**High Voltage DC Transmission**

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**Module No. # 01**

**Lecture No. # 02**

**Comparison of HVAC and HVDC Systems**

Welcome to this module number one; lecture two, and in this lecture, I will discuss about the comparison of HVDC and HVAC systems. In the first lecture, already we saw the evolution of the power system, where we discussed how the DC was faced out? That was low voltage DC, and then, we took over the AC power system, and again now, we are talking about this DC is going to be taking place only in the transmission system. So, to see why the DC is going to be popular in the transmission system now? I have to compare this AC with the DC system.

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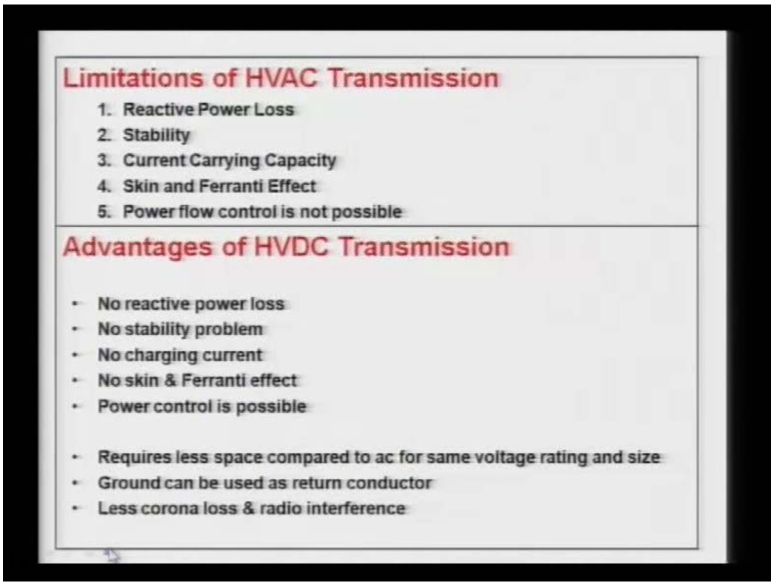


See the limitation of HVAC transmission system, here the first limitation of AC system is that the reactive power loss. The reactive power as you know, the due to the inductances form and also the capacitance form in the transmission lines and also there are so, many elements that is, corresponding to the reactive power loss will be one of the concern in AC system. Second concern is the stability as you know, already I discussed even though in last lecture, the stability is one of the concerns in your AC system, if your system is highly loaded though that system is more prone to the stability of the system another is current carrying capability.

Here, we cannot have long cables, we cannot have a long transmission lines due to the huge charging, and especially in the extra high voltage system and due to this we cannot load the line fully to their thermal limit, even though we cannot have a longer distance cable. So, that even though charging due to the excessive charging it is not possible to have a long distance cable and so, that we have to go for the DC cables in that cases the skin effect and the Ferranti effect is also prominent in the AC. The Ferranti effect basically says, if the system is system is lightly loaded or unloaded then your receiving end voltage is higher than the sending end voltage, and already I discussed in the last lecture, that to control the Ferranti effect. We normally use the reactors.

We have the three types of reactors one is your line reactors, bus reactors and the tertiary reactors, skin effect is basically; if the two conductors are there and the AC current is flowing. So, due to the effect of current and flux and the first first coil it will be affecting another coil and thereby; it will change the reactance and the impedance of the line. The one of the major concern of the HVAC system is, the power flow control; it is not possible to control the power in the AC system without using any extra device. If you are using flexible AC transmission system.

Which we will discuss later on that, then we can control in the AC system as well, but in the actual AC system, it is not possible to control, it depends upon the current will follow depending upon the impedance seen by the current with this five limitations, if we will see in the HVDC transmission system all these four concerns are eliminated, and that becomes advantage of the DC transmission system means, there is no reactive power loss at all, because reactive L and C has no impact on that then, there is no stability concern, because there is no P angle delta it is curve at all so, the stability concern does not arise and thereby we can load our transmission lines up to it is thermal limit.

However; in the AC systems, we cannot load up to thermal limit, especially for the long EHV transmission lines because your stability concern is will be on the major concern for secure and the reliable operation of the power system another as a limitation was this your charging and here there is no charging. So, we can go for the longer as long you can have the cables DC cables and also the DC transmission lines without any problem.

Similarly, there is no problem of the skin as well the Ferranti effect again; these are arising due to the capacitance form or due to the flux linkage of one conductor with another conductor. So, that is also means, it does not arise in the DC transmission system major problem of the DC system AC system was power control now, that can be eliminated means, we can control the power very efficiently in HVDC transmission system.

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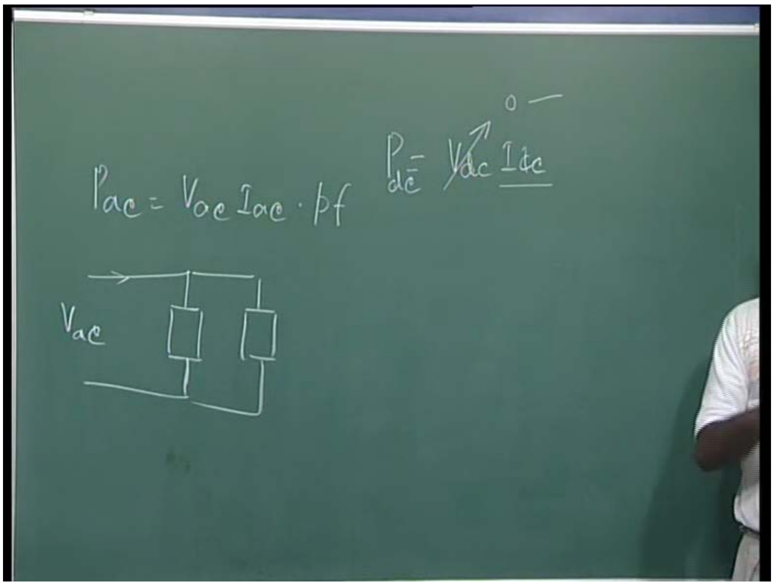


As you know, this power control here this in the DC system, we have the P the dc is nothing but your V dc into your I DC now, this P dc can be controlled by either voltage or by control controlling current or by controlling both but normally what we do we? (()) in HVDC system current is normally kept constant and the voltage varies. It is just reverse in AC system in AC system if you are writing the P ac it is your V ac into your, I ac and sum multiplied by the power factor.

In most of the AC circuits, if you will see here normally; the voltage of that applied to the any appliances, it is fixed we never vary this voltage. However; the current keep on changing that is, taken from the source for example, if you this is a source; this is your load; which is supplying you're here, this V AC. You are supplying, if you are connecting another load, you have to connect in the parallels what happens? The voltage across this is same voltage across is same, but the current drawn is now, going to be changed due to this connection of the impedance. So, the AC system always works in the parallel.

This is different here what we do? Here, we vary the voltage however; the current in the whole link is constant. Only the voltage is changed so, the power control here now, you can say the power here that is, a taken from this source is basically the voltage constant only, I is changed due to the connection of the impedance. So, this is the totally difference in the AC and the DC system.

So, this voltage here normally, we vary and thereby; we can control the power more advantageously, here it is not, that we can vary this from 0 to certain value, but it can vary in the both direction means, it can be negative also, the flow of the power can be even though changed in the one direction to another direction.

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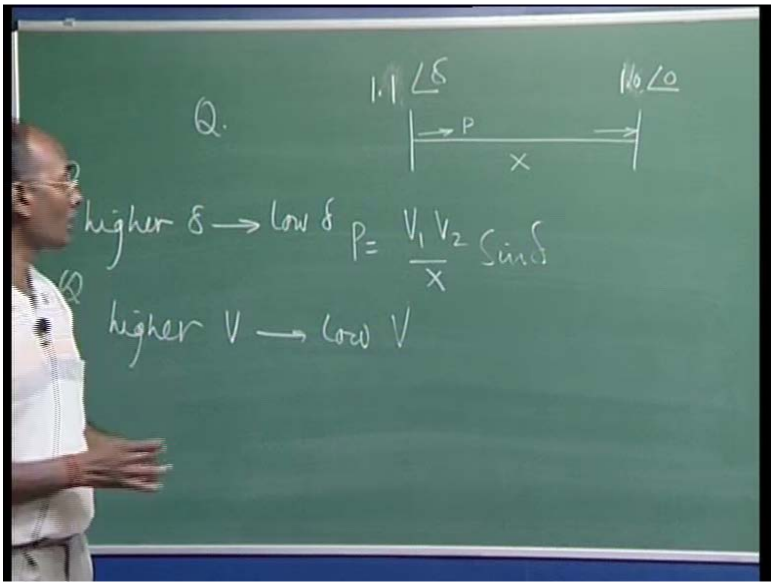


If you will see in the now, there is two fundamental rules, here in the AC system let us, suppose this is your bus, this is your transmission line power that is, let us, suppose this is your voltage V 1 angle delta 1 and this is your V 2. Here I am taking as a reference, and this is X of the line. So, we can write the power flow here, P V 1 V 2 over X sine delta now, if this delta is positive means, power will always flow from this direction, means real power, I am talking it will be flowing from this node to this node, because this if delta is positive, if delta is negative, the direction will be the change and always the P in any transmission line is unidirectional means here, if the power is flowing this power will be coming out, that will be flowing that direction.

The magnitude, may be different and that magnitude difference is due to the losses in this transmission line, but it will be here flowing it will be going out from this transmission line if you are going for the reactive power your Q in the ac. Here I am talking about, AC transmission system the reactive power system, here normally always flow. So, here I can generalize this real power P flows from higher delta to low delta. So, this is a general rule. By looking the bus voltages, here angles you can see whatever; the magnitude here, only you have to see the delta and that is, only true in actual operating condition there is something other sometimes voltage is so, absurd in that case it may not valid. So, in actual operation condition, here the real power always flows from higher angle to lower angle.

Similarly, the reactive power here it flows from higher voltage to low voltage that is, also true. Now, in this case let us, suppose this V 1 is your 1.1 and this voltage here 1 now, it shows that reactive power will flow from here to here, but it is not true because that depends upon this transmission line loading. As well because no doubt this voltage is higher compared to this voltage but we do not know, the voltage profile of this line because there are some distributed capacitance in the line that the voltage may be up and voltage may be down for this transmission line.

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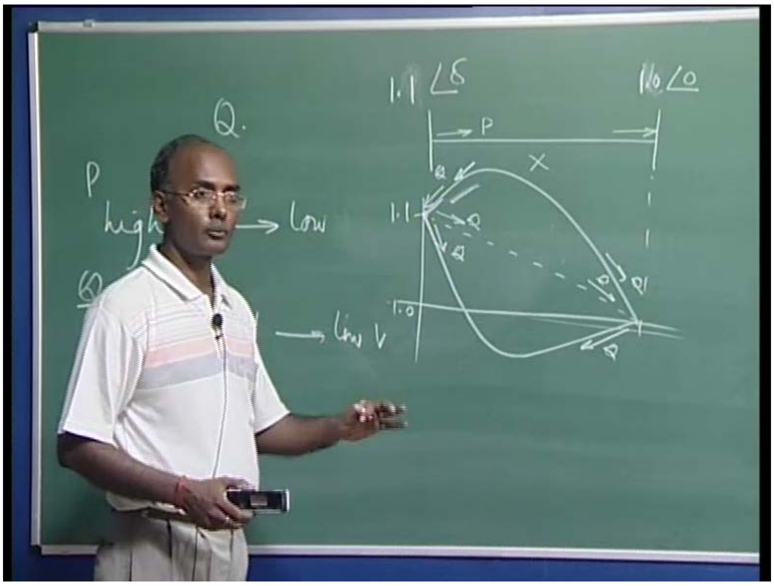

So, if we will draw the voltage profile of this transmission line for the different loading here the possibilities are here your voltage is 1.1, here voltage is 1 so, this voltage here starting here to here, there is a possibility that voltage here flag. Voltage throughout this transmission line, there is a possibility that it will from here it is going to 1 per unit, but again if the loading is less here, there is a possibility the voltage here is going like this if loading is higher the reverse scenario is there may be like here.

So now, you can see this concern, here the rule that is, a Q reactive power always flows from higher voltage to low voltage is still valid, but we have to see the voltage profile throughout the line as well not only looking at the node. So, that is why the reactive power can flow in either direction? For example, if you will see this is the case, then your reactive power here will flow like here Q and this will be going here Q, because always this end is higher than this end. For example, if you will see this case now, this voltage is higher some wherein mid in between the line. So, the reactive power will be flowing from here to here and this will be flowing like here this is Q and this side it will be flowing here Q.

Now, you can see the reactive power flowing in the both side means, it is going to both nodes and again it depends upon the loading this is the case, when it is lightly loaded and this voltage profile is coming due to the distributed parameter here charging of the transmission line, if the transmission line is long and lightly loaded we can land up with this scenario. Similarly, if the line is highly loaded highly loaded means, more current flowing in the line so, this scenario may arise and you can see the reactive power is flowing here and here also reactive power is flowing. So, the Q here we cannot say, it is unidirectional however the P is a unidirectional, it can flow in either directions all the possibility for possibilities are there.

So, in this is a general rule and that is, true for all transmission system, and if voltages here are within the operating range if it is a very absolute. Let us, suppose here 0.7 here 0.4 this scenario may not valid, if you just write then equations and then you can see the flow of the power. Now let us see; some more other advantages, other than the major advantage which I discussed those advantages, five advantages where basically just opposite to the disadvantages of the HVAC system. So that, I said there is no reactive power loss; no stability concern; no charging current; no skin, and Ferranti effect, and the power control is possible, some other minor advantages are, it requires less space compared to the AC for the same voltage rating and the size.

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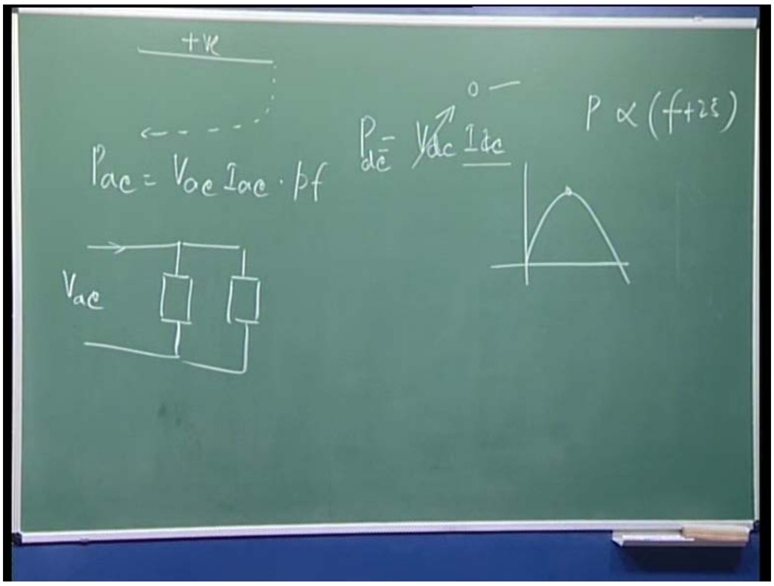


Now, you know, why I am talking because in the AC always, we design our system and AC it is this we always design for it is maximum peak value. However; we calculation here we always take the rms value. So, here I am saying for the same rating if you are talking about the rms same rms here and here the DC value you have to design your system for this peak value means, you have to multiply by root 2.

So, you require more space for your clearance; you require more tower spacing, etcetera, and that is, why it is said? it requires less space compared to the AC system for same voltage rating and size, because we have to go for the peak value here under root 2 times another concern here is means advantage, here; your ground can be used as a return. In AC system, we cannot use ground as a return, because due to the frequency. You know, the penetration comes in to the picture but in the DC the ground can be used as a return and thereby; we can reduce at least, suppose you are working as a DC here the positive polarity then you can use the your ground can as a return current.

So, you require only one conductor that can even though give the power to your load end however; in AC at least you require 2 1 is your positive, another will be return conductor or neutral conductor. We will see although this is advantage but normally it is use rarely meant it is used only in the emergency condition, because even though you are using ground here there may be. So many pipes; so many things, are underground, that will be the erosion and corrosions in that system.

So, it is used only during the emergency condition, suppose; there is some fault in the system, then we can use ground as a return, and also to make it, this we have to we will see the grounding rod etcetera,. Those are used in substation; we will just discuss when we will discuss about the components of HVDC system. Another advantage that it requires means HVDC transmission system gives less corona loss and the radio interference corona loss you know, the empirical formulas are there it is always your corona loss P is proportional to f into 25 f is operating frequency in the DC f is 0.

So, always it will be lesser compared to the you are AC and also that is, another factors even though weather is bad then this loss also very excessive in the AC system however; it is very less in the DC system. The radio interference also related with the frequency, if the DC system is there, it does not affect, there is other communication system but it is affected by the communication wire, but if it is AC system this frequency 50 hertz or 60 hertz that will affect your communication system as well, and that is why, there is radio interference problem in HVAC transmission.

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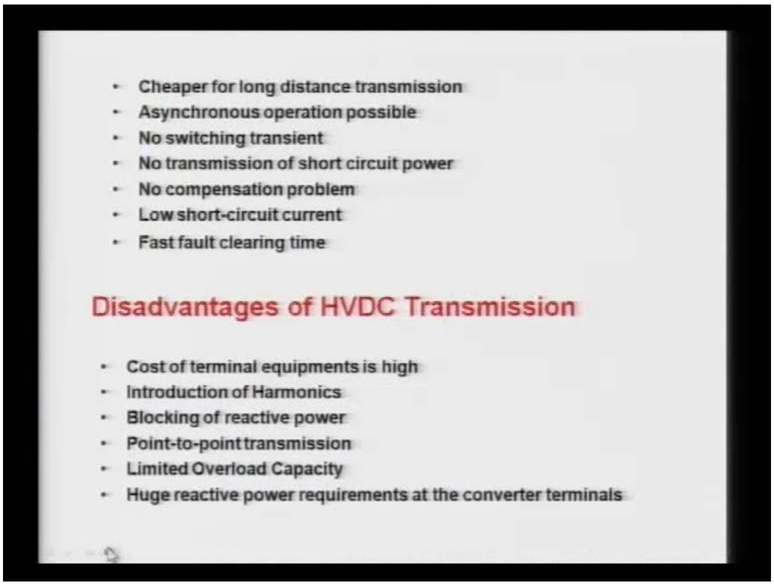


Another advantage here; it is a cheaper for the long distance transmission, to understand this here let us, see the breakeven points for AC and DC normally,

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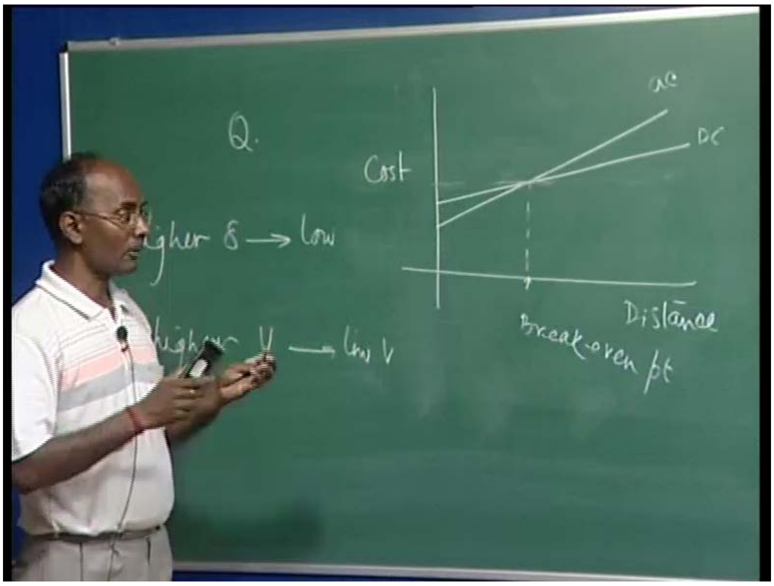


If you will see the cost characteristic, this is your distance and this is your cost, then if you will see your this AC system here it is going like this and your DC system sorry this is not so, straight line it is somewhere here like it is a DC system. So, now, you can see here initially the DC system is more expensive means if the distance is less and this point is called your breakeven point this breakeven point means, if your distance you are going to transmit power for longer distance here more than this distance you will find the DC is cheaper compared to your AC.

So, initially you will find the DC is more expensive due to the terminal equipments, we require the converters, we require the substation and so, many other auxiliaries filter smoothing reactors at the substation, and those are very very expensive. So, that is, why the cost of the DC in the initially here it is very high? But if you are going for the long distance, including those here if you will see this AC becomes more expensive. Now, the question arises why if the distance increase then AC becomes expensive? This is only due to if your this AC is distance is increasing, you have to go for the compensation due to the huge charging you have to use some intermediate station compensating devices to control the voltage in the transmission system and thereby you have to have a substation and this will be more expensive.

Earlier this distance was more than 800 kilometers the breakeven distance but now, due to the advancement in the power electronic devices and now, they are commercially cheaper available. So, this distance has come down to 600 kilometers evens 0, if you are going for more than 600 kilometer this DC becomes better option compared to the AC option but now, a days this is not only true because this HVDC system is not only used to control or to flow the power from one distance to another distance. One advantage of the DC as I said, the power flow control sometimes, we require to power control from one area to another area, distance is not larger but it is boundary is there.

So, it is the distance may be 10 meters may be 1 kilometers for that purpose all now, we are using the DC system, and that is called back to back connections; means converter and inverters are with a same substation may be. So, that intention is to control the power only then the distance is not a significant for us. Because this is the only, we are calculating the power bulk power transmission system, if our intention is to control the power, where it is not possible here in the AC system, we only want to control; then we should not see the cost; we have to go for this DC system as well.

But if you are going for the bulk power transmission and the distance is more you have to go for your AC system even though see even in India we do not have any transmission line more than 500 kilometers this AC transmission system but the DC transmission system. We have more than even the 900 kilometers you know, from Rihand to dadrit here is a huge it is a big transmission line it is approximately I think eight 100 kilometers. It is 1500 megawatt is flowing from Rihand to dadri and we require that power because our Delhi region requires huge power over there.

I will come to back those points later on. So, here I want to tell you the cost, if the distance is more, this is going to be cheaper, otherwise; this is going to be expensive for the bulk power transmission. So, that is, why it is written the cheaper for the long distance? Long distance Means more than the back even otherwise; it will be expensive another advantage here is; the asynchronous operation is possible you know? In the AC system always all the frequency of the interconnected system should be same in the steady state. But in the suppose you have the two frequency system, you cannot connect by the AC system and the option is that you have to connect by the DC system.

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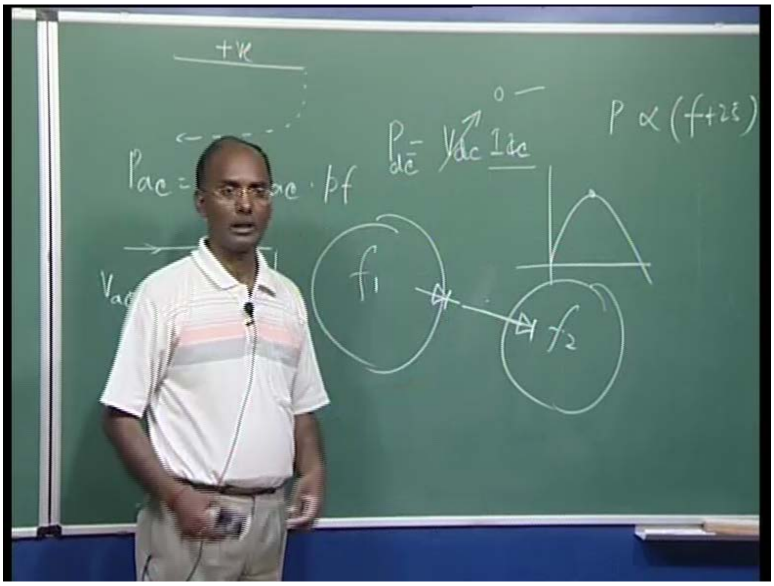


For example, if you are having here one system, this operating at certain frequency f and another system here having you are having frequency 2 then, you cannot connect here by AC it is not possible. So, what we can do here? We can use by the DC interconnections, we can have the DC here and then it is possible so, this is called asynchronous connection means two different frequencies can be connected with the help of the DC lines, and that is, one of the another concern suppose you have a one island of the operating the different frequency main land is operating different frequency, then the only option that you have to go for the DC system.

Another advantage is, basically no switching transient, you know, the switching transient basically arise due to the energy storage elements, that is, your L and C. If your circuit is purely resistive there will be no transient at all, but the presence of these two elements, and which is very common in the AC system, and the transient arises, and again the transient magnitude depends upon their magnitudes their distribution or number of elements, it depends upon that. So, in the DC system there is no because this L and C in steady state there is no L and C although, we use the smoothing reactors reactors are there, but only, you are switching then, it will be there or after that, there is nothing, and here this is more prominent in AC system.

Another advantage here is, no transmission of short-circuit power what is the short-circuit power in the AC system normally? If you are keep on connecting, the several lines at one bus.

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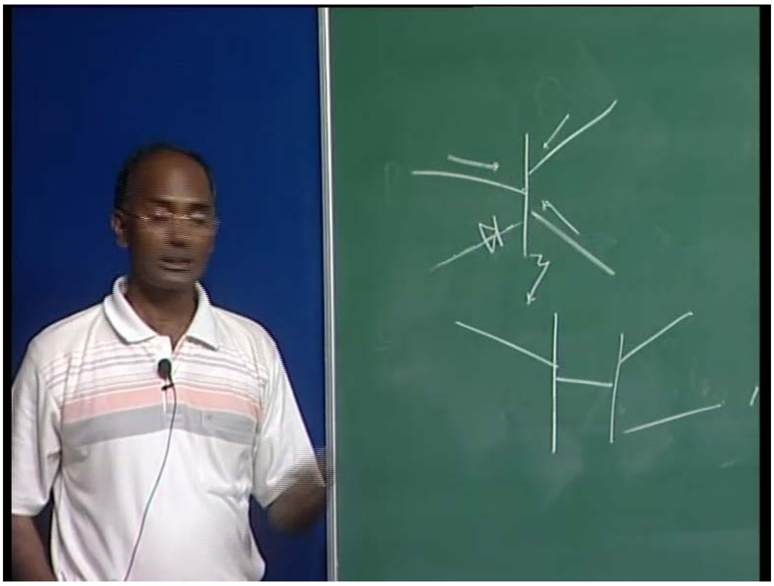

Let us, suppose this is a bus, where so many lines are going, then if what we do? We calculate the fault level at this bus, we go for the three phases short-circuit, and we calculate what will be the fault level? If there is a fault here, and this is basically this fault is contributed by these lines. So, if you are going to connect another extra line here what happen the fault level of this bus will increase because the impedance seen by this point to the ground', if we again the parallel line you are connecting the impedance will keep on decreasing means fault level will increase that is, short-circuit current.

I can tell you, what happens this; there are so many locations here even though, in our u p itself. So, many buses are there are so, many lines are connected and thereby huge short-circuit current is there. So, if there is any fault bus, fault here this circuit breaker here they must be tricked and the ratings of these circuit breakers are basically decided by this fault level there, in case if you are connecting. So many lines and some fault occurs. If the rating of the fault current will be much higher than the circuit breaker ratings here.

Even though; sometimes what happen? you have the let us, suppose; three lines you are connecting 4th lines that is, going to change, the fault current level you have to change the even though sometimes the circuit breaker of these line because this circuit breakers are decided they are having some standard rating may be it is a 40 kilo ampere, 63 ampere if the fault level is more than that, then there is no option, you have to go for another option, what we do? We go for the bus splitting bus splitting, what we do? Few lines are in connected here, then we have another line and the few lines are connected here. So that, reduce the fault level and thereby; we can say the cost of the circuit breaker replacement.

So, even though; I our u p system we several locations it is planned, when we are going to expand our network, this bus splitting means same position we have the two buses so, that fault level can be reduced. So, but now, how it is advantageous, if you are having the DC system let us, suppose I want to connect here DC system instead of AC system what happens if the fault occurs this will not contribute any fault because this control is very fast so, no current will contributed by this so, this is just blocking the fault current from this line and this is 1 of the advantage of this HVDC system as well.

So, that is, why it is here it is written no transmission of the short-circuit power from another side on that bus so, it is advantageous on that case also another advantage is that the no compensation problem the compensation, I mean to say that if you are having a long transmission line.

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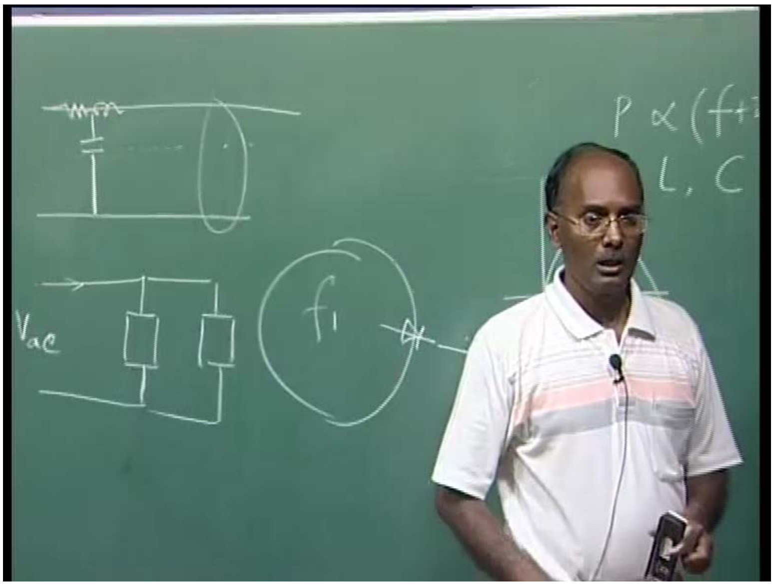

Then this transmission line will have your is your distributed parameters this is your, r l and we can say the capacitance and it is with distributed throughout the line. What happens due to these capacitances? We have to compensate it; otherwise what will happen? The some of the mid of the voltage will be very high, compared to your sending and the receiving end, and there will be the flashover. So, what we do? If line is very long we have to use some compensating device in the intermediate. So, that we can absorb some of the reactive power generated by this capacitors distributed capacitor.

However; in the DC this concept is not there and thereby the no compensation is required. We can operate line very smoothly; another advantage is this low short-circuit current, this is related to this, it is a blocking also, here as I explained it is blocking the short-circuit current flowing from this line, and also even though; you are connecting it is not contributing in this fault current. So, the fault current level here is also going to be reduced by this HVDC system so; this basically reduces your fault level of that bus.

Another advantage is; there is a fast fault clearing time due to the switching these are the very fast switching devices. We can control them very effectively; very efficiently so, that we can maintain our the stability of the system by the controlling these switches appropriately and that is, why the fast clearing can be done, if the fault is occurring in this line let us, suppose this is a DC line here.

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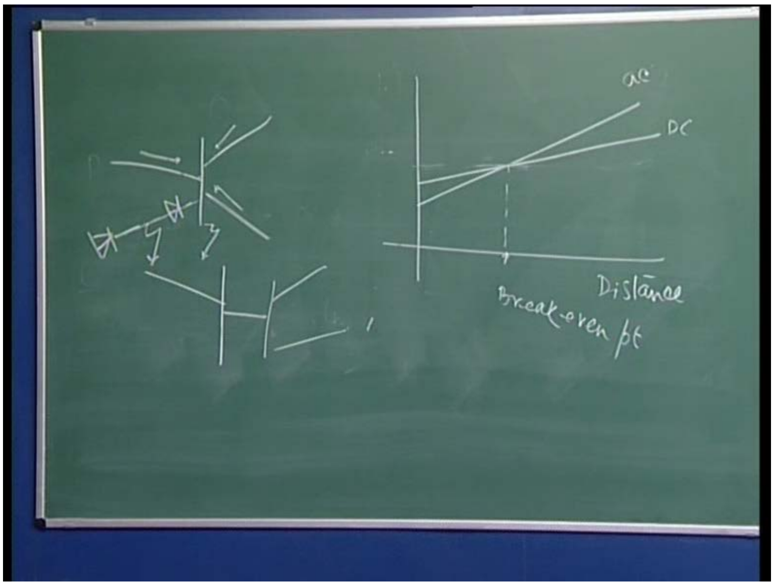

Here, if fault is occurring, here we can control these two switches so, that this fault cannot be propagated in the AC system and very fast we can control this the fault can be cleared because in AC system the fault fault clearing mechanism. If you know, the there are relays they will sense whether there is a fault or not in the system and this relay will give the command to the circuit breaker. Circuit breaker will take some because it is a mechanical device it will take some time and then it will try to open so, this mechanical system always it will be sluggish than the electronic system that is, why this is the HVDC system fault clearing is very very fast compared to your this is conventional AC system so, these are the basically the major advantages of HVDC system there are so, many minor minor will be also there but I am not concerned about this.

So, I discussed some of the major and then some of the you can say not so, major but it is still very significant for the HVDC transmission system. So, we saw this advantage of HVDC system compared to the AC system, but we should not forget no system is free from some problems and therefore, this HVDC transmission is also having some problems and those problems are listed here.

You can see that, I have written the cost of the terminal equipments is high it introduces harmonics it blocks the reactive power, although reactive power sometimes; we require from pone area to another area. It is blocked another concern is, point to point transmission. I will explain all this, and then it has a limited overload capability due to the power electronic devices, they are having the limited overload capability and although DC system does not require any reactive power but still you will see at the converter station we require huge reactive power supports basically the smooth operation of converters.

I will explain one by one; first one is the cost of the terminal equipment is high; already I said that here even though, if you are going for the long distance transmission, you can see even though, distance is very small some cost is required, and that cost will be associated due to your inverter and the converters, they are the very expensive device, it is not converter even though we require some cooling device for the converter, and inverters. We require some filters because the filters are used for controlling some of the harmonics filters are there they must be cool. So many auxiliaries are required in the DC transmission system and that is, why the terminal equipments are very expensive?

You know now, the even the cost is not so expensive, because due to the advancement in the power electronic devices so, the cost is going to reduce no doubt, but still it is higher compared to the AC. So, if you are going for AC substation of same rating or if you are going for the DC substation you will find the cost of the DC substation is more compared to your AC transmission system. But we hope in future again the cost will be keep on reducing due to the advancement in the power electronics technology and let us, see in the future another concern is the introduction of harmonics.

In the beginning as I said, it was the valves. Now, then we move to the thrusters. Now, we move to the g t o s and now, we are talking about the i g b t s for this the converter technology. When we were using the thrusters, they have some in he rent problem, that it was not able to turn off automatically, we required some turning of components some devices to turn it off, but now, with the help of g t o s we can turn off, and we can go for the pulse with modulated converters thereby we can reduce the harmonics.

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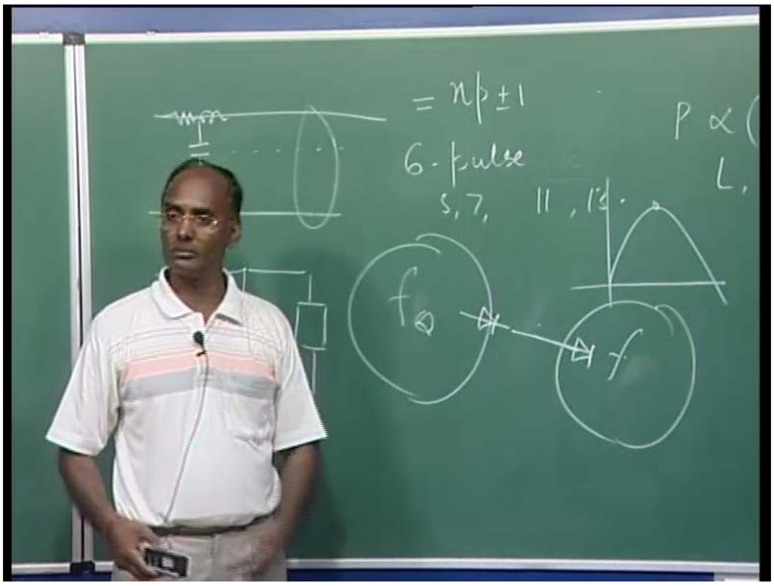


So, in the conventional-grade thruster basically we were having the harmonics that is, n p plus minus 1 this is your the harmonics component. Where n is your integer p is number of pulses and here one is again the real value. So, if you will see for 6 pulse converters if you are using the conventional thrusters so, you are going to have the fifth seventh then you are going to be eleventh and thirteenth and so on. So, these are the harmonics are present and these harmonics are called the characteristic harmonics.

Even though; other than these harmonics are also present in the system due to the over lapping of one valve is conducting another is going to be off, it will take some time and due to that, we are going to have some uncharacteristic harmonics, other than these in the system and that if you are not they are not filtered out properly, they are going to propagate in your AC system and that may create so, many other problems, that we do not want. No doubt once we are going for higher order harmonics the magnitude are kept on decreasing. The magnitude of this will be highest compared to your higher order but still if you are having so, many devices in any area so, your harmonics component which is going to be injected in the system will be more if you are not using the filters

But now, even though with the help of pulse with modulated converters the harmonics levels are going to be reduced but still it is not free from harmonics because this is a switching device. So, any AC signal that is, a switched on and off it will certainly generate some harmonics may be the magnitude is less but still it is going into the system. So, introduction of harmonic leads that, we have to go for the filter option but it is not possible to go or to filter out all the harmonics we allow some of the harmonics to enter the system and if the magnitude are less, but that is, if you are having perfect sinusoidal that is, always better and it is desirable.

Another is, you are the blocking of the reactive power, as I said, this is here; this you can imagine the two systems. Let us, suppose they are operating on the same frequency, even early matter and it is connected by the DC link the reactive power which is here cannot flow from this end to that end, because here in the DC there is no reactive power concept. Now, the questions arise again, why we require the reactive power here? Normally the reactive power concept is local phenomenon. We do not want the reactive power should follow from this remote end and this should go here reactive power normally should be compensated locally, because this is related with the voltage however the real power is the global phenomenon that is, why the frequency of the whole system is same?

Now, but sometimes during the emergency condition let us, suppose this system needs somewhere there is some fault here some problem in this here temporarily we require some reactive power support from another region and if it is a AC system you cannot provide even though that reactive power support. So, it blocks the reactive power from one end to another end, and sometimes; we require this reactive power should flow from here to here or here to here and that is, a problem with the DC system. The fourth problem, that is, very important is called to point-to-point transmission. Point-to-point transmission means, that here; if you are one converter is there; another inverter is there means, you cannot tap the power in between means; if you are supplying the power from from one end.

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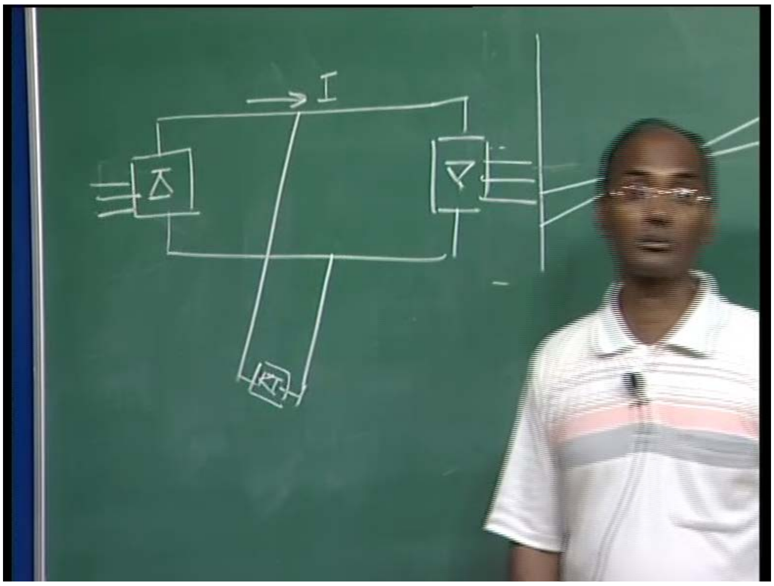

For example, if I will say here, this is your sending end; this is your DC line; this is your inverter; here three phases; the tapping power in between is not allowed, in the DC system because we here this power flow control or power flow is maintained the current, which is flowing here it is made constant. If you are tapping here, then must be this converter should know, where the power current is flowing but in AC system wherever you want, you can just tap the power, you can put the power; (()) you can take the power; wherever you want, but in DC system the point to point transmission means. Here if you are injecting power, you are going to draw the power at this point only means in between you cannot take.

So, this is called the two terminal HVDC link terminal one here terminal two however now, it is even though multi terminal HVDC links are also possible so, what we do here there is a possibility we can have another link here and we can have another terminal here. So, now, it has a three terminal means for tapping the power you must go for another terminal and if you are going for more and more terminal it becomes more and more complex controller we will see the controller later on that. Even though for these two controllers they are communicating the signal to each other now, if we are having another terminal now, all these three will be communicating to each other and if we are going more then it becomes very very complex so, this is called three terminals.

So, I mean to tell that the point-to-point transmission is not so, practically feasible in HVDC transmission system normally, it is from one end power you must be injected to another end and that is, called that is, a problem that is, the point to point transmission is not feasible in HVDC transmission. So, multi terminal HVDC link is also possible and it is a existing in the word but only up to the three terminal not more than that and it is not desirable to go for multi terminals here because that cost will also increase because if you are adding one terminal.

It is not so, simple you have to go for all the substation here the converters are there and the communication and the controller equipments must be there. So, the cost is increasing for tapping the power in between the 4th limitation is your limited overload capability. So, as I said the point-to-point transmission is another problem and another problem that is, a limited overload capability of the system it is not due to the transmission line it is due to the power electronic devices, that we are going to use you know, the power electronic devices basically they are based on certain voltage and current rating, if you are exceeding there will be excessive loss in that and thereby there is a possibility of that that device switching device may damage.

So, it has a limited the converters and inverters are having the limited capability and thereby we cannot go for the even though for short duration, we cannot go for the higher rating or higher power or overloading of the system. So, that is, another problem here in this limited overload capability in the HVDC transmission system another concern here is the huge reactive power requirement at the terminal station.

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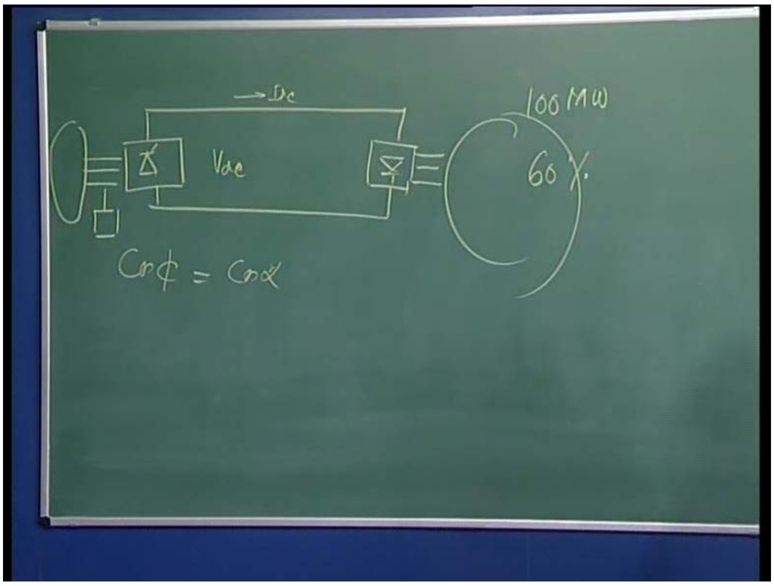


Terminal station I mean that again, thus we are having here your rectifier end that is, a three phase here we are having your inverter and we require the reactive power support at these two terminal station as a thumb rule if the rating of this line is hundred megawatt we require a 60 percent of the reactive power sources at the both end of this converters. No doubt there is no reactive power involved in between this is the converter now, the question again arise where is this reactive power goes this converter system requires because you know, if you will see it is a normal thrusters. We will find the Cos phi is your equal to your cost alpha is your firing angle if you remember the power electronics the converter topology.

If you are using the thrusters here the power factor, here will be equal to your this delay angle cosine of the delay angle. Why it is required? Because we want to control the power and and this power control is basically controlled by the V DC, because here I DC is the constant if you want to control the power in these lines you have to change this DC and the DC will be only changed from the highest value to lowest value by the firing of this alpha you have to delay it.

If you are delaying it, then what happens? If the more alpha the power factor deteriorates. So here we require that, compensating device to maintain that, we should not draw huge reactive power from the AC system, because this sides are we are having the AC system, here also we are having the AC system. So, it is always better because reactive power is a local phenomenon so, we put here the reactive power sources huge reactive power sources at this two ends.

So, normally as a thumb rule, we have to go for the 60 percent reactive power sources in the both end and that is, a very very high reactive power sources are required even though sometimes, we used here filters they are also providing the reactive power support, we will see later on, how they are even though they are used for the filtering the harmonics, but at the fundamental frequency, if we will see they provide the reactive power support means, they behave like capacitors but other than that still we require the reactive power support, if there is a some problem here you are not having then you cannot control the power here, because the controlling here the V DC we are talking.

So, we require huge reactive power support at the two terminals now, with the help of pulse with modulated schemes with the g u s and i g b t s that value can be reduced but still you are the i g b t s are not in the high voltage rating so, you cannot go for the high rating of this transmission system, but in the future, it may be and then that reactive power requirement can be reduced, and thereby we can save huge amount of power and cost of the devices.

Now, another question may arise, that the point-to-point transfer may not be advantageous? It may be; it may not be a problematic, it will be advantageous, because due to the theft here, we do not want that people should tap the power.

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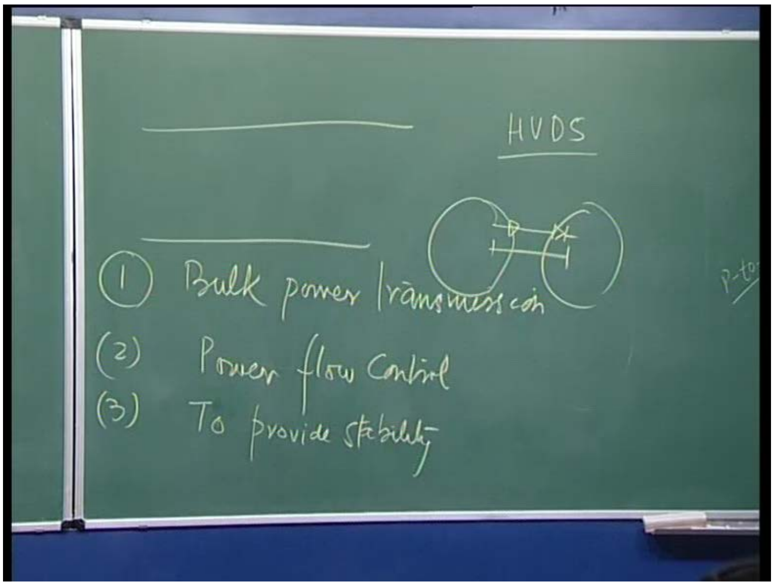

That as question arises here here? I do not want the people should go for tapping here ,but here we are talking high voltage. The utilization is always at the low end and low voltage and thereby here the DC system we are talking it is for the high voltage DC we are not talking about the low voltage DC then again as a same question arise when we will saw the evolution of the whole AC system, because if we are talking about the low DC system there will be huge I square R loss and your I R drop the voltage drop will be there so, here the concern is we are talking about the HV not LV if your LV then these concerns will be there you cannot operate the system.

No doubt, here the tapping is not there now, the question arise to avoid the theft no doubt some schemes are advised and that is, called HVDS it is called high voltage distribution system means, the transmission lines are high voltage, but again the customers are using your the low voltage. So, the lines which is running in the streets, it is high voltage may be 11 k v or 33 k v, and then they are putting a small transformer for individual customers so, that person cannot tap the power at 11 k v or 33 k v and the small transformer is there and from there it is given to the customer.

So, that theft problem is basically minimized with the help of the HVDS system and normally, it is used in the urban areas especially in Delhi and regard noida side. So, we saw the advantages and disadvantages of HVAC and the DC systems. And now, we can realize that the DC system is for the transmission is the better compared to the AC system, if you want now, again is based on your objective. The first objective that you want to transfer the bulk amount of power second objective, if you want to control the power then these two options are very very important, and very good, for this going for the DC system even though another advantage of HVDC system that, it can modulate the power over the DC AC system.

I mean that, you are having other two areas here and is connected by here tie-line is AC, tie-line it is a possible that, we can have another DC system here parallel to this to stabilize this system, what happens this tie-line? If it is a weak, there is some problem here, this tie-line may be tripped and then system may be again again problem, but this DC system, we can very fast control the power from one area to another area, and thereby; we can stabilize both of the system very efficiently. So, the here the purpose is to stabilize the system then there is no consideration of the cost there is no consideration of harmonics and we have to go for this system, because we want the smooth reliable and secure and stable system operation.

So, we now, the three major objective I can say one is we want if we are going for the bulk power transfer over the long distance the HVDC system is the best option. So, I can write here this bulk bulk power transmission over the long distance then HVDC is better option second if we are going for the power flow control and third that we have to stabilize the two area systems with the help of HVDC. The purpose is to provide stability so, for these three purposes. I think HVDC is the better option compared to the AC system that is, why we are going for this HVDC along with the HVAC. In the whole the grid in our Indian grid also we are planning. So, many already we have so, many HVDC transmission lines are existing, but in the future it is plan is much wider much more HVDC links are there.

Because we want the power should flow from the northeast, which is far off and that should come to Delhi side, and there is no other option, because the distance is more than 1500 kilometers. So, we have to just go for the DC lines so, many HVDC lines are planned and in future we will see the HVDC lines will be existing just parallel to the AC system as well.

Now, looking all these advantage and disadvantage. Let us, see the various types of HVDC links; those are possible; those are existing. So let us, see the various types of HVDC links; normally this HVDC links means, can be categorized in three broader categories, one is called monopolar; second is your bipolar; and third is your homopolar.

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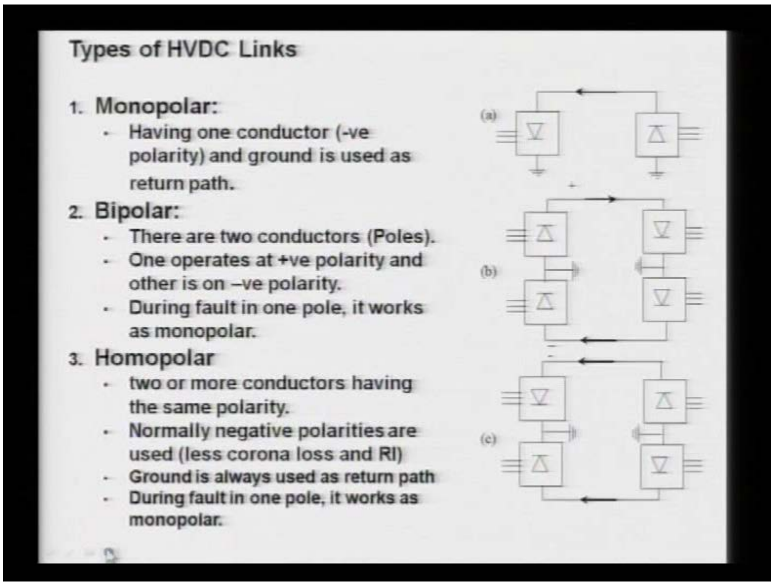


This monopolar as its name the pole is 1 means, one conductor and the ground is used as the return, you can see here, in this is your we are having only one conductor and the ground is used here as a the current is flowing through the ground normally this polarity here is used as a negative polarity, rather than positive polarity. It is possible to have positive it is possible to have negative, but the negative is preferred due to negative polarity, we will have the less corona loss compared to the positive polarity and that is, why this is operating at the negative polarity.

The major problem here is, that, if there is any problem in this link, either in the converter or in the DC system, you have to stop the power flow, and completely it will be the power, cannot flow from either end. So, this is a monopolar means, you are having only one pole means, only one wire pole means, wire and the ground is used as a return. Another problem here, that during here, the current which is flowing through the ground there may be so many pipes; so, many other devices; inside the ground, that will be huge corrosion due to the DC current flowing there. So, this is normally is not practiced in the system but conceptually it is possible because sometimes we will see the type two and type three they operate as a monopolar

So, that is, why it is explained that is, monopolar you should know, second category of the HVDC link is your bipolar as it is name there is a two poles means; two poles here is that is, a two wires here. One is go; another is a return conductor; in the bipolar here you will see, 1 conductor is on the positive polarity, and another is on your negative polarity, to make this you can see here, the in the normal operation the current will not flow through the ground, because current will flow here through here through this converters and this is your positive and another will be your negative or vice versa, it can be positive this can be negative again based on the operation of the converter. So, there are the two conductors means, two poles are there one operate at positive polarity and another operates at the negative polarity.

Here advantage of this system, if there is any problem in any side of pole, if there is a problem here either in the converters, here any of the converter here or in the line, we can just open this converters and we can use half of the link here and the power can flow so, half of power we can maintain.

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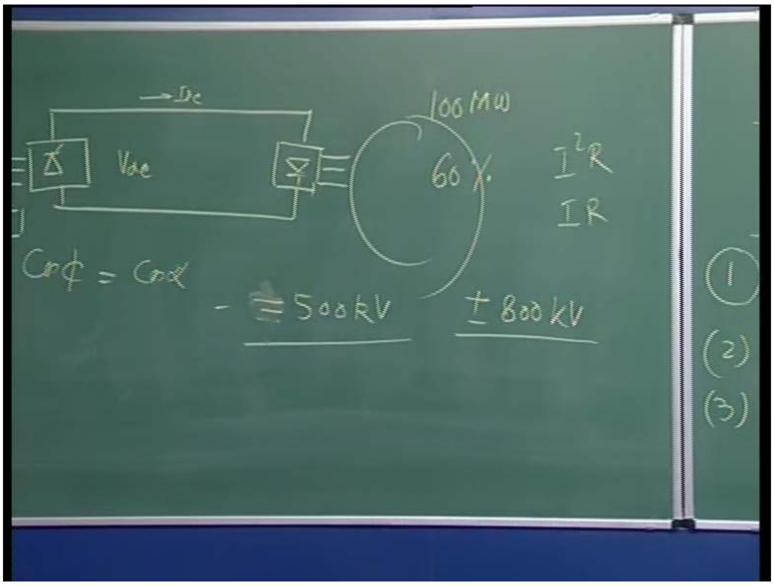


So, whatever right, now, we are having from rihand to dadri it is operating at your plus minus 500 kilovolt and this shows the plus minus means 1 is operating at plus another is operating at negative. So, this sign is normally used in HVDC links this shows that you are having a bipolar operation. The plus responds one and here and negative here this so, the this is plus 500 this is minus 500 means voltage difference between these two it is 1000 kilovolt so, the advantage of this that even as I said here even though one pole is down we can provide half of the power that is, flowing from one end to another end and that is, very very advantageous.

Otherwise; what happens if one for example, here if there is some problem, here you are not providing the power from one end to another end, and this is used for the bulk power transfer and this is blocked so, you have to your condition and you have to manage your system. So, this is your bipolar and it is a very popular here another is your homopolar in homopolar the difference between the bipolar here again, we are having the two poles but the poles are of same nature means, both are operating at the negative again due to the less corona loss because they are operating at high voltage is the 500 kilovolt so, huge corona loss will be there and thereby what we try to do we try to reduce the corona loss by going for the both negative poles.

But major problem here that this, is the current is flowing, here this current is flowing and the ground is used as the return path. Once you are using ground return again that creates lot of problem to the system, may be the some voltage is induced sometimes corrosion is there; sometimes even though some your the ground rods are broken; that again that creates problem. So, this is also not very common the advantage of here is again, if there is some problem in one of the pole here you can still use half of the pole and you can provide half of the power that can flow from one end to another end.

So, this is a major difference between the bipolar and homopolar so, normally in homopolar it is simply written it is minus or simple minus it is sufficient for this because if homopolar it will be not it will be in the negative both pole, it cannot be positive because more loss and we can operate the converters successfully in the negative voltage operation as well. So, we can broadly we can classify in the three category conceptually it is possible but this is more popular and half of this is a possibility suppose one fail here you are going in the monopolar operation. So, that is, why I explained the monopolar but to reduce the corona loss et cetera here we can go for the monopolar and we can use the ground as a return path.

In both cases here the double of power is flowing from this monopolar because this is a voltage the current is rating of the pole is same we are going to have here the voltage here multiplied by2. So, twice of the power is flowing here but no doubt we have the two monopolar here one monopolar here another here also we are having the two monopolar so, the power step up of the single monopolar. So, these three category of HVDC links are basically practically possible but the bipolar is the better option and it is existing in India and it is planned several in India we are going to have recently plus minus 800 k v

DC system and so, many locations are planned. So, that we can go for the higher and higher voltage again the concept appear going for higher voltage means you can transmit more power. Because the current which is flowing here in these lines are limited again the conductor size, if you are going for more conductor size to reduce the losses, then it will be very bulky, then you will have to go for bulky towers, and so many other problems should occur. It is also option, that we can increase the voltage and the maintain the current same so, your losses will be less, and we can operate the system satisfactorily.

So, today is lectures now, I can summarize, that we discussed about the HVAC problems with the HVAC system then, we saw the HVDC  V DC advantages and also we discussed some of the limitations of HVDC system and we found that for if your purpose is the bulk power transmission or your purpose is to power flow control or to provide the stability to the AC system. Then HVDC system is the better option compared to the AC system and also we saw the three types of links that is, the bipolar monopolar and homopolars are existing and that is, feasible and but the bipolar is most common.

So, with this we will see in the next lecture about this various components of HVDC systems and that we will discuss in the next module next lecture. Thank you