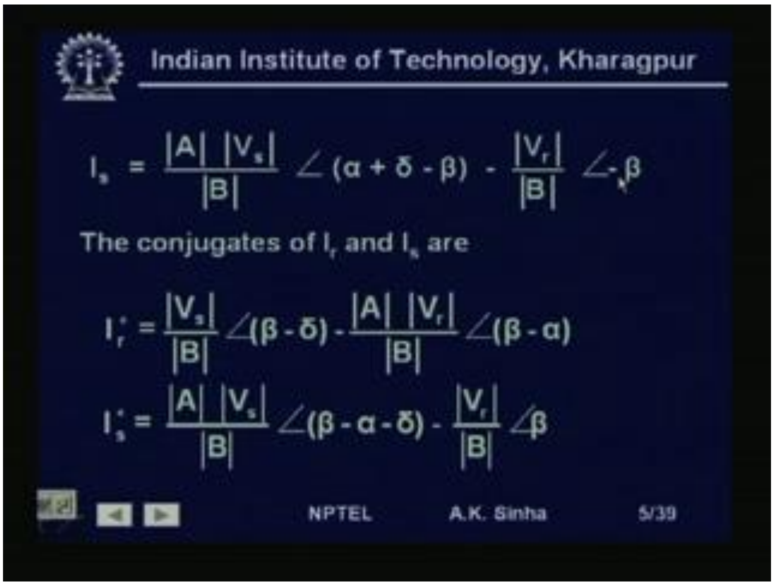

Because, earlier we had here, we had I s here, we had an angle of minus beta. Therefore, I s conjugate is given by this relationship A V s by B, angle beta minus alpha minus delta minus magnitude of V r by magnitude of B angle beta. So, once we have got these conjugate of the currents at the receiving end and sending end. We can write down the power relations now.

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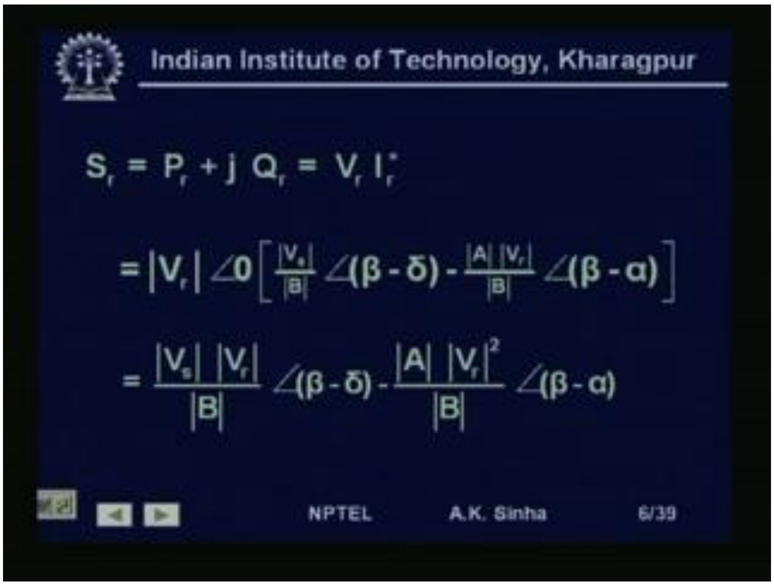

The power, which is received at the receiving end or received by the load S r is equal to P r plus j Q r, where P r is the real power and Q r is the reactive power and this is equal to V r into I r conjugate. And since, we have already calculated the value of I r conjugate for getting the value of S r. We need to multiply that relationship by V r. Since, we know V r is equal to magnitude of V r an angle 0.

So, we multiply that relationship by V r with an angle 0. And we get this as V r angle 0 multiplied to V s by B angle beta minus delta minus A V r by B angle beta minus alpha. This can be written as V s into V r, magnitude of V s into V r by magnitude of B, with an angle beta minus delta. Minus magnitude of A into magnitude of V r square divided by B with an angle beta minus alpha.

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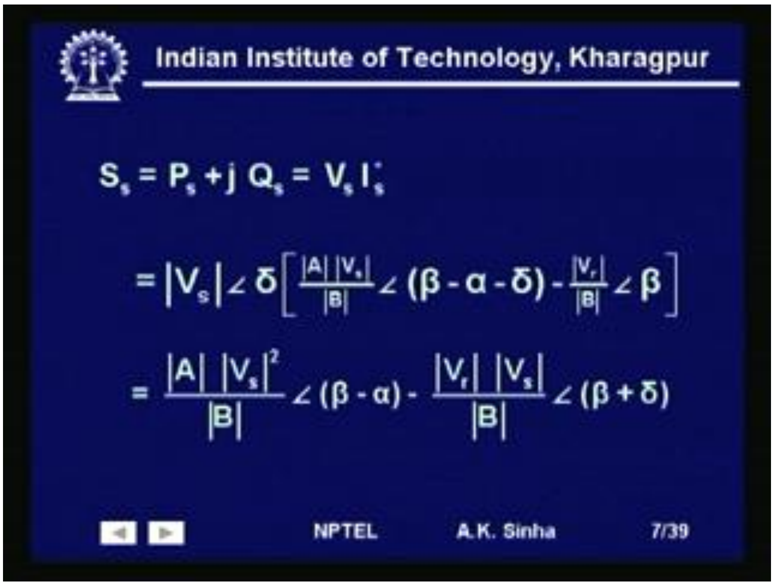

Similarly, the power at from the sending end, that is the power, which is sent by the generator is S s. And that is equal to P s plus j Q s, the real power of P s, from the generator and the reactive power Q s from the generator side. This is equal to V s into I s conjugate. So, again, what we had already calculated this I s conjugate. We multiply it by V s and V s; we know is magnitude V s with an angle delta.

So, me multiply this, then we get V s angle delta, multiplied by I s, which is equal to A, magnitude of A into magnitude of V s divided by magnitude of V, with an angle beta minus alpha minus delta. Minus of magnitude of V r divided by magnitude of B, with an angle beta, which when we simplify this whole thing, turns out to be magnitude of A into magnitude of V s square, divided by magnitude of B with an angle beta minus alpha. Because this delta which is plus delta, will cancel out with this minus delta, minus V r magnitude of V r into magnitude of V s divided by magnitude of B into angle beta plus alpha.

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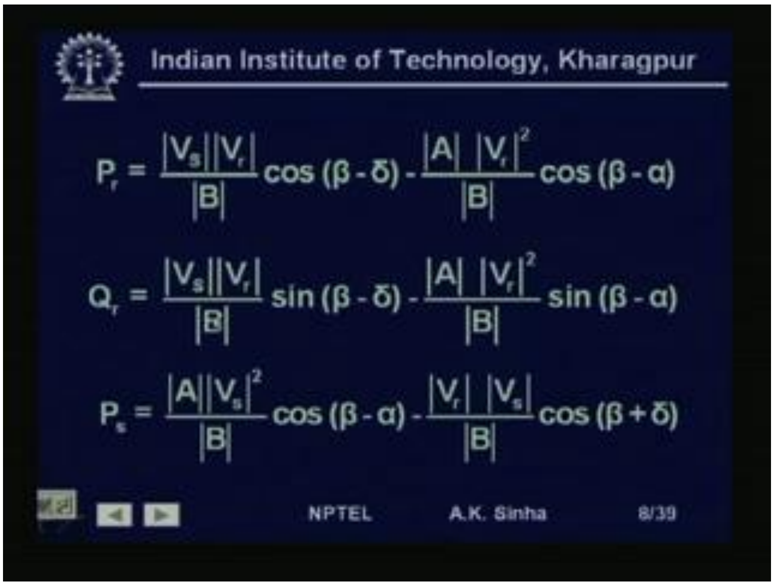

Now, if we take out the real and reactive parts, from this complex powers S r and S s. That is we take out the real and reactive real and imaginary part of these equations, these complex equations. Then, we will get the real power and reactive power. So, P r will come out to be V s into V r by B cos of beta minus delta minus A into V r square by B into cos of beta minus alpha. And Q r, the reactive power at the receiving end will be equal to V s into V r by B into sin beta minus delta minus A into V r square by B sin beta minus alpha. Similarly, the real power at the sending end will become equal to P s. And P s is equal to A V s square by B into cos beta minus alpha minus V r into V s by B, cos beta plus delta.

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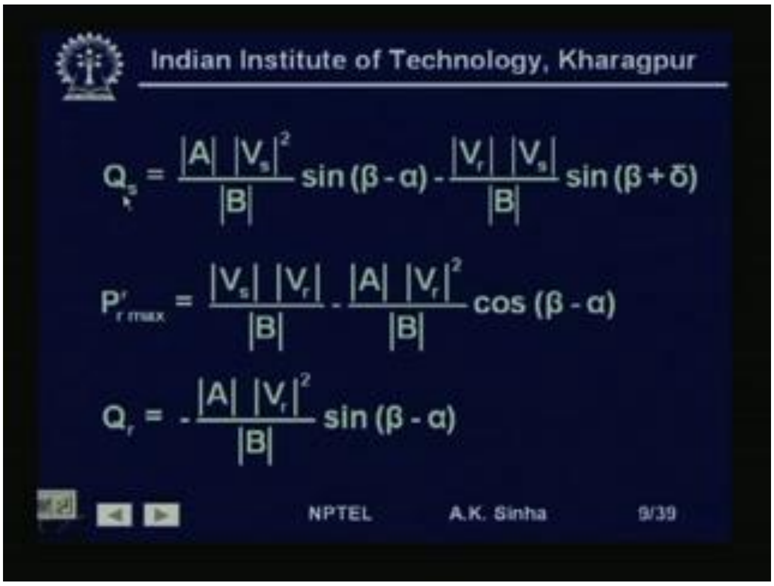

And Q s the reactive power at the sending end will be given by A into V s square by B, sin beta minus alpha minus V r into V s by B into sin beta plus delta. Now, these quantities P r, Q r; P s, Q s are giving us the relationship for real and reactive power, supplied at the sending end and received at the receiving end. Now, from this equation Pr equation, we can see that, for a given system voltage level V s and V r will be very near to the system voltage. And they do not change much.

That is, if you have a 400 kV system or a 220 kV system. These values will be very near to 400 kV or 220 kV. Whereas, this beta is basically the angle of the impedance of the transmission line, that is, if we are using a pi equivalent circuit or these parameters beta, alpha, all these are transmission line parameters. And once the transmission line is already there and then these parameters are fixed.

So, we see for any given transmission line, with the system voltage. For a given system voltage, we have only one parameter, this parameter delta which can be varied, which is the power angle or the voltage phase angle at the sending end. And we can get a maximum power, which can be transmitted or which can be received by the load on this transmission line for a given system voltage level.

That will be equal to P r max. This is equal to V s, V r by B and when, we make this beta equal to delta. Then, this cos beta minus delta is equal to 1 and this will be the maximum values. And that is what we get here Vs, V r by B minus A V r square by B into cos beta minus alpha. And corresponding to this maximum power, that will be flowing; we have the reactive power at the receiving end given by minus A V r square by B into sin beta minus alpha.

Now, what we see from here is, that if the real power is maximum. Then, the corresponding reactive power received at the load end has to be negative. Means, the power has to be transmitted for a leading power factor load. That is the load power has to be leading for this condition.

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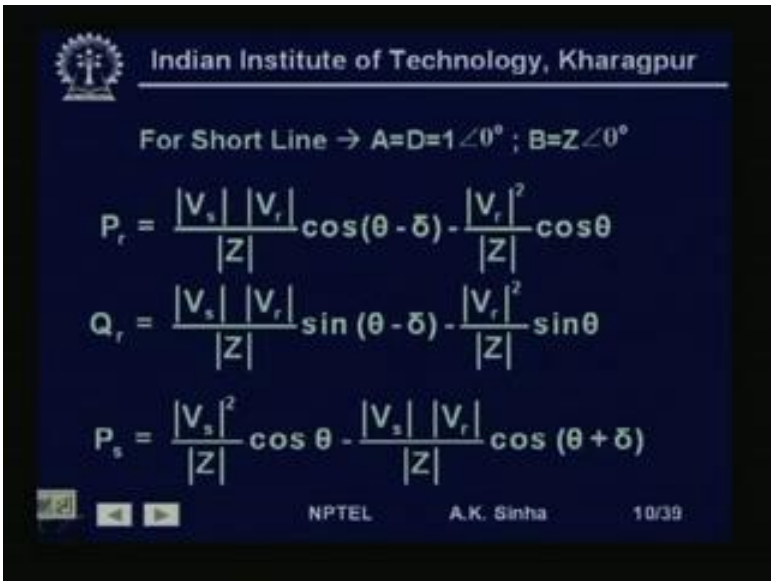

Now, in order to understand these phenomena of what actually is happening on the transmission line. And get a better concept of this power flow and how it gets affected. We would like to make to our system much more simpler. So, let us first make this line as a short line. And for short line, we know A is equal to D is equal to 1 angle 0. And B is equal to Z angle theta. Z is the series impedance of the line and theta is the angle of the impedance.

Then, substituting these values, we get Pr is equal to V s, V r by B, B is now Z. So, we have got V s, V r by Z cos of beta minus delta, beta is now theta. So, theta minus delta minus V r square, because A is now 1, V r square by Z into cos beta was the term. So, here it is cos theta. Similarly, we can write Q r, Q r is equal to V s, V r by Z sin theta minus delta minus V r square by Z sin theta.

For the sending end powers, we can write the similar relations for the short line. P s is equal to V s square by Z cos theta minus V s, V r by Z cos theta plus delta.

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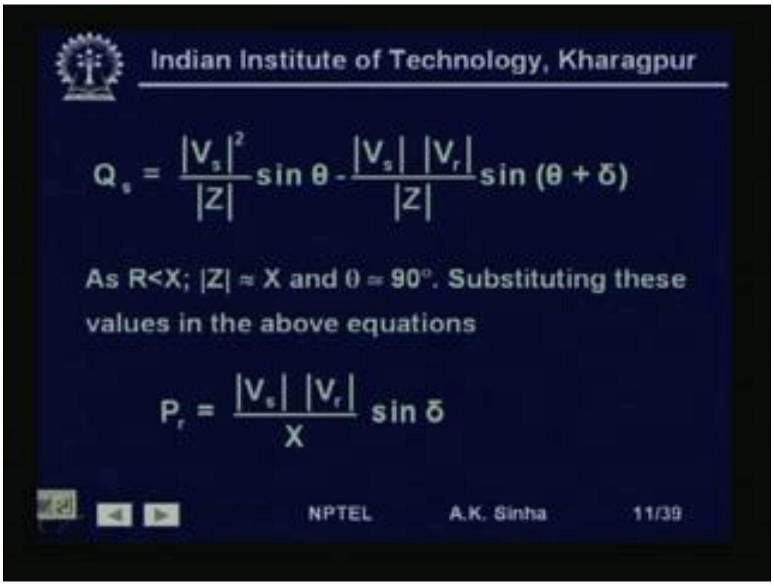

And Q s the reactive power at the sending end will be equal to Vs square by Z sin theta minus V s, V r by Z sin theta plus delta. Now, in most cases for the transmission line, the resistance is much smaller compared to it is reactance. And therefore, we can say that magnitude of Z is very much equal to the magnitude of x, the reactants. Because, we know Z magnitude of Z is equal to the square root of r square plus x square.

Since, r is much smaller, most of the transmission, like overhead transmission line. The value of r will be either one-third or even less than that of the reactance of the line. And therefore, we can say the magnitude of Z is approximately equal to the magnitude of x. And we also can say that the angle theta in this case will be very close to 90 degree. That is, we are saying, that the line is purely reactive in this case, because resistance is much smaller and can be neglected. Therefore, substituting these values, that is Z is equal to x and theta is equal to 90 degrees. We get P r is equal to V s, V r by x into sin delta. This is a very important relationship for power flow on the transmission line.

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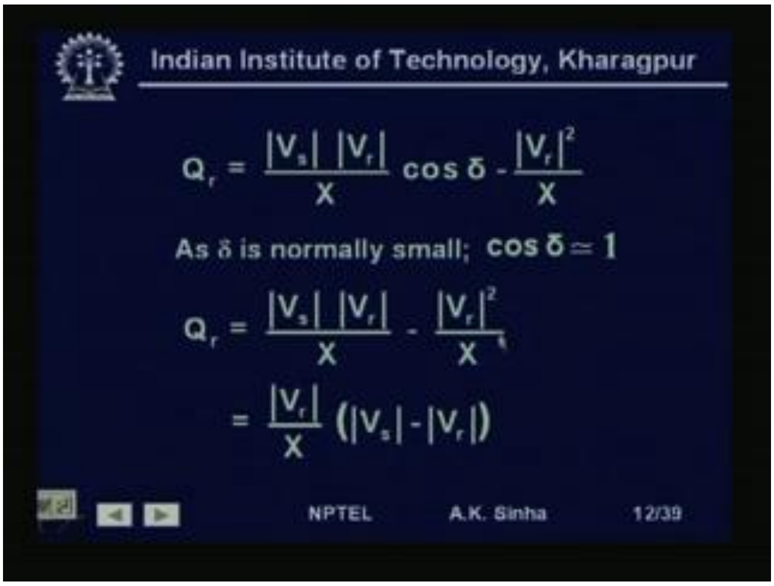

Similarly, we will get Q r is equal to V s, V r by x into cos delta minus V r square by x. Now, for power system operation, normally the angle delta is small. And therefore, we can say that cos delta is nearly equal to 1. Therefore, if we substitute this, then we have Q r is equal to V s, V r by x minus V r square by x, which can be simplified into V r by x into V s minus V r.

Now, these this relationship for Q r and this relationship for P r. The real power received at the lower end and the reactive power at the lower end, as these are very important relation, especially for understanding what is happening. From these relationships, we can draw following conclusions.

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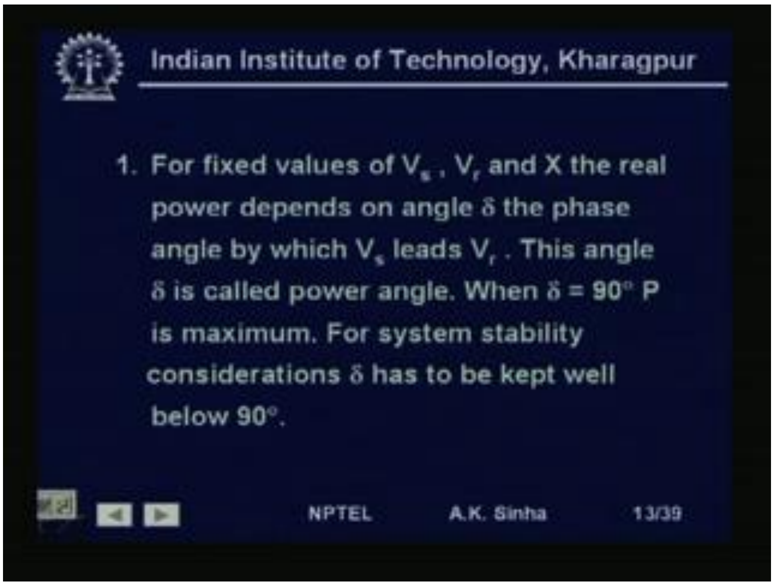

That is for fix values of V s, V r and x. That is, for a given transmission line and given system voltage. The real power depends on angle delta, the phase angle by which V s leads V r. This angle delta is called power angle. This is mainly, because this is the angle delta, which is determinant, how much power is going to flow on the line. Therefore, we call this as power angle.

When, delta is equal to 90 degrees; P is maximum. That is the maximum power. That can be transmitted through this system can be when this delta is 90 degree. Then, sin delta is equal to 1 and then the natural power that can be transmitted is V s, V r by x. So, when delta is equal to 90 degree; P is maximum, that is maximum power. That can be transmitted. For system stability considerations, delta is generally kept much smaller, that 90 degree. It is normally work, in the range of 20 to 30 degrees only. Because, any certain large disturbances can make system unstable, if we work very near to 90 degrees.

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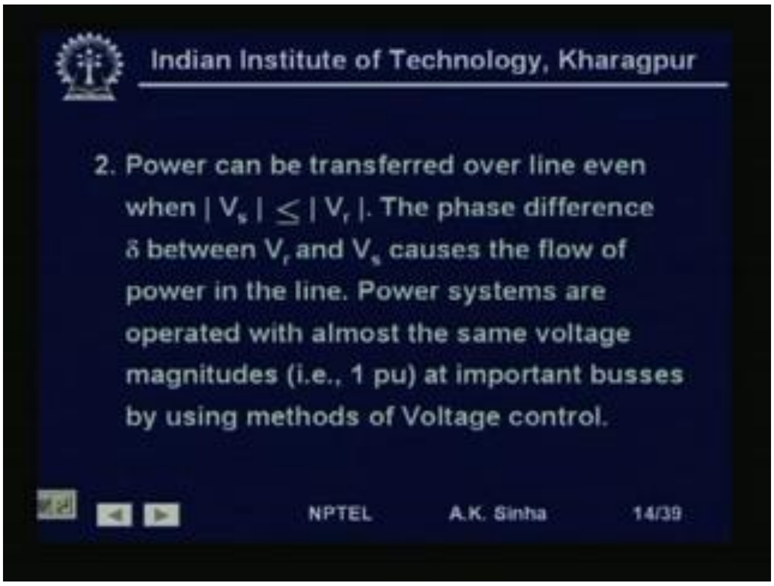

The other inference, that we get from this relationship is, that power can be transferred over a line, even when V s magnitude of the sending end voltage is less than or equal to the receiving end voltage magnitude. Normally, we always assume that the voltage at the sending end must be greater for power to be transferred. This is the case for a DC system.

If a power has to be transferred from one end to other end, than the sending end voltage must be larger than the receiving end voltage. But, in case of AC transmission system, this is not necessary. The value of the sending end voltage magnitude, can be lower than the receiving end voltage magnitude, still real power can be transmitted over this line. It is the phase difference, delta between V s and V r, which determines how much power, is going to flow.

If delta is positive, that is V s leads V r, then the power will be flowing from the sending end to the receiving end. If delta is negative, that is if V s lacks V r, then the power will be flowing from V r side to V s. So, it is this phasar angle, which determines the direction of power flow and not the voltage magnitude. This is a very, very important concept in AC transmission.

Now, most of the power systems are operated with almost the same voltage magnitude. That is, what we do is, in order to keep out system properly. We keep the system voltage at most of the busses in the system, very nearly equal to nominal system voltage. So, say for a 220 kV system or a 400 kV system, we would be keeping the voltage magnitudes at most of busses very near to 220 or 400 kV. Because, this provides us, a much better operating condition, for the system.

That is power systems are operated with almost the same voltage magnitude. That is one power unit at important busses by using methods of voltage control. This is, what we will talk about later in this lesson.

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The third inference, that we can derive from this relationship is the maximum real power transferred over a line increases with increasing V s and V r. That is the sending end and there receiving end voltage. An increase of 100 percent in V r and Vs, that is, if we double the voltage level of the transmission line. Then, the power transfer increases to 400 percent. That is, if the line initially was capable of carrying 100 MVA.

Now, if we double the voltage, it will be able to carry 400, sorry, if it was able to carry 100 MVA. Now, if we double the voltage, it will be able to carry 400 MVA. And this is one of the main reasons, why we keep going for higher and higher voltage levels. When, we want to transfer more and more power.

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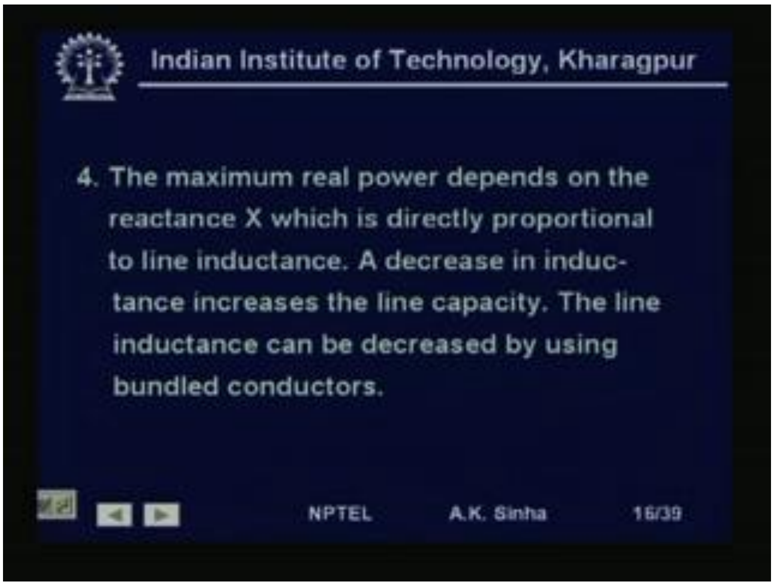

Another important inference, that we can derive from this expression is the maximum real power depends on reactance x, which is directly proportional to the line inductance. Now, as we have seen, P max is V s, V r by x. Therefore, if we decrease the value of x, P max will increase. A decrease in inductance, increases the line capacity or the power transferred capability of the transmission system.

Now, which means, we need to decrease the inductance. As we had seen earlier, we can decrease the line inductance by using bundle conductors, because bundle conductors will increase the effective radius of the conductor. And therefore, reduce the inductance of the transmission line. Reducing the inductance of the transmission line, will reduce the reactance. And therefore, it will increase the power transfer capability or the maximum power that can be transmitted on that line.

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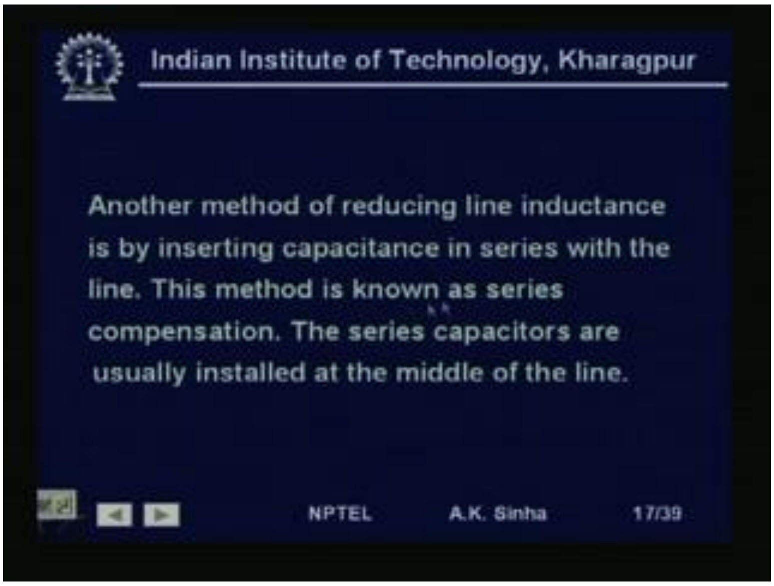

Another method of reducing the reactance is by connecting a capacitor in series, with the line. Now, if we connect a capacitor in series with the line, then the total effective reactance of the line will get reduced. Because, the reactance of the capacitor will be negative and will be reducing the effective reactance of the total, the effective series reactance of the transmission line.

This method of connecting a capacitor in series with the line is called a series compensation of the transmission line. And this is generally done, in order to increase the power transfer capacity of the transmission line. Because, as we had seen in the earlier lesson, most of the time, we run our system at much below the thermal limits. Mainly, because the stability limit is are the major problem and we have ensure that, we run our system properly.

Even, when there is sudden large disturbance, which takes place in the system, like short circuits and tripping of lines or generators, even, when these take place. Still, the system should run synchronously. And for this, we need that delta angle should be much lower than 90 degrees. That is in the range of around 20 to 30 degrees. And that is why, unless we reduce the reactance of the transmission system. We cannot transfer large amount of power through that transmission system.

Now, as I said we can reduce by using series capacitances. That is connecting a capacitance in series with the line. The series capacitors are usually installed at the middle of the line. This is generally done, for one simple reason, that if we install them at either the sending end or at the receiving end. Then, when the loads are low, the voltage values at these ends can go very high. Because, of the large amount of compensation, which is available at those ends. Whereas, if we put them in the middle of the line. The voltage profile generally will be much better.

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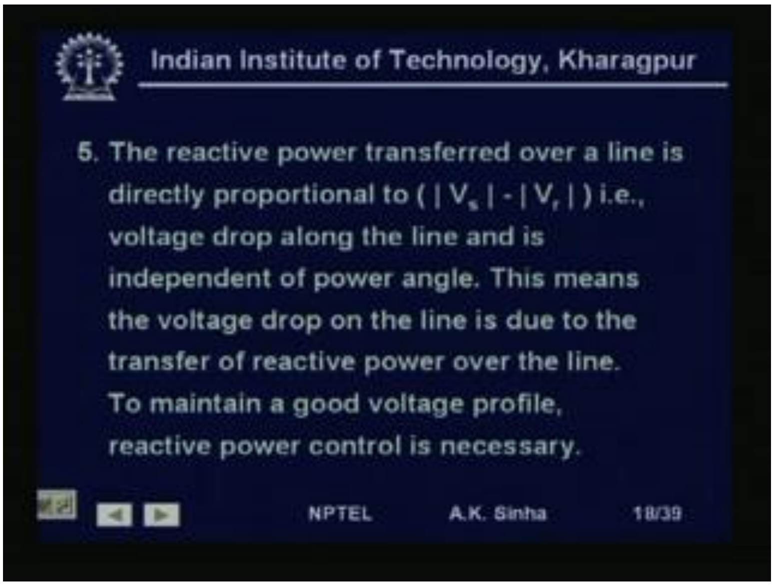

The from the reactive power relationship, we derived the following inferences. The reactive power transferred over a line is directly proportional to V s minus V r. That is, if we go through this relationship Q r is equal to V r by x into V s minus V r. That is Q r is directly proportional to the difference of the voltage magnitude V s minus V r. Therefore, we see that the regulation, that is the voltage difference. That comes, when the line is loaded is very important. And that governs the reactive power flow on the transmission line. So, reactive power transferred over a line is directly proportional to V s minus V r magnitude of Vs minus magnitude of V r. That is the voltage drop along the line and is independent of power angle.

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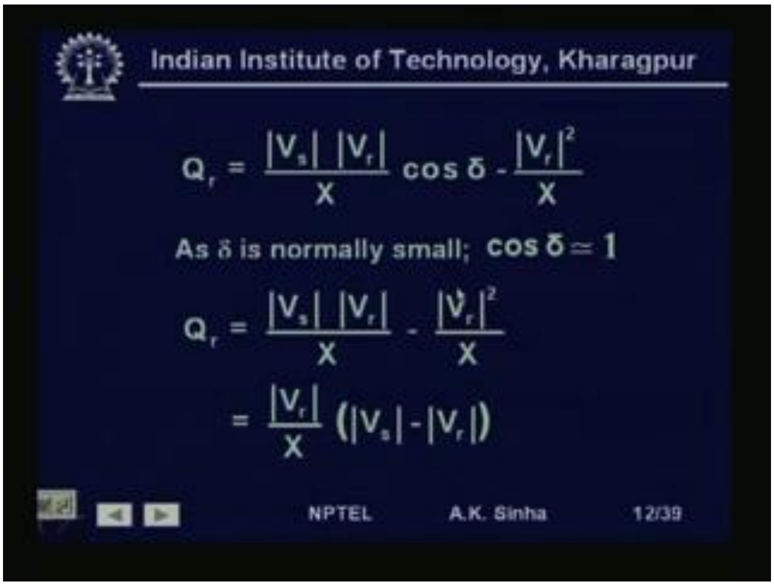

That is in this relationship, we do not have any power angle delta coming into picture. This means, the voltage drop on the line is due to the transfer of reactive power over the line. That is, it is because of the reactive power, which is being transferred over the line, that there is a large drop in the voltage. To maintain a good voltage profile, reactive power control is therefore, necessary.

That is, if we want that the voltage drop is not large. Then, we have to see that, the reactive power transferred, over the line is reduced as much as possible. This is done by means of, what we call reactive power compensation of transmission lines. So, now, we will look into, how we control the voltage. And so the reactive power flows on the transmission line.

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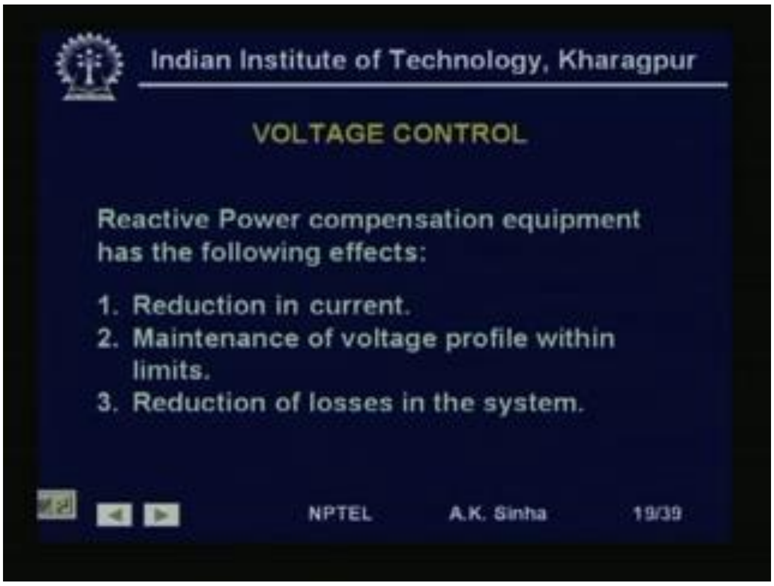

Reactive power compensation equipment has following effects. Basically, why we need this compensation, we need this compensation mainly, to see that the voltage profile of the line is maintained, as near the nominal value as possible. Now, the question comes why it is so important. Well, if we go at higher and higher voltages, what we have is, we need to insulate these lines from ground. As well as the insulation, between line to line, which means, that we need to use insulators.

And these insulators will be expensive, if we need to provide large amount of safety factor. That is why, at extra high voltages of 400 kV and above the safety factors, may not be very large. In order to make the transmission system economic and for this purpose, we say, that we work these lines or these transmission systems at a level of only around plus minus 5 percent.

That is the voltage, which is allowed to change is up to a level of plus minus 5 percent, from the nominal value, which means, that the maximum voltage drop, that can be allowed on a transmission system is only of an order of 10 percent. And therefore, it is necessary, that we use some control equipment to keep this voltage within these limits. Where, the voltage drop is not allowed to go beyond this. And if it goes some compensation equipment has to be there to boost it up. And keep the voltage drop within the permissible limits.

Now, the reactive power compensation equipment has the following effects. First is reduction in current. When, we are reducing the reactive power flow in the transmission line, what we basically mean is the current component of the reactive power flow is also getting reduced. Because, we known the complex power is P plus j cube and if V and this is equal to V into I conjugate. And therefore, if we reduce Q, then we are reducing S and we are there by also reducing I. Because, V is very near to the nominal voltage.

Therefore, if we reduce the reactive power flow on the line we are also reducing the current. We are also able to maintain the voltage profile within limits. If we reduce the reactive power as we said, if the Q r is given by V r by x into V s minus V r and this V s minus V r will be reduced, if Q r is reduced. Since, the current flowing gets reduced, therefore the losses I square r losses on the transmission line will also get reduced. This is another advantage in having reactive power compensation on the system.

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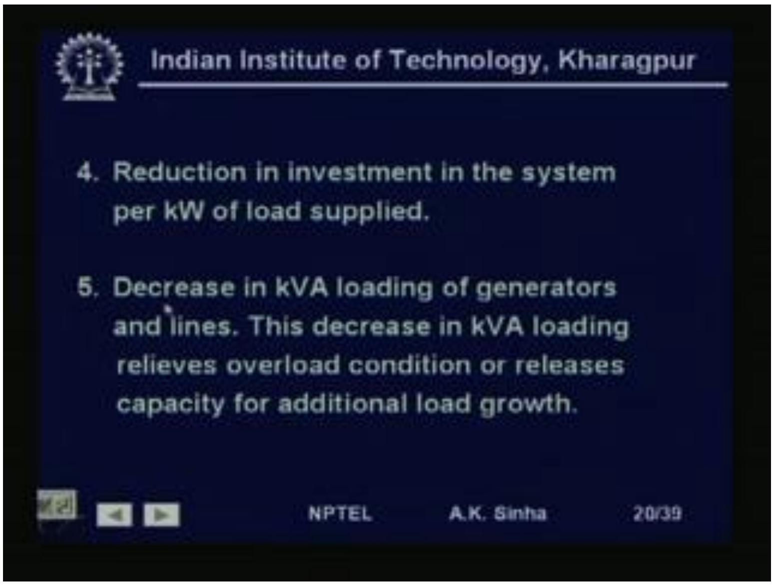

Of course, this means that, the there is going to be reduction in investment in the system per Kilo Watt of load supply. For this simple reason, that if we are reducing the reactive power, we are reducing the current. And therefore, the transmission line, that we are using, can be of a smaller diameter as such, which will reduce our investment. Also, all the equipment that we have is rated in terms of their k V A or MVA capacity. That is the volt ampere capacity, not the Kilo Watt or Mega Watt or watt capacity.

This is because, all the equipment has current rating associated with it, which is basically dependent on the, I square r losses, that can be dissipated from that equipment. So, that the temperature of the windings and other parts of the equipment is maintained within a give limit. Otherwise, the insulation of the equipment, well deteriorate very fast and the machine will go out of order, because it will lead to short circuits.

So, by using reactive power compensation, we are reducing the reactive power requirement of the system. And therefore, we are also reducing it is k V A requirement or we are reducing the investment in system per Kilo Watt of the load supply. Now, decrease k V A loading of generators are lines, happens because of this. And this decrease helps us, because this decreasing k V A loading relieves the overload or condition or releases capacity.

Suppose, I am running a system to it is limit, say I have a 50 MVA generator and I am running this generator at 50 MVA at 0.8 power factor. Now; that means, the load is going to be only 40 Kilo Watt and the MVA is 50. Now, suppose I increase the power factor 2.9, then what happens? Keeping the generator capacity or still running this generator at 50 MVA. Now, I will be able to supply 45 Mega Watt. That means, this 5 Mega Watt capacity is now released. So, I can supply more load from the same generator. Therefore, the reactive power compensation helps in relieving extra capacity or relieving overload on the equipment. And that is generators transmission lines, etcetera.

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It also helps, as I said if we increase the power factor. It helps the generator also, because it will have to generate, less amount of reactive. Power, which means, that the excitation system, will be working with lesser current. We do not have to over excite, the generators. Of course, for the consumers the advantage is, that is going to be reduction in their k V A demand charge.

Because, large consumers are charged, not only on the basis of the energy they consume. But, also on what is their maximum k V A demand. Because, basically the utility, which is supplying to these consumers, have to build the transmission system, the transformers have to be installed. All this have to be done on the basis of, what is going to be their maximum k V A.

So, if we have improved the reactive power requirement. Then, what we have done is, we have reduced the k V A requirement. And therefore, the k V A demand charge, which is charged by the utility will also get reduced. Now, how do, we provide this compensation? Now, there are different ways in which we can provide this compensation. Like, static compensation, we have rotating compensation and also, we can use transformers for compensation or control of voltage on the transmission line.

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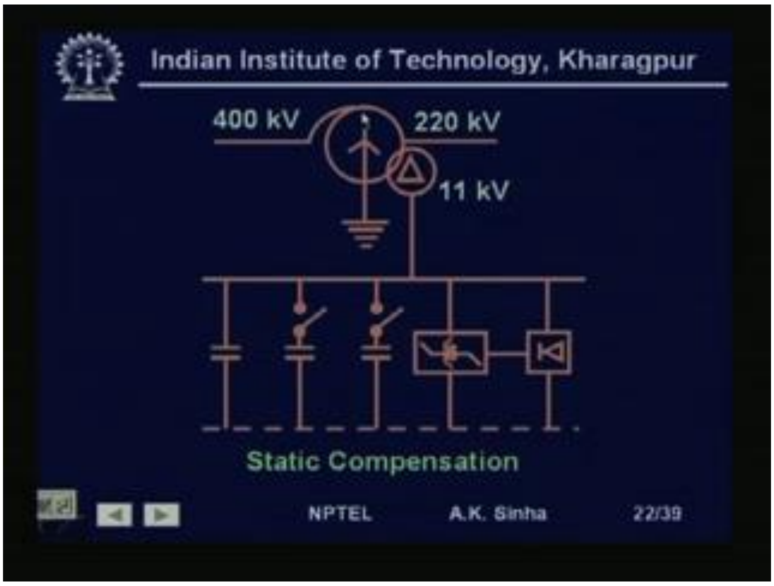

So, let us take first the static compensation. Well, static compensation basically consists of two ways in which we can do it. One is, the shunt compensation and the other is series compensation. Normally, series compensation is done, mainly for increasing the transmission capacity of the line. Whereas, the shunt compensation is used, mostly for voltage control, because, what it does is, it supplies the reactive power to the load.

And the reactive power, which is demanded by the load, is no longer flowing from the sending end to the receiving end, because this is now being supplied locally at the receiving end by the compensating equipment. And there by, releasing capacity on the transmission system, now what this shunt compensating equipment. Consist of normally, at the receiving end of the transformer, which will be a three winding transformer. The tertiary winding is normally a delta connected winding.

So, suppose we have a 400 kV to 220 kV transformer and it is tertiary is a 11 kV. Now, the compensating equipment is normally connected at the low voltage or the tertiary winding, which is at low voltage. And this equipment consists of basically some capacitors, which are permanently connected. Some capacitors, which are switchable and can be connected or disconnected depending on the demand. And variable reactor or a saturable reactor, the current of which can be controlled by means of thyristor or GTO.

So, this is a controllable reactor here. The current following through this reactor can be controlled. And therefore, this reactor becomes a variable reactor. And therefore, using equipment with this capacitors and variable reactor, we can give any value of compensation. That we want.

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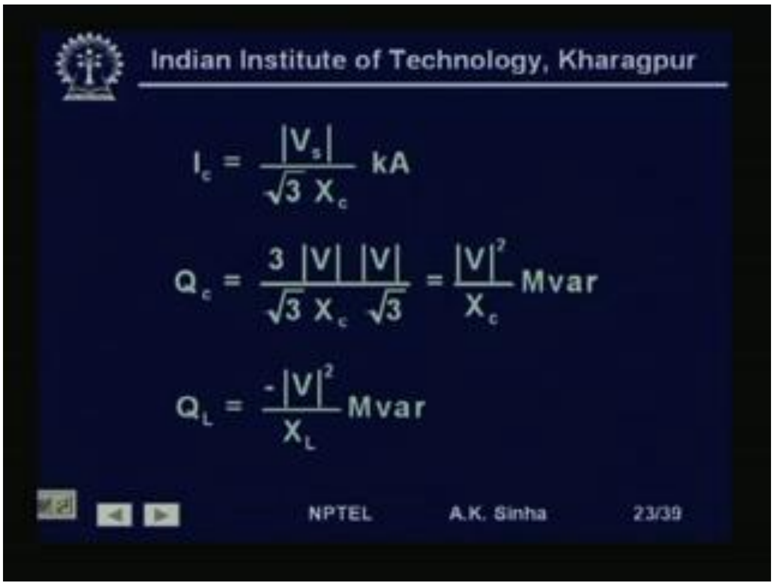

Basically, if you see, it is how much the capacitance, that we are providing, that will decide, what how much compensation we are doing. Normally, when the load is high or during the peak load period, the loads being mostly inductive in nature. It will be the lagging reactive power, which will be demanded by the load. So, the loads will be absorbing this lagging reactive power.

And therefore, the compensating equipment will have to generate this lagging reactive power to supply it to the load. So, that the transmission system is relieved of supplying this reactive power. Now, how much is that, that can be found very easily. We have the current flowing in the capacitive, shunt capacitors given by V s by root 3 into x c, where x c is the capacitive or the reactance of the capacitors and V s is the voltage, which is line to line voltage or the system voltage.

Now, for a three phase system, if we assume these capacitors to be connected in star, then the for the three phase system, we will have the total three phase reactive power. Supplied by these capacitors, will be equal to three times V by root 3 x c into this, is I c into V. That is per phase voltage or phase to neutral voltage V by root 3. This comes out to be equal to V square by x c.

Similarly, for this reactor will be absorbing the reactive power and that will be given by, again this relationship Q L is equal to minus V square by x L. If we are writing this voltage in Kilo Volts, then these values will be in terms of Mega Vars. Now, when the load is low or we have very light load condition. In those conditions, what happens is, these high voltage transmission line has large amount of charging capacitance.

So, there is large amount of charging current, which flows through them, which produces large amount of reactive power. And since the load is low, there is not enough absorption of this reactive power. Because, of this, what happens is the receiving end voltage goes up right. Sometimes, this voltage can go much higher than that of the sending end. This again is problematic, because we have said earlier, that we work within a voltage range of plus minus 5 percent.

And if this voltage goes beyond that, then there is a chance of insulation failure for the insulators on the transmission line. Because, the voltage will go beyond their rated capacity, this cannot be allowed. And therefore, we under light load conditions, we have to absorb the reactive power and that is done by this reactor. So, we have both absorption of reactive powers, when we want and generation of reactive power. Most of the time, when the load is low high, we need this part more and this part very less. Whereas, when the load is very low and the voltage is going higher, then the current through this can be increased and these can be switched off. And again, the voltage can be maintained.

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Now, instead of using static compensators, earlier people where using rotating compensators. These rotating compensators are nothing but synchronous motors, which are not mechanically loaded. That is, they run at low load. So, they are designed as synchronous motors, running at low load. It is only the excitation, that we vary and varying this excitation, we can make these machines either absorb reactive power or generate reactive power.

So, a synchronous compensator, can supply lagging vars up to it is rating. That is, up to it is design capacity. So, by over exciting this, synchronous machine, we can supply large amount of lagging vars. And by making this machine, run under excited, we can absorb the lagging vars. That is, generally these are rated to absorb up to 50 percent of it is rated capacity, in terms of Mega Watts.

So, thus a synchronous compensator of a certain rating is equivalent to a static capacitor of that rating. That is, because it can supply lagging vars with that capacity, which a capacitor also can do. Therefore, we can say it is equivalent to a capacitor or a static capacitor of that rating. And since, it can absorb up to half of that rating, it is equivalent to that of inductor of half it is rating.

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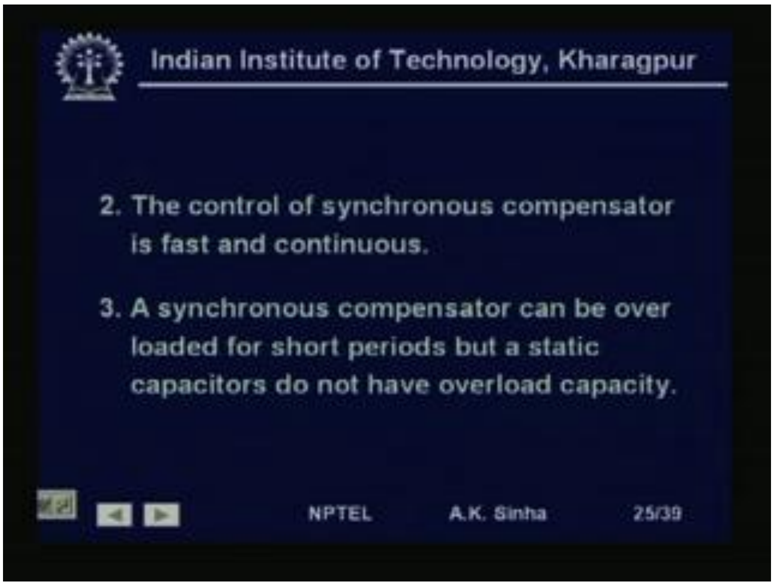

The advantage of synchronous compensator is, that we can very smoothly vary the reactive power absorption or generation by this machine. Another advantage of the synchronous compensator is that, it can be overloaded for short periods. Whereas, this is not possible with static capacitors, because if you try to overload them, they will normally puncture, whereas these synchronous machines have some amount of overload capacity for short periods.

Another major advantage for the synchronous compensators is that a drop in voltage causes the synchronous compensator to supply greater vars. Because, the difference between generated EMF and the terminal voltage will increase, which means the excitation will have to be raised, which helps in arresting the voltage dip. So, it can supply more var, when the load demands more. Even, if the voltage drops and if the voltage drops by increasing the excitation, we can raise the voltage of the terminal.

Whereas, in case of static compensation, if we are using static capacitor, if the voltage drops. Then, what happens is the reactive power generated by these capacitors will also drop. If you can see this relationship, this Q c is proportional to or is equal to V square by x c. And if this voltage drops, then Q c generated will also drop, which simply means, that when we need more reactive power. That is, when the voltage drops, we need more reactive power.

The voltage drop occurs mainly, because the load is drawing more reactive power, at that time, it is unable to supply larger reactive power. In fact, it reduces it reactive power supply, which will further dip the voltage unless we have other sources of reactive power, around.

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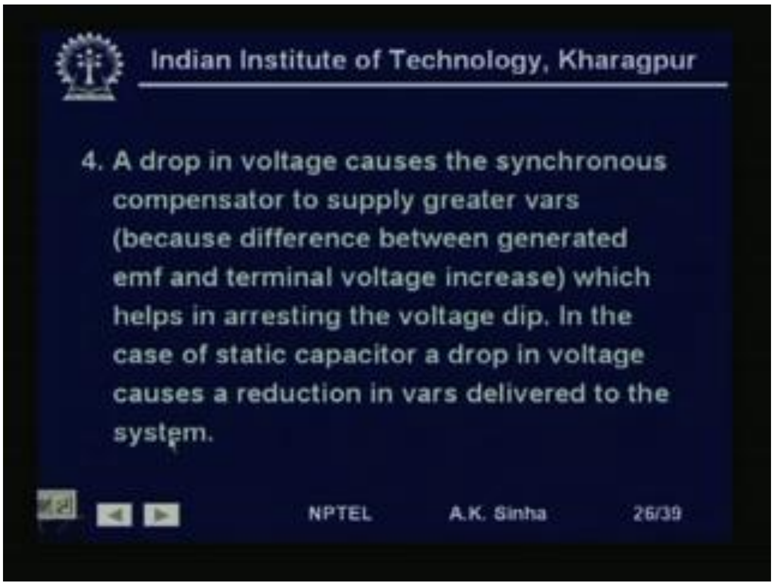

So, in case of static capacitors a drop in voltage causes a reduction in var delivered to the system. That is, it is unable to do or the function for which it is basically used, that is, it can help. But, if the voltage goes down the help also reduces. One another advantage of synchronous compensator is that, it is a rotating machine, which means it has large amount of kinetic energy stored in it. Because, of the inertia of the rotating path and therefore, it helps in making the system more robust and more stable.

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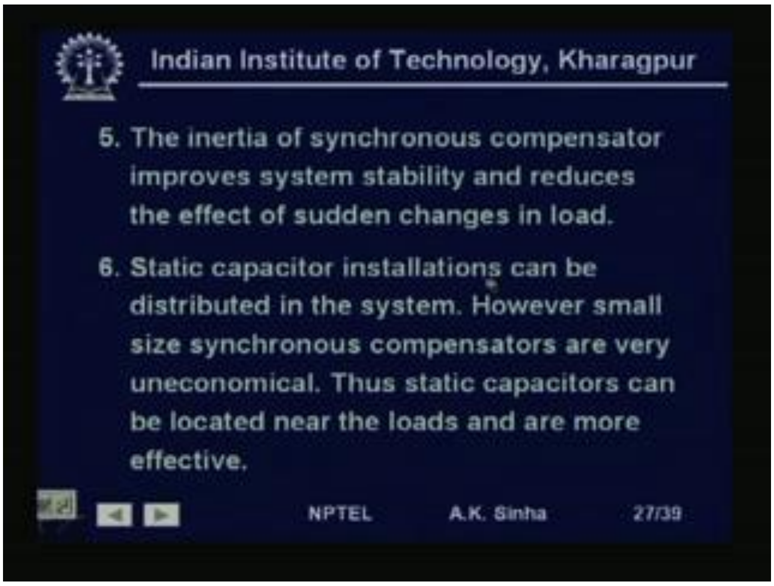

So, inertia of a synchronous compensator improves system stability and reduces the effect of sudden change in load. Because, any sudden jerk is taken up by the larger inertia and the system response is not that great. Static capacitor is installations, can be distributed in the system. However, small size synchronous compensators are very uneconomical.

The main reason of not using synchronous compensators nowadays is, synchronous compensators are comparatively much more expensive as well as they need maintains. Whereas, static compensators can be installed at various locations, almost any substation, we can install them and they do not need any maintenance or personal to look after them, because they are static equipment. Therefore, the static capacitors can be located near the loads and are more effective.

We can use small static compensators, as per the requirements and put them very near to the loads substations or at the load substations depending on the load requirement.

Especially, with the use of power electronic devices, this has become now very easy to do. And therefore, this is what we are putting more and more in the system nowadays, with this we will stop here. We will talk about some other compensating equipment in the next class. And we will work out some problems on transmission lines, which will make things, much more clearer.

Thank you.

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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 and the 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.

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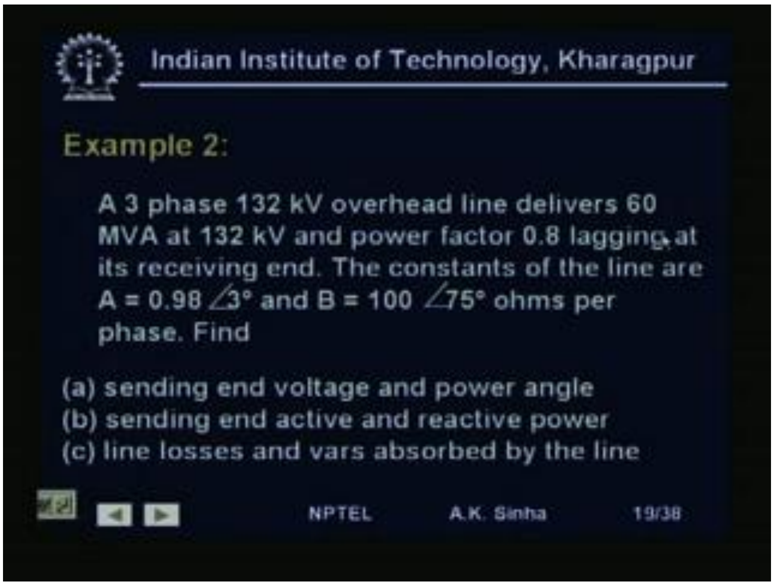

Now, we will take up another problem. Now, this problem states a three phase 132 k V overhead line, delivers 60 MVA. Mind it, this is 60 MVA not Mega Watt 60 MVA at 132 k V and power factor 0.8 lagging at it is receiving end. That is, V r or V 2 is given as 132 k V and the P S r is the MVA value is given 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 end active and reactive power, C line losses and vars absorbed by the line. We will end today's lessons and in the next lesson, we will review. Whatever, we have learnt about the transmission line.

So, thank you very much.