High Power Multilevel Converters – Analysis, Design and Operational Issues
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Lecture – 42
Other Converter Topologies

Hello and welcome to another session and today we will talk about some Other Converter Topologies of multilevel converters. Now, there are hundreds of converter topologies for Multilevel Converters and it is impossible to summarize them in such a small lecture, but what I thought is to include in this other converter topologies is to introduce you to 2 or 3 topologies and then some other cell structure for MMC.

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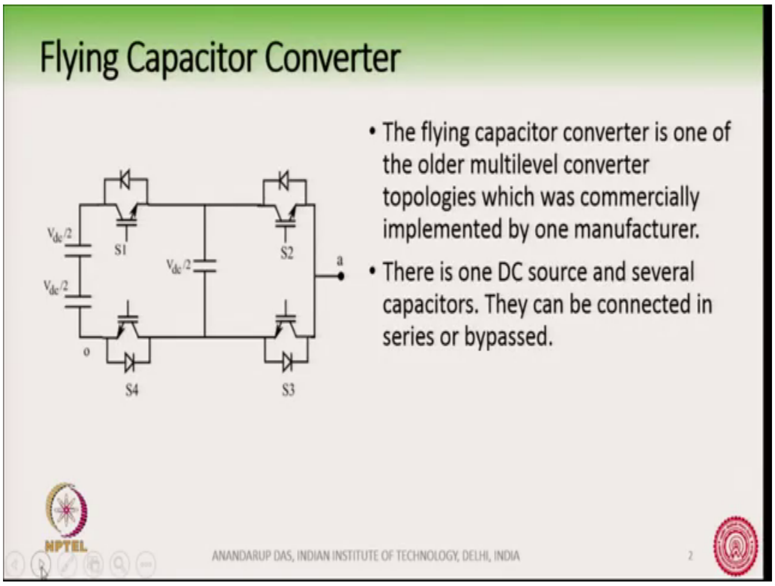

So, this was the main idea behind having this subject of topologies. Of course, what we will cover here are basically one topology that is called the flying capacitor converter, we will cover that then we will cover, alternate arm converter which is variant of MMC and the third one that we will cover are different cell structures, I mean the in MMC we know or MMC or HCHB we know that there are half bridge or full bridge cells.

So, the third part will be like what are the variants in these cells. So, basically we are covering 3 topics here, first the flying capacitor, second the alternate arm converter and third different cell topologies for MMC. So, let us see what is the first one? This is the flying capacitor converter in short FC converter or FCC ok.

The this converter was, one of the older multi level converter topology which was commercially implemented by one manufacturer that is why I have included it in this subject or in this lecture session. However, if you when you fully understand this converter, you will see that there are some drawbacks for this converter for which it has not gained a lot of momentum.

However, the concept is interesting and we should know the concept because based on this concept it is possible to have other variants or we can include it in some, include it along with some other conventional topologies. So, what is there here in this converter? So, if you see here in this topology what do we find basically the word flying capacitor means in this converter there are a number of capacitors ok.

And there is one DC source, there may be several capacitors and these capacitors can be connected either in series or they can be bypassed ok.

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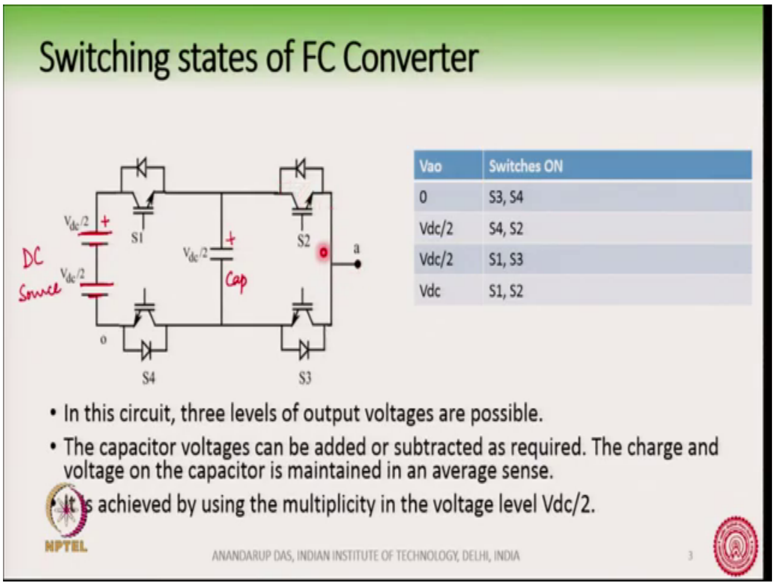

So, let us understand the operation by seeing one capacitor which is connected to the DC source here ok. So, this side is DC source I mean ideally we should have this is a DC source. So, it is like this ok, it is not capacitor this is DC source.

So, this side is the DC source and this is the capacitor. So, how are we going to operate? So, you can see here that this DC source is connected to the capacitor via these switches here ok. So, basically what are we doing here is that we can insert this capacitor either in series with this DC source or we can bypass the capacitor. For example, suppose I want to get I want to see this voltage a o V a o.

So, if I turn on switches S 3 and S 4 here then what will happen is that this V a o voltage will be 0 ok, this voltage will be 0 if I turn on the lower 2 switches. Now suppose this DC source is having a voltage of V dc and this capacitor is charged to V dc by 2 that is half of this DC link, then we can suppose I want to get V dc by 2 in V a o then what can I do I can turn on these 2 diagonal switches then what will happen is. So, starting from here I go like this and like this here.

So, V a o voltage will be equal to the capacitor voltage once I turn on S 2 and S 4 and the capacitor voltage suppose we maintain it at V dc by 2. There is also one other path by which we can realize V dc by 2 and that is going from here through S 1 through S 3 and getting like here, this is also possible you can see here this is also possible. So, by turning on S 1 and S 3 or turning on S 2 and S 4 we can get V dc by 2 voltage available between a and o point of course, the last option is to turn on S 1 and S 2 and then we get V D c voltage here.

So, you can see that this capacitor is sometimes getting bypassed and sometimes connected in series to the DC source ok. So, by this method we are getting this 3 levels of voltages between a and o and so, this will produce 3 levels of output voltage. Now you can easily understand that this capacitor is not a stiff source. So, therefore, it will, when the current is flowing through the capacitor it will either charge up or it will discharge.

So, therefore, we must in order to keep the voltage at V dc by 2, we must maintain the voltage on the capacitor in an average sense. So, we should if the current is flowing for certain duration we will charge up the capacitor and for certain duration we will discharge the capacitor and this will be possible by using this state here. Only is in this state the capacitor that is the V dc 2 state, V dc by 2 state the capacitor can be charged or discharged whereas, in 0 and V dc state the capacitor has no effect, the voltage on the capacitor has no effect.

So, therefore, we have to apply these 2 voltage states by using the 2 multiplicities and thereby it is possible to maintain the capacitor voltage we have to go on doing this all the time. So, as to keep the capacitor voltage at V dc by 2, you also note that these 2 switches must be operated in a complementary fashion otherwise you are going to short circuit and we also note that the rating the voltage rating of all these switches here is equal to V dc by 2 ok, all the rating is equal to V dc by 2 the current rating is equal to the load current.

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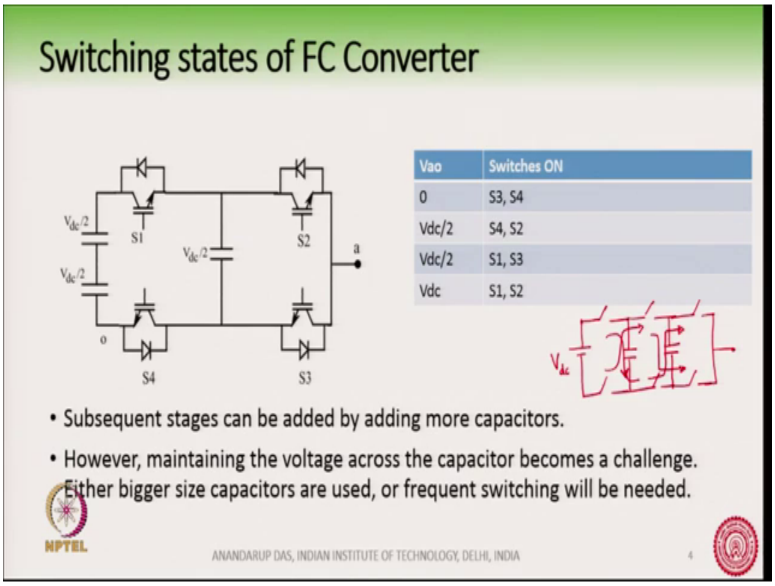

Now having understood this very simple circuit you can then add more number of capacitors to get more number of levels. So, for example, you can have this as V dc here and then you can have one switch here. Now, I am drawing a generic switch. So, you can have one set of capacitor here and then you can have another set of capacitor here and like this ok.

So, in this case by using different combinations of these switches you can allow the current to flow this way or you can allow the current to flow this way ok. So, therefore, in a similar way for this capacitor you can allow the current to flow this way or you can allow the current to flow this way here. So, now, you can see that using these combination of switches we can charge or discharge the voltage or charge or discharge the capacitor and you can have several such stages.

One advantage of this topology and you is that you have a single DC link and you are creating more number of levels by introducing these capacitor. So, it was commercially implemented by one manufacturer; however, there is a drawback and as you can understand here that the load current is always flowing through these capacitors right, the load current is always flowing through these capacitor.

So, in case of a multilevel converters we know that the load current can be quite high. As a result these capacitors must be big in size, otherwise because of the high magnitude of the load current they will quickly charge or discharge and their voltages will quickly change from the nominal value, if the voltage is change from the nominal value then we do not get the multilevel waveform which we desire.

So, therefore, in this topology bigger size of capacitors must be placed. The other way if you want to keep a small size capacitor then what is the other way is that frequent switching has to be done. So, you are continuously charging or discharging the capacitors. So, the switching frequency of these switches increases. So, that is the compromise either you put a bigger capacitor or you increase the switching frequency and hence switching losses in this converter.

However, the idea is sometimes used in other types of converters. For example, flying capacitor can be, the flying capacitor topology can be integrated with NPC so, as to get more number of levels like that. So, this is what about the flying capacitor converter.

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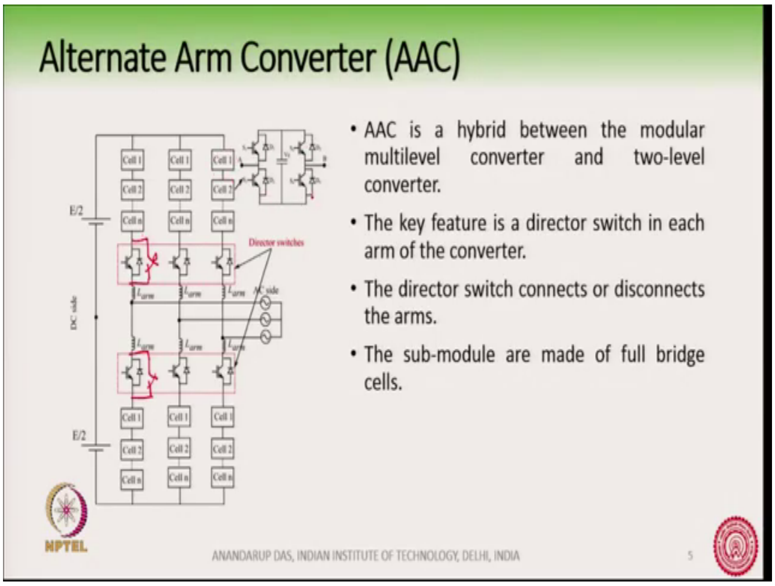

The next topology that we will see is the alternate arm converter ok. Now what is the alternate arm converter? Alternate arm converter has been proposed more recently after MMC has been proposed.

And this is a variant or is a hybrid topology between MMC and a 2 level converter. As you can see here this topology is having a very similar structure like MMC, you can see there are lot of cells and there is as arm inductance. However, there is a additional component here which is called the director switch. Here in this figure we have shown the director switch to be a single IGBT, but in practice it is basically a series connection of several IGBT's.

So, this is the key feature of an alternate arm converter, which is this director switch the function of the director switch is to connect or disconnect the arms. So, with the help of this director switch you can either connect this arm or you can disconnect the arm. So, basically the converter is operated in such a way so that only one arm is operating in one half cycle of the AC waveform, in the other half the director switch is opened.

And this arm is completely removed from the circuit. I will explain it little bit in more details, but what you can think of is that this director switch is nothing, but a switch here this is a switch here. So, during the positive half of the AC waveform that is the positive half of this AC waveform, we will use this upper director switch and we will open this switch here in the negative half of the AC waveform, we will use this director switch and we will open this one.

So, the one arm is only used in one half of the AC cycle. So, therefore, it is claimed that this topology will give us lesser loss as compared to the conventional MMC, we will discuss it a little bit in details after a few minutes. The sub modules here are usually made up of full bridges.

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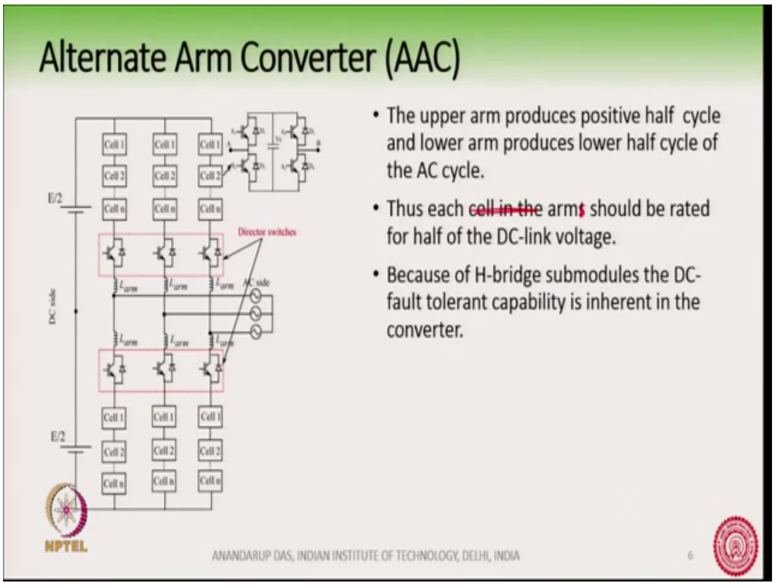

So, that is what I have just told the upper arm produces positive half cycle and lower arm produces the lower half cycle of the AC waveform. So, each cell in the arms should be rated for half of the DC link voltage, rather I will say not each cell, each arm sorry each arm should be rated for half the DC link voltage ok.

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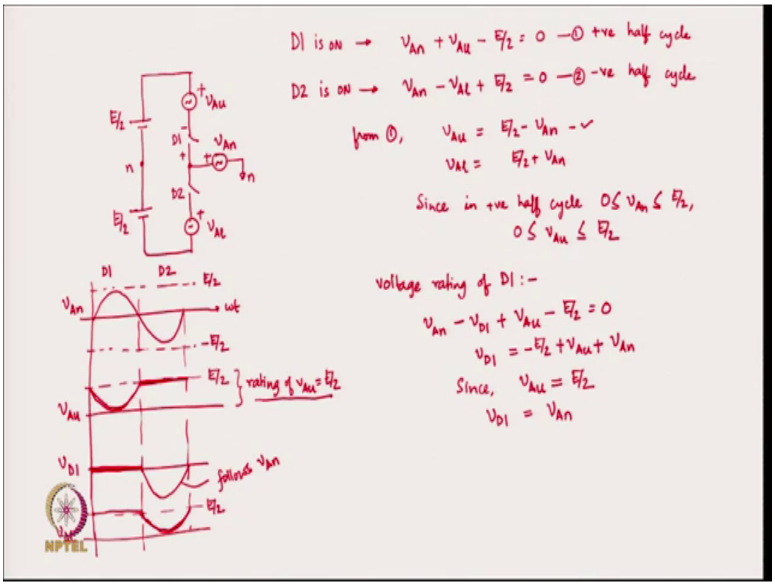

So, let us see how this happens what we can see here is, we can draw the equivalent circuit of alternate arm converter which is very similar to the conventional MMC. We are not drawing the arm inductors, we are neglecting the drop across the arm inductor.

So, here are is the directed switch D 1 and D 2 and we also have this as V A u and this as V A l and we have E by 2 here and E by 2 here and this is the V A n voltage, the AC voltage. So, we can understand the operation of the converter. So, as I told you D 1 and D 2 are complementary, it is not exactly complementary there is an overlap time period.

But let us first understand that, suppose let us assume that D 1 and D 2 are complementary. So, when D 1 is on ok, what will be the equation? If I write the KVL here so, then V A n plus V A u minus E by 2 is equal to 0 and during this point of time D 2 is off. So, this side is off, this switch is off.

Now, next portion D 2 is on, next half cycle ok. It is a, this is the positive half cycle of the positive half cycle of the AC waveform and this is at the negative half cycle of the AC waveform and during this time D 2 is on and so, the equation is V A n minus V A l plus E by 2 is equal to 0 ok. So, I can give it as number 1 and number 2 equation.

So, therefore, I can write from 1 V A u is equal to E by 2 minus V A n and V A l is equal to E by 2 plus V A n right. So, let us then draw the waveforms. So, let us first draw V A n and this is the V A n waveform and let us assume that this is spanning between E by 2 and minus E by 2 ok. So, therefore, what is how should we draw V A u voltage.

So, if you see here V A u voltage this is omega t, if you draw V A u voltage, as you can see V A u voltage during the point, the positive half cycle of the AC waveform that is during this time. So, there are 2 half cycles. So, during the positive half cycle it is E by 2 minus V A n. So, therefore, if this is E by 2 therefore, this waveform is E by 2 minus V A n. So, it is like this and then the V A u voltage and then D 1 goes off.

So, D 1 is on here and D 2 is on here. So, therefore, during the first half cycle V A u voltage is like this and in the second half cycle it is completely out of the circuit and so, V A u voltage becomes flat like this ok. So, this is the waveform of V A u and you can clearly see that the rating of V A u is equal to E by 2.

You can see here the rating of V A u is equal to rating of V A u is equal to E by 2 which is half that of conventional MMC. Remember in conventional MMC we had said that the voltage rating of the arm is equal to the total DC link voltage; here the voltage rating of the arm is half the total DC link voltage ok. Now looking into this equation once more we can also say that the rating of V A u is a because in their positive half cycle.

So, in the positive half cycle, so, since in positive half cycle 0 less than equal to V A n less than equal to E by 2. So, therefore, we can say that 0 less than equal to V by u less than equal to E by 2 this you can say ok. So, therefore, this statement is valid what is the voltage rating of the director switch D 1?

So, voltage rating of D 1, how much is it? The voltage rating of the director switch D 1 can be obtained when D 1 is off and D 2 is on ok. So, the voltage rating of D 1 can be seen, suppose you write it like this. So, therefore, V A n minus V D 1 minus V A u, sorry plus V A u minus E by 2 is equal to 0. Therefore, VD 1 is equal to E by 2 minus V A u minus V A n ok, sorry now there is a mistake.

So, therefore, VD one is equal to minus E by 2 plus V A u plus V A n because you see here during the negative half, that is during this time the V A u voltage is clamped to E by 2. So, we can say since V A u is equal to E by 2 therefore, the voltage is of this one is equal to V A n ok.

So, this means that the voltage rating of director switch is equal to the peak AC voltage ok. So, therefore, voltage across D 1 so, if I plot the voltage across D 1, here the voltage across D 1 will be equal to 0 in the positive half because it is conducting.

So, this voltage will be equal to 0 here and the voltage is equal to V A n when it is off. So, therefore, this will be equal to V A n. So, this is follows V A n voltage here ok. So, this is what appears across the director switch D 1 and accordingly we have to design it, the last part you can also similarly draw V A l I am not deriving it, but V A l also has a voltage like this which is this is E by 2 and this is V A l voltage is something like this ok.

So, this gives you a basic understanding of alternate arm converter. Now this cells, so, it is also to be noted that AC voltage in the converter may not be less than E by 2 that ac voltage even can be more than E by 2 and so, full bridge modules or sub modules can be used and because of this full bridge modules, we have seen earlier that inherent fault tolerant capability of the converter can be provided.

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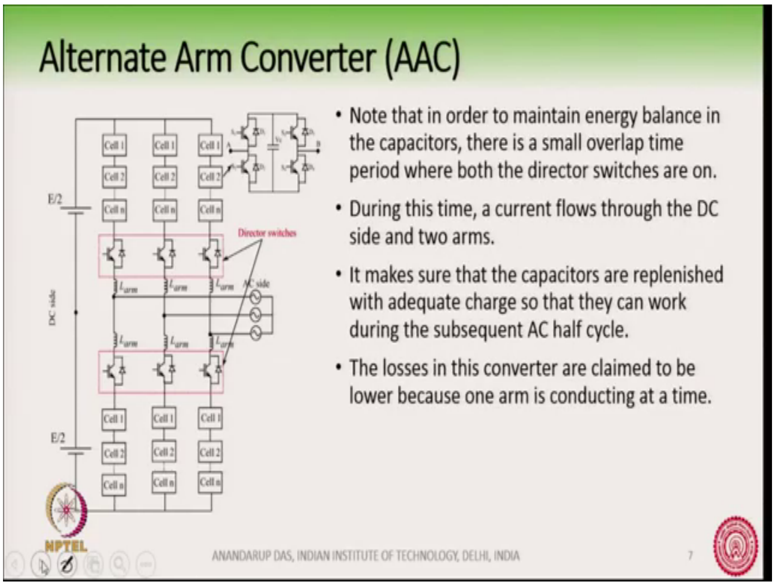

One thing that we should observe here that fine this converter the arm voltages are half the DC bus arm voltage rating is half the DC bus, that is a very attractive feature, but then what about the capacitor balancing ok. These cells are all made up of capacitors and we should have a similar strategy like MMC in order to keep the energy balance.

Now, so, for this to happen there is in the operation of the converter there is a small overlap time period and in this overlap time period both these switches are turned on, both the director switches are turned on. When they are turned on, it is as if like there is a short circuit and a current will flow through this path through the DC link and through both the arms.

And a DC current, this is the DC current that will flow and this current makes sure that the capacitors are again charged back. So, that they can work in the subsequent AC half cycle, remember like in MMC active current is flowing through the capacitors in the arms and so, it will lose energy and somewhere, somewhere in your cycle somewhere in the half full cycle you have to replenish this charge of the capacitors.

And this time is this overlap time. During the overlap time these 2 switches for a brief period of time they are turned on and so, the DC will flow through this whole arm and we will replenish the capacitor.

So, this is an alternate strategy this is an alternate strategy as compared to MMC in MMC the DC circulating current or the DC current was flowing continuously and that is why we always had these 2 cells the DC was flowing continuously. However, in this case what we have done, we have not, we are not allowing the DC to flow continuously rather for a short period of time maybe during the end of the half cycle and the beginning of the half cycle, a short period there we will short or we will turn on both the director switches and the current will flow.

This will make sure that the capacitors are properly charged up. So, the losses in this converter because are, lower because one arm is conducting at a time and half cycle. So, in one half cycle this arm is conducting and in the other half cycle this arm is conducting. So, you can see in the web there are many publications. Now coming up with alternate arm converter I just wanted to introduce you to this topology.

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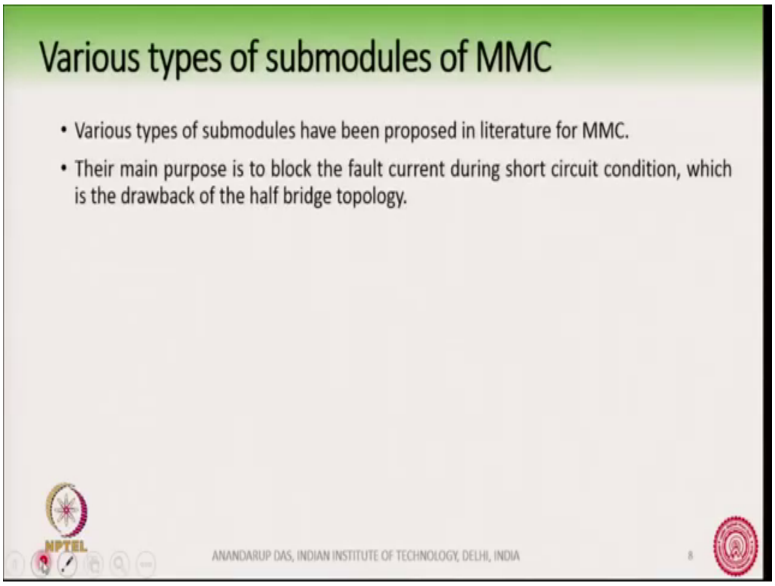

Next part as I told you there are 3 parts of this lecture we covered the flying capacitor, we covered the alternate arm converter and now we will cover what is the different what are the different types of sub modules proposed for MMC.

Now half bridge is the most economical and the easy to implement and the simplest topology half bridge based MMC, but half bridge based MMC has a serious drawback and that is that during fault condition that once we have turned off the IGBT's it is a totally uncontrolled, it works totally like an uncontrolled rectifier the diodes are on and the fault current will flow you cannot stop it ok.

So, people have come up with other types of sub modules the main idea here is to limit the fault current along with some additional beneficial features we will see 3 or 4 of them now. So, for example, this is one such thing clamped single sub module.

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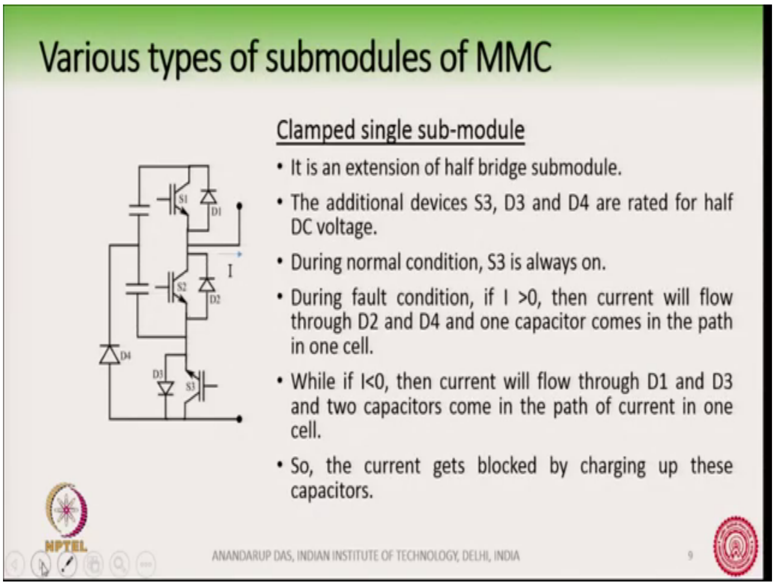

So, you can see here that in this topology we have this half bridge here along with additional switch and diodes here, they are all rated for half the DC voltage ok. Now when the normal, during normal operating condition this switch S 3 this is always turned on ok. So, this point is connected to here and so, there is absolutely like a half bridge operation of this converter. Now, when there is a fault note that this current will flow here. So, that this diode is reverse biased ok.

Because, this point potentially is half V dc and this is 0. So, this is reverse biased, but what happens at fault condition? So, at fault condition what happens is we will shut off these

IGBT’s here ok, if the fault current is greater than 0; that means, the current is flowing like this, then how will the current flow? The current will take a path through like this it will so, this is the current is flowing out like this. So, it will go in like this here it will go like through this D 4 through this capacitor D 2 and like that it will go out ok.

You see during in the path of the fault current this capacitor is present ok, if the current I is less than 0; that means, this is the current flowing and we have shut off all the IGBT’s then the current will flow like this, it will go like this go through like this come like this go like this and like this here ok, like here through D 1 through the whole DC link through D 3 and go like this here if I is less than 0.

We see that in this topology during the fault condition there is always these capacitors which are coming in the path of the fault current, this is also the strategy that we had adopted when we used full bridge during the operation of conventional MMC what was the advantage of a full bridge as compared to half bridge MMC, what happened there in half bridge MMC?

As soon as we shut off the IGBT’s there was only diode in the path there was no capacitor whereas in a full bridge if we had, if we shut off the IGBT’s even then the, when the diodes are conducting there is always a path through on which there is the capacitor present and why is the capacitor important?.

This capacitor has already a voltage and that voltage will or the capacitor rather I will say that the capacitor acts in the path of the rising current rising fault current and so, the voltage of the capacitor acts like a back emf or it will oppose the rate of rise of the fault current. So, the fault current tries to increase, but you have put a capacitor in between.

So, it will see a big impedance this capacitor and it will first charge up the capacitor. So, the energy of that fault is somewhat getting absorbed in the capacitor in the form of half cv square. So, this is the advantage of suddenly inserting the capacitor in the circuit.

So, the capacitor voltage will increase and it is as if like it is kind of like restricting the rate of rise of the fault current. So, here also in this topology we see the same effect where during the fault condition even, if only the diodes are conducting the capacitors are getting inserted in the circuit. So, this is not only true for this topology, but all the next topologies. So, let us see the next one.

So, this is the clamped double sub module ok. This topology was proposed for DC fault tolerant capacity, but it has a reduced loss as compared to the edge bridge ok. So, how does it operate basically you can see here this is there are 2 half bridges ok, there are 2 half bridges here and these 2 half bridges work in series by turning on this S 5 or D 5, when this switch is fully turned on here they are working in series with each other ok. So, it is like this is the path of the current.

For example, now, when fault happens right when fault happens, if this current I is greater than 0 then we have turned off these switches. All these transistors have been turned off. So, you can see that the current will have now 2 paths. So, one path is like this current comes say I is greater than 0. So, current comes here through D 1 through D 7 through this capacitor through D 4 and goes out this is one path of the current the other path of the current is through this D 1 through this capacitor through D 6 D 4 and goes out ok.

So, again you see that the capacitor is coming in the picture and it will restrict the fault current ok. If I is less than 0, you will see the D 3 D 5 and D 2 will conduct. So, let us see if I is less than 0 go through D 3 through this capacitor through D 5 and through this capacitor D 2 and goes through 0.

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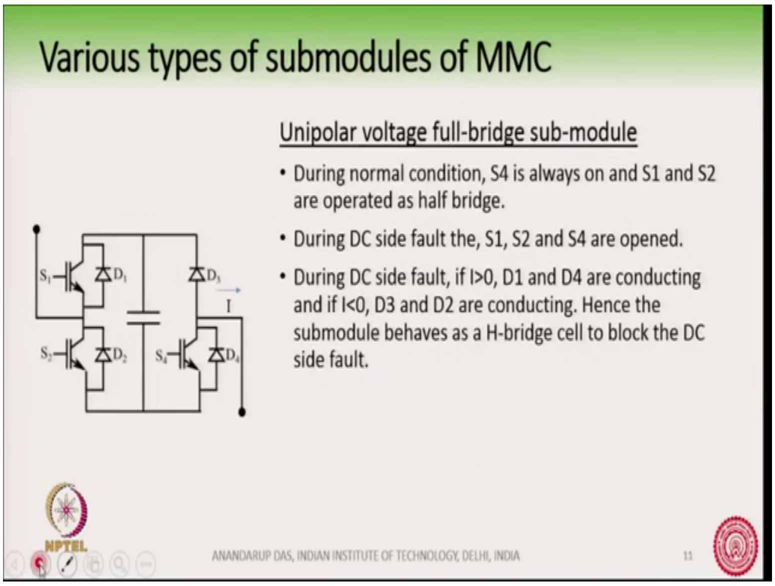

Again there is also another sub module. So, there are I will explain 1 or 2 more like unipolar voltage full bridge sub module. So, this is like normal condition, this is a half bridge kind of thing, this switch is always turned on and S 1 and S 2 is working with a half bridge configuration ok. Now, when there is a DC slide fault then these switches are opened. So, these are turned off and if I is greater than 0. So, you will see I is greater than 0. So, this diode will conduct.

And this capacitor will conduct and D 4, this is how it will form. So, again the capacitors have come. So, all these sub modules have some advantages. So, all these have the same functionality like the full bridge, but you can see here in this topology one switch has been reduced ok. These switch here as compared to the full bridge it has been removed.

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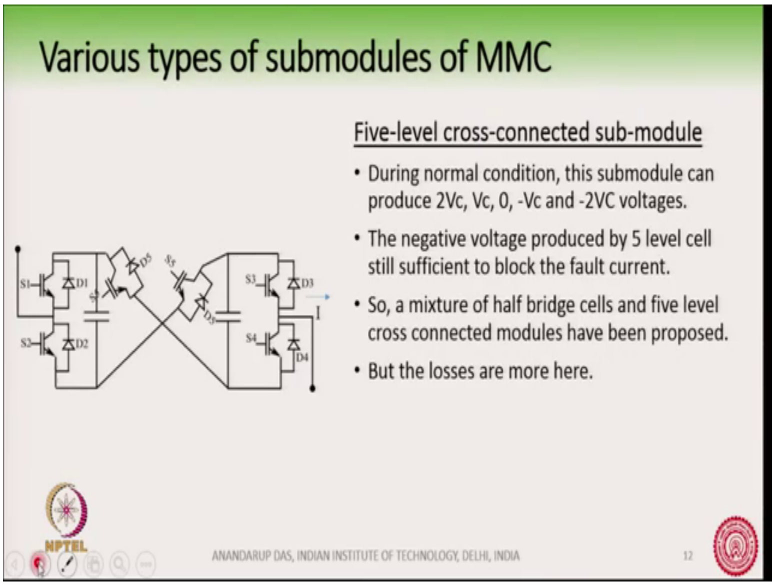

Again there is one more here; this is also interesting because this will give a five level cross connected sub modules. So, this voltage here will become five level, how can it become five level? You can make it like this is Vc and this is Vc. So, this is VC and this is also Vc. So, therefore, you can see here you can get 2 Vc, Vc 0 minus Vc and minus 2 VC between these 2 levels these 2 points.

So, how can you get 2 Vc say here comes here this is plus Vc and another plus Vc. So, if you go like this here like minus Vc minus 2 Vc goes out like here, sorry and you can have Vc only, how can you get a Vc? Suppose this voltage is here it goes like this Vc goes like this and goes out like this here. So, you can get Vc how can you get 0? If you get this then you got Vc.

And no this you go here and then you directly go out here bypassing the 2 capacitors. So, you can get 0 ok. So, in this way you can get five levels of voltages from 2 half bridges connected in this fashion. Again if you see that during fault condition the capacitors will come into picture ok. So, a mixture of half bridge cells and five levels cross connected modules have been reported.

But again the losses are more here. So, what I want to say here is that there are different types of sub modules also possible, it is not like that only half bridge or full bridge sub modules can be used in MMC, but as of now commercially only half bridge or full bridge have been used. These are all kind of like in the research stage at least I have not seen like this kind of a sub module being used in a commercial application.

But maybe in a future this will some of them may be used, we saw 3 different structures one was the flying capacitor, it is kind of like capacitors connected in series or bypassed. We also saw the alternate arm converter which is a modified or a hybrid version of A 2 level converter and MMC and we saw some different types of sub modules so many of these. So, although FC is commercially implemented, but some of these can be used in for commercial application, maybe in near future ok. So, with this we end the technical course, technical content of this course.