High Voltage DC Transmission
Prof. S. N. Singh
Department of Electrical Engineering
Indian Institute of Technology, Kanpur

Module No. # 07
Lecture No. # 02
HVDC Light/Plus

So, welcome to lecture number 2 of this module module number 7, and in this module, I will discuss the HVDC Light and also sometimes called as HVDC plus. Basically, this HVDC light, the nick name or trade mark given by ABB; and HVDC plus is given by Semen's. So, but the technology and concept is the same, that is why I will be using in this presentation as HVDC light.

So, to start with let us see, what are the various problems in HVDC in a conventional HVDC transmission system? And to you can see, the mostly the HVDC transmission system is used for the long distance point to point transmission.

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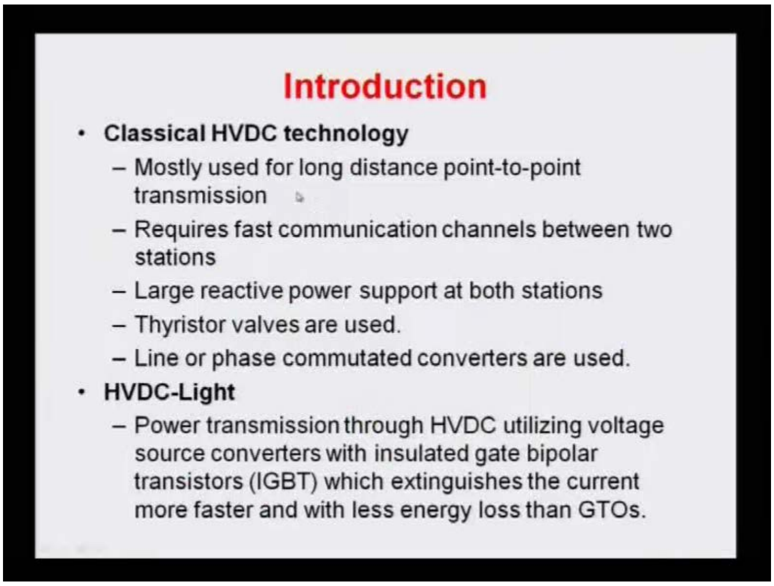

No doubt, we saw also that we can go for the multi terminal HVDC links or transmission system, where we can tab the power in between, not it is one to one, so but it is again becomes very complex and also we have the limited terminals like whenever you are adding more than two convertors, you are you doing any extra convertor, then it becomes multi terminal HVDC. So, already in the previous lecture, we saw this multi terminal DC link. So, it is said that is a mostly used for the long distance, point to point transmission, all though some people may argue that it is not only for long distance, bulk power long point to point transmission.

But now-a-days HVDC links are also used, and they are known as back to back connections, they are very near to each other, and the purpose of this HVDC link is to control the power from one region to another region, one system to another system or can provide the asynchronous connection between the two systems, two regions as well. But in the early, when thus people were talking about the long distances of HVDC applications, there are mostly concerned about the transmission bulk amount of power from one region to another region, that is why it is said that it is mostly used for the long distance point to point transmission, but it is now not so.

Now, we are also using back to back connections that as I said to control the power from one area to another area, and also the sometime the HVDC system are also used to stabilize the AC systems. Normally, they are the modulating the power and that is why AC, DC transmission systems are running parallel. So, we know the point to point, because we are going to tab the power in between, then you require some extra convertor, and also you have to change the control philosophy, which we saw in the empty DC transmission system.

Another problem in conventional HVDC technology, that it requires the fast communication, channels between the two stations or the three stations. So, (()) you are having a multi terminal, then you require the communication channel between all the sub stations or converter stations. Why it is fast because, we saw the control characteristic in our control philosophy, that that module we saw that what will be the characteristics of the rectifier, what will be the characteristics of the inverter, they are the difference.

So, once is operating in either either say, thus it can operate you know rectifier is there, so it can operate the two modes, one can be your CIA mode, that is a constant ignition angle control, that is a alpha minimum control or it can operate in the constant current mode. Similarly, the inverter side, it can operate in this control mode that is CEA mode, that is a constant extension angle control, as well as it can also happen it in the constant current mode. In the constant current mode also there in a inverter side, people are also argue that we can add the constant voltage or a constant beta control, especially at this connection of this CC and CA, where we require due to the various region, already we had discussed it, in our previous modules.

So, we require that if, one converter station is working for one dedicated to voltage control or current control or there will be taking care of voltage current or voltage vice versa. And also we require a dedicated control that is what will be the current margin, as we known in this conventional HVDC, the main concern, that we are using the constant current source convertors, the (()) the current is basically, maintained constant and voltage is keep on varying varying and there were we are controlling the power.

So, this is a second problem in classical HDVC technology, another that is it is a large reactive power support at the both the station; we know all though this is the DC system does require any reactive power support, and the DC line as well as say. But, at the convertary stations and already we have proved that, in the ideal case already it has been improve, that the power factor is equal to your cos alpha, and alpha is the delay angle of the convertor station.

So, now we can find, if the alpha you are keep and delaying you are changing the voltage, and cos alpha is a directly related to the DC voltage and the power is controlled by the DC voltage. Once your power is controlling from either reversing or zero to certain value you are going, the alpha is change, once alpha is change what is happening, then your power factor requirement at the convertary station is going to be high.

So, in the thumb rule normally people say that if 100 mega watt HVDC line is there, and you require at least 60 percent (()) for support at the both the terminal station; terminals means two terminal, then you are having a rectifier and inverter, so you have to put. So, huge rectifier support is required, that is basically to take care of the voltage variation of the convertors.

Then you have to put that is insulation and again it is become very very bulky, and a station becomes very very large, because we have to put a huge rectifier support, and its (()) it capacity support, we require at that end. Third tested in a conventional HVDC technology in the beginning we started using the thyristor, and you know the thyristors are basically, the line commutated convertors, we can have and you know the commutative once you are going to turn it off, you have to make this is a primary requirement of the thyristors, if you want to turn it off, the current flowing a through the thyristors should be zero.

So, in the normal way, it is keep on flowing the constant current, so you cannot turn it off. So, to make it turn off the current should be zero, and the voltage a cross the thyristors should be the reverse. So, to make current zero, we can use some (()) circuits and based on that we can make some way, that we can make the zero, a cross this and then we can turn off the thyristors. So, the conventional thyristors are valves, valves means is the series of the thyristors, in the series and parallel make certain voltage level and the current carrying capacity, because one thyristor unit is not able to provide complete support for that rating of the your HVDC station.

So, we can use the valves and valves means, that we can use this series or the thyristors as well as the parallel to make the particular rating, so and they are use the line commutate convertors. Some other concern about HVDC already explained that is also, in the conventional HVDC system, they introduce harmonics and not only the normal harmonics, characteristics harmonics they also introduce the uncharacteristic harmonics.

Characteristics harmonics, if you remember this already discussed, this NP plus minus one those are even though current harmonics, the DC side also we are also having NP the p is number of pulses, N is number of integer, so in DC side also we are having one harmonics. So, we require the filters for those and already in the AC side that for current harmonics we use, if it is a 6 pulse convertor we use 5th and 7th harmonics and filters also 9th and 11th harmonics filters are used.

At the same time, they provide some rectifier support as well as the providing the minimum (()) path to that one. So, this is the filters are used and it is very bulky and also require the huge phase. So, the harmonics and other concern are these major concerns, the cast and other things are keep on declining, so cost was also when beginning concern, but again thanks to the power electronic development and so on, so forth.

The costs are declining and in the future again in break even, when the AC and DC may go down primary, it may be 6 to 700 kilometers, but it may again in future it may go down. So, to avoid all these problems this conventional HVDC system, the HVDC light or HVDC plus, again I want to re trade that, HVDC light the trade name given by

HVDC, plus it is a name given by a Semen’s, but the concept is the same. And both are using now instead of the CSC that is a current source convertors, now they are going to replace these by using the voltage source convertors, and we know the advantage and disadvantage of the current source and the voltage source convertors well, I talk in the beginning, in this module 1 or module 2 there.

So, what changes they are doing, in this the basic change that the power transmission through the HVDC utilizing the voltage source convertor as I just mentioned, and there using the IGBTs. IGBTs is nothing but, insulated gate bipolar transistors, now just see here it is a transistor technology, how where in the conventional, we are using the thyristor technology both are different. So, using this which is the estimation the current faster, and the less energy loss than the GTOs and GTOs are gate turn of thyristors.

So, this is another grade of a thyristors, the conventional thyristors you cannot turn it off by simple giving the gate pulse, you have to make the current across the flowing through the thyristor should be zero in the conventional thyristor. But, in the GTOs by putting the negative gate pulse, you can turn it off even though the current is flowing full capacity, current flowing through GTO. But, you have require some of the circuits, because there will be some transient was suddenly the current is stainless, so that we use some extra circuit to minimize those transients.

So, this HVDC light, the basic concept, the (()) convertors, it is a current source convertors are replaced with the voltage source convertor. And they are utilizing the IGBTs that is, it is a insulated gate pole transistor, so the major difference here, that the transistors are used that is thyristors.

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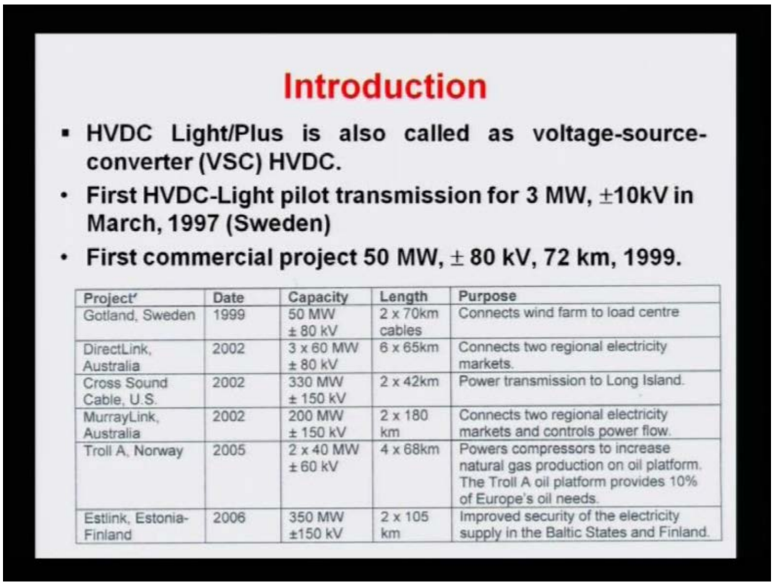

So, it is again that is here, I have written the HVDC light or plus, that is why here I am right now using both, but in the some of my presentation we define only HVDC light, because as we find more literature on the HVDC light compared to the HVDC plus. So, but, again as I said the, they are using the voltage source convertors the VSC of HVDC.

If you see, the first HVDC light, the pilot transmission for the 3 megawatt only it was only small, it was pilot project 3 megawatt and the plus minus 10 kilo volt in the mass 1997, it was establishing Sweden and the plus minus plus minus 10 KV as indicate, so it is a bipolar. And the bipolar that is why it is one is operating on the positive polarity, and another is operating on negative polarity.

And the voltage level between these two poles, it is a 20 KV, because from the 0 is a 10 KV from below the 0 it is a minus 10 KV. The first commercial project, because this was the pilot and the project. So, the first commercial project basically, just came into the practice in 1999, and this was having the carrying the 50 megawatt, and that it is a plus minus 80 KV, you can see from here, the summary or the various projects commercial projects, it is instable written in stable.

This see this is nothing but, this is a Gotland, Sweden project, the Gotland is one island already explained this in the beginning of the this HVDC course. That the Gotland is Island of the Sweden, which is almost it is a 70 kilo meters away from the main land, and that is and it is this provided this HVDC light project, and it was commission in (()), it is started operated in 1999. So, current carrying capacity this is power capacity was 50 mega volts and the voltage level was plus minus 80 KV means, again it is a bipolar. The distance here, you can see it is a 70 kilo meters, it was (()) cable and it is a two cables are used, because it is having the bipolar. So, two cables one is negative, another positive it is operating and it connects even wind farm to load center, because that Island is having the full of wind potential, and that is connected through this that cables, and that is (()) cable.

Second project of it is there is so many smaller and smaller projects also came in, the Europe as well as in other part of the world, but the here it is listed those are the bigger projects, and bigger commercial projects here. So, another is called the direct link that is in Australia, and it was commissioned in 2002, and it was carrying 3 into 60, because the 3 lines where there.

So, why it (()) one bipolar is having 60, here you where using this 50, so here you can see 3 means, we are having the 3 bipolar operation of this 60 each means the total capacity, that is flowing it is your 180 megawatt. And again the voltage level was plus minus 80 KV between the 2 bipoles, that is why here you can see here it is a 6 we have multiplied, because we are having the 6 cables, one cable for positive, one cable for negative, so it is one bipolar. So, similarly we are having 3, so it is a 6 multiplied by 65 and it connects basically, the two regional electricity markets and here, this length is a 65 kilo meters.

Another which was basically established, this is the a cross sound cable, in US 2002 again, and it was having huge power that is 330 megawatt and the voltage level also you can see, it is a plus or minus 150 voltage, so it is says larger side. But, here again it is a 2 cables again the bipolar and the 42 kilo meters and basically, it was a power transmission to the long Islands; it was for used in the Australia again the Murraylink, that is a Murraylink is called in Australia in 2002.

Again it was having the 200 megawatt and again the voltage level they increase, from the 80 here kilo volt to 150 kilo volt, and the line length now you can see, it is 180 kilo meters. So, it is not possible to have a cable, it is a more than 100 kilo meters, even though earlier people only having the cable of the 50 kilo meters; but now, it the different you know polymers and different (()) materials here and there, now it is said that we cannot have a cable more than 100 kilo meter, because whatever the power you are injecting, it will be the taken only the charging of this cable. So, this basically, this link connects the two regional electricity markets and controls the power flow between the two regions, that is very important, so it is used to control the power over there.

Another in the Norway in 2005 this Troll A, this it is again the its voltage is not so high, but it came later and it is again the 2 into 40 megawatts means they had, the bipolar operation plus minus whenever, you will find it is a bipolar. So, it is the 2 bipoles and that is an each is having the 40 megawatts, so total power carrying capacity over this entire link is your 80 megawatt, and it has a 68 kilo meters.

So, here 4 is 2 multiplied by 2 is a 4 cables and this is a power compressors to increase the natural gas production on all platform, and Troll A platform provides 10 percent of the Europe’s oil, that is needs, this is the basically used there to in the oil platform basically. Another in the field land, it is now then 2006, it is a very high and it is you can see, it is a 350 megawatt power, that is carrying and the voltage level is also very high this is a plus minus 150 kilo volt.

And distance also you can see, the distance is 105 kilo meters and the 2 bipoles are there, the improved security of electricity supply in the bulk state and the Island this is used and this is the bigger one. So, it is only listed the some of the commercial projects, that is here I have listed the 5 commercial project, but from 2000 onwards also they are so many projects are commission. And also the some of the project are under the process undergoing, and then future again will have more and more first type of HVDC voltage source convertor base technology, for the HVDC transmission system.

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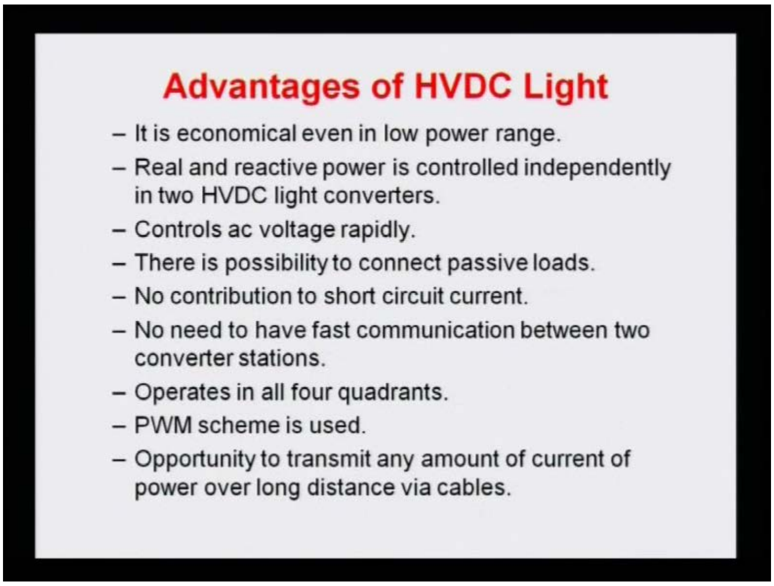

Now, to these are the first I talk about the problem of the conventional as transmission system, then I talks about the various projects, those are already existing. And now, let us concentrate on the advantages of HVDC light. These are taken from some of the reports here and there and collected from the various sources, it is not my own advantage which is I am just expressing my views, but it is taken from the various literature, which is existing, either from Net or Google or you can say there explore. So, you will find all this things which I have summarized here.

So, it is said that this HVDC voltage source convertor base technology is economical even at the low power range, no doubt if you are going for the conventional technology, for the low power range, it is very expensive because of the cost of the convertors, and the convertary stations, it is very expensive. Because, it have to put filters, you have to put the convertors, you have put cooling etcetera.

So, all if you see then breakeven points becomes very large, if you are going to have carrying the less amount of power. If the power transmission is more, you will find that the breakeven point that is a preference of HVDC is a better than (()), if you are going for large power. So, this HVDC voltage source convertor base technology, is basically economical event at the low power range means, if you are going to transmit lower like that 30, 40, if you see here, the most of the powers are not very high it is a 60 maximum is 350 megawatt.

But, if you see the conventional power HVDC transmission system, there are carrying more than 1000 megawatt more carry more than 2000, 3000 megawatt power, so it is very very high. So, this is even the economically forward the low power range as well, another major advantage of HVDC voltage source convertor technology, is that we can control real and reactive power independently, in the two HVDC light convertors.

So, here if see the control philosophy, that we were using in the conventional HVDC transmission system; it is basically we were controlling the voltage and the current, and that they were power. One is controlling this current, another is controlling the voltage and we were maintaining.

So, it was not possible to control the power DC power, we are controlling the real power it was we were controlling, but we were unable to control the reactive power independently, no doubt, once your firing is changing, your reactive power is also going to change. So, you are doing, but is still, is not independent control based and the power.

But, here in this technology, we can control both active that is real power and also the reactive power that is the q power is control independently in the two HVDC voltage source convertors. And that is a great advantage here, the power are independently means you can control the DC power, you can control the reactive power, that we need and that is a and that is a beauty of the HVDC voltage source conventional technology.

Another advantage is it a stated, that this HVDC voltage source convertors, can control the AC voltage rapidly compare to your convectional HVDC transistors system. The reason is that. The convertor which we use in the conventional HVDC transmission system, they are the line committed and there are lot of (()), in that one. And sometimes they say, it is a controls much faster even the 20 times faster than, you are the conventional HVDC transmission system. So, it controls the AC voltage rapidly compare to your the conventional transmitter conventional HVDC transmission system.

Another the major advantage is that with the help of HVDC voltage source convertor, we can possibly connect the passive loads, as I said it was not possible to connect the passive load, in thus conventional HVDC, because we had to control the current one way in one convertor, another there. So, what is happening here in the passive load, I mean that you can have the one convertor, you can directly connect the load and then you can utilize and you can see the power control and the reactive power, which is not possible.

So, here this since we do not require big communication channel between the two convertors with this technology, we can control independently. We can control the real and reactive power independently; thereby we can also control the passive loads independently without any problem. Another here, advantage although this is also an advantage of conventional HVDC transmission system, that the no contribution to the short circuit current, whenever there is a fault normally you know the circuit bakers, there is a bus you are having, so many AC lines.

If the fault is there at that bus, now we calculate and will see how much the fault is consider by this lines, if your HVDC line is there and you can control very fast, then we can say the fault level contribution by that line is almost nil.

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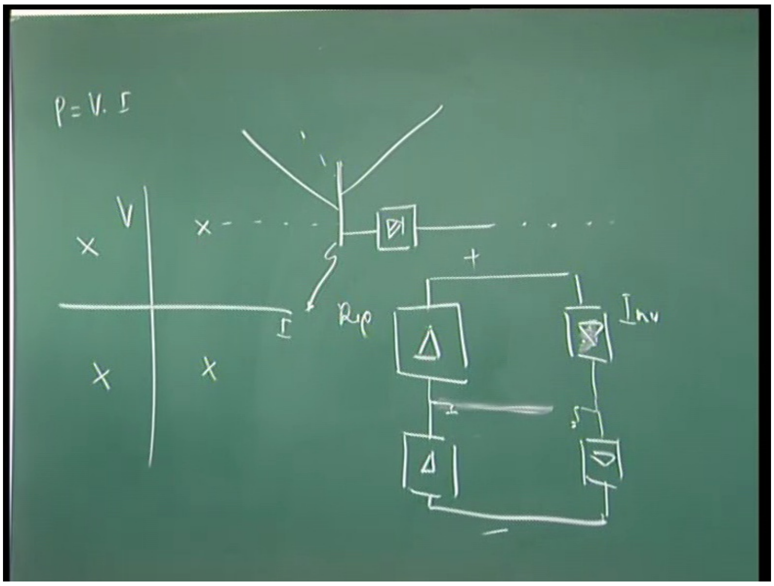

No doubt in the HVDC line, what is the fault level this I will explain here, suppose you are having here a bus where so many, so many this is your lines are AC lines are there, and if you are having a DC here conventional I am talking here, the conventional your convertary station, and then you are having.

So, whenever there is a fault here, three phase fault, now we can see the contribution of fault current from this line, this line and if other lines are there, and what will be the contribution was from this HVDC link, if this is a slow, so during that fault, during that fewer cycles, fewer mill seconds this will be also contributing the fault current.

But, if can control very effectively, very fast we can say the fault contribution here can we can make it zero, and sometimes we can take in other way; we can stabilize a system by controlling this one. So, that is why here this advantage is mention that no contribution to the short circuited current, because we can control very fast. So, that is line is almost we can we can assume that, it is not going to contribute the fault level at that bus. So, whenever you are adding the transmission line the fault level at that bus is going to increase as you know, the impedance seen up for this fault.

If you are adding another line here, the fault here will be going to increase, because all this lines going to be parallel of this. So, that is why we require that the designing the circuit baker etcetera, that what should be the circuit baker reading etcetera, that is use to for that is a that is a calculated based on the fault level or that bus and contributed by the various lines.

Another advantage is that the no need of the fast communication between the two convertary station, as I said we can control these two convertary stations independently; even though there is only one convertor station, if you are connecting a convertor station with the passive loads, only one convertor station. So, here the communication between these two, suppose you are having two bilateral here, that one is the rectifier another is inverter.

So, this is a fast communication is not required between these two channels, they can work independently and that is the beauty of this HVDC voltage source convertors. Another here advantage is that, HVDC transmission system based on the voltage source convertor technology, can operate in all the four quadrants of the operation means, if you are hiding here, you can see this is the four quadrants, and if you see our conventional thyristor HVDC transmission system.

We had, if it is your I, this is your voltage we find that we can have the operation is this 2, here this is your rectifier mode. And if you are going this side, then it is a inverter mode, because the power voltage is reverse, the power is you know the power is just technology, p is your v into I p voltage at the reverse, then you are going in the inverter mode (Refer Slide Time: 23:25). But, with the help of this, we can even though operate in this quadrants, at this quadrants as well, having the voltage on the y axis and this is your current is x axis.

So, we can operate this, because we have the full freedom into control and then, we can operate in all the four quadrants that is the beauty of this and where you want, you can control here and there. So, this that is why it is said, this can operate in the all four quadrants of the V I plane. Another y basically, y it is a possible to use, that we can use the pulse width modeling, its PWM is clean, that can be used and you know the if we are using the P pulse width modulate scheme, you can a achieve a lot of advantage.

Those where the problem in the conventional HVDC, because there is a harmonics and other things, we can minimize the harmonics, we can minimize the reactive power demand, we can fire in a such way using the pulse width modulated control, there is a various type of the pulse width modulated schemes are there, that can be used here and based on that, we can solve the various problems, those where in the conventional HVDC transmission systems.

So, using the pulse width, we can improve the power factor, we can improve the harmonic injection means, there is we know in minimum harmonic injection in the system, and also we can operate very effectively in all the four quadrants of V I plane. Another thus advantage that opportunity to transmit, any amount of current of power over the long distance via cable, here the apart opportunity to transmit any amount of current of current of power over the long distance, I mean to see that, it is also in HVDC that we can load the system up to its thermal limit.

What about the current is that, is a is the thermal limit is there, we can go up to that limit and we can load and in this cable because, the DC cables are going to be more more popular, because the AC cable you know the charging is a big concern, and you cannot load even up to their thermal limit, because the charging is a huge requirement. But, if you can go here, then you can use this HVDC light means, one side you can have a convertor, then you can have DC cable and then you can have AC, so it is no limitations and you can go for the longer distance.

And it is a very small and you can control all the way independently, real and reactive power. So, this is giving opportunity to transmit the current limit, not is a any amount which we cannot go after infinite amount, there is a some limitation means, that we can go up to a thermal limit without making any problem.

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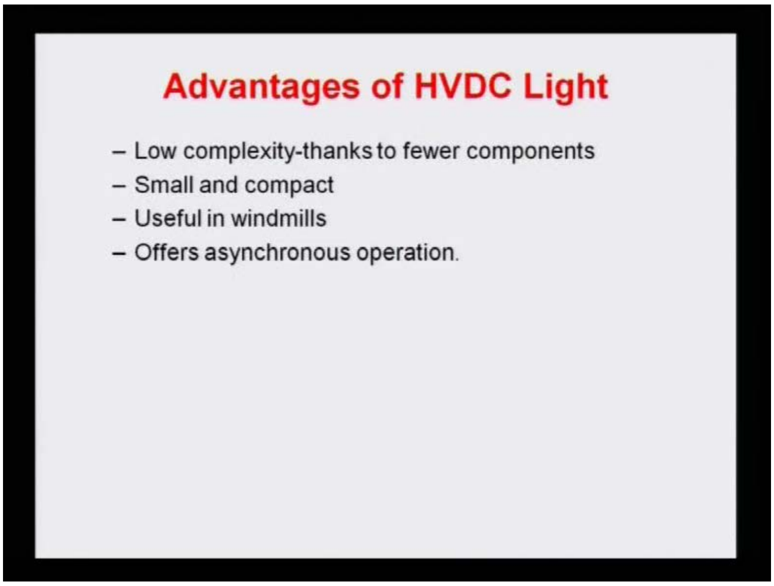

Another people say, now a question is why this HVDC, (()) the has a call it HVDC light, that it is the say, it is a really light in weight, what is means, it has a low complicity and why the low complicity, because it requires the fewer components. Because, we do not require the filters, we require the filters of certain magnitude, because we can minimize the filters by control itself.

So, the we require the fuel components, so we require the lesser size, lesser speed, let us sorry space and thereby, we can say it is a light in the weight, means it is it will see the conventional HVDC convertor station is very bulky you require a big room for your convertary station. Then you require the cooling, then you require the filters all the things we are keep on adding is a very bigger station, but with the help of this voltage source convertor, we can minimize, so many things.

And you know the size of reactors are nothing but, they are size of rate transformers, we require a smoothing reactors, we require the various filters, and if you see the inductors another while are used, you see for the even though higher the lower order frequency 5th and 7th you see find there reactors just like a transformers.

So, and next here, I can say this complicity is low and I can say thanks to fewer components those are used, also we do not use the line commutate circuit for commutation of the thyristors, we can simply turn it off and turn it on, whenever we require. But, how were in conventional grade, if it is technology if we were using thyristors, then you require some extra circuit, to turn it off the thyristors while they are conducting; also I said there are small small in the sense, the small is space is require, they are very compact and that is why it is called HVDC light. Another advantage that you know that is, now the windmills or the wind forms, whatever you are calling, now people are putting all this wind form not only on the on so, but they are also off so.

And there are also putting in the sea, because most of the European sees, they are the favor and the most of the forms are in the sea and by the way we have to collect the power from them. So, then if you are using you are AC cables, now the question is which type of wind form you are using, you are using the w fed injection generator or you are using your injection just simple squirrel case injection generators or you are using the permanent magnet synchronous generators. All this here the technology these existing, but we have to most commonly used the w fed injection generator for the larger capacity.

So, if we are using the induction w fed injection generator DFIG we call it, then the power which you are putting connecting to the system, it is an AC power. So, once you are having the AC power, and then you are using the long AC cable may be of 70, 80 or 100 kilo meters, then the charging and other problems in the big concern. So, what we can use, we can use the DC cables, we can use the convertary station very near to in the very near to the in the collector of the wind form.

If you are using the conventional, then it becomes a very bulky as I said, you require huge space and and in the sea putting all this is very very expensive, but now since having the fewer components, the smaller compared, we can put the HVDC voltage source convertor near to the collector system of the wind forms or windmills. And then we can have the DC cable and finally, we can take it to the show and finally we can again transmit, in terms of or we can convert from DC to AC and finally, we can connect with the grade or distribution or transmission whatever the grade you want to connect.

So, it is very useful for the wind mills, and will see some of the application in our previous in the next lectures, this I will discuss about. Another advantage that it can half asynchronous operation, this is true and this is equally valid for all the applications, even though even though conventional HVDC transmission system, can also can also connect the two or synchronous means the two different frequency systems can be connected by the DC links, that is no doubt. But, this offers more advantage that it can be very fast control, very better one in the various way we can control real and reactive power as well. So, this offers the more advantageous in asynchronous operation compared to the conventional HVDC transmission system. So, with this advantage I can say it offers a lot of advantage, and but still we can see the IGBTs base technology is still, it is not so cheap compared to our conventional HVDC technology. Because, here the IGBT are still expensive compared to the thyristors.

So, the whole convertor is still you can see just in this example as I saw, here the ratings are still not very high compared to your thyristor technology. But, again we can thanks to the power electronic development, and we can say in the future there will be surprises, we can go for the all this things, we can go for the more than 1000 megawatt power over this higher voltage may be plus minus 500, approximately 800. Once this IGBT technology will be more measure will have, when the lesser cos higher rating development etcetera will take place, and then we can go for this more and more.

So, that is why this HVDC voltage source convertors, now there is ABB, semen's all other manufacture companies, now there is doing lot of reaches, lot of other development is happening in this area. So, that in the future, we will find this HVDC that is the base standard voltage source convertor, will be more useful compared to the current convertors, so these are the advantage we saw.

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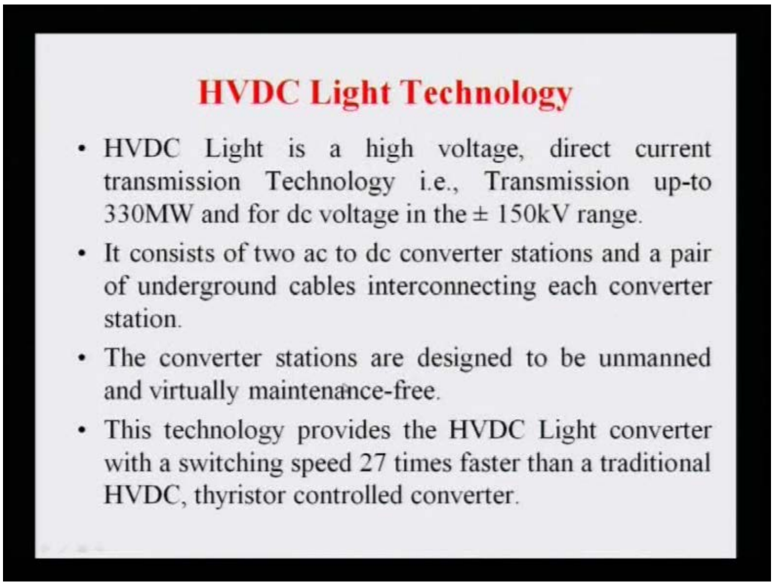

Now, we have to go for (()) HVDC light technology, HVDC plus here basically, the

HVDC light is a high voltage, direct and transmission technology, and the transmission up to this 330 megawatt and for the DC range the 150 voltage. So, we saw with the various application here, even though we saw some times some sort some ratings is 350 megawatt, and but the voltage level is right now is only limited 150 kilo volt. But, again some of the going to be synchronizes with maybe even though not I have notice, but may be the voltage rating is more than this 1 plus minus 150 kilo volt range.

But, I am sure in the future, we are going to get higher voltage level and higher power transmission via, the voltage source convertor HVDC system. So, here in this, it consists of again to AC to DC convertors stations and appear of underground cable in the connecting each convertor stations means, what here we are getting that is the similar to that here, we are having this is a one station and that is we require two cables, if you are using two bipolar and here you are having another sorry another convertor here, that is the inverter here (Refer Slide Time: 32:51).

I can say and here you are having the rectifier and if you are having the bipolar operation then, it is a grounded and then you are having another one here, and then you can operate here with this this is a grounded and then I can say this is your. So, this is your operating positive, this is negative and then it is a bipolar operation that we are having. So, this technology provides the HVDC light convertors with the switching speed 27 times faster than the traditional HVDC thyristor control convertor, comparing the thyristor based HVDC transmission system we are converted technology, which is used in the transmission system, it is more than 27 times faster.

So, that it is almost very fast and then we can, that is why we can achieve whatever the advantage, whatever the problems where there that we can overcome and we can get the advantage by this voltage source convertor based HVDC transmission system and technology.

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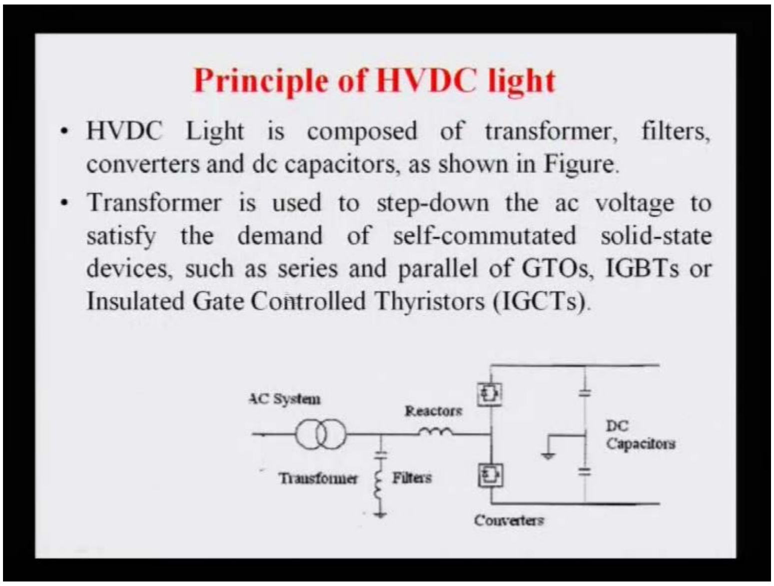

Now, we will go for this principle of HVDC light, so the principle of HVDC light that can be understood by this diagram, you can say the HVDC voltage source convertor is basically composed of whole transmission. Basically, I am talking is composed of transformer, you can see this is a transformer, this is a convertor transformer we call it that is connecting you are AC system, then with the convertor system, we are having the filters, we also need the filters.

As I said in the beginning, that is not that even, we using the here the thyristor are even as IGBTs it is a free from harmonics, some harmonics are injected. So, we require some of the filters, may be it is again the band pass filters etcetera that we can use the some filters, and filters are used. And then we require, the DC capacitors that is more important, we use the here the convertors, you can say this is a convertors here, we use the reactors here and we also use the capacitor.

One big difference you will find from your HVDC conventional, HVDC transmission system, that earlier we were using this, we using the transformer, we were using this filter, we were using this convertor, and no doubt those convertors were based on the thyristor, based or the GTO base technology. But, we were using here the reactors, especially to smoothen, the ripples of the DC as well as to have the constant DC current, we are using the inductors that were the series of this convertor.

But, instead of that we are using the capacitors and that is called the DC capacitors and they are use in this way, and there are basically putting here the voltage constant. So, that is why it is the voltage source convertor, and it is not a current source; we are using current source, you have to use the current constant and is a ripple free and then for that you have to use the your smoothing reactors. So, the transformer is used to step down the AC voltage to satisfy the demand of commutated commutative solid state devices and self commutate, there are not line commutate.

So, they are self commutate and such are the series and the parallel combination of GTOs, IGBTs are the IGCTs now the again people are talking the insulated gate control thyristors, that can be also used. Here, the transformer here we are using, if you are taking this is a convertor you can say from AC to DC, here means your AC voltage is higher and your DC voltage is lower because, the again due to the limitations on the convertors side, the voltage is again as say that we are going up to only plus minus 150 kilo volt.

And this side we can have even though 760 kilo volt or may be AC side we can have the 1100 kilo volt, so this transformer is basically nothing. But, the step down transformer, if you see from here this is your primary, always you know the step up and step down transformers are designated and this classification is only valid, if they are connected in this system. So, which is your primary source, which is your secondary, when it is connected when you can call the step down?

So, if your power is flowing from the high voltage to low voltage, then we can say this step down transformer. So, this is the step down transformer from high voltage AC to DC and then this side the lower voltage, and then we are rectifier here and that the DC voltage is coming here. So, this is a step down, same way this is a rectifier operation, because from AC to DC. But, if you are using the same, if here concept that power is flowing from this side to this side.

So, this because this becomes your inverter, and this inverters you can say this lower voltage DC, now it is coming all the way here, we are going to step up, because the this both side the voltage is lesser than compared to this side. So, this power is flowing from this side to this side, then this transformer is just as a step up transformer and here this is used to the self commutate side, the solid state device, because we are having the limited the voltage rating and another things, and that is why, we it is used.

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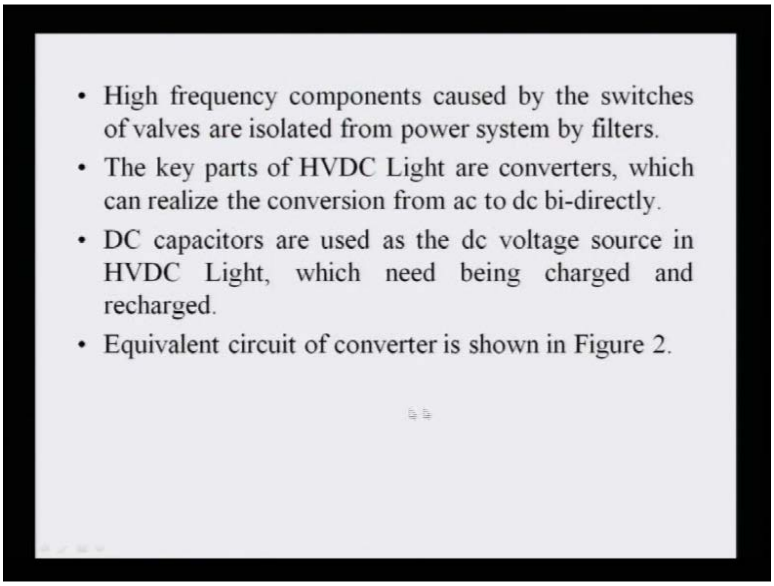

Now, the high frequency components caused by this switching or switch is of walls or isolated from the power system by the filters, the filters are use that whenever the high because, the switching is very fast, and the switching harmonics those are going to enter in the system, they are used by this filters basically. So, whenever the switching harmonics are there, they are coming here in the AC system that must be filtered out here, and that is why the filters are used, so we can filter out the high frequency.

So, we can pass the high frequency, and put it to ground and only we can pass the fundamental (()) nominal frequency book power in that side. So, the keypad of this HVDC lights or the convertor, which can be realize by the conversion of AC to DC by directly. So, it is always from AC to DC or DC to AC that can be utilized and it is very fast control, that is a possible.

Another difference as I said, thus we are having here the DC capacitors, in this HVDC voltage source convertor and you know the voltage source convertor, means you are connecting the DC with the capacitor. If you are using your inductor, means it is a current source convertor it is very well and general, it is very you know wake differentiation, although people would defining this voltage source, and the current source convertor in different way.

So, the DC capacitors are used as the DC voltage source, because here the charging and the discharging is done by the DC capacitors. In this this system which need being charged and the recharged recharge, because your charging and recharging, whatever the power which is showing, this basically the capacitor here, walks as shock absorber; means whenever the power is going from here. And it is not transmitted completely to another end, this capacitor gets charged, means store that energy and the voltage raise and then whenever, it is require suppose you are putting less energy and more energy is withdrawn, then this capacitor is discharged.

So, charging and discharging are done here the capacitors are used for this to the always charge and discharge and we require a big DC DC capacitors, and that is a major difference. However, in the conventional we are using in the inductors, inductors were also storing the energy, whenever the currents is changing with the frequency of the current were changing, so half I square you know the current is there, so energy is stored but, there is a current base.

Now, to see this whole here the philosophy, which I said here suppose this is a one side, you are having another side, so that can be here is in by the equivalent circuit, you can see how we are going.

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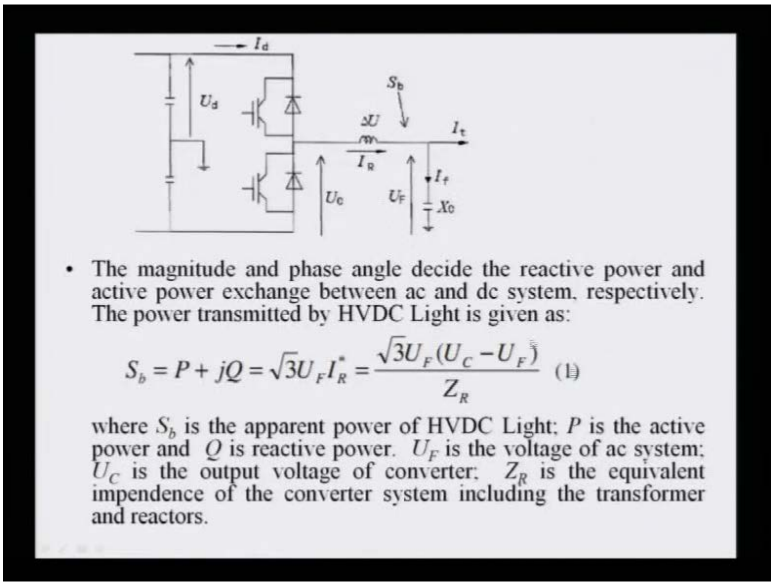

So, this is you can see, this is the current which is flowing from here, we are having this is this inverter operation, we are having single phase is represented by you can say I d is flowing and thus we are having our I g, it is your based technology. And this is the voltage that is from 0 to this U d and I can say, this is your inductor which is connected and the current is flowing, and this is going this side. So, we can write, what will be the power, that is a here the magnitude and the phase angle decide the reactive power and active power exchange between the AC to DC system, here the DC this side this is AC. And believing this power is flowing from the DC to AC side.

Similarly, the same concept can be utilized from the AC to DC system as well, the power transmitted by the DC light is given by, how much power thus we are showing from here, that will be basically the voltage here, this is a side we are having the AC. So, this apparent power that is complex power here, S b if taking the it is apparent power, but this S b is the complex power, that is the you are having real and reactive component, there is a real component is P. And your reactive component is Q that can be written, no doubt here since, we are having the single phase.

So, it is a three phase multiplied by the phase voltage U and multiplied by I R the current which is flowing here. So, this you can say (()) I conjugate it is a very well formula you know, under root three term is appearing, because the voltage here we are taking the single phase, the phase voltage. Because, if a 3 phase system, so it is a then under root 3 multiplied by here, the line to line and this is a current, so we have this U F we are taking line to line, so this a 3 phase power. So, what about the DC power it is going it is going to be the 3 phase AC power.

So, this always, if as we assume the converter is loss less, then we can say the DC power real power will be equal to your AC real power. So, this under root 3 basically term is appearing, because this U F we are taking line to line, if we are taking this phase then this will be 3. So, this under root 3 term is appearing, you know it is a very very basic concept of electrical engineering, and this is I conjugate and thus I conjugate, we can write what is I R here, it is a the voltage this minus this because, we have taken this direction.

So, this U C minus U F and then here sorry we have left this conjugative you can make here conjugate. So, this is we are putting divided by your Z R and Z R is nothing but, this is what is the impedance between this your U C and U F. So, you will see that terminology which are use, S b this is the magnitude here, it is a is apparent power of HVDC light, P is the active power, Q is reactive power, U F is the voltage of AC system as I said is AC system side here, U C is the output voltage of the converter which is coming here, and Z R is correctly you can see here is the equivalent impedance of the converter system, including the transformer reactors etcetera, that is coming all together here in this impedance.

Now, you can say what is the reactors, you can see this, you are having reactors, you are having the all this impedance here of the transformer etcetera, all these together is basically clubbed in this your Z R. So, this is there and this S b we can write here, from here if you are putting this all the values, if you are writing in this phase or form, these values these are the best complex variables. Complex U and Z everything complex here, Z R should be also conjugated, because whole this term is the I conjugate, we are writing.

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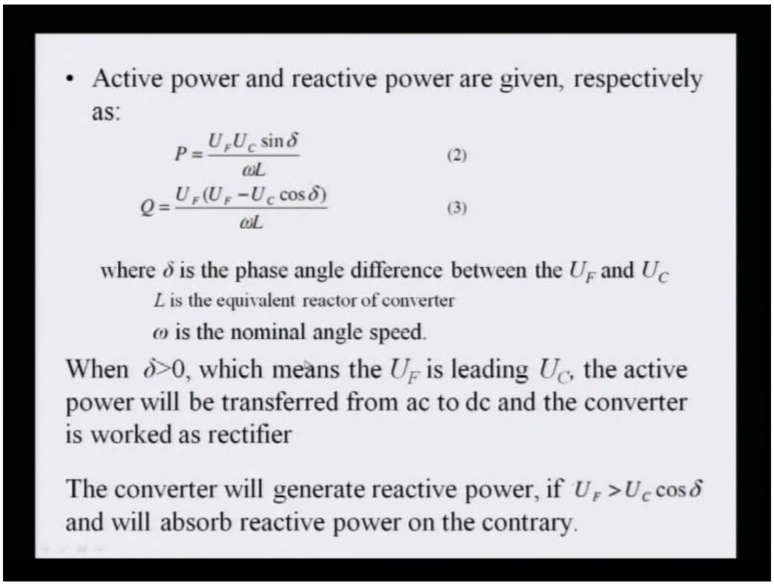

So, I am putting all these things, we can write this real power that is a active power and the reactive power can be separately derived from that equation one that we can write the real power will be equal to your U F into U C sin delta divided by omega L. We are assuming the L is the inductance of that is appearing, due to the transformer as well as the reactor, and the reactive power can be written by U F that is U F minus U C cos delta upon omega, that is x we call omega L.

So, the delta is basically, phase angle between the U F and the U C the voltages, and the L is the equivalent reactors converter of the equivalent reactance of the converter along with the transformer etcetera, and omega is the normal normal this is speed, that is radiant per second, this omega is a frequency of the system, that is a 2 pi F, you know it very well and F is a frequency of the system. When alpha is greater than 0 means, alpha positive, means this P it becomes the positive, which is flowing from your going to the AC system. And since, that is you can see this U F is the leading U C, and the active power will be the transform from the AC system to DC system, and the converter it is work to rectifier.

Now, if you are taking that is another here in this derivation, I took for the inverter system, but we can equally write the equation for the rectifier system, and based on this delta, we can say whether it is going into this rectifier system or it is coming out from the rectifier system, it decided by the delta, what is you have taken the is U F delta a U C delta, all these things you can very clearly, you can define and you can find the power is going here.

One thing you can find here, this reactive power the reactive power here, we are having the U F and U C and your delta. So, this reactive power that you can control as I said it is a very control variable, we can independently this and this we can control, because here you can control the U C. And thus converter will generate reactive power, if this value is positive which U F is more than U C cos delta, then this value is positive, means it is generating reactive power in the rectifier side; and it is again the reverse is also true and you it will be absorbing the reactive power on the contrary if it is a reverse only that.

So, you can see this real and reactive power, they can be control independently, we can control the delta here one side, we can control the U C and by these, we can control the p and your real and reactive power independently. So, in this and the remaining things we will discuss in this our next lecture, now here I want to summarize (()), in this lecture what we did we basically saw, the various problems of conventionalize HVDC transmission system. Already I just discuss, it very in detail although, the same thing was also discussed in the very first lectures of the module first.

Where we discussed the various problems compare that time I compare your AC system and the DC system, in this one I had compare the HVDC voltage source converter, and the HVDC source converter, current source converter based HVDC transmission system; means you have thus we the conventional system. And whenever we are talking this voltage source converter base HVDC system, this is HVDC light or HVDC plus, we also saw the various components, then we saw the what will be the real and reactive power, how it is a flowing and how it is going, and that is also derived in this this lecture.

In this next lecture, we will see the various control philosophy, we will see the various cable approaches and also I will talk about the hybrid transmission system having the HVDC light, already having in the AC and DC system; means if you are having already DC conventional DC system, if you are putting this HVDC with the voltages source converters, what will be the advantage, what will be the what will be the various impact basically, we will discuss in the next lecture.

Also we will find that is the multi in feed HVDC system, because you are having the multi terminal systems, where you are having then, and then you are having HVDC light, and then what will be the various gain, we can have that will be discuss in our next lecture, thank you.