**High Voltage DC Transmission**

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**Module No. # 01**

**Lecture No. # 03**

So, in last two lectures, we saw the advantage of HVDC systems over the HVAC systems and we found that, HVDC transmission is the one of the major area, where we can go far.

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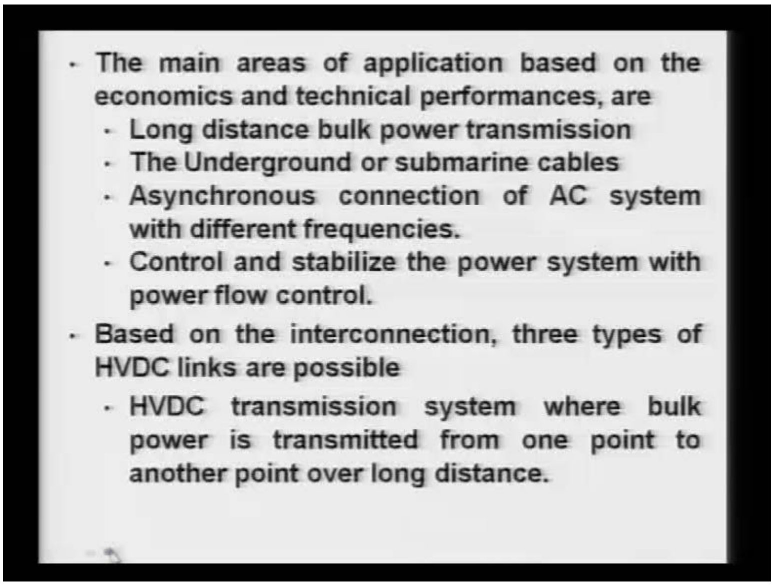


So, I can summarize the main area of application based on the economics and technical performances are that we can use the HVDC for the transmission purpose not for the generation and the distribution and then that is, why the three different categories, I just summarized that is, we can use for the long distance bulk power transmission.

We can use for even though, underground and submarine cables, and we can have this asynchronous connection of AC system with the different frequencies, we can use HVDC system and last but not least, that we can control the power with the help of HVDC transmission system and also, we can stabilize the power system efficiently. So, we can say that HVDC application is again, again I can summarize here means, based on the interconnections the three types of HVDC links are possible one is the HVDC transmission system, where bulk power power is transmitted from one point to another point over the long distance.

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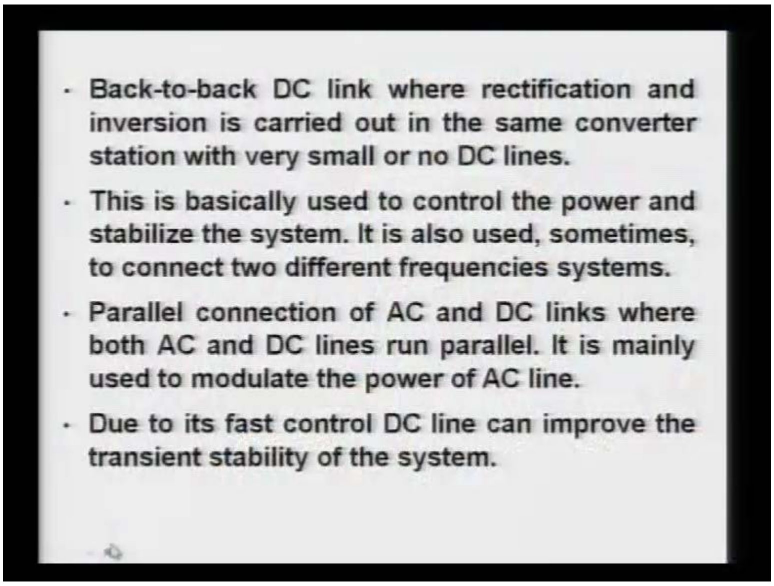


Another application, that we can use this HVDC system for the back to back connections where the rectification and inversion is done at the same place or may be very near to each other and the major concern of this is to control the power from, one region; one area; or to another area or one region to another region. It can be also, used sometimes to connect as, I said the two different frequency system, but also, we can use the AC and DC parallel to stabilize the AC system by modulating the power over the AC lines this is also, very fast control DC control lines are there and thereby we can reduce the fault level and also, we can go for the fast clearing time that can be achieved by the HVDC system.

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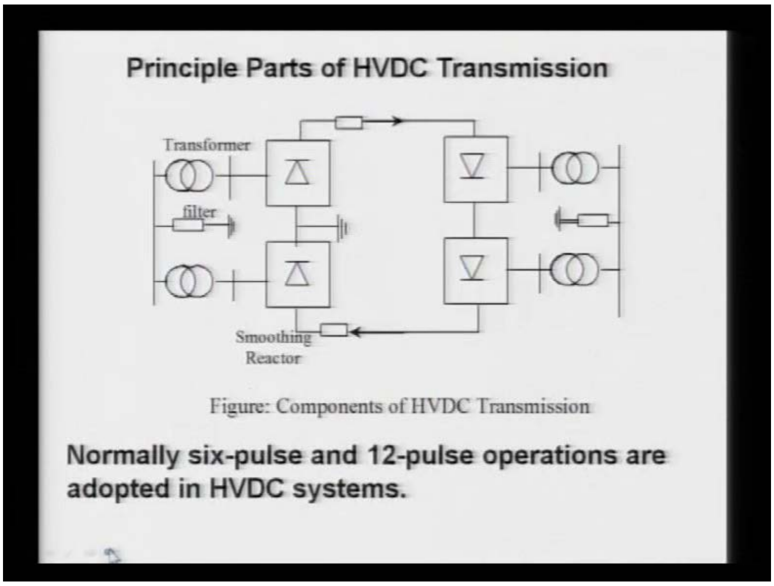


Now, we have to go for the major or principle parts of HVDC transmission system, if you will see this figure where the various components are the shown to you here if you will see that we have the converter this one station here converter here normally it is called rectification if the power is flowing from this end to this end and this is called your inverter. So, the major portion here in the HVDC system or very important part of the HVDC system is your converters and we require at least two converters that is, in two terminal HVDC link another aspect is the transformer.

So, we are here this configuration basically used for the 12-pulse operation, we will discuss the 12-pulse operation later on what is the 12-pulse? What is the six-pulse operation? That is, why here it is written normally the six-pulse and the 12-pulse operations are used in HVDC transmission systems. So, here one here system is giving six-pulse another is giving your six-pulse. Normally if you are combined with the two different type of transformers. So, again I will discuss if we are having star-star connection one transformer another we are having star delta we are getting 30 degree shift and thereby we can get the 12-pulse operation.

So, here we are having the transformers and these transformers are called the converter transformers. These transformers are not the similar to the conventional transformer we will see the property of the transformer later on today itself. So, we are having the transformers at the rectification end and also, we are having the transformer at your inverter ends. Apart from that, we are having the filters as you know, the use of filters to filter out the harmonics and these filters also, at the same time provide the reactive power support at the fundamental frequency, they are filtering out the harmonics at the various may be fifth and seventh or eleventh and thirteenth harmonics, but at the same time they provide the reactive power support to this station at the fundamental frequency that will be also, proved later on.

Apart from that, we are using here the smoothing reactors, to reduce the DC current triple in the DC transmission system and here this is no doubt, we are having the transmission line that is, a DC lines apart from that here, if you are using the ground as a path, if one terminal here this is a basically bipolar operation is there so, if you are using one terminal only then ground will be used as the return path. So, we require the grounding rods to provide the path so, that will be also, discussed today.

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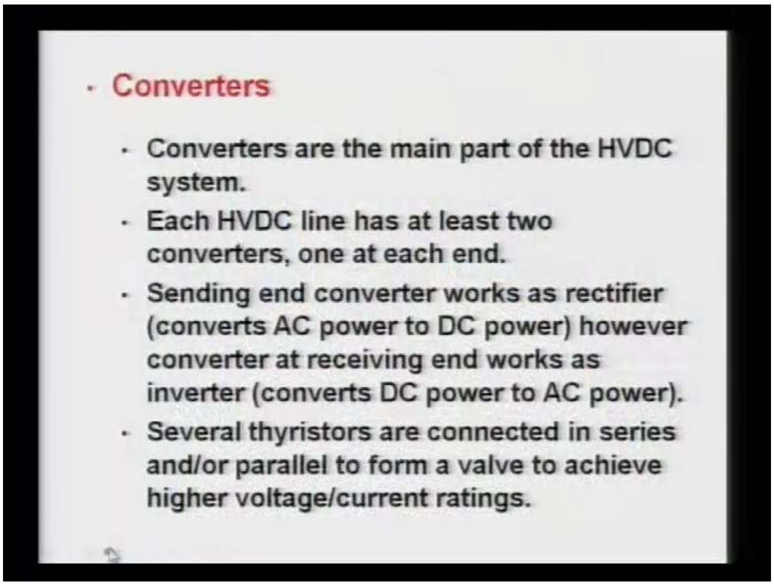


Now, let us, first start your converters the here as I said the converters are the main part of HVDC system and each HVDC transmission system has at least two converters one at each end so, it is called the two terminal HVDC. If you are having the three terminals HVDC then you require the three converters so, the sending end converters basically work as a rectifier from AC to DC power. It converts and however the converter at receiving end works as your inverter means it converts the DC power to AC power.

But here in actual operation, it is very difficult to say which converter is working as a rectifier which is a inverter because if it is only power is flowing then only you can say that this is a rectification, this is inversion but this rectifier can work as inverter and this inverter can work as rectifier if the reversal of the power is required. So, means that is, why here we are calling is a converter rather than inverter and the rectification converter means it can operate in rectification mode as well as the inverter mode.

We know, this converter here basically it is a different type of converter configurations are possible and several thyristors are connected in series and parallel, to provide the reasonable voltage and normally, if you are connecting so, many thyristors in parallel and series here normally in this course, I will refer as a valve. Valve is nothing as switching device we are just consisting of thyristors they are connector either in parallel or in series to provide the voltage and the current ratings.

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Table: Comparison of power semiconductor devices

| | Thyris-tor | GTO | IGBT | SI* thyristor | MCT | MOSFET |
|---|---|---|---|---|---|---|
| Max. voltage rating (V) | 8000 | 6000 | 1700 | 2500 | 3000 | 1000 |
| Max. current rating (A) | 4000 | 6000 | 800 | 800 | 400 | 100 |
| Voltage blocking | Sym./ Asym. | Sym./ Asym. | Asym. | Asym. | Sym./ Asym | Asym. |
| Gating | Pulse | Current | Voltage | Current | Voltage | Voltage |
| Conduction drop (V) | 1.2 | 2.5 | 3 | 4 | 1.2 | Resistive |
| Switching frequency (kHz) | 1 | 5 | 20 | 20 | 20 | 100 |
| Development target max. voltage rating (kV) | 10 | 10 | 3.5 | 5 | 5 | 2 |
| Development target max. current rating (kA) | 8 | 8 | 2 | 2 | 2 | 0.2 |

* SI: Static induction, MOSFET: MOS field effect transistor

Now, you know, the simple single thyristors are GTO here this table shows that the various switching device that is, a power electronics as semiconductor devices including thyristors GTO S IGBT SI thyristors normally it is known as the static induction thruster MCT and your MOSFETS. Now, you can see although this table is not very lightest but still you can see the maximum voltage rating available for a single thruster unit is 8 kV and it can handle almost 4004 kilo ampere current similarly, if you'll see the GTO s it is less than here but current rating more IGBT s also, it is less and others are still having the less voltage as well as the current rating.

This shows that is, voltage blocking whether, it is symmetrical and unsymmetrical also, the gating what is pulse or current or continuous mode voltage and current it is given the conduction drop across each individual unit. It is here it is also, written in the voltage the switching frequency is even though thyristors conventional thyristors may go up to 1 kilo hertz even though your GTOS it is 2.5 and IGBT S even though higher. It is we can go for 3.5 20 kilo hertz but it is also, expected that we can achieve these devices up to even though thruster can go up to 10 kilovolt even though GTO S also, can be available for the 10 kilovolt and research are going on and we may expect in the future all these things.

But still it is single thruster is not sufficient to provide the complete rating of the HVDC transmission system, because we are talking high voltage means we have to go for the various individual units they should be connected in series and parallel to give your complete power capability that is, required for the HVDC system. Even though sometimes we will see the requirement voltage for a system let us, suppose you are talking about the monopolar operation.

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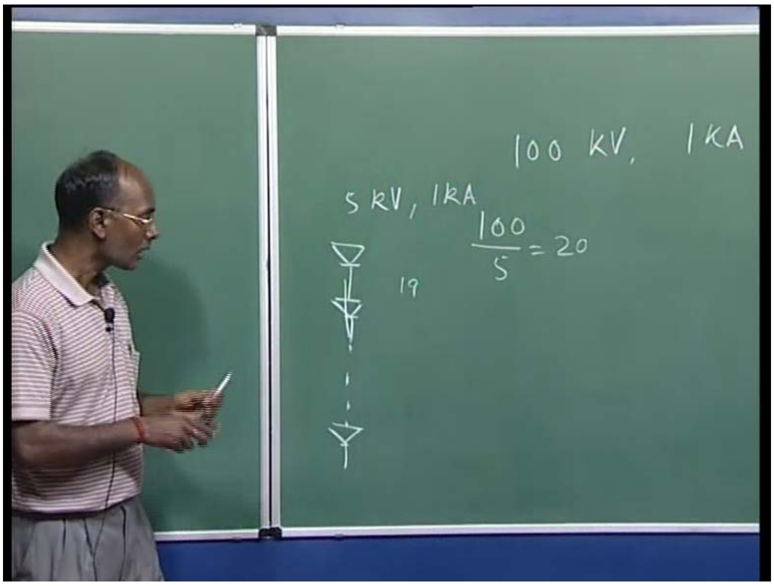


We require 100 kilovolt systems consisting of 1 kilo ampere here current this converter configuration means power is here your 100 mega watt. The required unit let us, suppose one thruster it is your 5 kilo kilovolt is required, we should always go for more and more more than here what is required suppose we are adding here if we will divide by this it shows that 100 divided by 5. It shows that you require 20 thyristors they should be connected in series this thruster let us, suppose it is having 1 kilo ampere but that is, also, not sufficient what we have to do this rating is no doubt is same but sometimes if 1 thruster fails then we should have some other so, that it can take care of because it is not possible to take out the converters every time from the service and maintain it.

So, what happens even though one for example, if you will see here the 20 we are just connecting here 20 and here you can say even though one converter here the thruster fails failing means, what normally it becomes puncture. So, what happens if you are using 20 here in series now, if one get puncture now, you are having only nineteen what will happen all will be punctured because that that cannot be your the voltage which is required for this 100 10 100 kilovolt.

So, what we do we go for the some safety margin, so, we go from more than the 20 required here also, it is one kilo ampere means we have to go for the parallel to give more capability. So, we have to go for to increase or to provide the converter configuration we have to go for large number of series and parallel combination normally to increase the current rating we have to go for the parallel as you know, if you are going to increase the voltage rating. You have to go for the series thyristors or GTO s and then you can have the combination of all these to give the required rating of the converters sometimes it is not only valve we can have the converters in series means we can have all the six-pulse converters we can have in series that can also, increase the voltage capability as well as the current capability.

So, that is, why here it is written if you want to increase the current capability of the converter station, then you can options are you can increase the valves in the parallel thyristors in parallel. Now, the question arise what is the difference between thyristor and valves. As I said the valves are combination of several thyristors, it is not only one thyristors while I am talking so, many thyristors and your they are series and parallel and we are making one box like this. So, the either you can make the valves in parallel or you can make the thyristors in parallel or you can go for the bridges in the parallel or you can have the combination of all these.

Similarly, if you are going for the voltage rating of converter station then you have to increase the valves or the bridges or the combination of these to make required voltage capability of this converter.

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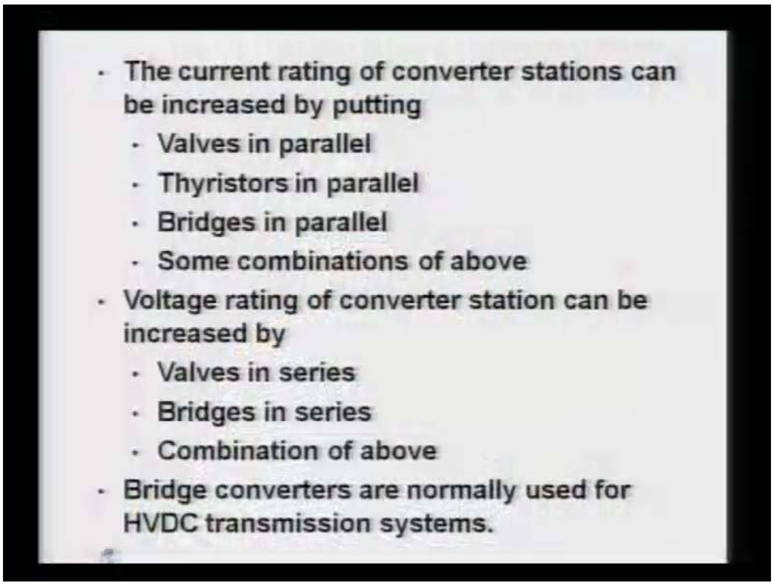


Normally, the bridge converters are used for HVDC transmission system and we will proof and we will see in the next lecture how? Why we are using the bridge converters? What is the capability? What are the major features are required for the converters? We will examine and we will find the bridge converter is suitable for HVDC systems.

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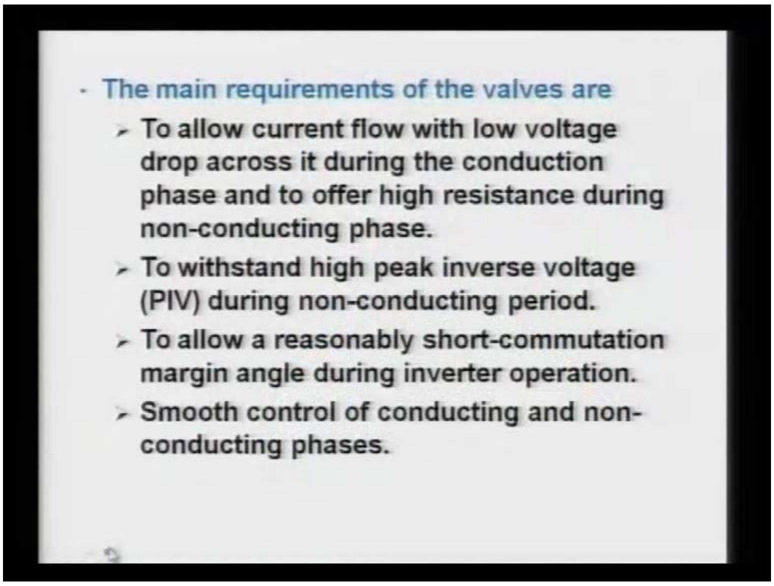

So, that is, why here I have summarized the main requirement of valves are that as you know, it is a main require means it is main requirement of the switching any switching circuit any switching device. So, once it is conducting, it must allow the current flow with the low voltage, drop across it during the conduction phase and it should offer the high resistance or impedance during the non-conducting phase, this is just like it should behave like a ideal switch. If switch is closed it should offer the minimum impedance and if it is opened it should offer the infinite impedance.

Another requirement is that it should withstand the high peak inverse voltage during the non-conducting phase, if you are making the converter as you know, there may be the various types of converter conduction modes. It may be two valve conduction it may be 3 valve conduction it may be 4 valve conduction again we will see how these boards of operation or conduction of the valves or converters are coming up.

So, in during that time if the two are working the remaining will experience the reverse voltage and it should have the peak inverse voltage capability otherwise, what will happen the this thyristors or your valve may get get damaged. Another capability require that it should allow a reasonably short-commutation margin angle during the inverter operation this commutation margin angle also, we will see when we will analyze the inverter operation that that is, required for proper this off of the converter or you can say valves during the inverter operation, otherwise what will happen there will be commutation failure and if commutation failure occurs means they are so, many harmonics are going to be generated in the system.

Another requirement that there should be smooth control of conducting and non-conducting phases. phases Here again build the 3-phases we will see the from the conduction from one phase to another phase, it should be very smooth transition from one phase to another phase it should not be abrupt. If it is abrupt there is also, there are so, many transient so, many other things will arise and that may lead to a failure of your converters.

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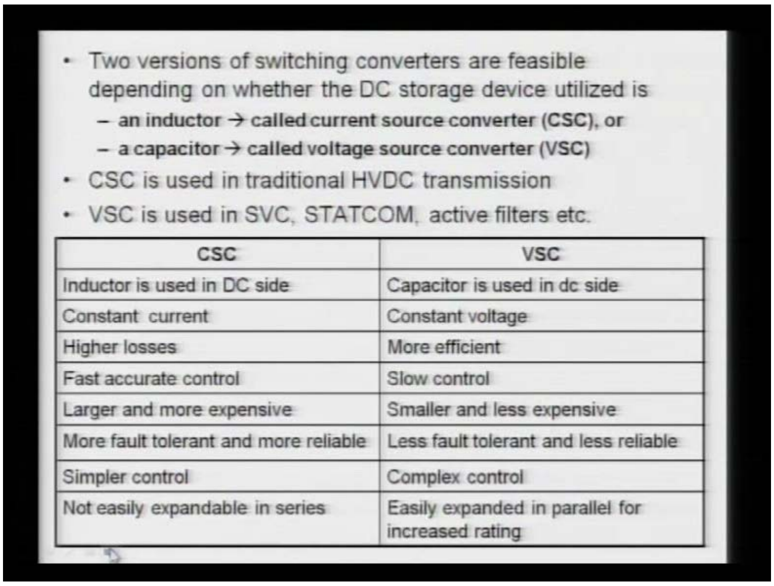


Let us, see here you know, there is a two type of converters in terms of your storage device which is used normally we can say the current source converters and the voltage source converters in the current source converters basically we use the inductors and here in the voltage source converter we use the capacitors normally they are treated as the CSC and the VSC but here in HVDC application we use the CSC however, the voltage source converters are used for the SVC and the statcom applications even though for active filters also let us, compare this CSC and the VSC in the CSC. Here I think I should explain here this as I said at its name that here current source converter means current is constant we are dealing with the current. So, here inductor is used in the DC side however, here the capacitor is used in the DC side this is in the CSC mode, we operate the constant current mode means current is normally kept constant however here the voltage is constant of the DC side.

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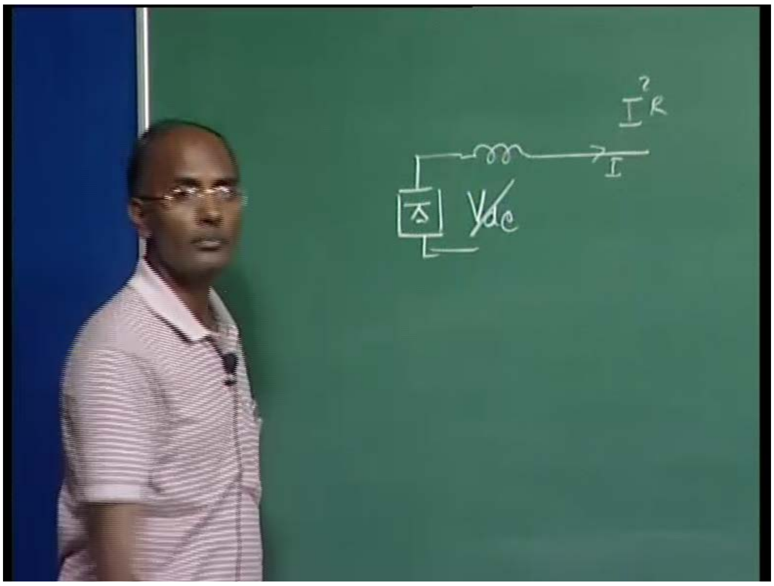


The CSC is giving more loss the reason is that even though what happens for example, here the current is always constant. Even though, you are changing the voltage your I square R loss will be the always same and it will be the highest however, here you are changing the current and voltage is constant. So, I square R loss will be changing means depending upon your loading of the system this current is changing means your loss is also, changing.

However, here the current is always constant and that is, why I square R is always higher in the current source converters, this is the fast and accurate control is possible but this control is slow due to the capacitor because the capacitor here, the always you cannot due to the capacitor basically the control becomes slightly slower here but this is large and expensive because you require the smoothing reactors and reactor size we will see it is very very large and it is very expensive compared to the capacitor. This is expensive and the large this is smaller and the less because capacitor you can have even though higher rating with the smaller size.

This is a more fault tolerant and more reliable here it says that the VSC is not so, much is less tolerant and the less reliable but the control here, the of CSC is the simpler compared to the control of this 1. It is a complex control or is required in the voltage so, and it is not easily expandable in series but you can expand here because voltage you can add it here the current is constant so, you cannot add in series that is, the difficulty.

So, if you will compare here and there it is very difficult to say which one we are going to use but normally in HVDC we use the current source converter the reason is that here normally we want the huge power transfer from one end to another end and we keep the current here constant if you are going for the current constant controller here. So, we have to go for your inductor and your converter here which we are using that will be the VDC here basically it is controlled however in the VSC this is a constant and current is controlled.

So, in HVDC system we go for the CSC and it is we will see the controller becomes very very simple and that is, why the current source converters are used we will again analyze detail about this converters. Here we will see and then we just go for this switching circuit will be modeled as the uh equivalent electrical circuit.

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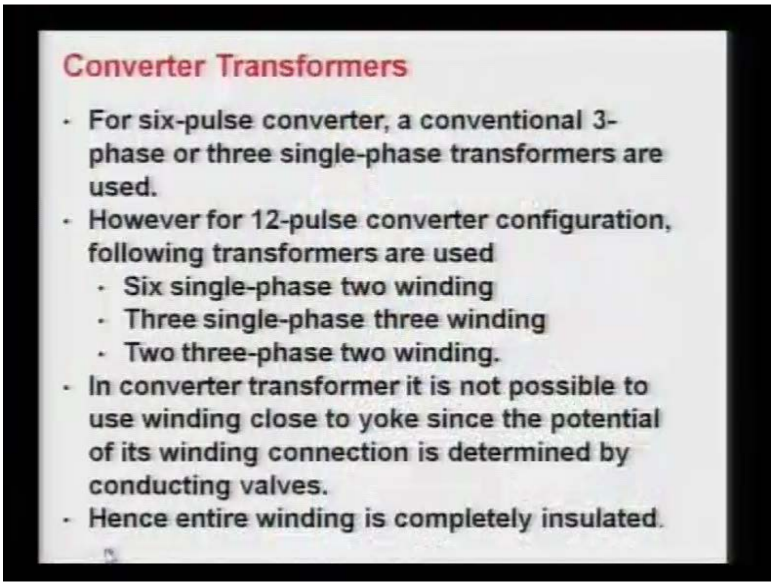


Now, let us, go to another important element in HVDC transmission is your converter transformer, here we call it the converter transformer because it is very near to the converter and this is a not a normal transformer it is a especially made converter transformers are used because it should have a some features especially if you will see this converter transformer there are so, many if you are switching any device there are so, many transients are generated. So, many harmonics are generated that is, passing through this converter transformer and that is, why this transformer should made of a special so, that it should not get damaged it should operate satisfactorily and also, we will see these transformers require on-line load tapping changing the OLTC options should be there.

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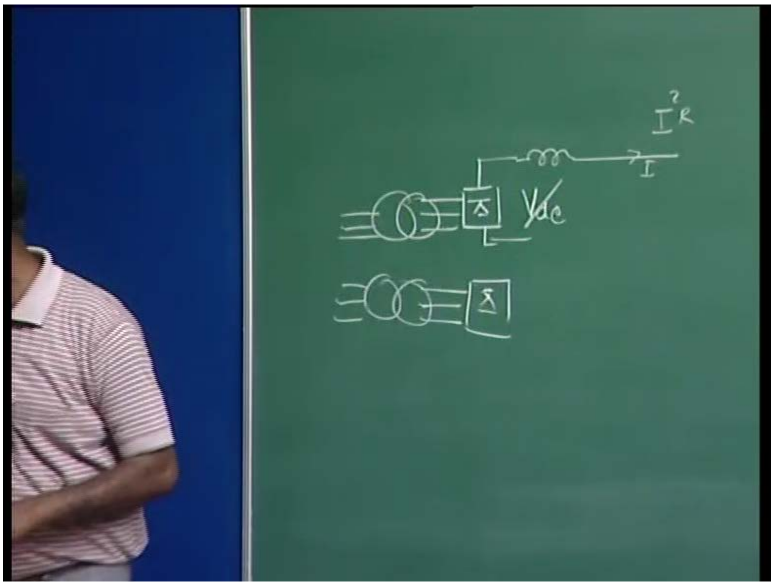

Means on load or on-line tap changing transformers means there tapings that keep on changing very frequently here. So, for a six-pulse converter a conventional 3-phase or 3 single-phase transformers can be used because if you are having the 3-phases for example, here we are having 3-phases that should be basically a transformer here that is, a 3-phases so, either you can use a single transformer of 3-phase or you can have a 3 transformers of single phases you can also, use.

In the 12-pulse converter configuration the following transformers are used you can use for each here the phases here the 3. Now, now, we are going to have another pulse here means here three now, we can have this one for each so, we require six single-phase two winding transformer because this is a two winding this is 6-pulse this is 6-pulse is going to add it with the some shape. So, we require here either six transformers of the two winding or we can have the three single-phase transformer of the three winding transformer or the reverse is also, true or we can go for the 2 3-phase two winding transformer means here you can say we are using 2 3-phase transformer with the two winding means this is a primary and secondary primary and secondary.

So, in converter transformer as it is in here is not possible to use the winding close to yoke since the potential of it is winding connection is determined by the conducting valves means here all the windings, even though if you are very near to yoke or very near to your core are surrounding they can be withstand very high voltage because someone if one conductor is one valve pair of valve is conducting other valves are experiencing some voltage and that voltage can be reflected back to the transformer winding.

So, huge voltage is appearing across the winding so, all the windings must be properly insulated and it should withstand, the complete voltage we will see when we will talk about the voltages of these valves, then it will be clear that, what much how much voltages they are experiencing during the conducting phase and during the non-conducting phase as well.

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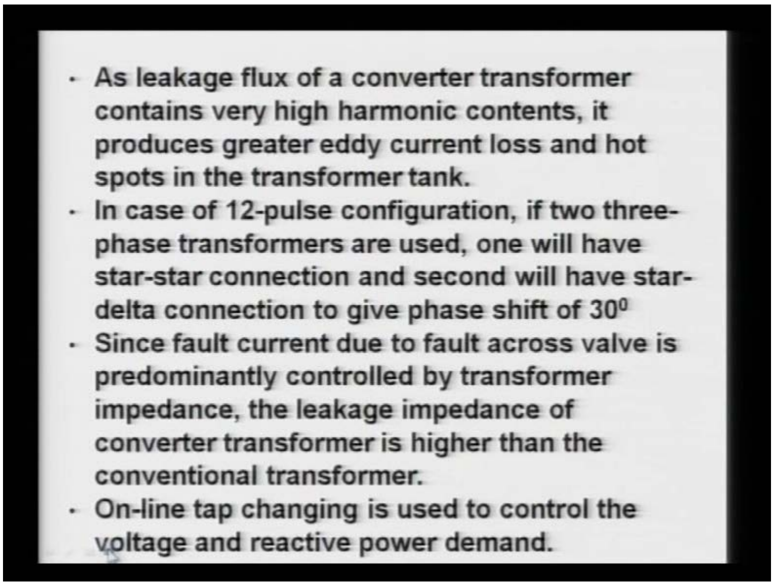


So, as a leakage flux of a converter transformer contains very high harmonics contents, it produces great eddy current loss and hot spots in the transformer here as we will see due to the switching of the converter valves there is so, many transients and harmonics are intervening with the transformer so, there is a huge and they are of high harmonics component.

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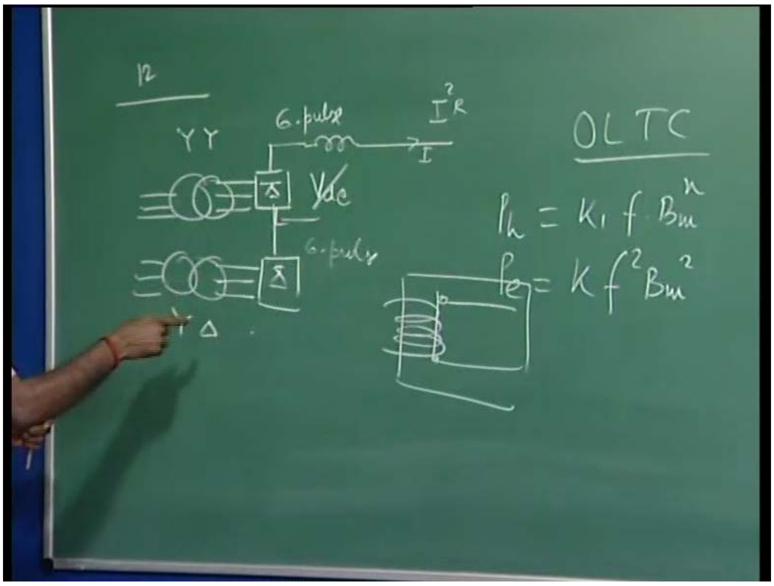


So, you know, the eddy current eddy current and your core loss here this hysteresis and your eddy current loss here some constant it is f square B m square here you must be knowing this is here K 1 f into B m k power n n is normally 1.6 so, they are related with the frequency if you are going for more frequency harmonics are there so, more loss will be there and more loss so, more heat dissipation is required and there is a possibility that hot spot hot spot is nothing but if your here the transformer is there and you are having windings there is at the core ends here there is more flux is flowing there is a there is a some sort of here puncture or some sort of hot spot will occur in the transformer winding in a course.

Now, for the 12-pulse here if you are using the two transformers then if you are using this is your star-star transformer, this transformer should be star delta what it happens with this you are getting here the bridge converter it is giving 6 -pulse this is also, giving your 6 -pulse individually if you are connecting here with this transformer what happens this six-pulse is going to be shifted by the 30 degree due to this transformer winding and thereby you will get your 12-pulse operation 12-pulse means there is a pulses in one cycle so,6 -pulse means in one cycle you are getting 6 pulses.

So, here if you are using the two transformers and going for the 12-pulse you must use here star-star and star delta means you have to shift the 30 degree so, that you can get the 12-pulse operation another here since the fault current due to fault across the valve is predominantly controlled by the transformer impedance that is, why the leakage here impedance of the converter transformers are made higher than the conventional transformer.

In the normal transformer normally we try to minimize the reactance because if your reactance is more then the power flow in that line will be less as you know, here,

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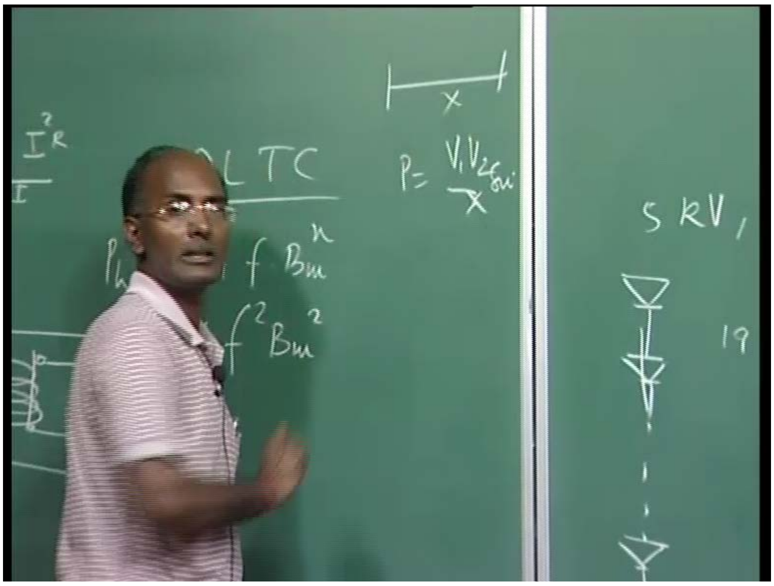


If you are having the two elements it is your X you know, this power flow from here to here it is a V 1, V 2 over X sine delta we try to minimize here in the conventional transformer but here we intensely make go for the more leakage impedance because this transformer is something going to wrong here or some fault is there.

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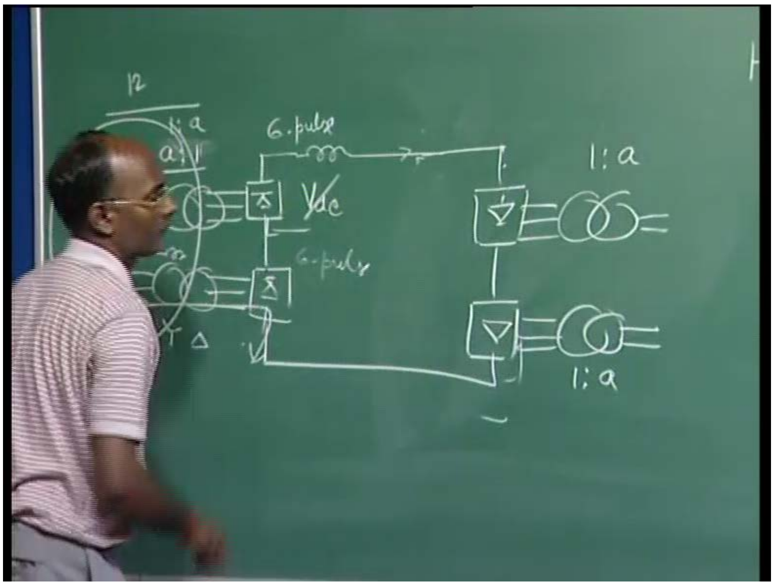


The whole current will be going to flow here because there is no resistance in the circuit and if only the inductance is there so, normally we go for more leakage reactance so, that at least it can limit the current and thereby of course, the control action will come into the picture and finally, it will try to open this converter finally, the current can be stopped. Another feature of the transformer is here your on-line tap changers are used here what we do the on-line tap changers means you know, the tapings of one of the side of the transformer is keep on varying.

You know, there is two types of tap changer are available one is your one is your offload tap changers and another is your on load tap changer. Offload tap changers are once you have to take it out and then you have to change the tapings and then you can put it into the service however in the on load tap changers it should be automatically kept on changing during the operation and we go for the special arrangement so, that if you are changing from one position to another position in the winding there should not be any spark so, we made some special arrangement, so, that the voltage change from 1 to 1step it should not be very abrupt and thereby a special mechanism is used and that is, why it is expensive.

And in this case it is so, frequently used because your controller always try to see to change this event because here the controllers we are using it will be that to change the voltage it will be changing here if this is exhausted it will try to change here so, it is so, frequently changed because this a is changed.

Normally you will see this a I am not writing a 1 this is to a the representation you know, it is made in the one of the side but we are representing in this side because we will see this E A should come in the AC side and then we can go for the Y bus another things that is, coming in the Y bus path here this one is appearing because this variable is changing so, intensely here it is 1 to A it will be will be written and we will see when we will talk about the AC DC load flow why we are making a is to 1.

Similarly, we are also, going this side also, means another side that is, your inverter side because the same transformers are used and it is your this is your inverter and here it is here we are writing 1 1 is to a similarly, if it is 12-pulse. So, we are having another transformer three windings and it is also, one is to a so, on-line changers are used so, that we can control these valves these HVDC systems very efficiently.

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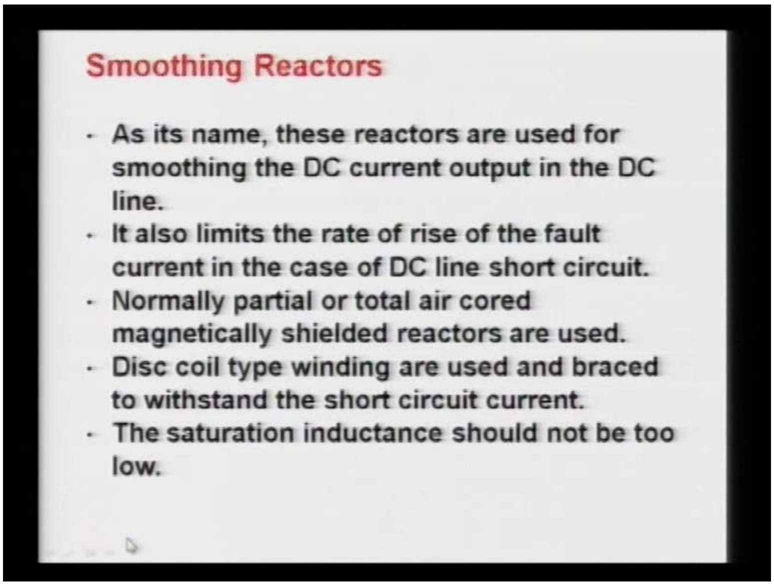


Another even though this tap changers can be used to provide the reactive power support you know, the changing of your A, it means that you are changing the reactive power from one end to another end.

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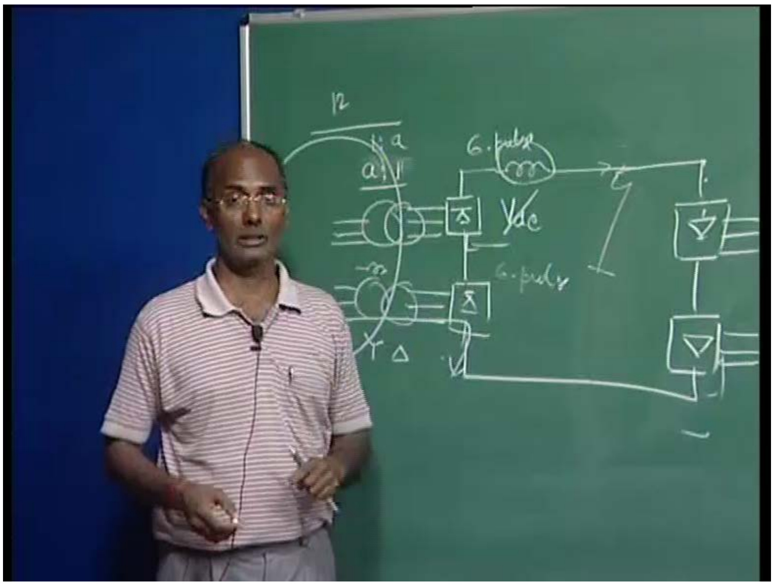

Another important that is, a component of HVDC system is that just we have to go for the smoothing reactor this reactor is used to reduce the ripples of the DC current that is, flowing in the transmission line. So, as it is name here it is written these reactors are used for smoothing the DC current ripples output in the DC line it also, limits the rate of rise of fault current in case of DC line short circuit means if here there is some fault from this voltage to ground so, this inductor will come into the picture and this current rise will be not so, fast and it will try to limit it and due to this limitation.

The current will rise of course, because this will work as a short circuit in the steady state but by that time the converter control will take action because it will see the more current is flowing and it will try to operate this valve in a such fashion to reduce the current here, but in the beginning it is required. So, this smoothing reactor is also, providing some sort of safety for the fault current which is happening from line to ground or line to line. So, a special type of reactors are used normally the partial or total air cored magnetically shielded reactors are used even though sometimes the disc coil type of winding are used and the braced to withstand the high short circuit current because this current will be very very high and that is, why it should withstand otherwise it will be damaged.

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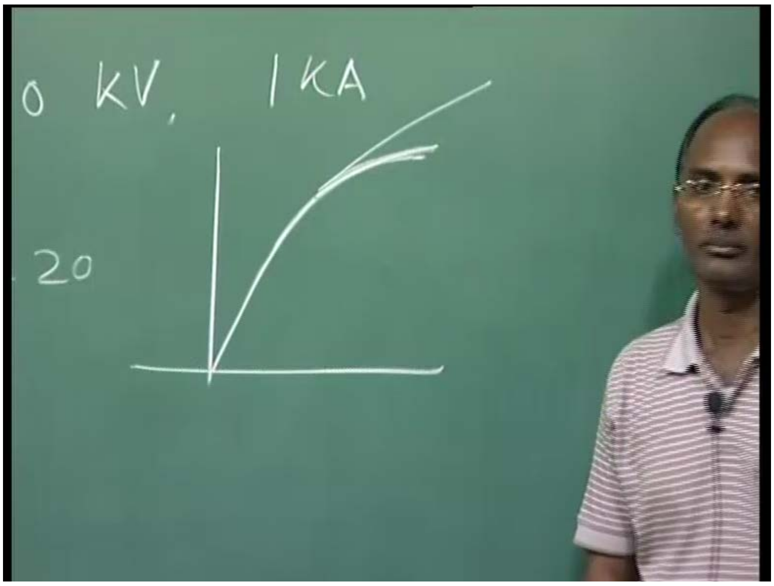


Another option here we made you know, the transformer saturation because if you will see here you know, the saturation here curve now, this zone we just we go for the longer one so, that is, the saturation reactance saturation inductance should not be too low means this flow should be normally here.

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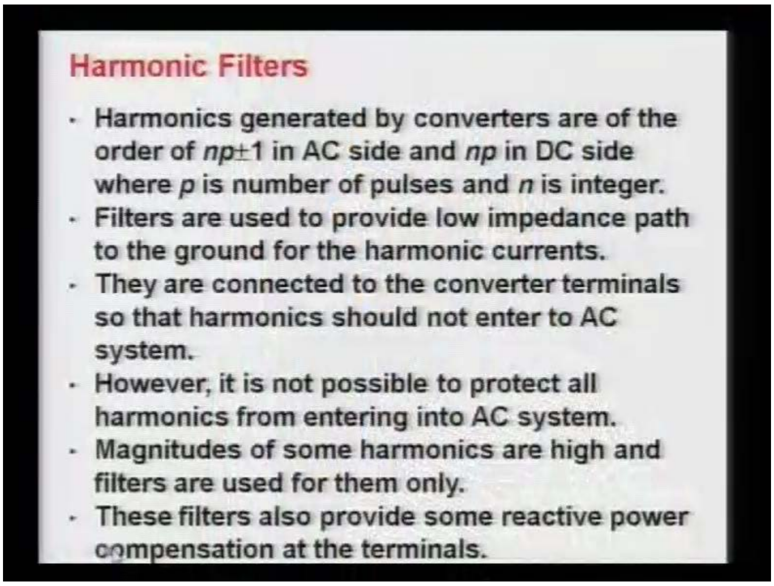


Now, another component that is, we will see is harmonic filters even though we can go for the various type of pulse with modulated control, but still we cannot avoid the harmonics generation by the converter circuit it will generate the harmonics to the system and if you will you are using the conventional thyristors.

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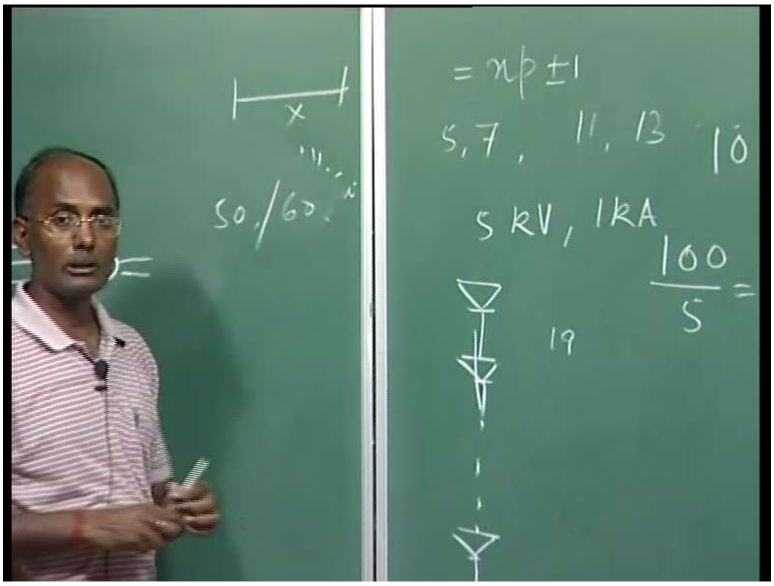


And we will see and we will analyze that the characteristic harmonics will be your n p plus minus 1 will be the characteristic harmonics where n is integer so, far and p is a number of pulses.

If you are operating the 6-pulse converter means you are using only this one half of this so, we are going to have the our harmonics is 5th and 7th 11th and 13th and so, on magnitude of the 5th and 7th will be completely higher compared to other harmonics and then we have to provide the minimum impedance for this type of currents that it should be grounded. So, the harmonic filters are basically provided the low impedance path to the ground for the harmonics for which it is designed..

Now, you know, the two type of filters are there again we will discuss the more filter design later on in this course but the two type of filters are available one is called the tune filters, another is a band pass filters. So, here normally we use the tune filters for the specific components here here here and then we put in the system. So, an extra advantage of putting the filter here of the tune because this tune filters they will be providing the minimum impedance for which they are designed but at the fundamental frequency that is, your 50 hertz or 60 hertz.

It will provide the reactive power support that will be required to the your your converters so, the filters that is, why here it is they are connected to the converter terminals. So, that harmonics should not enter to the your AC system normally this converters the filters are basically used here this is your bus bar we normally use the filters here we are not using the filters here we are using the filters here and this transformers are basically prone to bear the harmonics current here.

So, it is not possible as it is written it is not possible to prevent or to protect all the harmonics entering from the DC side to AC side it is not possible because we are having large number of harmonics, but their magnitudes are very very less and thereby we can ignore and that can be allowed to the system that flow in the system. Sometimes here the these are the frequencies other than these frequencies may also, present in the system and those are called the non characteristic harmonics that due to the overlapping of the valve conductions we will see it is not only this we are going to having some intermediate frequencies as well and thereby we should also, protect but it is a very very difficult and that magnitude is very less.

So, we go for these because these are having the line share the highest magnitude and we try to put the filters for only the limited number of harmonics here as you know, if you are going for the large frequencies are increasing and going to put the filters for that the size of filter of here it will be lesser compared to here in 13 again due to the l and c combination for the tuning of those components. So, as I said here these filters are also, providing the reactive power support at the fundamental frequency that is, required for the smooth operation of HVDC link.

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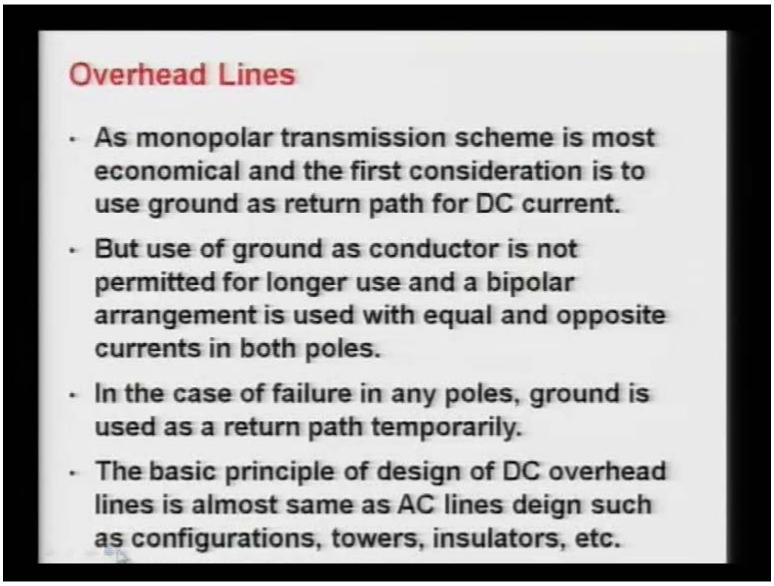


Another component is your this overhead line basically this design difference in the line here for the AC and DC is not much different we use the conventional conductor itself and here these lines are designed and operating on the actual voltage however, your the transmission line for the AC system it is we are designing for the peak voltages because here we are talking about the average the DC is the constant.

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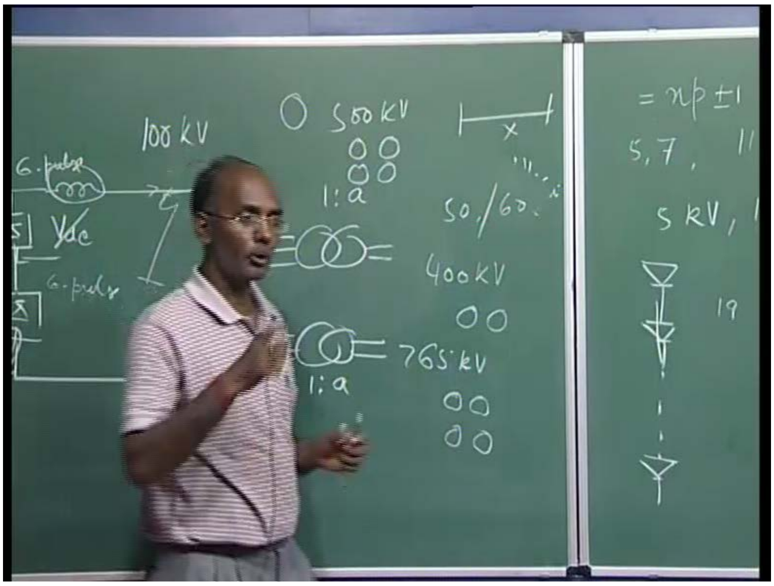


Suppose you are talking here is your 100 kilovolt this line will be the end for the 100 kilovolt only but if it is AC system then 100 kilovolt AC system means it is 100 multiplied by under root 2 it should be operating. So, the design should be almost same only just we have to see how many conductors are required if you are using bipolar operation then the two conductors will be going if it is a monopolar operation you require only one conductor and if even though you are going for homopolar you require two conductors and they are going on the same tower.

Again in this case also, you'll find the it is not a single conductor we go for the bundle conductors also, if you are going for higher and higher voltage if you are going for lower voltage may be 100 kV a single conductor is sufficient if you are going for 400 and 500 kilovolt system even though either AC or DC you have to go for the bundle conductors In normal practice we will find if you are going for more than 400 or 400 kV system you have to go for the two conductors if you are going for even though 6 7 65 kV system you will find here four conductors this I am talking about the AC system

In India we have the 500 kV system and then we are going for the four conductors four bundle conductors they are operating at the same potential means for 500 kV system here

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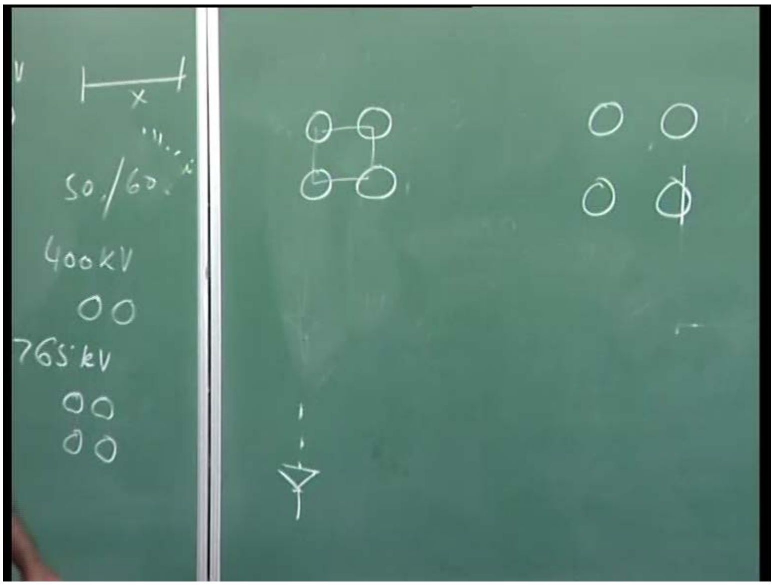


You are going for one pole it is your four conductors and you are having another that is, here that is, you are having the four conductors so, you are having all these are connected bundles means they are connected at the regular intervals means they are operating at the you can say go conductors. So, another is your return conductor you can say we are using the bundle conductor is advantage you know, because they reduce the corona loss because if you are going for higher voltage the corona loss will be very significant so, we are going for the bundling here so, that we can reduce the corona loss and thereby we go for this.

However if you are going for AC here you know, it also, changes the inductance and capacitances that is, very much required for the surge impedance loading of the conductors so, in the monopolar operation the transmission scheme is the most economical and the first consideration is to use the ground as a return path for the DC current.

If you are using only monopolar then you require one pole and ground will be used as the return path but use of ground as a conductor is not permitted for the longer duration as I said here in the monopolar operation as I said the current will be flowing through the here ground but it is not allowed for the longer duration due to the several reasons for example, that that will be there will be some corrosion there will be some problem of you can say radio interference and so, many other problems will be occurring.

So, the bipolar or homopolar operation bipolar operation are very very common and feasible for the HVDC transmission only normally in the bipolar operation. If one poles fail then the ground can be used as a return path for the temporary purpose the basic principle of design of DC overhead lines is almost the same as AC lines designs such as a configuration tower insulators everything will be same only we have to see the voltage that is, peak voltage in DC the peak voltage is equal to its operating voltage however in this AC it will be under two times of rms voltage.

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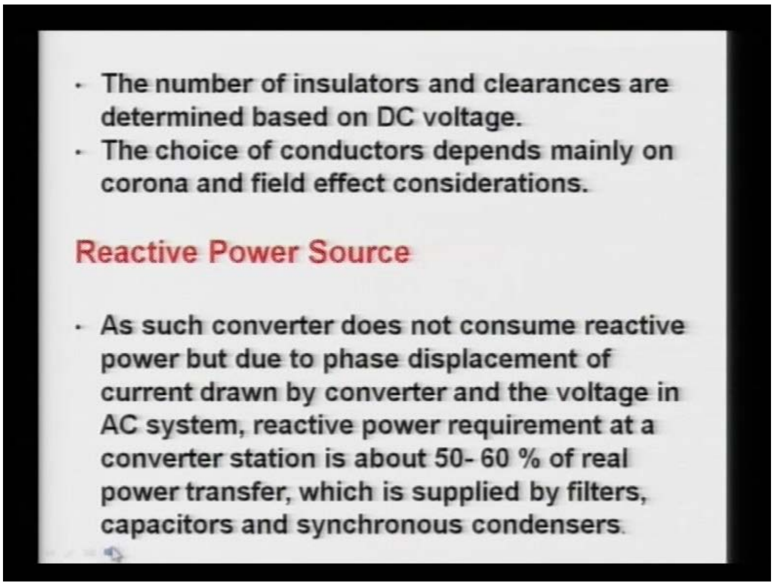


Number of insulators the clearance etcetera are required based on the DC voltage where where in AC it is required on the peak voltage choice of the conductors depends mainly on the corona and the effect of and the field effect consideration and that is, why if you will see here if you are passing from Kanpur to Delhi you will find the two conductors are on very huge towers having the four-four conductors bundle it is passing and that is, basically rihand dadri HVDC line.

Another component is your reactive power source so, the reactive power source is required in HVDC link basically at the terminal stations as we know, the converter does not consume the reactive power but due to the phase displacement, current drawn by the converter and the voltage in the AC system the reactive power requirement will be there and it is a normally it is 50-60 percent of the real power transfer over the transmission line and it should it is normally provided by the filters capacitors and the synchronous condensers.

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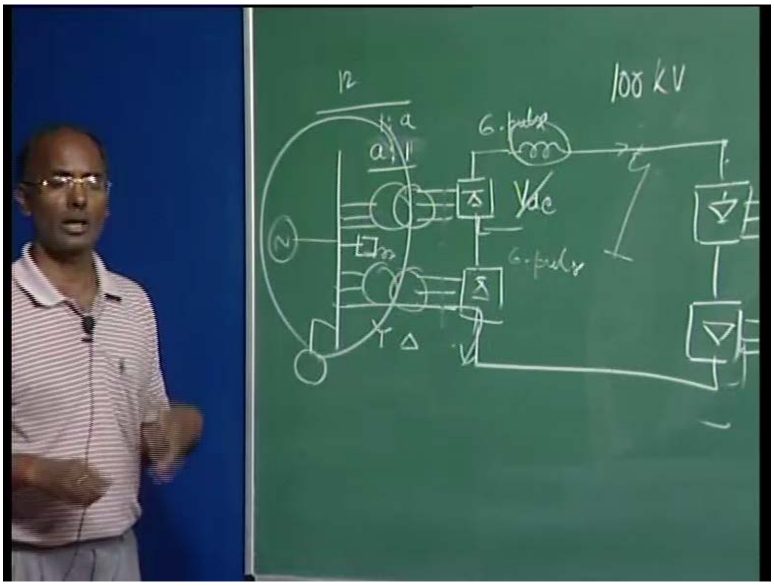

Sometimes even though your HVDC link is very near to the generating station so, generators are also, capable of providing even though if HVDC link is very near to your generating station. Here then reactive power support provided by this filter here the generator can also, provide the reactive power support supports whenever, required and also, sometime we use the synchronous condenser if the generators are not there or you can use the capacitor banks normally if it is in the load centers mid of this load centers we have to go for the rest of banks normally it is preferable because the synchronous condensers are expensive.

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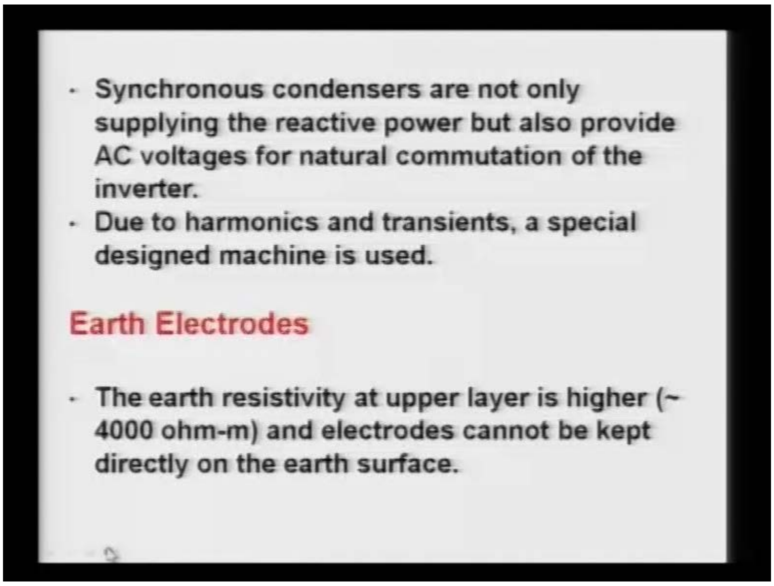

Sometimes the synchronous with mild synchronous condensers are used basically, it is not only providing the reactive power support but it provide the sinusoidal voltage that is, used for the using the for your converter circuit so, for it is basically for providing the natural commutation of the inverters.

Now, due to the harmonics and the transient a special designed of the machine even though synchronous condensers are used and the capacitors, we are using that they should also, withstand, the so, many the transients, so, many harmonics that may also, enter into the system other than what is they are designed for another component here is earth electrode as I said this ground is not used normally it is not used for the flowing the current but during the emergency condition. We have to use the ground as the return path for the conductor so, what happens? we have to use the grounding rods because the surface your as I said the earth sensitivity at the upper level is higher and normally it is 4000 ohm per meter ohm meter and we cannot put the conductor or we cannot just connect here earth and the current will flow.

So, we have to find where this resistivity is minimum, so, that the resistance offer will be minimum and the current should flow. So, that is, why here it is written the electrodes cannot be kept on this earth and it will be used for the return path.

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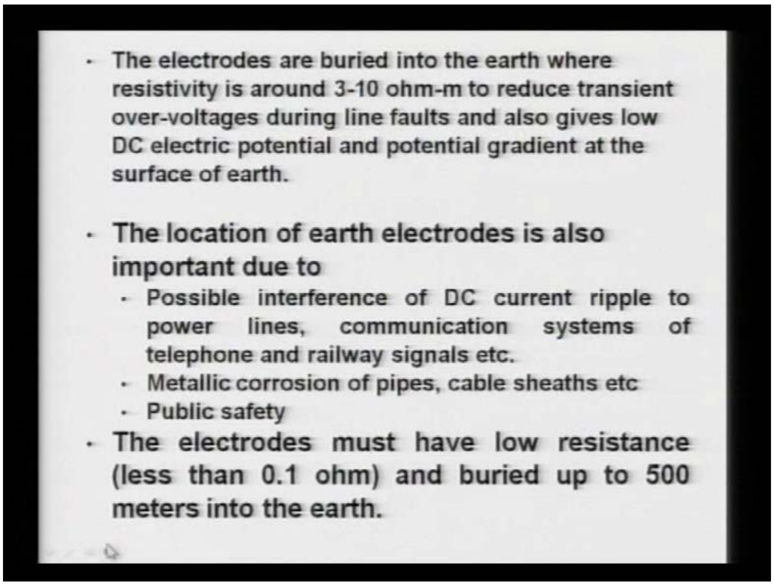


Electrodes are buried basically into the earth, where the resistivity is around to 3-10 as I said on the surface it is approximately it is varying from soil to soil area to area and again it depends upon. So, many weather and geographically configuration meteorologically and geographically locations but it is around the 4000 with the surface and if you are going deeper and deeper you will find the resistivity is from 3-10 ohm meter and so, we have to bury our conductors so, that we can get this resistivity.

To reduce basically, the transient over voltage during the line faults and also, it gives the low direct electric potential and also, even though potential gradient at the surface of earth. So, the location of earth electrodes is also, important due to the possible interference of the DC current ripples to the power lines communication system of the telephones and the railway signal as well.

What happens? Even though your current which is following if it is not very buried inside it is on the you can say upper surface, then the current which is having some ripples that will interfere to your communications system. Even though this overhead transmission line is very far far away from the communication system but the ground current which is flowing it may pass some communication system, it may pass to the railway signal and et cetera so, it is important to go for deeper so, that it should not interfere to other systems as well.

Even though sometimes it also, gives the corrosion as, I discussed yesterday also, this metallic corrosion of the pipes and the cable sheath can also, be one of the concern another major concern is the public safety. If you are putting on this it is not deeply ground it is not properly ground then, what will happen there will be huge potential and that may give the shock to the working working people or may be other peoples. So, the electrode must have the low resistance it should have a normally it should be less than point one ohm and buried up to 500 meter into the earth so, you can see it is 500 meter it is buried and even though if we put so, many other chemicals so, that we can reduce the resistance and that is, why the resistance to the current flow should be as minimum as possible.

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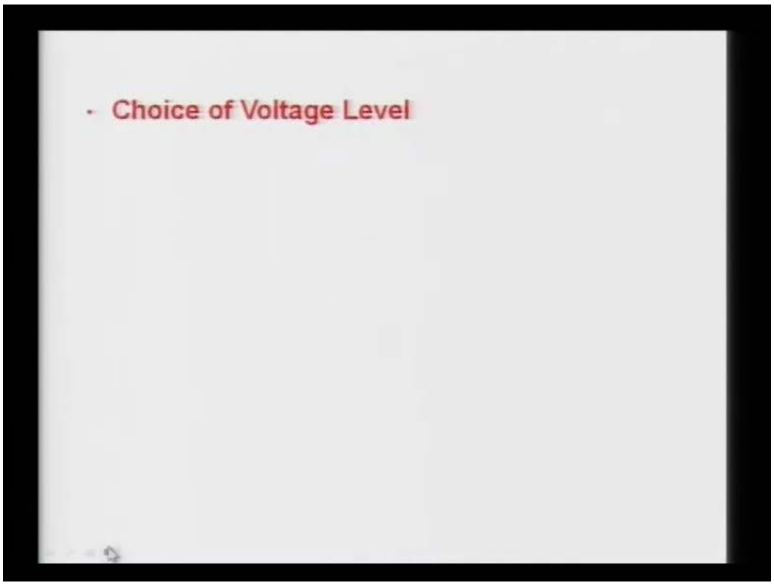


Another configuration is you are the choice of voltage how will you decide that which voltage level you have to go for.

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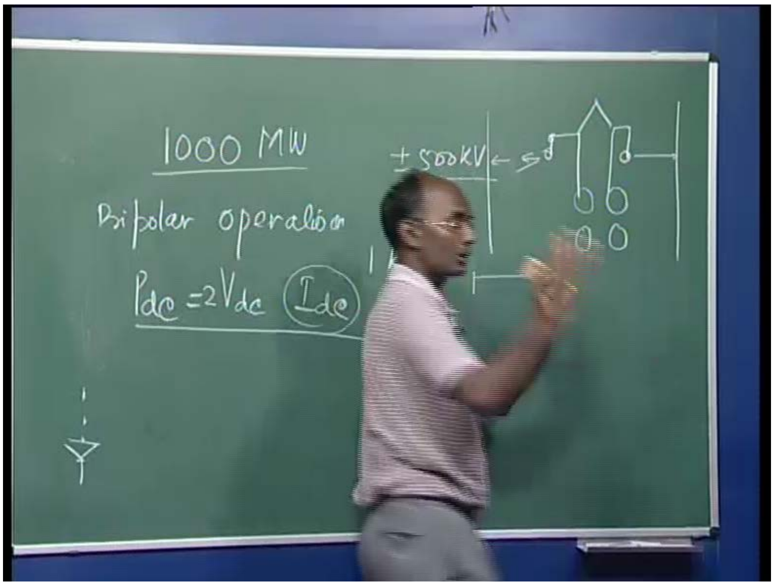


Because suppose it is given to you that, I want to go for one 1000 mega watt mega watt power to flow and it is also, decided that we have to go for the bipolar bipolar operation. Now, it is to decide what will be the your voltage level now, you know, the power is given to you and this power means it is the rated power is a steady state power that you can flow without any problem means you have the P dc here and you know, this P dc your V dc and then your I dc. The V dc shows if it is a bipolar then you know, here thus it will be multiplied by two because here we are talking this V dc of one pole here so, this is another is your this V dc. So, I the current which is flowing the wire this two are going to be added because one is positive another negative and then it is a twice of the V d c.

Now, we have to now, decide the current rating thus we have to see what will be the size of your conductor the conductor size are very standard in the region. They are very standards means, we have to see it is and you know, the conductors name that is, used in our country and Asia and Europe it is the name of all animals like, we use the dog, panther, zebra, moose, squirrel all these names of the conductors and they have a specific size and they are used. So, we have to see how much current that conductor can bear so, based on that once current is decided now, finally, for this power we can decide the voltage.

So, this current if suppose you are going for one kilo ampere then this V dc here is going to be 500 and this is that is, why we have our plus minus 500 here kV that is, basically main for the 1500 megawatt means conductor here current is one point 5 kilo ampere. So, we have to decide the voltage now, once the voltage is decided then you have to design you have to go for your this span length of the towers you have to see the height of the tower you have to see the spacing of the tower and then you have to complete see the routine of this you have to even though right-of-way.

Right-of-way is nothing but if you are having a conductor tower here that is, going to be there and this conductor is hanging here so, the distance here is called the right-of-way means we require this distance that should pass on so, we should cut all the trees another things because also, the ground we do not want the trees and this side also, because there will be flashover. So, we require some right-of-way and the clearance from various ministries and then we have to go for the passing of these conductors to reduce the ripple in the DC system basically we require the AC filters.

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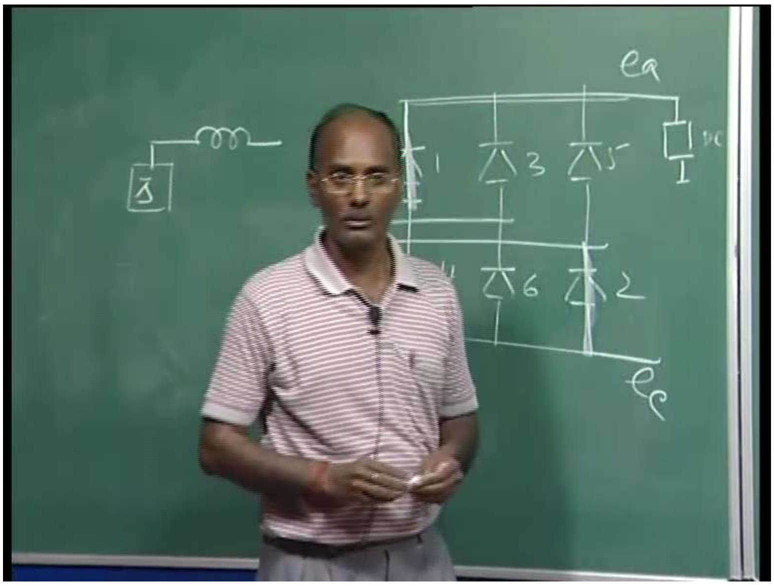

As I said here AC filter about this but I did not mention about the DC filters but we also, use the DC filters as well and another option here that is, you are having this is a converter, here we are using this smoothing reactors and due to this smoothing reactors the conduction of valves also, it is not a sudden.

It is for example, if we will see later on we are having this bridge converters this is if I will draw here this is your bridge converter this is 1 3 5 4 6 2 now, you say why I am using this number we will see later on this is very easy to remember. If let us, suppose your this is conducting this 1 and 2 this is a 3-phases means we are having here e a and this is conducting means we are having e c because this a B and c phases are there so, this pulse will be automatically going but due to this smoothing reactor and this leakage reactance here it will be not suddenly suppose from here you are 3 is going to conduct there is some overlap.

So, there is due to this even though some reduced reduction in the overlap and also, the current which is going to change this smoothing reactor will be there and even though this certainly it will exist we go for the here some filters that is, the DC filters we call it we have to go for the DC filters as well.

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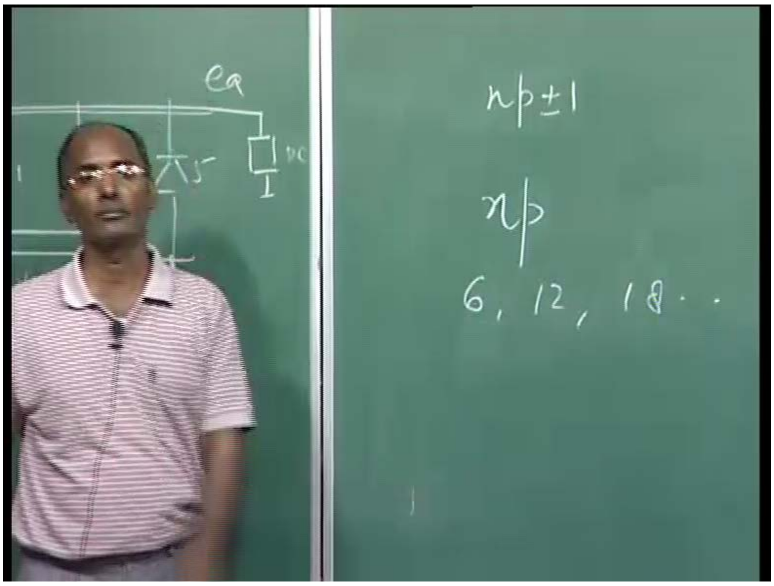


I did not mention here as I said this AC side harmonics it is your n p plus minus 1 it is AC side harmonics, but in the DC side we are going to have this n p harmonics means, here if you are having six-pulse so, it is 6 12 here your 8een these harmonics are there but the magnitudes are not so, very high but still we go for using some DC filters because we are going for the 6. If you are using 12-pulse then it will be here the 12 and then you have to use for the some DC filters here but still it will be there in your system yes in AC system we have different of protecting relaying and circuit breakers and out that from maintains and operation like in DC we have any protection equipments.

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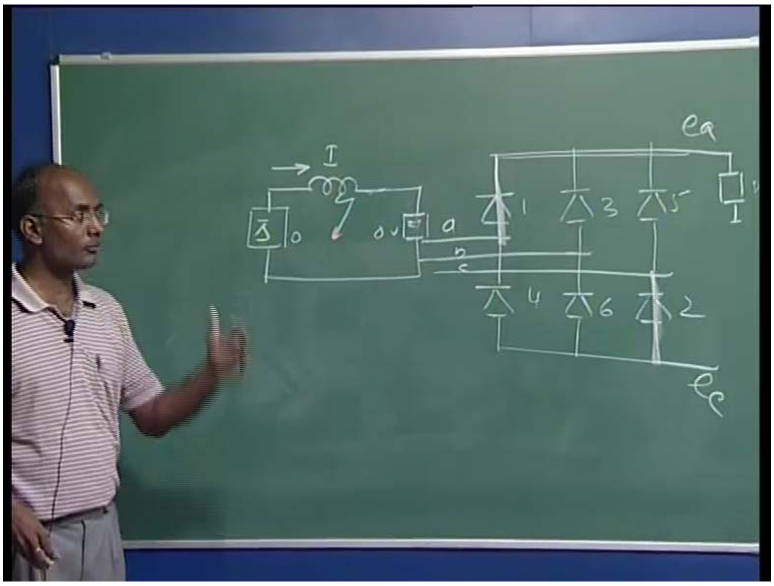

Basically in the DC what we do here this control of this valve itself work very fast and here this controller, here itself we design in such a way what will happen? Why is the protection system required in AC? If there is some fault then there will be the relay should sense and it should open your circuit breaker and clear the fault in that line means that faulty system must be isolated first and thereby then you can just see the actual problem and then you can reinstall that equipment later on.

Here what happens now, you suppose this is a converter, this is your line, this is your another inverter, let us, suppose this is your system 6-pulse now, if something goes wrong here there is some fault in this line or somewhere reactor what will happen huge current will flow and huge current is flowing. Now, the we will see later on one here converter will be it is looking for the voltage and other will be maintaining the current now, to control the power here what I just said here this I should be constant.

So, one converter control is dedicated for maintaining this current what will happen if here we will find any of the converter. Let us, suppose this is the voltage and this is current controlling, so, if this we will see this current is increasing so, what will happen if fault is there maybe power is flowing from here this is current here from this side also, current will be coming so, this we will see the current is increasing what will we do it will try to reduce the voltage and slowly and slowly the voltage will be 0

What will happen if voltage is 0, there will be no current flow from here similarly, he will also, find OH this voltage current is increasing this will also, try to see and finally, it will try to reduce the voltage and you know, this control is very very fast even though your mechanical system like a circuit breaker it is also, requiring several cycles 3 to 4 cycles for complete operation of a fault opening of the line it requires 3 to 5 cycles. Lesser than that time this controller can act and if fault is there they can operate if the 0 potential now, this 0 volt what is happening the fault is gone and then you can inspect where is the problem and then again you can go for this.

So, we do not use any here the circuit breaker here we simply the control of these two devices are right now, good enough to see the whether fault is there and it should be cleared. So, we will see how this controllers even though how even though first how they are going to energize how they are just going to see how it is going to be 0. So, that we can take it out for maintenance also, all this starting and start up of the converters will be we will discuss later on in the later our discussions.

So, I was discussing about the voltage level thus we saw that the voltage is decided by your power and then, you have to see, you have to go for the techno-economic analysis that which options are better and thereby the voltage and the current and conductors are decided. So, at end now, I can summarize in this lecture that we studied about this various components, we saw the converters, which is the major portion or major part of this HVDC transmission system we are going to have the two converters both at a rectification end, and the inverter end. If it is a two terminal HVDC system or we can go for 3 terminals if we are going for three terminal HVDC then we require three converters and in the converter as a whole, I mentioned as a broader category it is not a simple bridge converter here we require the controllers of these thyristor valves as well and that is, a very very special part of this converter.

So, converter I mean this bridge converter along with the controller and the controller is having the major portion which we will discuss dedicated, one module on the controller itself then, another component which I discussed the transformer and I just showed the this transformer is not a simple transformer. This simple means ordinary transformer which is used in the AC system is specially made your on-line OLTC transformers are used at both the converter stations and it should withstand the harmonics as well at that time.

Then we saw our filters filters are used to filter out the and now, we are going to have the filters at both AC as well as the DC side means, we are using the AC filters here and also, we are using the DC filters to filter out the harmonics at this side or harmonics at this side, but we are using the limited number of filters and other filters or other harmonics are flowing in the system that is allowed, because the magnitude is not significant.

Now, then I just discussed about the smoothing reactors and its purpose and finally, I just discussed about the grounding rods that is, used whenever in emergency condition we can use the ground as a return path. So, that we can use the lower level of the earth for the providing the minimum impedance to this and the transmission line, as I said the transmission line is not very special it is just like a simple DC HVAC transmission lines and the voltage level et cetera is decided based on the techno-economic considerations and and this is the basically major components of your HVDC transmission system.

So, on the next lecture we will discuss about the various we will go for the converters and we will see why we are going to use the bridge converters for these HVDC applications. Thank you.