Power System Operations and Control
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Module -2
Equipment and Stability Constraints in System Operation
Lecture 4

Welcome to lecture number four of module two. In lecture three we saw the capability curve of synchronous, and also we saw the various transformers and their uses in electric power system. In this lecture I will discuss about the capability of transmission line. So, before going to see the capability of the transmission line, it is important to see the various transmission lines, means in terms of their length, and what is the various representations so that we can discuss in detail. Now, at transmission line, as you know it has resistance, it has inductance, it has capacitances, and all these parameters are distributed in nature.

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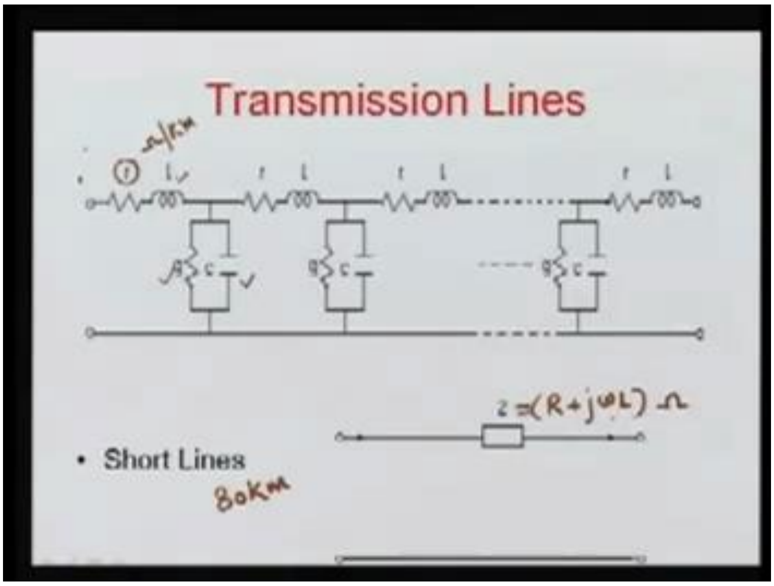

You can see this single line diagram where this I have returned, this is r is the resistance, and again this is per ohm per kilometer; means it is a once length is keep on increasing, the resistance is also increasing. Similarly, the inductance of the circuit, of this transmission line, and the inductance is of the form, because we are having the different phases, and then there will be currently showing of the different magnitude, and due to the magnetic flux is produced and then we have the inductances. Similarly, we have the capacitances, because the conductors are charged at the different potentials. So, there are some capacitances are formed, and it is a throughout the transmission line length. So, this is a capacitance, and that can be calculated using the different formulas, different concept. Again we can calculate using the GMD and DMGR concepts. Another term also associated in the transmission line distributed parameter; that is your g, and this is called the conductance. This is representing a resistance, means it is a loss component, and this loss components basically represents, because we are having the insulators.

And why we required insulators, because the bare conductors are hanged over this tower, with the help of your insulators, and there will be some leakages current which will be flowing on the surface of insulators, and there will be some loss. So, it is also distributed because the towers are distributed throughout this length of the line. So, this g is also a distributed parameter, but for analysis purpose, we normally go for the different representation for the different line, and then we can classify the lines depends on the length; first one is your short line. Short line is the line which length is less than 80 kilometer, or you can say 60 miles. In that case what we normally do that charging that is a c and g here, the charging capacitance as well as here, the conductance is ignored, and only we take the series impedance and that impedance is represented here as a lumped parameter; means here it is RZ it is your R, capital R I am writing here, your omega this I am writing this L. So, this is basically in ohm or in per unit, but it is not per kilometer, because we multiply by the length. So, this is the lumped parameter, means this resistance here as well as the here the reactance, due to the inductance it is the complete of the total transmission line. So, if it is as per kilometer then you have to multiply by the length of the line.

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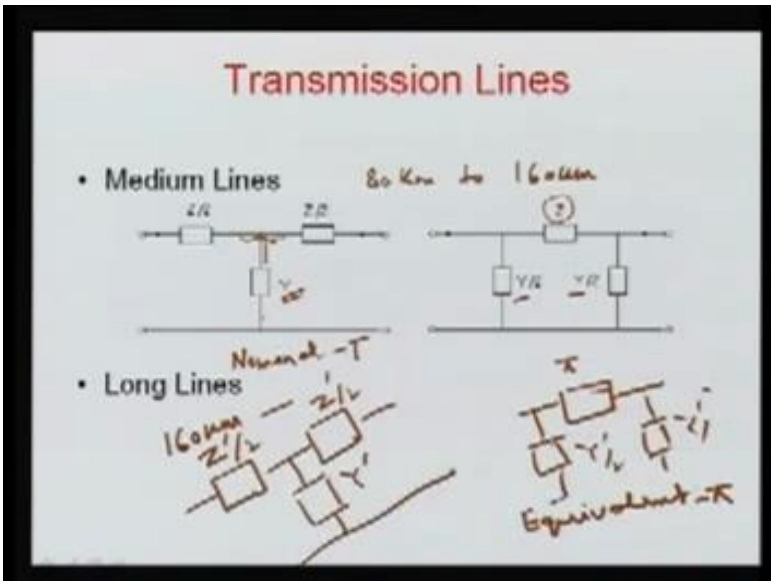

Another category is your medium line; medium line normally represent from 80 kilometers to it is 160 kilometers, and in some cases it is up to 200 kilometers it is analysis of the form using concept of the medium line. In the medium line also, we normally represent the distributed parameters in terms of the lumped parameters; means we have to lumped the total series impedances, or there is some impedances, but here in this case we cannot ignore this charging capacitances. Means we cannot ignore the capacitance value, and that is why we include here this y in this formulation. So, again we can lump, now you know this sump part is distributed. So, this sump can come in the intermediate of the line, it can come both end of the line. If you are it is represented under the intermediate of the line, we will see this is called the T representation, and it is called normal T, because here we have made some assumptions it is not equivalent T. We will discuss equivalent T here in the long transmission line.

So, this you can see just like a T here, and that is why it is called normal T representation. Similarly, we can also. Now if you are the shunt admittances, if you separate half of the separately here one end here another end, and here the series impedance here the complete is lumped in the between, then it is called nominal pi representation. And then we can go for the various analysis, and now this calculation becomes very simple. Now, what are the various calculations; normally we go for calculating the performance of the transmission line, and the performance of the transmission line is defined as the, here voltage regulation voltage regulation, and another is your efficiency of the transmission line. So, we can calculate the losses in the transmission line. We can calculate this, your sending voltage, receiving voltage, and then calculate the regulation. However in the long transmission line, if your line length is more than 160 kilometers in some cases 200 kilometers then it is not possible, to take the lumped parameter, and that calculation becomes very erroneous.

So, what we do, we go for taking the distributed parameter and using the distributed parameter concept, we can define the transmission lines in terms of the abcd parameters. We can even though go for the equivalent T and equivalent pi. Means here this is, you can see this is T, what we do normally if you would here this is T of course. This is we are taking T we are now representing in terms of lump, but taking the consideration of the distributed parameter. So, here your z prime, it is not sure here z by two here, similarly here z by two and here it is y prime. So, this y prime z prime are basically related with your distributed parameters. Here z and y are the lumped parameters; that is multiplied. Similarly, we can go for this pi representation, and that is called your equivalent pi, because what we are doing this distributed parameter we have represented, and then we are trying to represent that line in terms of equivalent of pi; that is why it is called equivalent pi. So, here what will get, instead of this we will get here, here we can get pi like this. This is your pi here. And here your y by 2, this is prime here y by 2 prime, and this is your z z prime again. So, we have to represent in equivalent form, and then it is called the equivalent representation of the long transmission line.

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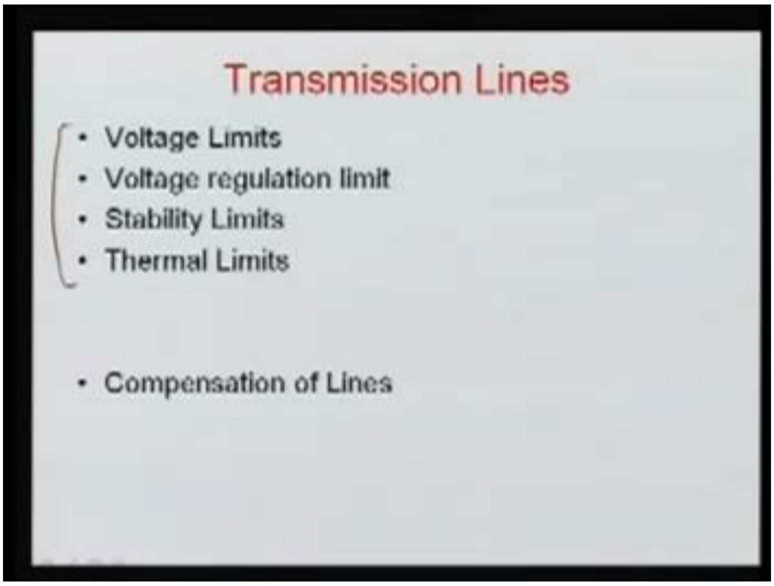

Now, the various constraints, various limits, those are imposed in the transmission line, and they are the restricting parameters, that we have to look into the matter before transmitting the power. First one is the voltage limit; the voltage limit is related to your dielectric limit. The voltage regulation limit that is how much changing the voltage from the full load to no load; that is also very important. Another is your stability limit; that is whether we can, how much power we can transmit power over the transmission line, without losing the stability of the system. Another is your thermal limits; thermal limit again related to that if you are keep on throwing more current, there will be some losses and therefore, what will happen due to this losses there will be more fag etcetera, then we will see. All these four limits we will see in the next few slides. To avoid several things here, especially the stability limits, we should go for the compensation of the line, and we will see the various compensation techniques also, and based on that we can improve the stability of the long transmission line. So, it was the thermal limit.

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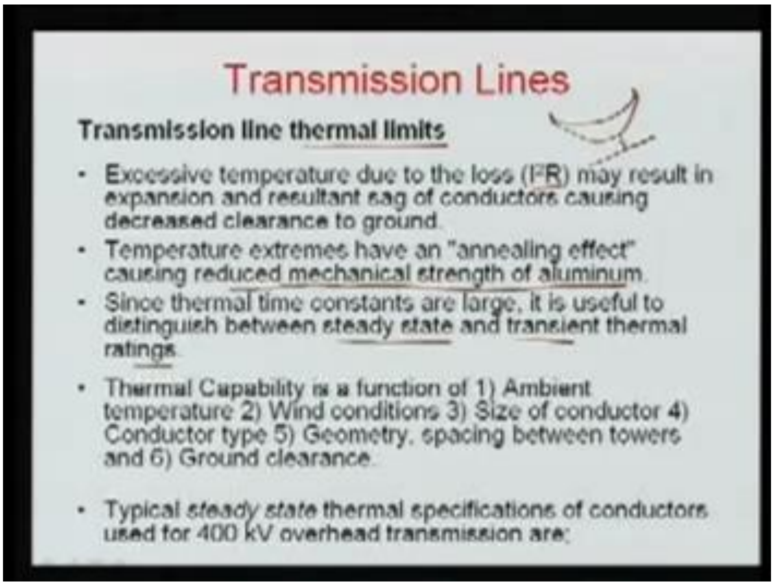

So, the transmission line thermal limit. The excessive temperature due to the loss what is loss, if you are going for more current in the conductors. So, there will be more current, more loading is more current, and if there are more current then what will happen I square R loss, R is the resistance. So, I square R loss will be high, and that may result in the expansion, because that there will be temperature raise, and the resultant sag of the conductor causing decreased clearance of the ground. What will happen, normally if you see this is your tower, suppose, and this is your transmission line which is a form of the capability. If the temperature will increase what will happen, this will go like this, and if have a ground here then what will happen, here the ground clearance is reduced, there may be possibility of the flash over, there may be possibility of the human damage, and that is not required. So, the excessive temperature raise due to the I square R loss, normally limits your thermal limit.

Now, another question why the temperature is excessive temperature. Once there will be loss, there are several conditions that is it is of lines of hanging in the sky air, and always once the loss is there, it is dissipated in the air, but if the loss that is more than the dissipation of this loss, but heat if less than what will happen, they will keep on increasing the temperature of the conductor. Once if it is keep on increasing, then will have the sag and that is the expansion on the sag, that is very dangerous. The temperature extremes have an annealing effect, causing the reduced mechanical strength of aluminum, at the same time it is not only effect; means if the temperature increases then this as the annealing effect, means it will reduce the mechanical strength. Normally we never the simple aluminum or the copper conductors, we had normally used basically different type of conductors; like ACS or we use, that is a aluminum conductor steel reinforcement to get the more mechanical strength of the conductor, but the aluminum which is used. Normally we use the aluminum for the bare conductors, and the copper for using the cable because that cable aluminums are cheap, so aluminums are used.

So, here what will happen it will reduce the excessive temperature in the strength of aluminum. Since the thermal time constants are loss. No doubt the thermal time constant is very loss. So, it useful to distinguish between steady state and the transient thermal rating, because the transient thermal ratings means there is a sudden change, sudden increase of, momentarily increase in the current how much loss is there. So, the temperature raise will be slow, it is not so instantaneously been increasing, and another is steady state that we can transmit the power without losing much side, and also without losing the mechanical strength of aluminum conductor. Thermal capability is a function, how much thermal capability of the conductor, is basically depends upon several factors, and one is very important that is ambient temperature, what is the temperature outside. If especially if it is a cold whether you can go for more current, because this heat dissipation will be more, means outside temperature is also very important. Wind condition, because if wind is there, so this heat which is around the conductor that is a generator due to the current that will be flowing, and this is a good way of the conduction of heat.

Size of conductor means size is very thin, very large, If size is larger then again the area will be more and the more dissipation of heat will be there. Again the temperature raise will be less. The conductor type again the different types of materials are used, and those materials also what is that thermal resistivity, and based on that we can also decide what will be the temperature raise. Geometry and spacing between the towers means, what is the towers what is the geometry the three conductors, because if the three conductors very close then heat generated by these three conductors will come into the picture, and again there will be more raise. So, it is a spacious, then again the cooling will be again better. Ground clearance is also very important, because the ground clearance if there will be more temperature raise, that clearance will be reduced, and then therefore, we can operate the line successfully. Typical steady state thermal specification of conductors used for 400 hundred kv over a transmission lines. The 400 hundred kv just I am going to talk, it is for the Indian condition.

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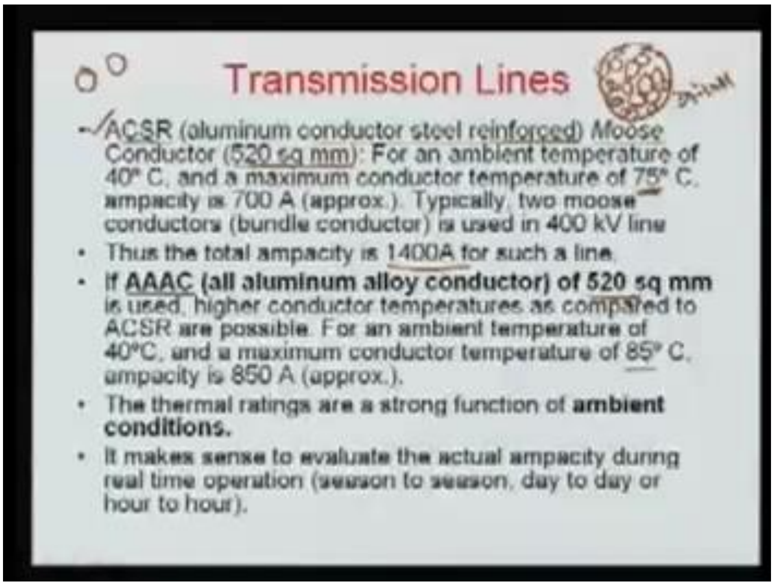

This ACSR as I mentioned it is aluminum conductor steel reinforce, means what we do we use the steel inside, and around this we use the aluminum conductors, and it is called; means there may be not only one layer of steel, it may be the one or two layer of steel and over and above we can go for here the aluminum conductors. So, normally this type of conductor is known as the stranded conductors. Means here the conductors have lot here touching here just like this, and the equation for this the number of conductors in any particular layer, is basically given by n square minus 3 n plus 1. Means if you are using one, n is equal 1 means one conductor; that is central conductor. If you are going for two layers, then we will find here 7 conductors will be around that. Normally for 400 hundred kv we use the twin moose, means we use the bundle conductor of moose, and that is here conductor 520 square mm, here the conductor area just I am talking 520 square mm normally. One thing is very particular you can note here the moose.

Normally in this 50 hertz cycle the conductors which are used, the name given are based on the animals. However in the 60 hertz a supply in the system especially in USA and the Canada they use the bird's name. Like in India this Paris conductor name, you can see this moose panther, zebra, and dog. So, all these, are basically the animals. And based on the moose if any person is a moose conductor automatically the area is decided. So, for 400 kv we use the two bundle conductors here. Always if you find most of the cases, you will see if the two conductors in one insulator it is showing, then it is called the twin moose, and then it will be most probably 400 kv transmission line. So, for the ambient temperature of 40 degree Celsius, and a maximum conductor temperature of 75 degrees. This ampacity, ampacity is nothing, but the ampere capacity and there is approximately 700 ampere half of this one conductor. Typically as I said the two mouse conductors that is bundle conductors is used in 400 kv line, thus the total ampacity is twice of 700; that is your 1400 ampere for such a line.

If a triple AAAC that is all aluminum alloy conductor of again the same square area 520 square mm that is used. Higher conductor temperatures as compared to ACR are possible, for an ambient temperature of 40 degree Celsius, and a maximum conductor temperature of 85 degree Celsius this ampacity is 850 ampere. So, in our country mostly we are having the conductor as ACSR, or it may this AAAC, and that is why the maximum temperature allowed here is 75 or 85. The thermal rating or a strong function of ambient conditions as I said of course, the ambient condition is outside condition what is that; means, if there is a rainy season, there is a windy, whether it is a cold season or hot season, this thermal rating depends upon the seasonal, and also you can say ambient condition, the condition outside the conductor. It makes sense to evaluate the actual ampacity during real time operation, especially due to the season to season, day to day, or hours to hours. So, even though hour to hour also this varies, because in the night, it may be the cold and the day time be hot. So, again the how much you can load, that depends upon the time to time, again hour to hour day to day, or season to season. Another limit is the dielectric limit, and that is basically nothing, but your, the voltage limit.

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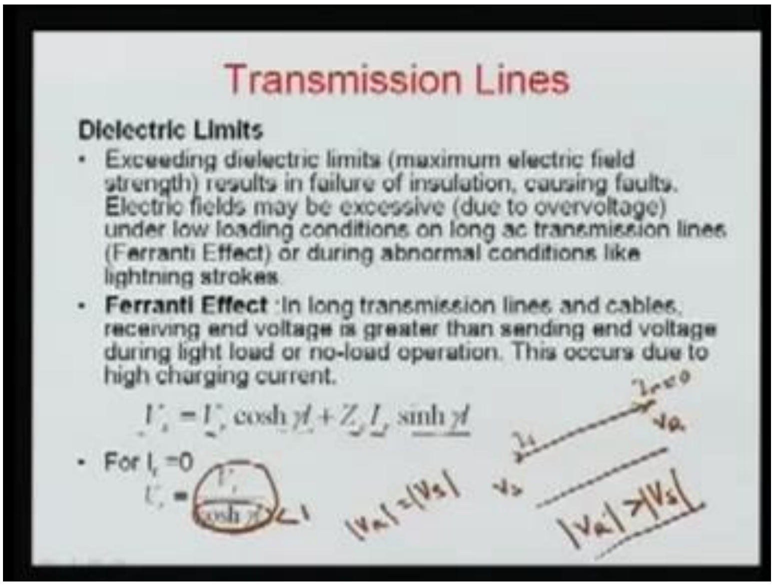

The exceeding the dielectric limit maximum electric field strength results in failure of insulation, causing faults. Electric fields may be excessive due to various reasons. Reasons may be due to the over voltage, and that over voltage again may be of due to the two reasons; one due to the low loading condition, or no low loading condition, in the ac transmission system, and that is called the Ferranti effect. I will discuss the Ferranti effect, or during the abnormal conditions like lightning strokes, or due to the faults. So, we observe the over voltages. As I discussed the conductors in the transmission line, they are the bare conductors and they are hind over the transmission line, and again the transmission line as well as the transmission powers, they are in isolated with help of the insulators. So, these insulators must sustain the voltage; that is your conductor is having. Means your operating voltage will be withstand by the insulators. So, we have a various type of insulators, normally we use the extinguish insulator for ehb transmission line. And again the utilization of these extinguish insulator are not hundred percent.

Means the conductor which is near to the bare conductor, is stressed highly compared to the conductor which is near to the tower. So, let us see the Ferranti effect; the Ferranti effect is nothing, but in the long transmission line and cable, the receiving end voltage, is greater than the sending voltage during the light load or no load. Means here your transmission line, this is your receiving end voltage, and this is your sending end voltage. So, during the light load or no load. Light load means very less load, we can say negligible load. Then this your Vr, means magnitude of Vr here, will be more than what you are supplying and what you are connecting, and this is known as the Ferranti effect. Why it is so, and this is nothing, but due to the charging of the transmission line. This phenomenon is very prominent, very more in the long transmission line, where the charging is very high. We can again this effect by mathematically, formulating this the sending end voltage. This Vs is nothing, but your receiving end voltage, multiplied by cosine hyperbolic gamma l plus Zc; that is a characteristic impedance, here your Ir is receiving end current here, and here it is your Is and sine hyperbolic function.

If your Ir is zero means if this current is zero or very less, then we will have Vr that is your sending end voltage will be equal to your; that is your Vs that is this is Vr. Sorry this is receiving end voltage will be equal to your sending end voltage, divided by cosine hyperbolic gamma l. And this while loop is always more than this Vr. Means this costs hyperbolic gamma 1 is less than unity; means you're the Vr will be more than the Vs. This value can be unity, because the gamma is very small value. So, this value can be unity, or it can be less than that. If it is unity, then it will be your Vr that is receiving end voltage will be equal to your sending end voltage, but for other cases if transmission line is long, this value will be not unity and it will be less than that, and finally, your receiving end voltage will follow this and this is called Ferranti effect. Now, this voltage if it is high then how to control this, because if voltage is very high. So, there will be flash over, over the insulators, and this line will not sustain and their protecting system will trip this line. So, deviation of voltage beyond certain limits, can also be considered to be an unacceptable compromise on the quality of power being supplied to consumers.

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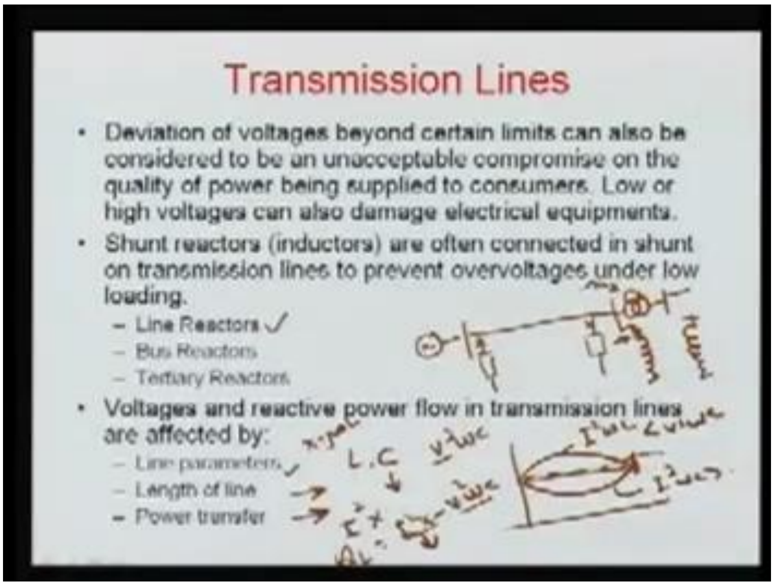

if this voltage, as I said the voltage deviation is not allowed beyond the plus minus ten percent in the most of the cases. In some of the cases it is not allowed more than plus minus five percent. Again it depends upon which voltage we are talking about. For the distribution system it may be ten percent that is allowable, but in the ehb system it should not be more than five percent. So, if voltage is more again there may be possibility, that will damage the operators or equipment's used by the customers; that is also not allowable. So, we had to have the some voltage limit, means voltage should not wall at the limiting value that is lower limit as well as the higher limit. No doubt we know the higher limit will rapture the insulator, that will be the short circuit, there will be heating and so on so forth, but the same time the lower limit is also very important, and that basically relate with the reactive power requirement of the system, because if the voltage is lows what will happen, then for the same more reactive power requirement will be there, and there may be possibility of the current in the conductor will increase and there will be more losses.

So, if the Ferranti effect is there, or a long transmission line there. So, what we do, we use summary of this, to reduce, because if your transmission line is energizing after the great collapse, then the receiving end load is normally it is nil. So, if you are connecting the sending end with some supply system, then of course, the send receiving end voltage will be higher, and there will be possibility that circuit breaker will be trip, due to the high voltage relay picked up. So, what we do, we use the various types of reactors, and again we cannot put these reactors permanently for all the time, what will happen, because these reactors normally absorb reactive power, and therefore, they will try to reduce the voltage. So, some time we do not what that these reactors should be permanently connected to the line. So, what we do, we go for the compromise. Means some reactors are permanently connected, some reactors are connected when they are when, they are required in the system. For example this first one is a reactor is your line reactor. If a transmission line is more than 250 kilometers.

We use the line reactors, means your transmission lines lets go here this is a transmission line, and this is more than 250 kilometers we use here reactors at both end and this is nothing, but these reactors are your simply your inductors. And they are permanently connected in the system; that is why they are called the line reactors. Now, doubt here we use the circuit breakers, again for the production and other, you can say maintenance purposes, but they are always connected in the system, especially in 400 kv transmission line, if the line is to more than 200 kilometers we had to connect the line reactors at the both end of the line. Unless until, let us suppose if you are having generator here, that generator may absorb and they may not be needed, but still if the generator as I said in the previous lectures that we should not allow generator, should go in this under excited, because at that time heating effect will be there, so normally we put the reactors as well (()).

Another is called your bus reactor, bus reactor is again switchable, and it is used when it is required, especially when there is no load, during the charging off peak loads we had used the bus reactors, and bus reactors you can see here we have to use one reactor here, and this is your here with the switch. So, they are only connected when they are required into the system. Another is your tertiary reactor. Tertiary reactors even though when I was talking about the transformer I said there will be three winding transformer, and that third winding as I said it is used for the circulating the triple and harmonics current inside the delta connected winding, at the same time we can use some inductors and capacitors, because this is at the lower range. What happens here you can see, if you are using here the transformer, and this is your load or whatever the line, if you are using another winding here; that is third winding here and we use this connection as a delta, than that delta the third harmonics keep on circulating inside this delta winding, and we can use here the inductor or a capacitor and then it will be used for absorbing all generating reacting power.

What is the advantage of this, because this voltage is very low, but this voltage are very high and then we had to provide the proper insulations are there so that, what happens if you are using at high voltage the cost of these could be very high. So, the voltage and reactive power flow in the transmission lines are affected by the line parameters; parameters your L and C. Your line length, how long it is, if line length far then almost, again depends upon the charging whether include or not, then it depends up on that and the power transfer. Power transfer again how much power you are transmitting over the transmission line. If will see the voltage profile and a transmission line. Let us see here, let us go this is your. I am talking about that the length of the line. This is your length. In the transmission line there are two components; one is your reactive power absorption, another is reactive power generation. The reactive power generation, is due to the capacitance, and the reactive power absorption due to the inductance.

In the transmission line if the current I is flowing, then I square x is your reactive power loss in terms of absorption of the reactive power due to the inductors; that is inductors basically found inductor they are not, we are not using lump inductor this is a inductor due to the different currents flowing the different phases. Another due to the capacitance, we generate v square over x c, or you can say here omega c, this is a reactive power generated. So, the total loss here, it is nothing, but your I square x minus v square omega c, or here x what is x x is nothing, but z is your omega L j omega. So, this here you can here; one is absorbing, another is generating. So, the voltage profile of a transmission line, depends on your the current which is flowing there. For the six voltage here, six capacitance and inductance, because once the transmission line is designed, there is no possibility is to change the l and c, and thus it is always here, it is the current we give what is the voltage profile of a transmission line.

So, let us see here, this value is basically, if this value is more your reactive power loss is more, and that can you can say I is more, means your line is highly loaded in that condition the voltage if you are maintaining the receiving and sending voltage, the voltage profile over the transmission line will be like this. Here I am talking this here maintain the voltage profile here, at 1 per unit here as well 1 per unit. Again in the reverse case, if this value is more then it will be the here like this. Means it is some voltage of very high in the mid of the line, what will happen, the insulator which is designed for the 1 per unit or rated value, if you are exceeding more than ten percent or so, then there will be so many flash over's and that we will cross the line to ground part, and we do not want that. So, this is basically the line loading is very important in deciding the voltage profile or the line.

So, this is the condition, when you I square omega L, it is your less than your v square omega c. However this condition your omega L is more than this, but if the voltage profile one, if both are equal there will be no loss, and that is called flight line. Means here in this condition both your I square x will be equal to your v square omega c. Now, let us see another parameter, that is very important in deciding the loading of the transmission line, and that is known as a surge impedance loading, or you can say normally it is very commonly used SIL loading.

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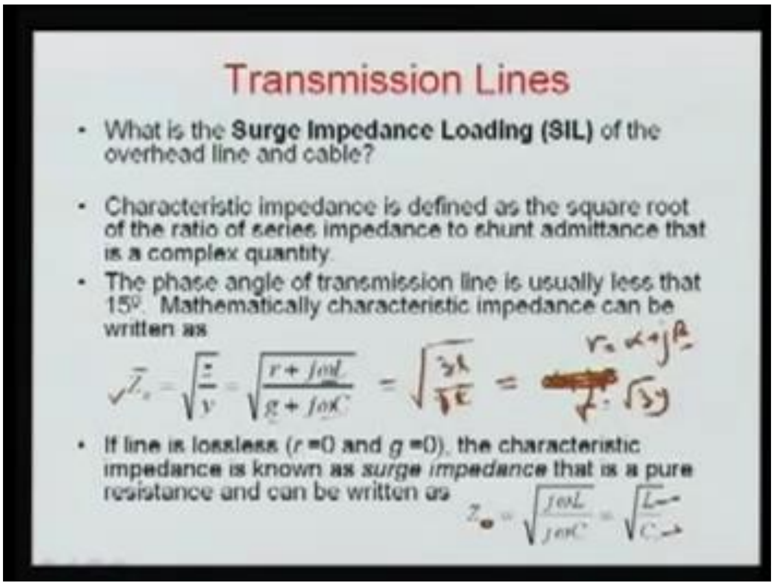

Means surge impedance loading, let us see what is that, before that surge impedance loading, the sum of the parameters are to be known before going for the surge impedance loading. First let us define are seeing what is the characteristic impedance of a line. Characteristic impedance is defined as the square root of ratio of the series impedance, to the shunt admittance, and that is a complex quantity. So, the characteristic impedance, you can see that is known as Zc that is a complex quantity, it is the ratio the square root of the ratio of Z divided by y. Now here you can see this Z which I have used, it is per kilometer, this is also per kilometer. If you are using here for the total length and length will be cancelled here. Means for example, that is also true here; that is zl and here your y l, means l l will be cancelled. So, this characteristic impedance is independent of length of the line.

This z is no doubt this distributed parameter r per kilometer, plus here this reactance of the line, plus here g and here j omega c. The phase angle of a transmission line, is usually less than 15 degree, and this phase here what we can write here this zc, it is nothing, but your omega j beta. So, this alpha is called accumulation constant, and beta is called the phase constant, and gamma, sorry this is not this value sorry. This value is basically the Zc itself, and here we will see latter, this is a gamma is nothing, but your alpha plus j beta, and this gamma is nothing, but under root Z y is called your gamma. So, this alpha here it is known as this determination constant, and the beta is called your phase constant. So, this is your characteristic impedance.

Now, if you see if you ignore the losses of the line, means if r is very small and negligible, if g iz zero, then we can see the characteristic impedance now become to surge impedance, and it is represented at here the z naught, rather than zg, and this z naught here I have removed the impedance r and j component, and then we will find L over C. Now, this parameter you can see, once your line is designed L is fixed C is fixed, means your z naught is fixed, and this z naught is independent and of your length of the line. At the same time this is a real term, means here L over C means, L is positive, this positive means here you are getting the real term. How Ever this Zc was a complex quantity, because here this complex and complex will take it out, you will get some complex component. So, the surge impedance is your pure resistance, and it depends upon again what configuration of your line, so it depends upon the line configuration. And also it is, means we have this value it depends upon you L and as well as C.

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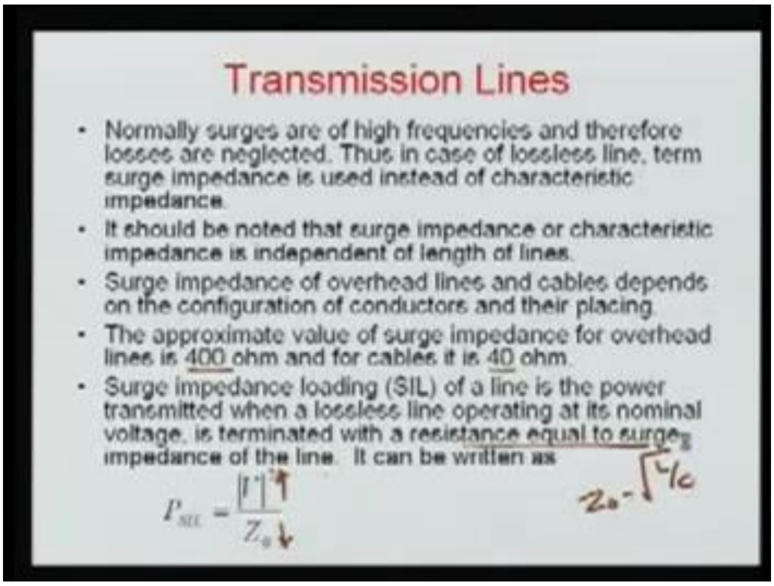

Normally, these surges are of high frequencies, and therefore, losses are neglected. Means for the high frequency, normally good losses are neglected; this in case of losses of line, the term surge impedance is used, instead of the characteristic impedance, means for the high surges. So, it is that is why it is called surge impedance, in surge of high frequency and the losses are r and g are reliable for those high frequency. So, we can say it is for loss less line, the impedance which is comes out to be it is surge impedance. It should be noted that the surge impedance are characteristic impedance, is independent of length of lines, both impedances are independent of lines. Surge impedance or overhead lines, and cables depend on the configuration of conductors, and their placing of course; you can see C and L. They depend upon radius of conductor, as well as how much they are how they are spaced. Approximate value of surge impedance for overhead line, it is approximately 400.

Again its value depends upon the configuration to configuration, and also for the cable it is 40 ohm. The point why this surge impedance for this cable is less, that the conductors are spaced, spacing between the two conductors is very less, and also due to that the capacitance here, as I said your z naught, here it is nothing, but your L over C. So, your L is small and C is very high for the case of the capacitors cable, because the capacitor value is very high for the cable, because the spacing between the two conductors is very small. So, we are having this value is very low and it is a ten times lower. So, the surge impedance loading is defined, with the help of the surge impedance, and it is defined as here that is called P surge impedance, because this is your ohm resistance is not a tensed. So, the v square, if the line is voltage is maintained to the v, and here nominal voltage that is terminated with the resistance equal to the surge impedance of line, it can be written as this.

Means if a transmission line is terminated with the resistance equal to the surge impedance, then we will have the surge impedance power let us say PSIL will be v square upon z naught. Now, you can see this surge impedance can be increased, by decreasing this or increasing the voltage. Again increase in the voltage is not possible, because both increase the insulators and other construction cause, and as well as the tower design etcetera will be very expensive. Same time for z naught reduction, how you can reduce, means you have to go for more less and less spacing, and also that may create the insulation problem and so on. So, there is some compromise, and we cannot load the transmission line more than SIL loading, especially for the long transmission line.

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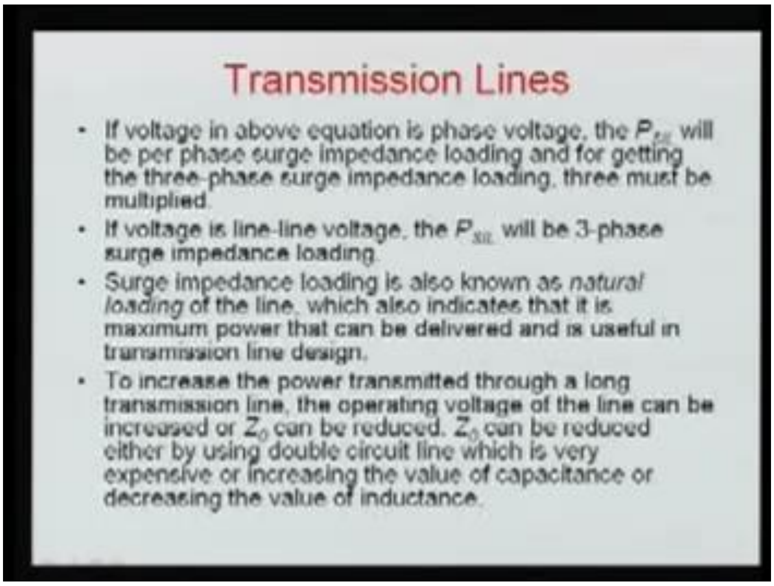

If voltage in above equation is phase. Now again this surge impedance loading how we can calculate, this PSIL will be the per phase, if you are using the voltage, here the line two phase line to neutral voltage, and for the three phase you have to multiply then by 3. If you are using the line to line voltage, that v square here this v square here, if you are using the v line line then the PSIL will be your three phase power. And if you are using

VLN the, is line to neutral, then you will get the PSIL in the formulation, it is your single phase. The surge impedance loading is known as the natural loading of the line, which also indicates that it is maximum power that can be delivered, and is useful in the transmission line design. To increase the power transmission through a long transmission line, operating voltage of line can be increased, or z naught can be reduced. Z naught can be reduced either by using double circuit line as I said. It is not possible to have the higher order, high voltage at the lower space, because then again if you are using air as a medium then there is a possibility of the flash over, so it is not possible. So, another possibility that we can go for the double circuit line, means we can have two line parallel to the parallel link parallel, and that make us more expensive, more cost. And increasing the value of capacitance or decreasing the value of inductance as another possibility again, for that we have to change this spacing, between the conductors.

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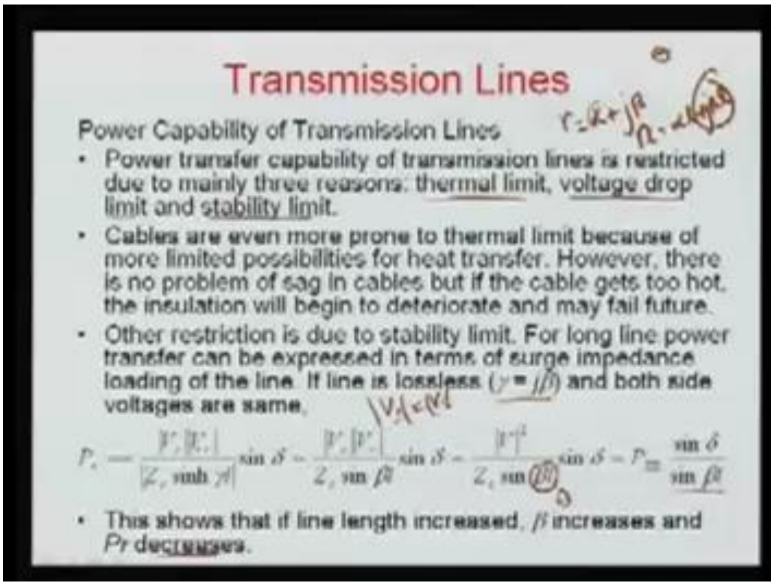

Now, let us see what is the power capability of transmission line, including all the limits. Limits; that is voltage limit, your thermal limit, and another that is the stability limit, and we will discuss the stability limit here. For capability of transmission lines, is restricted due to mainly three reasons, as I said here the thermal limit, your voltage drop limit, and stability limit. Cables are even more prone to the thermal limit, because of more limited possibility of the, because of the limited possibility of the heat transfer, because in cable you know, use the conductors very. The spacing between the two conductors are very less, at the same time the dissipation of again heat is also not so proper, as compared to the overhead conductors. How about there are no problem of sag in the cable, and sag problem is in your overhead transmission line, but if the cable gets too high, it is very much heated, the insulation will begin to detoriate and may feel in future. Other restriction is due to the stability limit. So, this was related to your thermal limit.

For long transmission line, power transfer press can be expressed in terms of surge impedance loading of the line as we saw in the previous slide. If the line is loss less that is gamma is equal to your j beta, and beta is your phase constant, both side voltage are in, both voltage side are here means Vr and your Vs, means receiving end I am sending as voltage magnitudes are same, then we can write this receiving end power, will be equal to your Vs Vr z characteristic sine hyperbolic gamma L. What is this gamma as I said. This gamma is nothing, but your alpha here plus j beta. So, your gamma L it is alpha L plus j beta L, and this beta L is nothing, but your theta, and this is called the line angle, electrical angle of the line. So, we can write this receiving end power P will be your this Zc sine hyperbolic gamma l multiplied by sine delta.

Again this delta is your load angle the voltages, the voltage angle between Vr and Vs. This can be again replaced if it is loss less, means your this alpha part is zero then we can go for this, and this beta l is again sometimes called at the theta, and we can represent this whole, because this is loss less. So, V square upon Zc we saw it is a PSIL. So, then it is PSIL sine delta upon beta l. This show that if line length is increased, if you are increasing the line length, beta is increased, and Pr is decreased, means your receiving end power is decreased. Means you can keep on increasing the length your power transfer over the line will be keep on decreasing. So, what does mean if you are going for long transmission, it is not possible to transmit more power due to this limitation of the transmission line.

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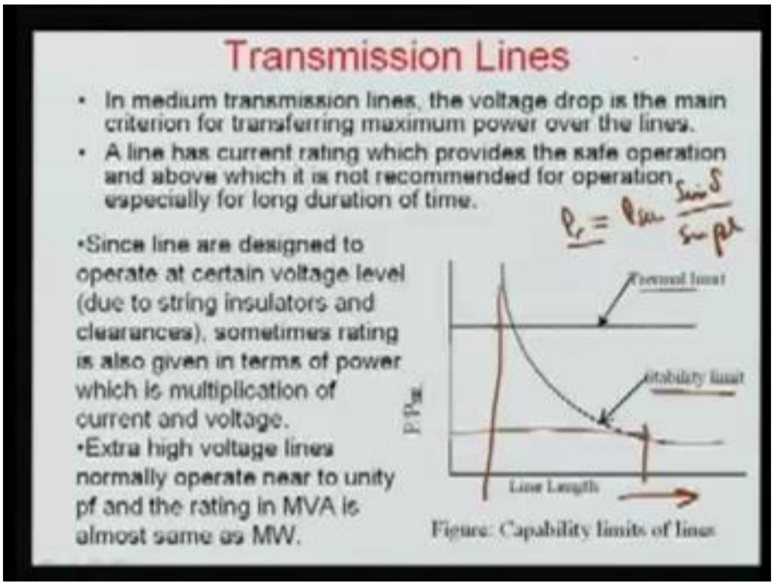

We will see again in the medium; however this is case of the long transmission line, as I said if the length is increased this beta l is again it is again the theta is increases, and therefore, the Pr will be reduced. However in the medium transmission line the voltage drop is the main criteria, for transferring maximum power over the line. A line has current rating, which provides the safe operation, and above which it is not recommended for operation especially for long duration of time. Now, you can say this is a length of the line you see this figure, and this is your P over PSIL. So, this is your stable thermal limit or the transmission line, and this is your stability limit. So, you can say the stability limit as I said, once the length of the line is keep on increasing, this Pr which we represented in terms of PSIL here sine delta divided by sine beta l. So, this Pr here divided by PSIL, here this is a function of line length.

So, this is you can say keep on decreasing. If your line length is increasing this value is decreasing, and this is due to the stability limit, this is basically due to the stability equation. However, thermal limit is independent on the length of the line; that is constant here. Now you can see from this, if your line is short. Let us suppose less you can see for this length, which limit is imposing it is your thermal limit is here; means you cannot load your line more than its thermal limit. But if your transmission line is long, let us suppose at this length, you can see your first limiting criteria are your stability limit. So, thermal limit is very far off from your stability limit. So, the long transmission lines are restricted due to the stability limit. Your short line transmission line is restricted due to the thermal limit.

Suppose, if you have and always this thermal limit is more you can say the stability limit especially for the longer transmission line. However in the medium transmission voltage line and medium transmission line length, length is less than the voltage drop, is the governing criteria. Since or line design to operate a certain voltage level, due to the string insulators and, sometimes rating is also given in terms of power which is multiplication of current and voltage. Extra high voltage lines normally operate near to unity power factor, and the rating of the line in MVA is same as in megawatt. In the transmission line, always this value, this power factor is almost unity, or it is very close to unity, and again it is very difficult the power factor in the transmission line at each point is a different. Let us say, why the power factor in a transmission line is changing with the length.

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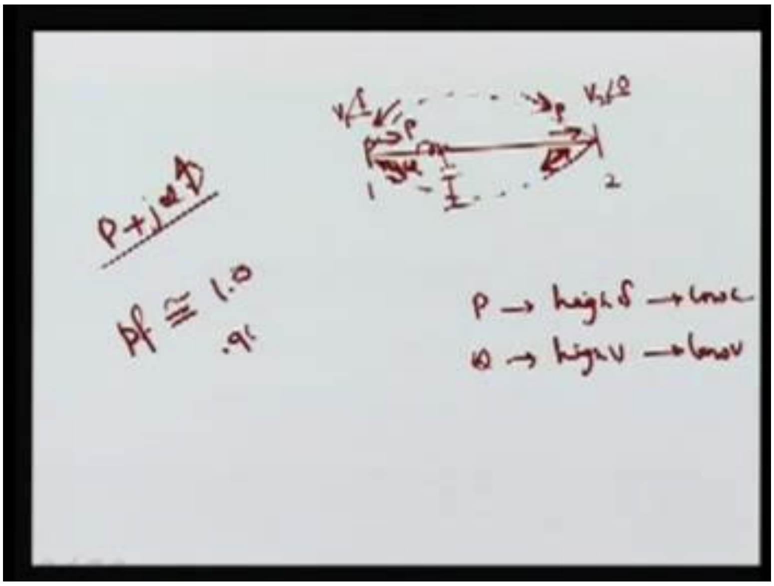

To see this, let us we have a transmission line here this long transmission line. This is bus one and the bus two. What happens here this voltage of this is, let us suppose V 2 and this is here V 1, and let us take here this as a reference angle is zero and here we are having delta. We know that the two fundamental are power system. The power system transmission, the real power P will flow from higher delta to low delta. Means here your real power will be flowing like this and that is your P. But you are the reactive power Q flows from high V to low V. Now if both voltages are fail, still there are possibility that the reactive power flow direction would be the different, means the voltage profile or this line may be like this, let us suppose here. What happens here, in this case your reactive power; that is higher voltage it is flowing for like this your Q, and here also it is flowing like this. However this p will be the unidirectional. Now, you can the power factor here at this end, this reactive power is coming here. So, it is leading here, it is lagging here.

Again it will take another condition here of the high voltage, means low loading of the line. In this case here this reactive power from higher voltage here. Sorry it is coming like this, and this is from here. So, you can see in this case that different scenario is appearing. So, it depends upon the loading of the transmission line, and again the loading gives us in previous slides I showed, that the voltage profile over the transmission lines at each point the voltage will be different, and what will happen the reactive power flow will also be different. And once the reactive power will be different, normally this real power is constant only the loss will be coming into the picture. So, the power factor at each point will be different, because we have here P constant plus this Q, and Q is keep on changing throughout the transmission line. Why it is changing, because due to the capacitances here those are formed; means this capacitance is generating reactive power, and the here there is a inductor and there is a loss. So, due to this variability, the power factor throughout the transmission line it is keep on changing, and of course, no doubt, this power factor is normally is very close to unity here. It may be leading or lagging, but it is sometimes it is let us suppose 0.98 or 0.95 almost close to unity.

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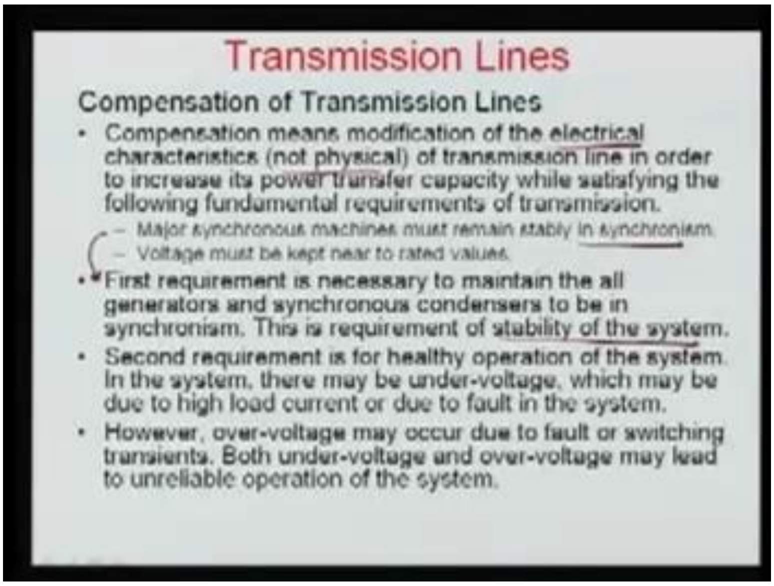

We saw this line, if it is very long, suppose. Now again the length of the line is not in control, because suppose you are generating station is very far and from your load center, then you have to build a transmission line. And the power must be evacuated taken from the generating station, to your load center for the proper utilization. So, the line length sometimes it is not in your control. So, you have to go for that length of the line. And we saw the stability criteria is major concerned for the long transmission line. So, how you can improve that, how you can improve the stability limit, because if line length is more, for the same 400 kv transmission line if the length is 10 kilometer, it is possible that we can flow more than 600 megawatt. But if the line length is more, let us suppose more than 400 kv kilometer then power can cannot be more than 500 megawatt. So, you can see now if line length is more you cannot transmit more power, therefore, what will happen. You have to go for some mechanism, and that mechanism is only way that we can change the electrical characteristic of the line, because physical characteristic you cannot change.

Physical characteristic means that your L and C, means your inductance and the capacitance form once the line is designed, you can achieve, by the way of doing something in this network transmission line. If you are changing the electrical characteristic that is known as the compensation of the transmission line. So, the compensation means, the modification of electrical current characteristic I said, not the physical our transmission line, in order to increase its power transfer capability, which satisfying the following fundamental requirements of the transmission. First fundamental is major synchronous machines must remain stable in synchronism. Means all this synchronous generators must be in the synchronism. There should be any loose and loss of synchronous machines.

Voltage must be kept near to the rated values, normal value, what is the operating voltage. First requirement is necessary to maintain all the generators, means major synchronous machines must remain stable in synchronism. It is your first criteria, and this was that it is necessary to maintain all those generators, and synchronous condense as well, to be in the synchronous. This is requirement of stability of the system. Requirement is for healthy operation of the system. In the system there may be under voltage, which may be due to the high load current, or due to the fault in the system. However in the over voltage may also occur in the system due to the fault, due to the switching, and both under voltages, and over voltages may lead to the unreliable supply of the system.

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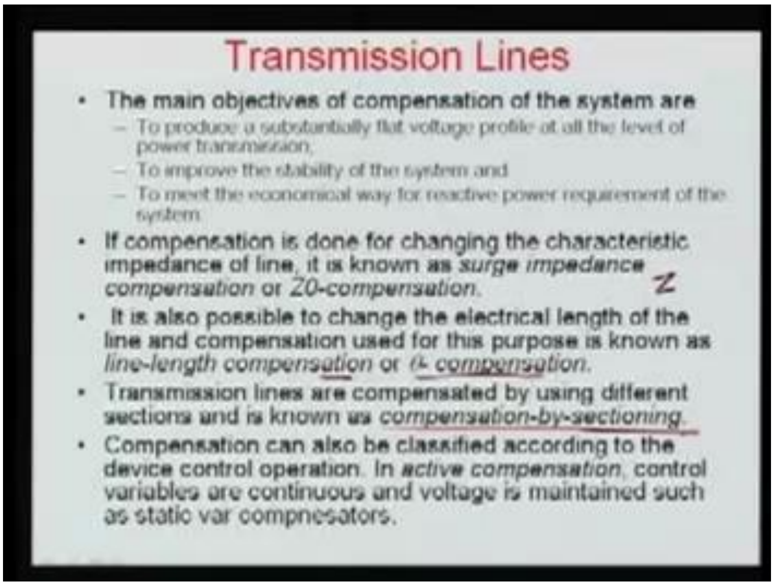

Then what we have to do. Then then main objective of the compensation of the system are to produce a substantially flat voltage profile at all the levels of power transmission, to improve the stability of the system, and to meet the economical way for reactive power requirement of the system. Again, that there are the various types of compensation techniques. I am not going much detail about the compensation, because you may read, you may learn these things in the different again courses. So, if compensation is done for the changing the characteristic impedance of the line. As I said, the characteristic impedance if we are changing that is your Z naught or Zc, then it is called your surge impedance compensation or Z naught compensation. It is also possible to change the electrical length, and electrical length as I said the beta. If you are changing the beta, then it is called the line length compensation or the theta compensation. So, basically based on the parameter, that is you are going to change in that one, by the compensation it is defined at the Z naught compensation or theta compensation. The transmission line are compensated by the different sections, means it is complete line if you are compensating in that way, and other possibility that you can go for section bisection, and this is known as the compensation by sectioning. Compensation can also be classified according to the device control operation, means it may be active and passive. In the active compensation control variables are continuous, and voltage is maintained such as static wire compensators.

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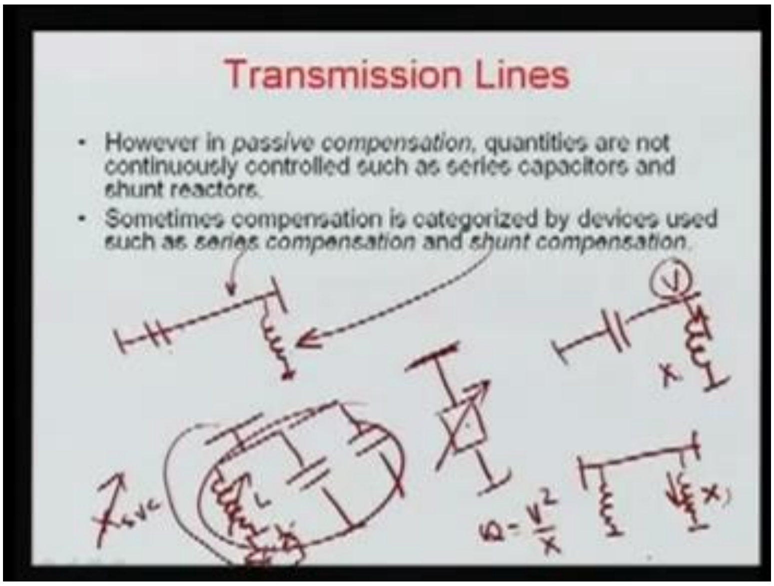

Means static wire compensators are nothing, but here at the bus, here we use the static wire compensators, and it will try to maintain the voltage here by varying its impedance. So, that is your active compensation. In the passive compensation, the quantities are not continuously controlled for example, if you are using the series capacitance in the transmission line here. The voltage is not controlled, and also if you are using here sun reactors. Here reactor is not going for how much voltage is there. It is depending let how much x it is giving, it depends upon the x is how much reactive power it is giving, it depends upon the voltage of this bus. Sometimes the compensation is also classified in terms of whether which type of compensation, means whether you are putting in the series or you are putting into shunt. So, in the series compensation, means we are going to put that device in the series for example, the TCSC, here your transmission line is there.

If you are putting your capacitance here, then it is in series of the line, then it is called your series compensation. However, if you are compensating, let us suppose you are putting here a reactor you are using here, then it is in shunt of this line here, and this is called your shunt compensation. So, again sometimes we will see in other lectures, that the various types of facts controllers. Now with the help of the power electronics devices, we can achieve these compensation mechanics techniques very efficiently, and then we can have the more performance, better performance of the transmission lines, by using power electronics devices, and that is called the facts controller flexible ac transmission systems, and those are very now a days popular. So, here the reactor means as I said it is shunt, then it is shunt, if it is in series series. If you are monitoring the regulated voltage here, the voltage of this bus and this by controlling, what is sbc.

You will see sbc is nothing, but here it is your inductor, and then we use the power electronic device here, and then it is vibrating basically by firing of this thyristors we can change the inductance of this, and we have the capacitances here, and they are the switchable capacitance. So, we can again by measuring this voltage, and giving the firing pulse to the thyristors, we can change this L and there by this whole x here of this svc, is basically variable. And by wiring we can provide the reactive power support accordingly. So, this basically here svc, and this is called your active compensation. In the passive as I said, here a transmission line to avoid the over voltages, I used here one reactor here, and reactor here, that reactor is not maintaining the voltage of this bus. Means here simply we have to put here some x, and this reactive power generation is here it is nothing, but your V square upon x at this point. So, if your voltage is less, it will provide the less reactive power no doubt. And if voltage is more it will provide more reactive power again, how much x means, how much x it is going to be here. So, this you called passive compensation.

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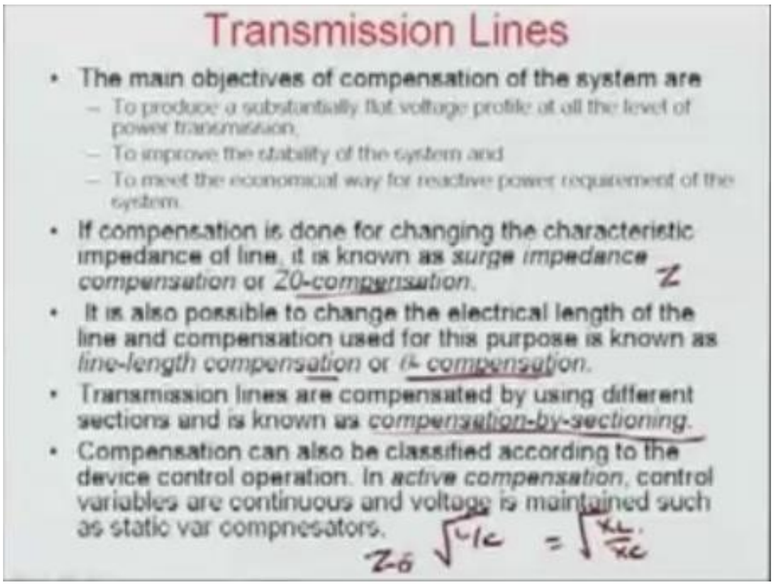

And already I discussed here this various compensations techniques again the z naught compensation, theta compensation; here z naught is here you can change your z naught is your L by C; means you can modify by putting some extra device.

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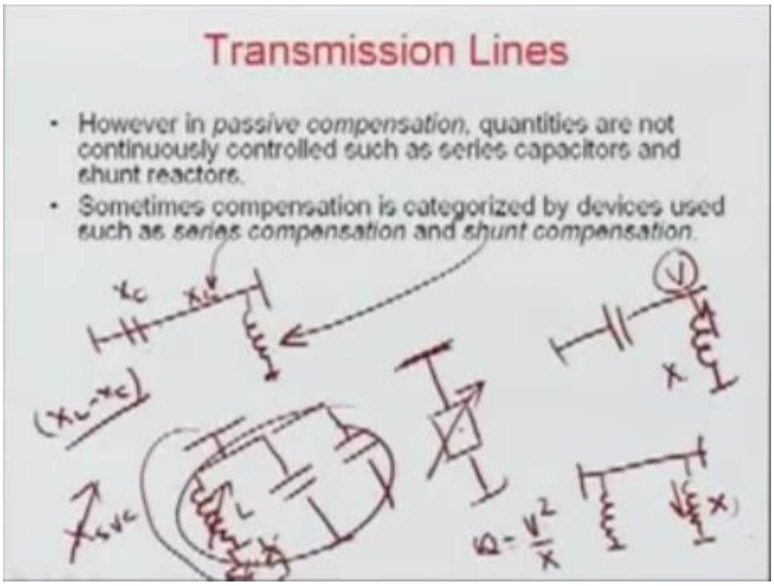

For example, if your transmission line here, your transmission line is this you putting here Xc here what is effectively happening, your XL was there other or the transmission line. Now, your XL minus Xc you have new parameters. Means if you are seen here this we can write, it is nothing, but you XL upon Xc nothing else. So, effectively what we are doing, we are changing here the series part, and then we are getting the different value of z not. We can reduce z naught by using here x naught reduction. So, this is in total means, we can compensate the line to improve the performance of the line, and thereby we can improve the stability of the lines, and then these are the various. So, in this lecture what I discuss, I discuss the transmission line, we saw the various limits, thermal limits, voltage limits, and stability limits and how we can improve this, that by using the compensation, we can improve the thermal stability limit, and with this is the end of this lecture.

Thank you.