Power System Operations and Control
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Module - 4
Lecture - 2

Now, welcome to lecture number two of module four that is introduction to power flow control and in previous lecture we saw this load curve and the unit commitment problem. Also, we saw that the generation economic dispatch is very much essential to reduce the cost of electricity, but to control the power flow the obvious choice is that we should have some devices in the power system. So, we can control power as well as other commodity in the system. So, that we can achieve our desired objective and one of them is your facts technology that is the flexible AC tech transmission system.

Another one is your HVDC that is called high voltage DC transmission system. We also saw the major components especially two components we saw in the previous lecture, one is your converter, and another is your converter transformer.

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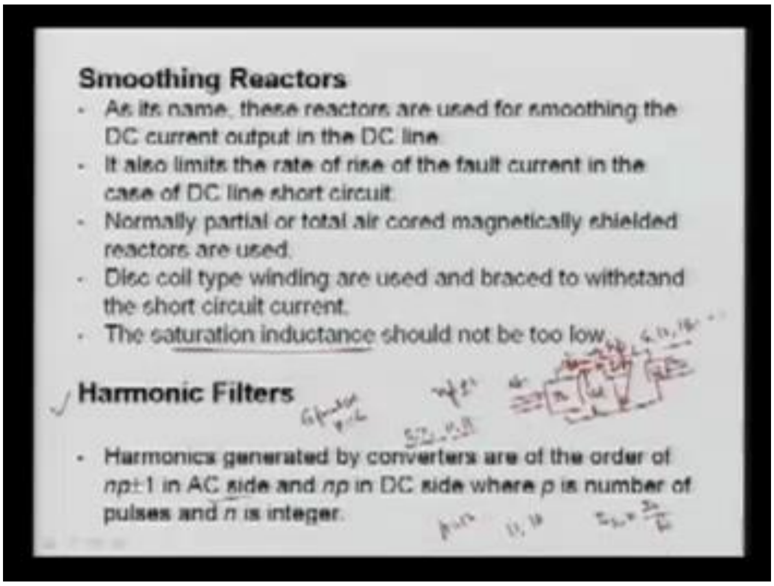

Here, just I am going to discuss other major components of HVDC systems or another that is called smoothing reactor smoothing reactor as its name, it is a reactor that is used for smoothing the DC current output in the DC line. As I said if you have having here, let us, suppose we are having in this figure this is your rectifier, we are using three phase

AC system and here the DC is coming, then the current, which will be flowing here it is your DC current because this side we are using. Another here inverter, and then we are getting three phase AC system. So, the current which is flowing in this DC link must be perfect DC current because there are a if you will see the voltage output here that is V d is a not perfect DC, it is having some repulse.

So, to avoid that to make this current DC we have to use some inductor here in the line so that we can smoothen the DC current output in the DC line it also limits the rate of rise or the fault current in the case of DC line short circuit. What happens if suppose you are not using this smoothing reactor inductance l? If there is some short circuit here to the ground or to the other line, then it is a huge current will be flowing here because the impedance of this transmission line is very less. The voltage that is the DC voltage is very high. So, this also limits the rate of rise current because there will be some capacitor is formed here and then we can reduce the rate of rise of fault current in case of DC line short circuit.

Normally, partial or total air cored magnetically shield reactors are used here as I said the air cored reactors are normally used we have to provide this smoothing reactor and to provide to smooth the DC current. Disc coil type winding are used and braced to withstand the short circuit current the saturation inductance should not be low. As I said because if DC current, which is flowing and there is some short circuit huge current, will flow, so then we should always try to arrive this saturation reaction reactance should not be low. It should be higher, otherwise again during that period, it is possibility that used fault current will be flowing another that is important component in HVDC transmission system is your harmonic filter.

Although it is not one filter, they are various filters, so that is why we call harmonic filters harmonics generated by converters are of the order of n plus p plus n p plus minus one in the AC side. Here, N p in the DC side, where p is the number of pulses and n is integer means the harmonics, which is increased here, it is your N p plus minus 1 and the harmonics this side it is your N p where p is the number of pulses.

Let us suppose if you are using 6 pulse converter means your p is equal to 6. So, the harmonics which will be entering here in the AC side it will be n is equal to n. So, we are getting 5, 7, 11, 13 and so on so forth. However, in the DC side, the voltage harmonics we are getting no doubt in the AC side we are getting the AC harmonics current the current harmonics; however, the DC side you are getting the voltage harmonics. That voltage harmonics here, it is 6, 12, 18 and so on. So, these are the harmonics that are in the DC side these are the voltage harmonics it is your current harmonics. That is why if you are going for higher fault number, let us suppose we are going for the 12.

Then, p is equal to 12, we will find that we are going to get 11, 13 means automatically your fifth and seventh harmonics are eliminated and that will be not into the system. So, the harmonics filters are used to filter out these harmonics, because the magnitude of these harmonics is higher compared to the higher other harmonics terms. Normally, the current which will be flowing here the highest harmonics order it is your I 1 that am the fundamental divided by your h h that is the harmonic order.

It means if you are going to see what the magnitude of your harmonics current of the fifth harmonic it will be I 1 that is the fundamental component divided by your 5. So, seventh it is less 1 upon 7 of your fundamental component and so on so forth, so for the higher order harmonics, the magnitude is very small.

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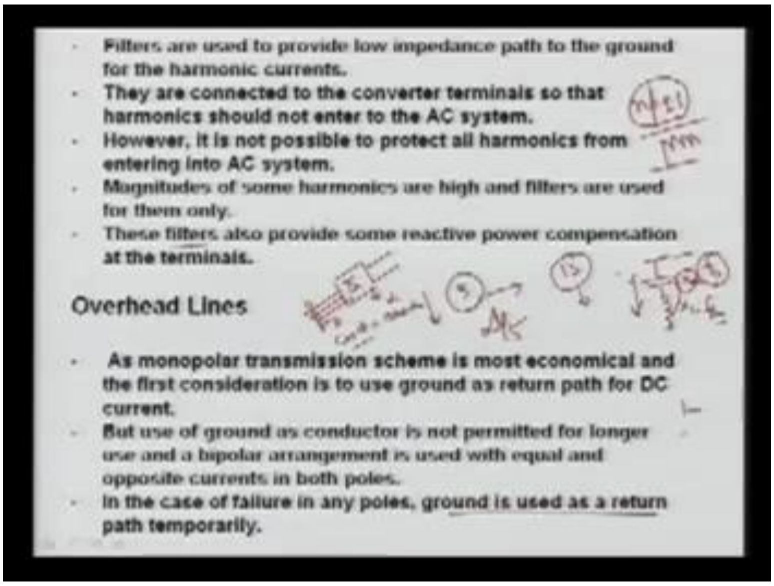

Therefore, we have to provide the filters for only the lower order harmonics because the magnitude of harmonics is higher. So, the filters are used to provide the low impedance path as usual to ground for the harmonics current whenever there is some current is flowing harmonics current. So, we can provide the minimum impedance path so that the current should not enter into the AC system and it should go to the ground. They are connected to the converter terminal so that harmonics should not enter to the AC system, means we use here these filter so that we should not allow these should go into the AC system.

That is not desirable, because it will fall into your AC system; however, it is not possible as I said I will explain why it is not possible to protect all the harmonics from entering into the AC system. If you are going to design the harmonics filters if your order are increasing, means for your going let us suppose if you are comparing the harmonics for seventh and the filter which is we are designing for 13 the cost of this filter is less compared to 13 because the size of here inductors and capacitors will be very high. We have to go for very expensive and also you can see magnitude of this harmonics is less because magnitude is proportional to 1 upon 13 here and here it is 1 upon 5.

So, we normally go for the certain level of harmonics elimination and we use the filters and remaining we allow into the system not only this. Basically, which I wrote the formula N p plus minus 1, it is the scale when we are having asymmetrical, means these are called the characteristic harmonics, why it is characteristic harmonics? This is calculated based on that you are here, whatever voltage is appearing here that is like this, means there is no overlapping, and means we are having the inductances source inductance very small, 0. It means the change of current from one valve one thyristor or you can say to another one it is a sudden we have assumed, but it is not.

So, there is some overlapping, means current will transfer from one length to another length of bridge converter. So, there will be some overlapping and the voltage will be different and the characteristic non characteristic harmonic will be other than this harmonics. So, they are entering into the system and again we have to vary causes, so we have to go for the tuning filter or we can go for the some combined filters so that we can eliminate these harmonics. So, the magnitude of some harmonics are high and the filters are used for them only as I said those are the lower order harmonics are filtered out, these filters also provide some reactive power compensation at the terminal.

No doubt the question always arises why the reactive power is required in this DC system because the DC, there is no power factor concept for that what we do. Basically, we know this is your DC system, this is your rectifier here the three phase system is coming and your DC output is going. So, basically this firing alpha angle and we can show the power factor at this side that is cos phi will be equal to your alpha phi cos alpha means once you are delaying you are reducing the voltage. The power factor of AC side will be the deteriorating and very poor. So, we do not want that and if you want to go for the complete control of alpha from its 0 to its certain limiting value, then you have to provide some reactive power compensation at this bus.

So, the reactive power requirement at the converter terminal both side inverter as well rectifier, we have to provide use reactive power compensation I will come to that point later. These filters you can see you can check also if these filters are providing path for these harmonics at that frequency. So, at the fundamental component they will provide the reactive power support. For example, what I am going to tell you? Let us suppose we are using one filter here this is a capacitor with this LC filter we are using. So, this as we know here this is XL here it is XC here, this is providing this tuning if you are tuning such that the impedance is minimum for this.

So, at particular frequency f this will be the 0 th, but at the fundamental frequency this value will be the capacitive in nature, and then it is acquired in the reactive power support. So, you can verify that if the minimum impedance at any fundamental harmonics component f h. Then, at the fundamental component it will be whole this impedance will be capacitive. It will be providing reactive power support to the system, and we require reactive power support due to the proper control smooth control of voltage as well as the power in the HVDC link.

Another major component of HVDC link is your overhead transmission line in the as we know mono polar operation or transmission scheme or HVDC link which is most economical because there we use the ground as the return. So, we require only one transmission line, but the use of ground as a conductor is not permitted for the longer period the bipolar element is used with equal and opposite current as I said I discussed the bipolar operation, I also compared with the mono polar. Then, we started bipolar is normally very feasible and it is used, but if there is one fault in one any of the link.

Then, we have to use ground as the return path so that we can provide 50 percent power transfer over the DC link. So, then at that time we have to use the ground as the return. So, we have to have the grounding as well and we will see that, but if you are a mono polar, we require one transmission line. If its homo polar or it is your bipolar, we require two transmit some wire; however, in three phase we require the three phases different phases again in one phases may be 1 or 2 conductors depending upon you require bundle conductors or not.

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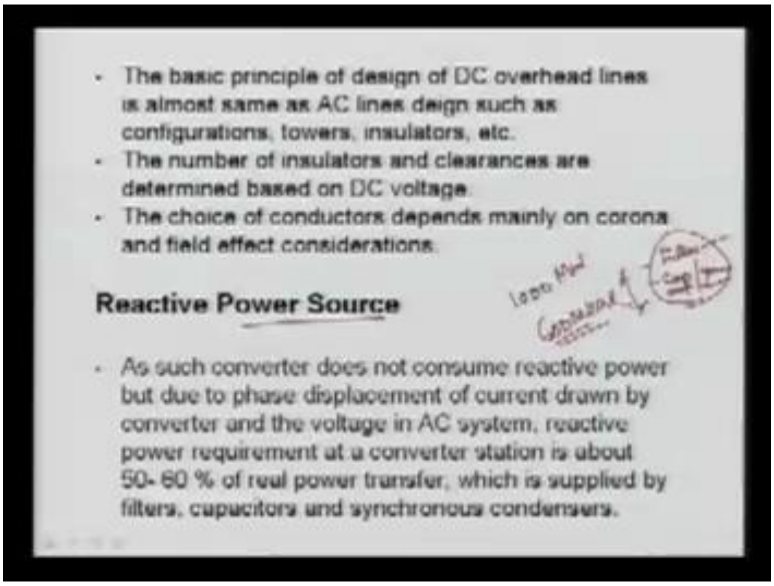

The basics basically the principle of designing of DC overhead lines is almost similar to AC transmission of line in terms of configuration tower insulation and even the similar voltage requirement. The number of insulators and the clearance are determined based on the DC voltage; however this number of insulators and other are decided based on its peak value that how much it can bear because in DC the peak and RMS value is same. However, in AC both are different, so their design and the peak value and we go for the insulator and clearance are assessed. The choice of conductors depends upon mainly the corona loss and the radio interference effect, normally we also know the corona is minimum in the DC line compared to the AC line.

Another component that we have to provide the reactive power source as such converter does not consume reactive power, but due to the phase displacement of current drawn by the converter and the voltage in AC system.

The reactive power requirement at the conversion is about 50 to 60 percent of the real power transfer, which is supplied by filters capacitors and synchronous condensers means if you are having a DC link. Let us suppose that is say for 100 megawatt, then you must require the 600 mvar reactive power support at the both end for the smooth control proper control of that. This you have to for that you have to put lot of reactive power support that is your capacitors. Also, we can use the synchronous condensers if required, but also the filter we provide as I said in the previous slide the filters, which are provide to provide the ground path for the particular harmonics will provide the reactive power support that is needed here at the fundamental component.

So, this we are talking the reactive power requirement at the fundamental component. So, whole this reactive power sources are basically we use the filters we use capacitors or generators if generators are there they can also generate reactive power support or synchronous condensers. So, these are the two options, so filter is always there and here either using capacitors or some generating stations are nearby. Then, we can utilize the reactive power generation of the generators, and then we can go for the reactive power support.

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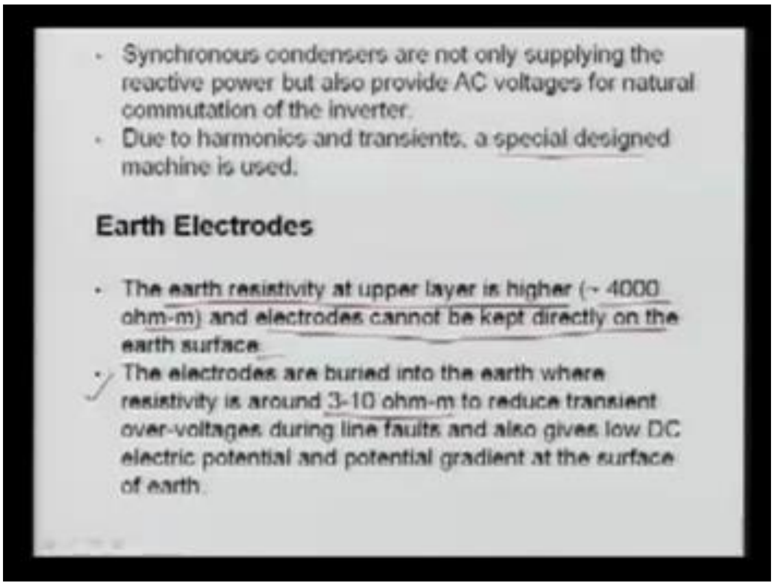

The synchronous condensers are not only supplying reactive power, but also provide AC voltages for the neutral communication of the inverter because this sometimes cans synchronous condensers are used.

Synchronous condensers give some AC sinusoidal generators and that can be used for your inverter operation because inverter operation is your big problem in your HVDC. Due to harmonics and transients or special design machines is used here, we use the synchronous congestion is special design due to the harmonics because the harmonics are there and also the transients are there. Another component that is your earth electrodes as I said we have to use the ground as the return if sing bipolar or homo polar if one pole is out or if you are operating as a mono polar, then we use the ground as the return.

So, we should have a proper grounding scheme so that we can here you can see the earth resistance at the upper layer or here is your 4000 ohm per meter means resistivity of earth here this and the electrode cannot be kept directly on the earth surface. We cannot keep there because there is lot of problem and the resistivity is more. So, we have to go deeper and deeper so that we can provide the minimum impedance.

So, electrodes are buried into the earth where the resistivity around three to ten ohm per meter. You can say surface four thousand or more and again it depend upon the area to area. It depends upon the soil it depends upon several other factors to reduce the transient over voltage during the line fault, and also give load DC electric potential, and the potential gradient at the surface of the earth.

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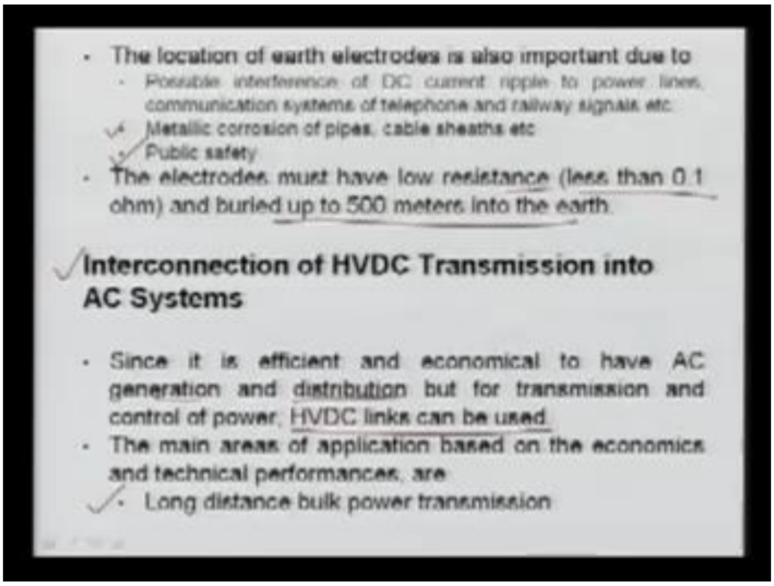

The location of earth electrodes is also very important because possible interference to the DC current ripple to the power lines communication system of telephones railway signal etcetera. So, that may create problem, also the metallic corrosion of pipes cables and seat here that is also it is taken into consideration and also we have to go for here the public safety. The electrode must have the low resistance means it should be less than 0.1ohm and buried even though sometimes 500 meters into the earth. So, the interconnection of HVDC transmission system into the AC system since it is efficient and economical to have AC generation and the distribution, but for the transmission and control of power HVDC links can be used.

No doubt the generation and from very beginning I am saying there is no alternative to generate and the distribute AC because we have the reliable generations three phase efficient robust and also the utilization part or we are having the similar. So, only option that we can have the transmission system that is a combination of your AC and the DC and here the AC, DC sometimes is very beneficial if you want to control the power in the transmission line. The main area of application based on the economic and the technical performance are the long distance here the bulk power transmission means just I will come to that point.

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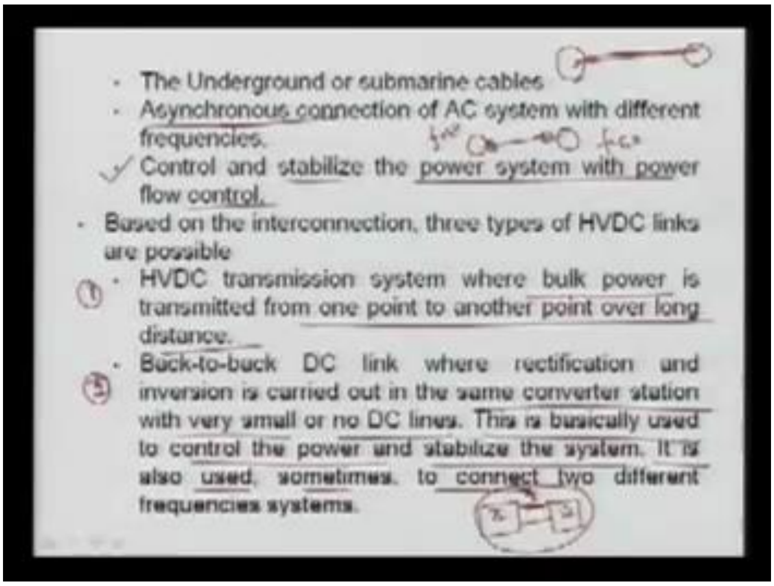

Here, suppose one area is here another is here and it is very far, so we can transfer bulk amount of power over this HVDC line.

It is not possible to transmit bulk amount of power on HVAC transmission line. If the distance is quite far means more than 500 kilometer, it is very difficult, we have to go for the compensation etcetera and the cost would be more than HVDC line. So, it is better to use HVDC, also the asynchronous connection of AC system with the different frequencies, means we can connect the two systems here. It means if it can operate at the 50 hertz, another can operate here at the 60 hertz. We can have the HVDC link here and still we can operate; however in AC it is not possible as I said the frequency of throughout the interconnected systems should be same and it will be.

Here, in the DC system it is possible basically the invention the first HVDC transmission line was basically relies on this principle. The first HVDC line that is a hot line between the Sweden island to the main land Sweden, it was more than seventy kilometers, it was not possible to have perfect AC transmission line. Then, they again went and again for both systems were operating with different frequency. So, the DC was option, so here you can use asynchronous connection or operation that is means two frequency system can be connected through the HVDC lines.

That is another great advantage another advantage is and that very important that we can control here the am stabilize the power system with the power flow control as I said the current in transmission line flow according to the impedances. You cannot have direct control over the electrons or currents flow unless until you use some device. So, that is why here HVDC can control even though not only control it can reverse the power. Also, it can stabilize the power system with your power flow control based on the interconnection the three types of HVDC links are possible. First one is your HVDC transmission system, where bulk power is transmitted from one point to another point over the long distance.

So, this is called your bulk power transmission system and here it is the bulk power is transmitted over the transmission line that is very long transmission line from one point to another point. Another type here I can say here it is one here it is your 2, 2 is your back to back to back is operation is of the DC link basically the transmission line is almost negligible very small. It means here if you are having let us suppose this is your converter station, this distance between this distance may be even the less than 1 kilometer may be less than few 100 meter like may be in same substation, here this inverter will be lying.

So, main purpose of here it is at one substation only the option here that we can control the power here. So, normally the two regions are connected by back to back means we can connect the power here by the two areas. Also, we can control the power over these sub regions, so this is here the back to back DC line with the rectification and inversion is carried out in the same converter stations with the various small or no DC line as we said. This is basically used to control the power and stabilize the system, it also uses sometimes to connect the two different frequencies system that is possible.

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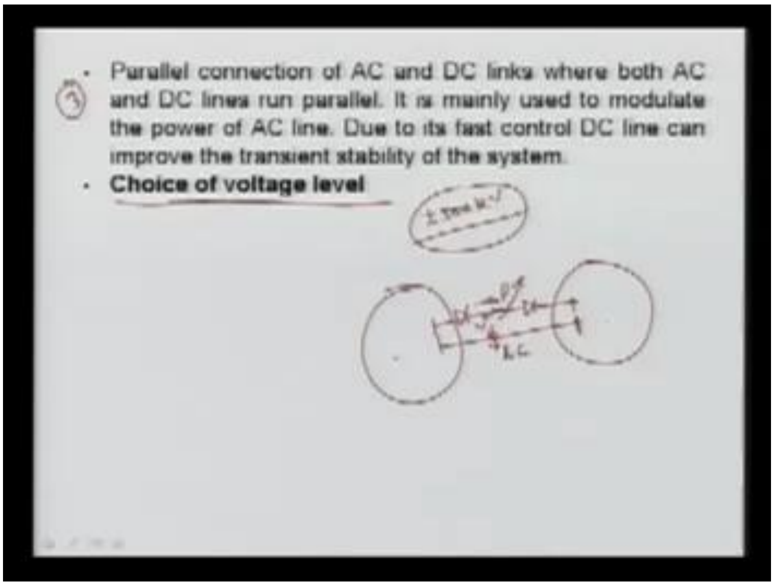

So, third is your parallel connection of AC and the DC links, where both AC and DC lines are running parallel. It is mainly used to modulate the power of AC line due to its fast control DC line can improve the transient stability of the system means here one area is this. Another area is this let us suppose we are having AC transmission line this is your AC now we can have a parallel DC line here let us suppose we have DC line here and in this area. So, with control of power here p that we can control here, we can modulate the power on this line and then we can improve transient stability of the system and basically it is used to stabilize the two area during the emergencies and various fault conditions.

So, these are the basically the basic motive of your HVDC system now the choice of voltage is decided by how much power you are going to transfer means what will be your the voltage of your DC link this is voltage we are talking .

Let us suppose normally the back to back, we have 500 kV system, then we want let us suppose how much current we are flowing, what will be the losses? So, depending upon your power requirement, we decide the voltage, and then we can go for other designing. For insulators, we can calculate the losses, we can calculate the performance in terms of voltage drop regulation efficiency. Then, we can go for similar patterns, basically this is similar to your DC transmission voltage selection procedure, now let us see another part, it is your analysis.

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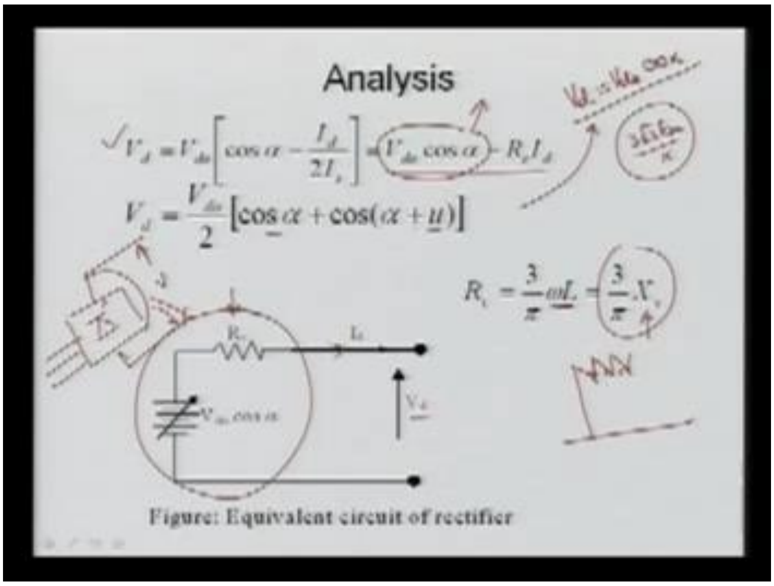

So, here for the analysis, let us see here you know that it is DC voltage or from the converter side, here it is nothing but it is called V d o cos alpha. In that case, if you are assuming there is no overlap u, here is the overlap angle and this video is again defined when alpha is 0, what your DC value is becoming? So, this is basically nothing but 300 and 3 EM upon pi, normally it is defined. So, if you are assuming the overlap, as I said overlap means here what you happened your DC voltage, which you are getting here like this, but it is not true. Normally, we go here like there is some overlap between these two and we can write the V c, we can define the DC output voltage.

Here, the V do upon 2 cos alpha plus cos alpha here plus u if you are putting u 0, you will get the same here, this expression that can also be retained here in terms of V d DC voltage here. We can write the V do cos alpha minus RC is th current, which is flowing here in this V c line and the RC is nothing but your 3 upon pi omega L and omega L.

L is your source inductance or we can write three upon pi x e, so this whole V d that is we are controlling the alpha by changing alpha, means we are controlling this component and this component it is called V do cos alpha that is why I made arrow. Thus, we are controlling and this R is called your commutation resistance X c is called your commutation reactance, and then we are getting the V d that is the actual. So, whole your converter basically this is the replacement of your this converter that is a bridge converter part here that is we are having.

Here, the three phase AC is coming and here we are DC, so this converter is basically replaced by this one and here we are getting this V d, as usual this is for your rectifier side similarly we can go for inverter side.

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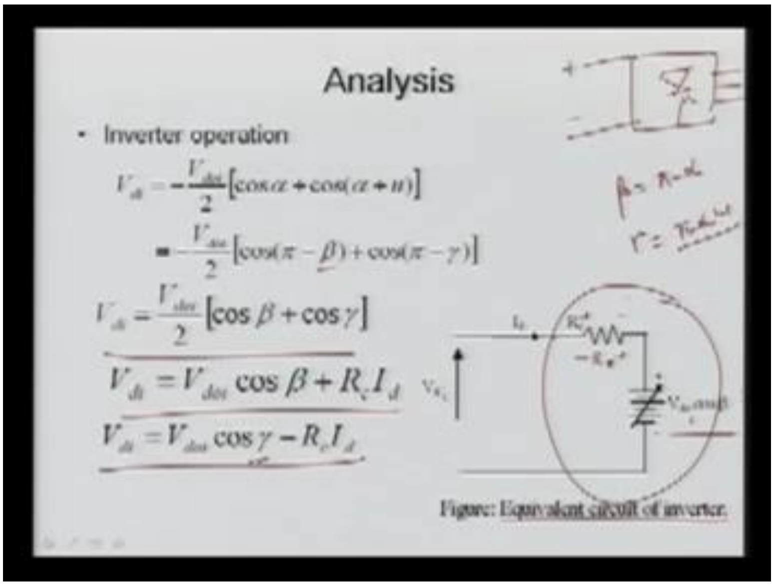

Same expression can used because the inverter side here, they are connected as I said it will be connected like this here and the DC is coming and three phase here AC is coming, so what is coming here? We are taking this is the plus and minus, then this is your negative, I have made here negative sign and then we are going to analyze and we will get here the V d I, this inverter voltage. Here, I can say V d I is your again the DC voltage in terms of cos beta if you are using. So, I can write this much, so this is your Vd I cos beta plus EC minus I d, you can say this is plus this is plus is going to be added, but if you are using your gamma, what is happening?

This is your positive, then it is negative, and this here is a negative resistance is minus RC is coming here. So, you can say in terms of the gamma, gamma is nothing but is advance angle means your beta is your minus alpha and your gamma here it is nothing but your pi minus alpha minus u. So, it is gamma and that is called commutation margin angle. So, this is your equivalent circuit of inverter here just we are replaced by this, now incorporating both two, we can have our circuit like I can show you here.

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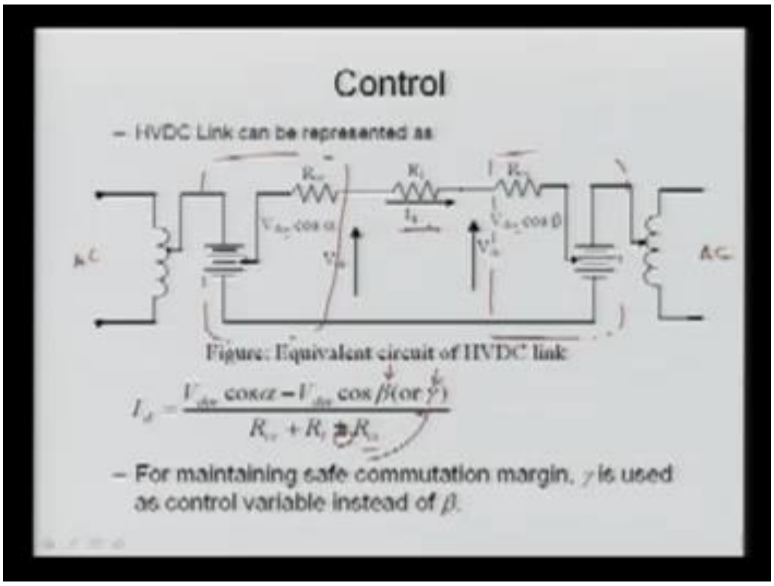

You can say this is your inverter this complete your inverter, this is your rectifier here now I have replaced V do r as the required rectifier side. I mean inverter side R CR means rectifier commutation resistance R CI is a inverter side commutation resistance and R L here is the resistance of the DC line and I d current is flowing. Here, we are providing this AC here, it is we are getting the AC from that side, and the power is flowing. So, this is your equivalent circuit, and based on that we can now calculate the current in this line will be here, now this alpha minus this voltage source divided by R CR here plus R L plus minus R CI, why we are doing R CI?

If you are using here beta, then it is a positive if you are using the gamma it is your negative. So, here the gamma negative source for the gamma as we saw our expression here it was negative you can see here it was negative. Here it was a positive, so based on that we have to go for here.

The control mechanics that is controlling the firing angle of valve can control the output of converters, and thereby the power control over the HVDC it should have the following feature. It means we have to now design the control, how it is doing the control? Let us see, we are having converter that is rectifier as well as inverter, which converters we are having, and then we have to control to meet our desired objective that is, we have to control the power.

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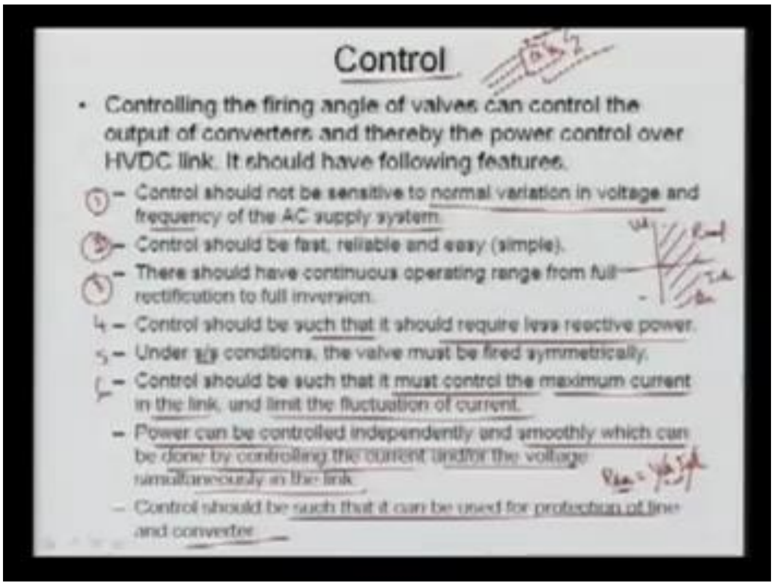

So, first here the first requirement or first feature is the control should not be sensitive to the normal variation of voltage and the frequency of the AC system. We know the voltage is keep on changing because the voltage load is changing voltage is changing frequency is changing load is also changing. So, there are some normal variations so that our control should not be very sensitive to that variation. If there is a certain variation of course, it should take care of, but the very small and the normal variation should not be sensitive. Second is your control should be fast, we want the fast control reliable and easy to implement and should be very simple.

It should not be very complicated; otherwise it will create another problem in the complication third one that it should have the continuous operating range from the full rectification to full inversion. It means I want to show that here your this is let us suppose this is your id this is your V d. So, this is your rectification because the V d and I d.

So, it should have the complete operation in that two range from here rectification operation here inversion operation voltage become negative current in the same direction. So, it should have the continuous range, should not be discrete operating range the control that is fourth control should be such that it should require less reactive power as I said the reactive power requirement is very huge in the GC system because these 50 to 60 percent of the normal range of the power supply of the HVDC transmission. So, we should have the control scheme in such a fashion that requires the minimum reactive power support.

Another feature that under steady state condition here is steady state condition, the valve must be fired symmetrically, means we have to fire the valve symmetrically so that here un symmetrical firing may clear lot of harmonics. So, we should fire the symmetrically so that harmonics can be minimized the control should be such that it must control the maximum current in the DC length and limit the fluctuation of the current. It means in the DC link, the current fluctuation can be minimized the our controller should be in such a fashion the power can be controlled independently and smoothly, which can be done by controlling current and our voltage simultaneously in the link.

It means the p DC it is your V d into I d, so we can control the DC power either controlling V d or controlling I d or we can control by both. So, that is possible and control that is a other feature that controls such that it can be used for the protection of the line and the converter. It means whenever there is some problem in the system, then we can control in such a fashion that we can save the converters and we can also protect the whole transmission line as well. For example, let us suppose here you are having a rectifier the DC line, which is going from here three phase if there is a short circuit DC huge current will be flowing. So, if we can control very smoothly, we can reduce this voltage to 0, what will happen?

We can take it out and then line can be avoided from the damaging. So, because this is the circuit breaker here, we are not having any circuit breaker in this line because the DC circuit breaker is again big problem. So, we can control this one in the very efficient way and then we can achieve our protection scheme by controlling this here converter valve. So, it should be such that we can protect the line as well as the converter from the severe faults, and then normal conditions.

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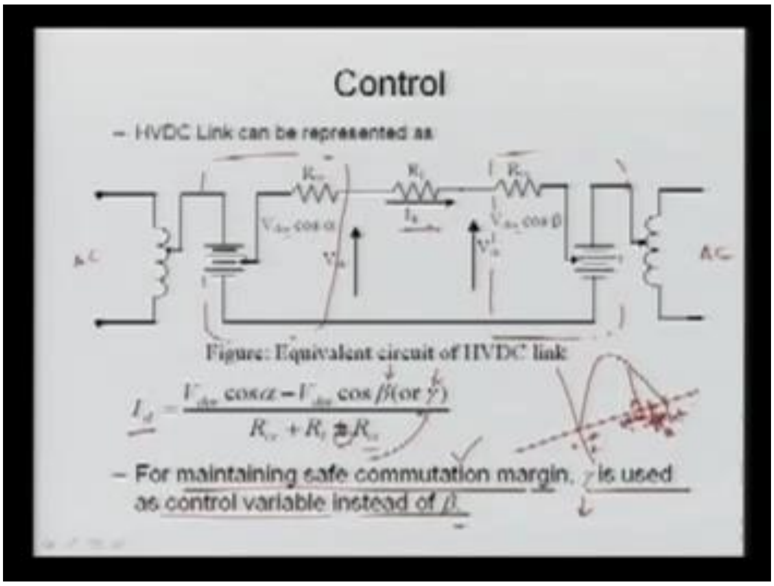

So, already I discussed the id we can control here. So, for the maintaining the safe commutation margin gamma is used as the valve variable instead of beta why it is. So, you can see while explaining here, basically this is your commutation voltage of any valve the alpha, which is start from here the beta we measure from here what happens here the measurement of beta is here. Let us suppose your measured the beta firing you are fixing this value, but due to certain problem, this value is reduced, and then your commutation from one valve to another valve should not take place in the desired value, then what will happen?

This will be going in another zone and the commutation failure will occur. So, instead of this beta, what we do? We fix this value gamma that it should be we can maintain the gamma minimum and then we can calculate our beta accordingly so that we can have the proper commutation. So, the commutation in the inverter side is very important. So, we have to go for the gamma resonant beta, so use gamma very carefully. You can see if you are using gamma here, it is a minus what happens, there may be possibilities this resistance in such a fashion the here denominator may be 0 and this I d will be very high and that is called case of resonance that is a very dangerous condition.

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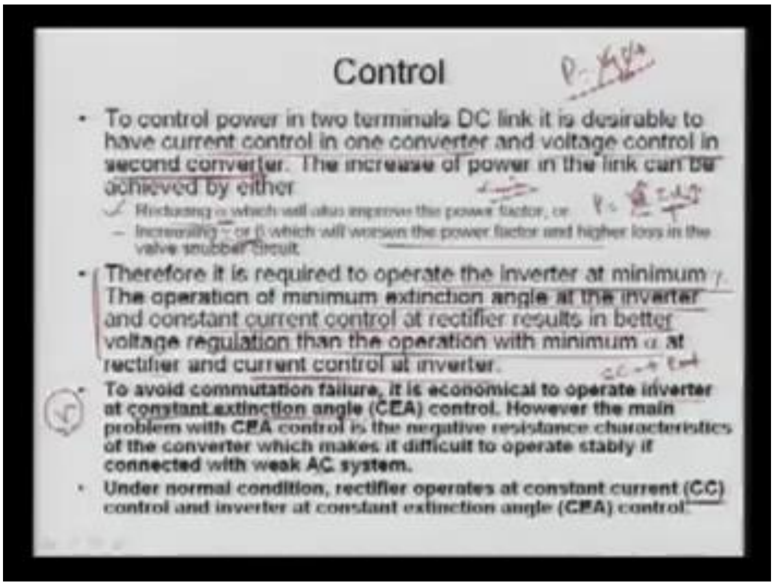

So, the control here let us see to control power in two terminal DC link is desirable to have current control in one converter and the voltage control in second converter means we have to control the voltage because we know power here is your V into I. So, power can be controlled here as well as here, so one converter can convert current another can control voltage. Then, we can operate system very efficiently to increase the power in the DC link can be achieved by either reducing alpha, suppose you want to increase the power p here it is V d into I d. So, if you are reducing alpha means your V d is increasing and that we also improve the power factor or by increasing gamma or beta, which will worsen the power factor and the higher loss in the snubber valve circuit.

It means if you are increasing this, you can go for no doubt, but here there is also possible that you can increase the current and to increase the current. If you will see what you have to do here this value must be reduced. This normally values are fixed because they are once converter is design it is fixed. So, only option that to increase the I d, you have to here this gamma must be also increased or here beta must be increased. So, if beta is increased here, then what will happen? The power factor becomes worth and worth if your firing here very close to 0, then it is power factor will be unity. So, with this increasing gamma or beta the power factor will be poor, and there will be more losses in resonance circuit and snubber circuit as well.

So, this option is better to go for reducing alpha, but alpha has also limitations you cannot go alpha 0. So, normally we can go up to alpha minimum value and thereby if you have reached that limit if you want to still increase the power then of course, you do not have choice, and then you have to go in this side to increase the current. So, therefore, it is required to operate the inverter at minimum here you can see increasing is not possible. So, its try that we can operate this id fix this gamma is fixed so that we can have the better power factor. Operate the minimum extension angle at the inverter and constant current control at the rectifier is the better voltage regulation than the operation with the minimum alpha at the rectifier and current control in the inverter.

So, what here I am just going to tell? So, we can operate the minimum extension angle here just we can at the inverter end and the constant current control at the rectifier end with the better voltage regulation. Then, operating the alpha minimum at the rectifier and the current control at that one, so what we do? It is always it is better to cc current control at the rectifier end, here we can control the current from rectifier end, and then we control basically the minimum extension angle at the inverter end. So, this is the better choice to avoid the commutation failure it is economical to operate inverter at the constant extension angle, means extension angle that is a gamma is here constant, it is called control.

We can fix the minimum, where the commutation in that degree commutation can take place properly. However, the main problem with the CEA control is the negative resistance characteristic of the converter, which makes it difficult to operate stably if the, connected with the weak AC system. As I said here due to your this minus R C if it is weak then it may create lot of problem under the normal condition rectifier operates at the cc. As I said, the inverter at the CEA control means V c that we should go for the cc at the rectifier end and inverter should go for the CEA control.

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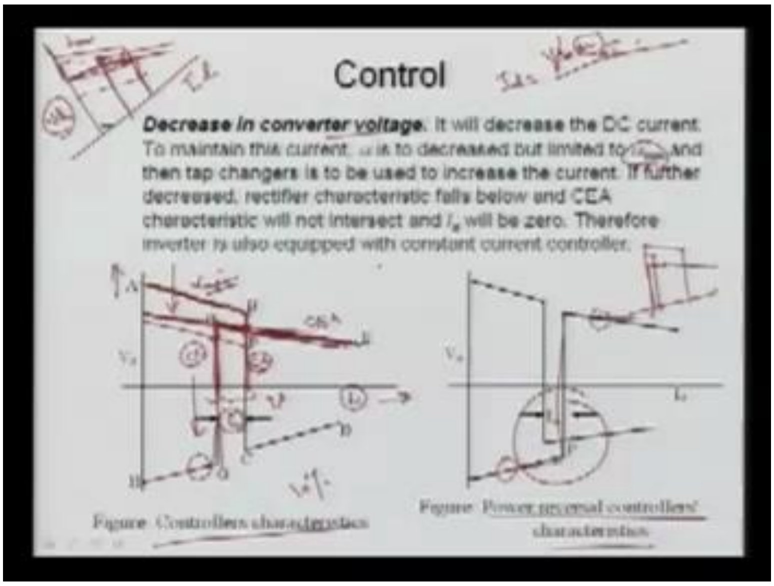

Let us see here what is this, this is your I D, x axis this is the DC voltage your y axis and this is your the constant current control that is your rectifier is doing and this is here your inverter operation here its say CEA. So, here as I was telling that the cc this is your rectifier and this is your inverter is operating other side we will see later why we have made some modification, again let us come to this point.

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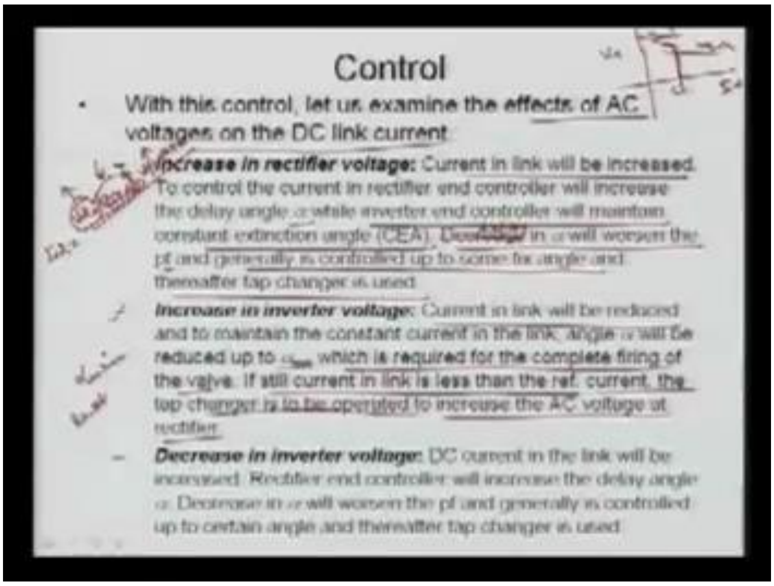

So, with this control let us examine the effect of the AC voltage on the DC link current means I said our controller here that cc here constant current, this is your ID, this is your

V d and then we have this CEA. So, CEA is for your inverter and this cc for your rectifier. So, again to analyze this behavior, then we can modify the characteristic accordingly increasing the rectifier voltage let us suppose there is a increase in the rectifier AC side voltage have increased. The current in the link will increase why because this id if you remember, this id I wrote here the V dr cos alpha minus V di cos gamma divided by some resistance.

So, if this value V dr increase the current will increase to control, the current in the rectifier end controller, what it will do? It will try to delay if it is increase this value, what will this value be? This alpha will also increase so that this value can be decreased. So, this will also increase and if it will increase, what will happen? That is very bad if this will be increased in delay angle, while inverter and controller will maintain at CEA. Let us suppose say gamma is constant, it will do but this increase will deteriorate your power factor, we do not want that. So, decrease in alpha will be worsening here the power factor and generally it is control up to the some fix angle and here tap changes are used.

So, here if you are increasing this value, then your current will increase to increase this whole cos alpha value must decrease and to decrease cos alpha must be increasing here that is means more delay. Due to this delay, the power factor will be poor, so what we can do? We can go only up to certain fixed value here, it is not increasing here, it is a delay in alpha value, another let us see the feature if we increase the voltage inverter in voltage is increased. It means this V di is increased, then current here will be reduced because this value is increased this is keeping constant. So, here we are this id is reduced and to maintain that current this inverter side. Rectifier side controller will try to increase this whole component here, it cannot do here, so what we will do?

This alpha will try to reduce and it will go up to alpha minimum which is required for the complete firing of the valve. If still the current link is less than the reference current, then tap changer is also operated to increase the AC voltage at rectifier. So, we can use this one again to increase, and then it is your alpha minimum it will reach up to that angle. So, what as I said here this is your cc and then if your voltage increased.

So, we can go for here alpha minimum control here in this angle means if current which is going to increase or decrease, means current is reduced here, then we have to go for here. This is let suppose the set value. So, if current is reduced here the case will be different case, case will be either reduction in the rectifier voltage or increase in the inverter voltage. In that case, we have to go for alpha minimum here, I will set means we have to go alpha minimum in case of your rectifier. Now, let us take a case here to understand this let us suppose your converter voltage is decreased, means your ID, which was here it was your V dr cos alpha minus inverter voltage.

So, if this voltage is decreased, what we have to do? We have to increase this and alpha must again be delayed and then it must be operate to alpha minimum value, otherwise this will again the commutation will be not taking proper place. Then, even still it is not possible, then we have to use the V dr value to change that act because the alpha control is very fast than the tap change control. So, we have to go for the firing of thyristors either inverter end or rectifier end. Then, we have to go for other control that is a tap changing here, so you can say again for this we are going for alpha delay. So, this was your cc control characteristic this was your CEA characteristic, but if the current was less, then we went for here.

You can see this is your called alpha minimum control now, so this is your complete characteristic of this one, now again what we can do? We can let us suppose want to revert this, means if your rectifier which is operating at the inverter and the inverter is operating. This we normally provide this alpha here the margin angle means there is a possibility, you can see the second case here, this case here as is said decrease in the inverter voltage. The inverter voltage is decreased the DC current in the link will be increased rectifier end control will increase the delay angle alpha. The decrease in alpha is inverse in the power factor, generally it is controlled up to certain angle again there after that changing is used .

Again, if the tap changing is also exhausted, what we have to do? Now, we have to shift that option from your inverter rectifier side to inverter side and for that we provide certain margin here. That is called your current margin means in the normal here this is your normal characteristic here, but if you current is still decrease more than what we can do, we can use another here cc of the inverter end and then this is your proper operation, why it is required?

Now, I will again explain let us suppose you have only this this is your alpha minimum and you have CEA, there is a possibility that your alpha here decrease further and way it is not possible here. So, this will be not cutting, so in that case it is always we have to cross section here. So, that this is your operating point let us suppose this voltage is further delayed further decreased and your current characteristic is here. You can see this angle and this angle is not interfering. So, we have to have here this now say from the current controller of rectifier to the inverter side because the intersection will be here.

To understand clearly, again what I want to say let us see this is your id this is your V d this is your characteristic alpha minimum here it is your CEA what happens? Let us suppose alpha minimum we are operating. So, these are the alpha minimum characteristic if there is sudden drop in the rectifier side voltage then your operating alpha minimum in this characteristic what happens this is not intersecting. So, we want that we should change the current controller from rectifier to inverter end because we should have here operating point here. We provide that current margin it is normally the ten percent of the rated current of the link. So, you can see this is the characteristic that is in the rectification operation this a, b, c, d, e.

That is the rectifier end and here h g f here why we are doing you can say once we are transferring from inverter to another operation, then inverter will become rectifier. So, this is alpha minimum and this cc and similarly you can see here now this is your zone here means the inverter, which was operating earlier. The rectifier which was operating as the inverter here, now this is operating as the rectifier and it is changed. So, this is basically the power reversible control characteristic and this is the basically the V I controller characteristic.

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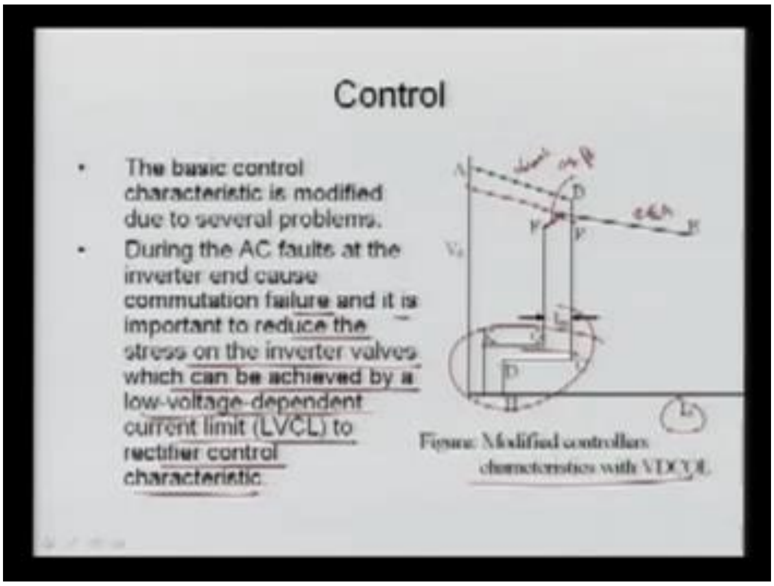

So, the basic control again we have some modification we have made based on our requirement. These modifications basically related with why we are going for all, now let us explain with this example what happens there is a possibility that here if you are operating here and this characteristic the slope of this characteristic may be equal to the CEA characteristic. So, in this if your characteristic like here, this is coming like what will happen? Then, you have a not only one point you have a reason of your stability and then it will be oscillating in this zone here because there is no only one point intersection because the both characteristic are lying, so what will be the point of operation? Then, it will be oscillating between this cc tool.

So, to avoid this, what we do? We try to do some here floating here so that even though this is reduced here, you will have another point it should not be parallel with it. So, we go for some here this can be your constant beta here beta this is your alpha minimum control this is your CEA control here the constant beta control or sometimes we go for the constant voltage control is also possible. We can go for some constant voltage and then we can go for this also during the AC fault or the inverter end cause commutation failure and it is important to reduce the stress on the inverter valve.

It can be achieved by the low voltage dependent current limit to control to rectifier control characteristic. Here, you can see here we have provided another modification because when the there is a AC fault AC inverter operation commutation failure.

So, there will be huge stress on the converter, so we go for the minimum current operation. We have reduced the current rating of the current rectifier so that it should not maintain that current. Then, we can again this is called low voltage dependent current limit or here that is we have applied. So, we can get another characteristic this is basically modified characteristic with the V d curve the voltage dependent curve and limited, so this is your control characteristic of HVDC link.

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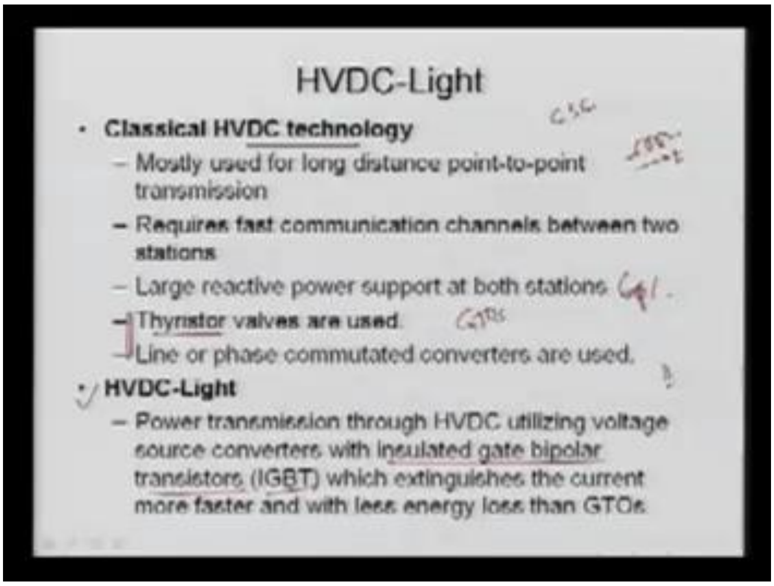

It means we are having both side of controller another there is a recently new development in HVDC that is called HVDC light this is very light in the weight and it is very popular and very efficient. Now, let us see what are the major problem in HVDC light is that the in conventional HVDC technology, which I was discussing earlier mostly used for long distance point to point transmission. It is back to back or it is modulate the AC power in the interconnected two regions it requires fast communication channel between the two station as I said if one is controlling, the control another is controlling the voltage, it can be changed.

So, it will be a fast communication link between these two channel two converter ends are required also huge reactive power requirement as I said its approximately 60 percent is required, thyristors valves are used. Of course, nowadays modern HVDC technology they are using GTOs, and then we can go for the various other pulse with modulated control in thyristor.

Basically, line commutate converters were used, and then we have to go for that commutation circuit design, and it is a very bulky and very complex and reliability is lost, but somehow here there are some changes here. Now, again here due to the fact and GTO and of course, it is very expensive, but people are using the GTO thyristors for the HVDC technology. On other hand, this HVDC line has the following advantage the power transmission through HVDC utilizing the voltage source converter again here in HVDC we use the current source converter. Why we use inductor smoothing?

Inductor means current is constant in voltage we use the capacitors voltage source converters with the insulated gate bipolar transistor we use IGBT. So, this is a transistor based concept here it is your thyristor based whether you are using conventional thyristor or you are using GTOs because gate turn off of thyristor, they are also thyristor based. So, here we are using thyristor, which extinguishes the current more faster and with the less energy loss and than GTOs, so it is efficient it is economical even at the low power range.

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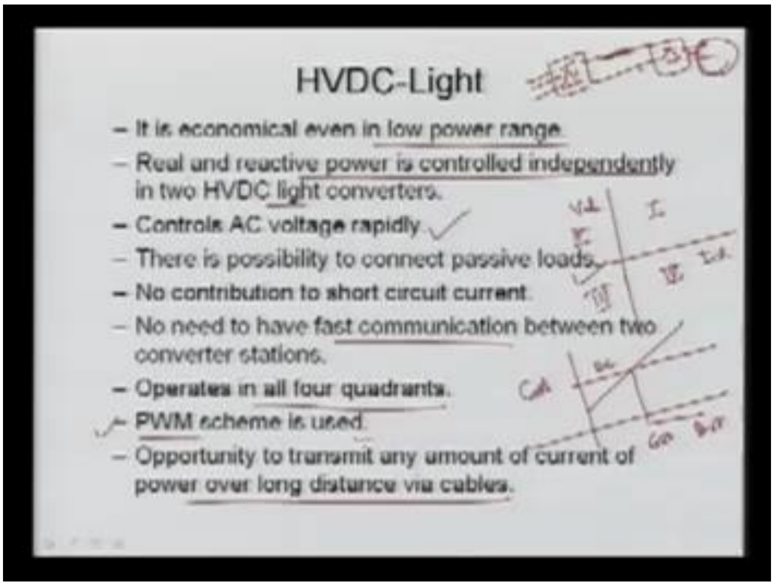

It means earlier it was for high power, it is economical if you see for AC system if as I said this is your distance, this is your cost then for the DC for AC this is this DC it is this. So, this was the distance the DC was cheaper after certain distance. This was approximately 600 to 700 kilometer, but here even though it is at low power range and even though for short distance, this technology is even though feasible and economical.

In this case, real and reactive power control can be done independently in the two HVDC line converters here; again the AC voltage control is very rapid there is a possibility to connect passive loads. You know in the HVDC it is not possible in HVDC what we do we connect the two systems here the one converter another inverter because here as I said this is your rectifier or one end. Here, we are having DC here, so we never connect the load ion between of this line because here the current will be different sense by this inverter and this one, so it is very difficult, this is AC. so what happens?

We have to connect the AC system here, we cannot connect the load that is passive loads here, but here we can connect and again we do not need the fast communication between the two converter stations. It operates in the four quadrants in the actual what I can see you can is this is your two quadrant operation in this normal conventional, this is your V d this is your ID and we can operate the conventional thyristor in the two coordinate number one coordinate number four, but this we can operate in your two and your three also. So, it is a four quadrant operation and it is very flexible in terms of coordination in this case we can use the pulse width modulated scheme so that we can improve the power factor as well.

That is why it is very reliable and reactive power requirement can be minimized using the pulse width modulated control scheme. The opportunity to transmit any amount of current of power over the long distance and via cable, so it can transmit any amount of current over the long distance via transmission line or your cable.

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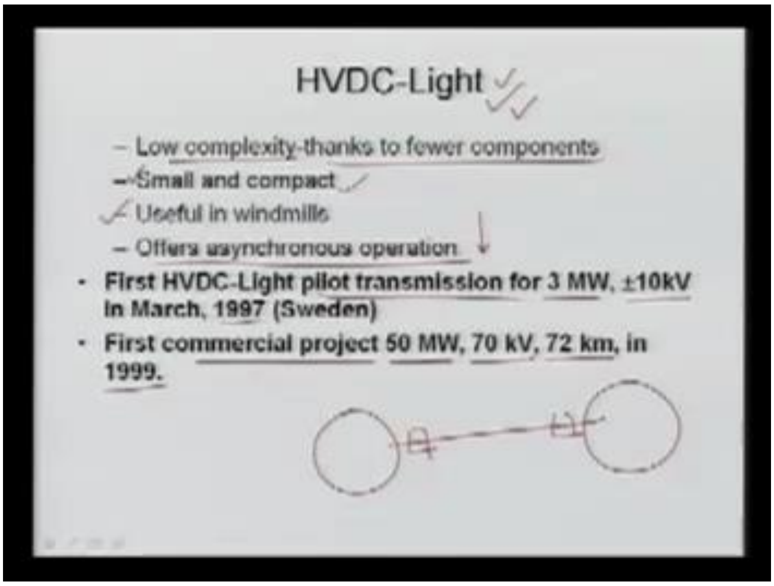

So, let us see other advantage that here HVDC light this is a this as I said low complexity thanks to fewer components in the conventional, we go for the several components like the filters like we are going for the smoothing reactor. We are going for other various auxiliaries that here we require fewer components. So, it is reliable and low complexity it is small of course, and it is very compact here losses are less, so the cooling system is very small. So, it is very useful and it can be used for the windmill that is very very important windmill you know they are very remote and they are transmitting less amount of power. So, we have to connect whole power and then we can transfer over the DC line.

We can use HVDC line very efficiently and of course, it also offer the asynchronous operation as the conventional thyristors HVDC transmission line used in conventional thyristors. So, it can also do that purpose, so we can see this HVDC light is another alternative. Although this technology is existing, you can see the first HVDC light the pilot transmission that is for 3 megawatt plus minus 10 kilovolt was here. It was operated in 1997 in Sweden first commercial project of 50 mega watt 70 at the voltage level 70 kilovolt and this was feeding to the 72 kilometer here and in 1999.

So, again there is lot of development and we are expecting the future we can have the HVDC light and there will be replacing although if the already HVDC in the conventional transmission lines are existing. It is not possible to replace, but the new feature project may be based on the HVDC light if the technology will be matured and it will be the economic, so in this now lecture now I can recap. We saw that HVDC transmission line can improve the system performance by controlling the power, we can even though reverse the power, we also saw various components those are required in HVDC transmission system.

We also saw that the control schemes that we have the good communication links between these two that at a rectifier end and your converter end together and. So, a fast communication link is required, we require reactive power support used in the conventional. So, the HVDC light can elevate the several problem of your conventional here no doubt the HVDC transmission system as I said they are introducing the harmonics into the system. Even though wherever you are going for a HVDC light or you conventional HVDC transmission system, both will introduce the harmonics, but this will introduce less compared to the previous one.

Still, they are introducing the harmonics, so although if harmonics magnitude are less, so it need not to worry, but if these values are very high, so it may be dangerous and that may create resonance in the your system. So, with this, HVDC is one alternative and it is only used in the transmission system the generation here AC distribution is AC only the transmission can be your DC part, and it can be helpful in the several ways.

In India, also we have the several schemes as I said we have HVDC link between dadri to rihand, we also having the several back to back connections like we are having because we are connecting our northern region to your western region. So, we are having all these connections and then again the purpose is to control to make the system to make the grid very rigid reliable and the very efficient operation.

Thank you.