High Power Multilevel Converters – Analysis, Design and Operational Issues
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Lecture – 43
Summary of the Course

Now, we come to the end of this course. So, this lecture is like a Summary of what we have learnt in this course ok. So, the main idea here was to teach you a High Power Multilevel Converters, the topologies, Analysis, Design aspects Operational issues. So, in this lecture, we will try to summarize what we have learnt in this course.

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So, it has covered about 12 weeks touching upon the following subjects. So, what have we covered? Half bridges, full bridges, sinusoidal PWM and 3rd harmonic addition, space vector

PWM. And then we went into the main multilevel converter topologies that is CHB, MMC and NPC, along with that we also studied a little bit about multipulse transformers and gate driver circuits.

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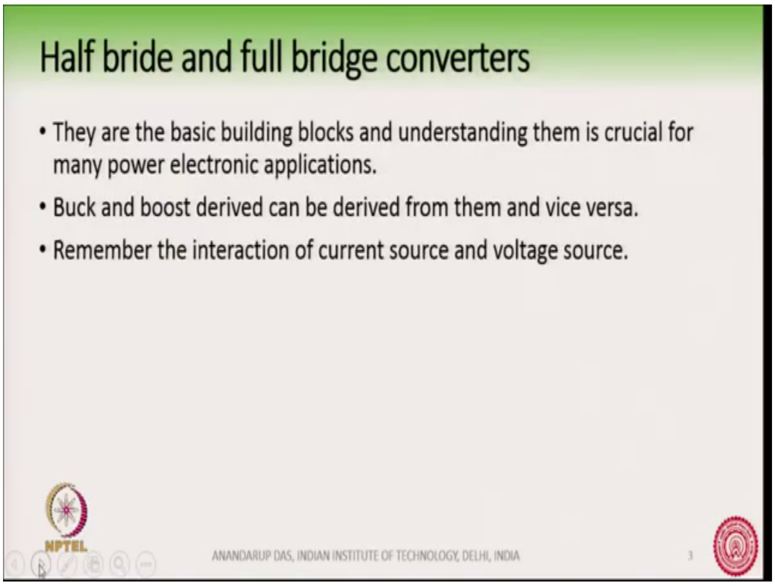

So we will try to summarize what we have learnt. So, when we studied the half bridge and full bridge converters, we understood that they are basic building blocks; not only for multilevel converters, but for many other power electronic applications. And there is a similarity between half bridge and full bridge along with the conventional DC to DC converters like buck and boost converter in particular half bridge.

So, they can be kind of like thought of they can be used interchangeably the thought process. In the thought process, they can be used interchangeably and many very often people do not understand the similarity between, suppose a buck converter and a half bridge or a boost converter and a half bridge like that ok.

So, it is important for you to understand the similarity of these converters so that it becomes easy for you to analyse them. The other concept that was useful is the interaction of the current source and the voltage source ok. As you can see here I have written.

Many times in power electronics the current source is very dominating ok and that will control the dynamics of the voltage source ok. So, it may happen that the voltage is negative while the current is positive. That happens many times in different power electronic application, because there is an energy exchange that which taking place between a current source and the voltage source.

What is the direction of flow of the current or the, yeah what is the direction of the flow of the current is dependent on what is the relative strength of these current and voltage sources. This is to be kept in mind. After this, we studied sinusoidal PWM. So, in sinusoidal PWM, we compared a sine wave with a high frequency carrier ok.

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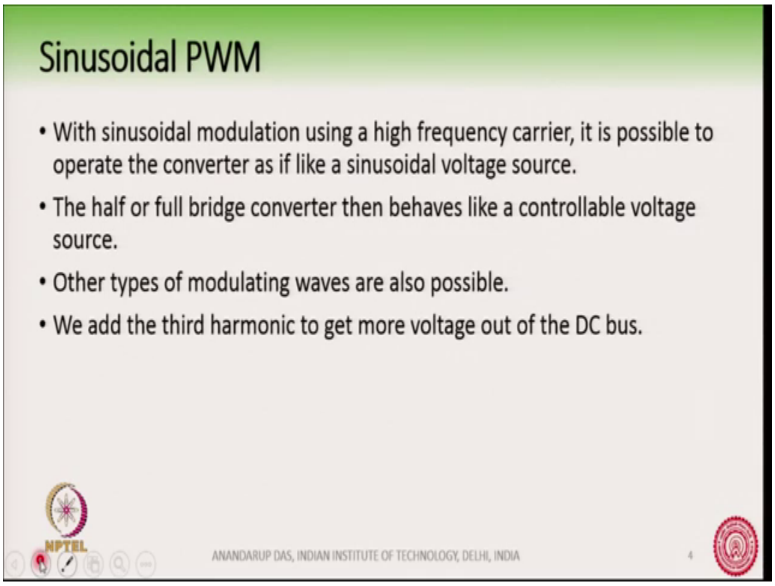

And with that, what did we achieve? We made sure or we, we operated the converter as if like it is now working as a controllable sinusoidal voltage source ok. So, the half bridge or full bridge that we had studied in the first section, they now behave like a controllable voltage source. So, we use the sinusoidal PWM to switch these switches

so, as to behave or so as to make this converter behave like a controllable voltage source.

Now it is to be noted that the other types of modulating wave forms instead of sine wave is also possible to be used. So, you can make non sinusoidal voltage sources also and they are particularly used for example, in active filters. We have not talked about active filters because this course was more focused on multilevel converters, but you can do that ok.

We add a third harmonic along with the fundamental we add a third harmonic. And why do we add the third harmonic? Because you would like to get more AC voltage out of the DC bus so, that is the reason why we added the third harmonic. And how much do we get? Maximum we can get 15 percent more as compared to the sinusoidal PWM.

And carrying forward and going forward, we see that the 3rd harmonic goes into space vector PWM ok.

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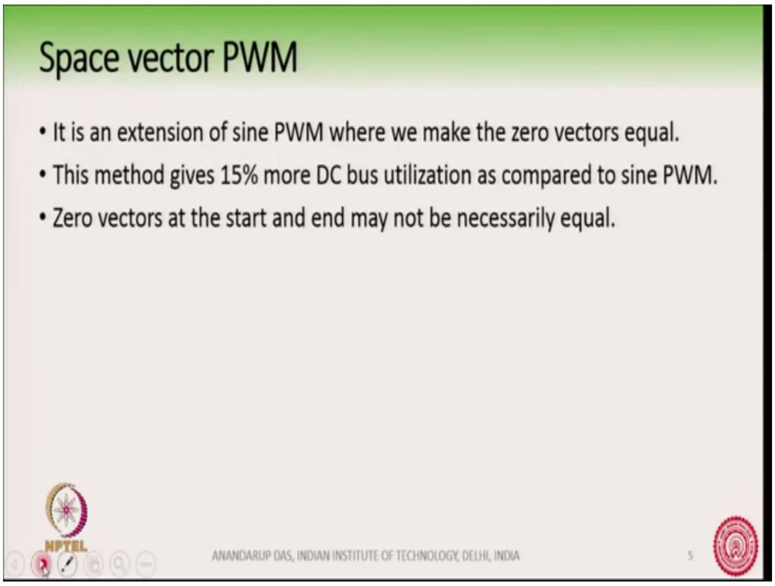

Again space vector PWM can be thought of as an extension of sine PWM, where we are adding a common mode voltage which is equal to V max plus V min divided by 2 ok. And the reason for this is that we are making the starting and ending vectors equal ok; zero vectors. These are called as 0zero vectors as per the switching sequence of the inverter. So, in sine PWM the zero vectors are unequal whereas, in space vector PWM the zero vectors are equal in time duration. So, it will give 15 percent more DC bus utilization ok. So, 3rd harmonic is also a common mode voltage like this V max plus V min divided by 2 like that.

So, they are basically adding this common mode voltage to a sinusoidal reference waveform. And you can have different types of common mode voltage that you can apply. You can apply one type of common mode voltage where you can shift one of the waveforms up and make it yourself make the waveform flat ok.

So, there can be different types of common mode voltage, you can add. So, one type of common mode voltage that you can add is like you add such a common mode to the sine wave so that for certain duration the sine wave touches the plus 1 or touches the upper boundary and get clamped there ok.

So, different types of common modes can be added. So, if you clamp certain part of the sine wave by adding a common mode, then you go to something called as discontinuous PWM o k. We have not talked in details, but it is you can understand that this is nothing, but an extension of what we have studied ok. You are adding a common mode, but this common mode can be of different you can add many types of common mode voltage because you are adding the three same quantities to the 3 waveforms.

So, you can shift the waveform up or down you can clamp it to the top you can camp it to the down which we call as discontinuous PWM ok, it is nothing, but an extension of what we have studied. So, in discontinuous PWM the 0 vectors at the start and end are not equal, which is unlike the space vector PWM ok. So, why we clamp these waveforms up or down because we would like to, sometimes we would like to control the switching and conduction losses. You would like to clamp a waveform so that there is no switching at certain parts.

Sometimes we do also clamping because we would like to achieve some form of a symmetry in the waveform when there is very low switching frequency application ok. We also do that clamping during that time.

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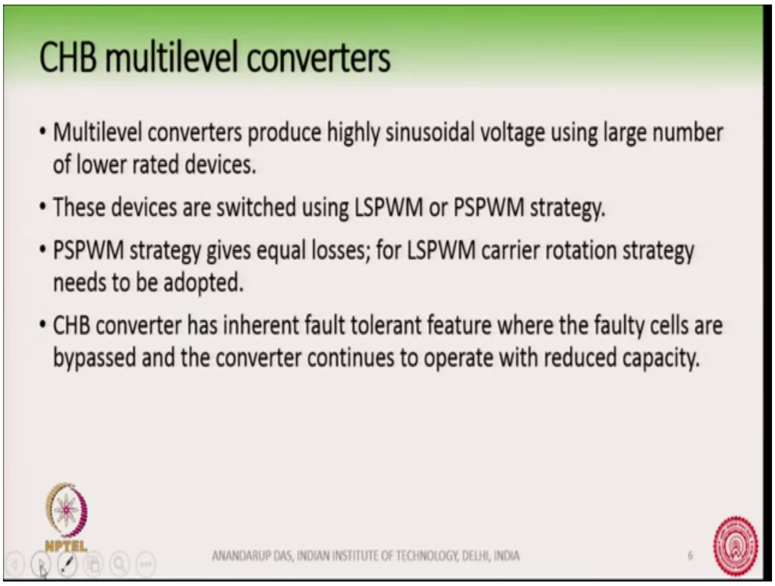

Next we went to the CHB multilevel converters so, why did we go into a multilevel converter? Because multilevel converters can produce highly sinusoidal voltage using large number of lower rated devices. So, instead of using a 6.5 kV IGBT, it may be attractive to the industry to use 31.0, sorry not 3 maybe 3 2.2 kV IGBTs 3 numbers of 2.3 kV IGBTs ok.

Often this is useful. There are several advantages and there are some disadvantages of using a multilevel converters. Advantage being that identical low voltage rated devices; so which on which you have more knowledge and confidence rather than using a very high voltage device and also the output voltage waveform getting more and more sinusoidal.

Now, important thing to keep in mind why we chosen CHB is that these cells which we have used in the cascaded edge bridge, they are all module learning structure. So, they are all identical device identical cells, but many of them working together. So, if you have a fault in one of them, then the converter continues to operate with a reduced capacity, bypass the faulty cell and you can operate the converter with a reduced capacity.

Of course there are some drawbacks, the drawback mainly is that the complexity ok. Lot of devices to control, but as we see in future the computational power of microcontrollers is increasing day by day. So, what appears to be complex now may not be so much complex for a microcontroller in near future. But apart from that apart from the complexity in terms of microcontrollers, there is also complexity in terms of so many devices to control; so you have so many gate drivers. You have many many

so, you have a lot of interconnections. This is always a drawback of a multilevel converter, this is true.

But for very high voltage applications the advantages of having a multilevel converter out ways the disadvantages, so that is why people have moved towards multilevel converters.

Now since there are many devices so, they can be switched either using level shift PWM or phase shift PWM ok. So, in phase shift PWM both are same basically level shift and phase shift both are same PWM or trying to achieve the same goal, but phase shift PWM gives equal losses whereas, level shift PWM has a carrier rotation strategy that needs to be adopted to have the same losses, this needs to be kept in mind.

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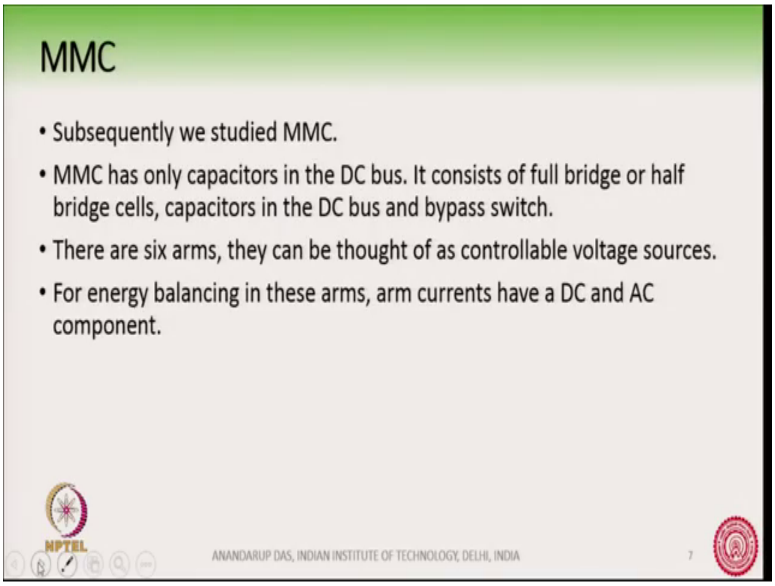

So, from CHB we move into MMC and why did we move into MMC? Because the CHB required isolated DC sources, that was the biggest disadvantage. Of course this isolated sources is obtained from a multi pulse transformer that improved the input current, input current quality, but MMC has inherently does not have that problem. It uses only capacitors in the DC bus along with full bridge or half bridge cells and of course, a bypass switch. So, MMC has found to be the most primitive promising solution for HVDC application as of now ok. And with MMC the voltage levels and the power levels are increasing day by day.

So, something like plus minus 600 kV or plus minus 800 kV even in future people are talking about plus minus 1200 kV. So, those voltage levels are achievable using MMC ok. Because here you go on cascade a large number of low voltage highly reliable transistors particularly IGBTs, in near future we may seek see also silicon carbide devices replacing IGBTs it may happen. Now the MMC has 6 arms and these 6 arm can be thought of as a controllable voltage source.

So, with this 6 controllable voltage source you have actually a great degree of freedom ok, you can manipulate them. And so MMC application is not only limited to high voltage DC transmission. So, people are now actively doing research on how to apply the concept of MMC in low voltage applications ok.

Now, one thing to note is that for energy balancing in these arms, the arms will have a DC and AC component this is absolutely essential in MMC, that you have a DC current flowing along with an AC. For example, it if its running as an AC to DC rectifier or even if it is running as a DC to AC rectifier, the converter remains the same. So, you will have both DC and an AC component of current in the arm and both these are essential for keeping the energy balance of the capacitors.

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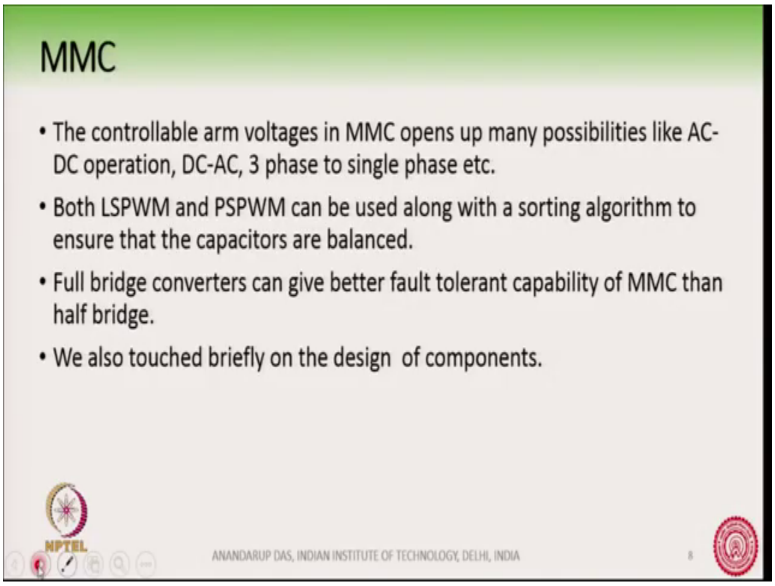

So, as I told you the controllable arm voltage in MMC opens up many possibilities, AC to DC, DC to ACl AC 3 phase to single phase bi directional power flow three phase to three phase and bi directional power flow and many other things. So, there is a very active research going on in MMC because of the many advantages that this converter possesses.

Now, both LS PWM and phase shift PWM can be used and along with a sorting algorithm, so that the capacitors are balanced. Sorting algorithm is primarily used because the capacitors are inserted in the circuit in a round robin fashion. So, that their energy or their voltage remains balanced ok.

So, we had studied this sorting algorithm. We also noted that the full bridge converters can give better fault tolerant capability of MMC rather than a half bridge, full bridge has the capacitors in the DC bus. When you shut down the IGBTs, the current will flow through the capacitor and this capacitor can act kind of like an back EMF opposing the rise of current; so, that is the advantage of having a full bridge converter.

We also briefly touched upon some of the design aspects of MMC.

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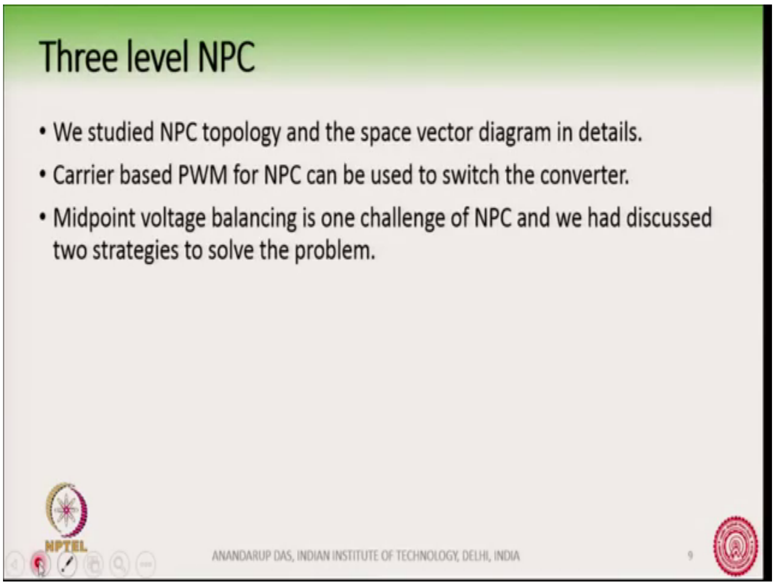

After the MMC, we had studied the neutral point clamped converter. So, neutral point clamp converter is probably the 3 level neutral point per camp converter is probably the most popular multilevel converter topology ok.

So, we studied the circuit, we also studied the space vector diagram ok. And continuing in the same fashion, we also saw the carrier based PWM strategy for NPC which we will use to switch the converter. Now midpoint voltage balancing is one challenge of MMC that is the as you access the midpoint because the MMC has a capacitor and the midpoint is accessed to get the 3 levels of voltages midpoint of these capacitors. And therefore, it is important to balance the voltage at the midpoint ok.

So, we discussed two strategies ok, we discussion and as of now this midpoint voltage balancing of NPC is kind of like a very well established solution.

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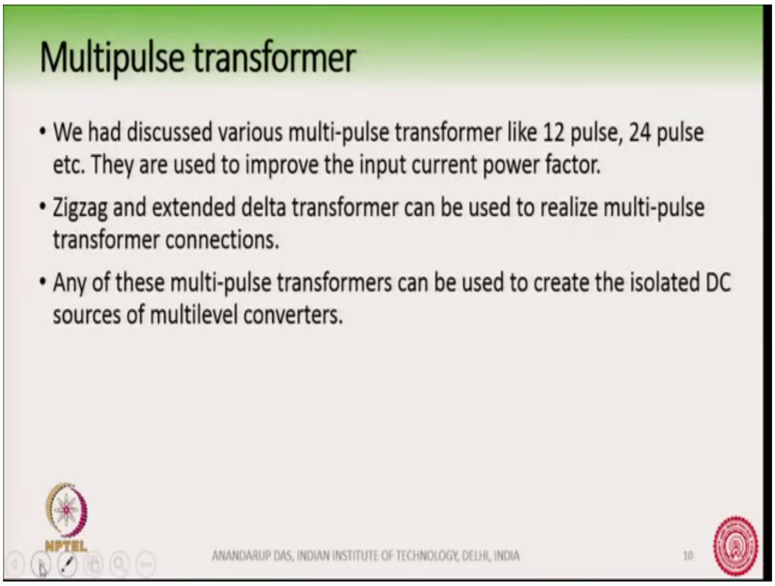

Subsequently, we discussed some multipulse transformers. Multipulse transformers like 12 pulse, 24 pulse etcetera they are used in multilevel converters in particular with cascaded edge bridge to get isolated DC sources and also to improve the input core input current power factor ok.

So, we studied apart from the 12 pulse start delta transformer, we also studied zig zag and extended delta transformers as part of the multilevel multipulse transformer concept ok. So, you can use any of these multipulse transformers to create the isolated DC sources.

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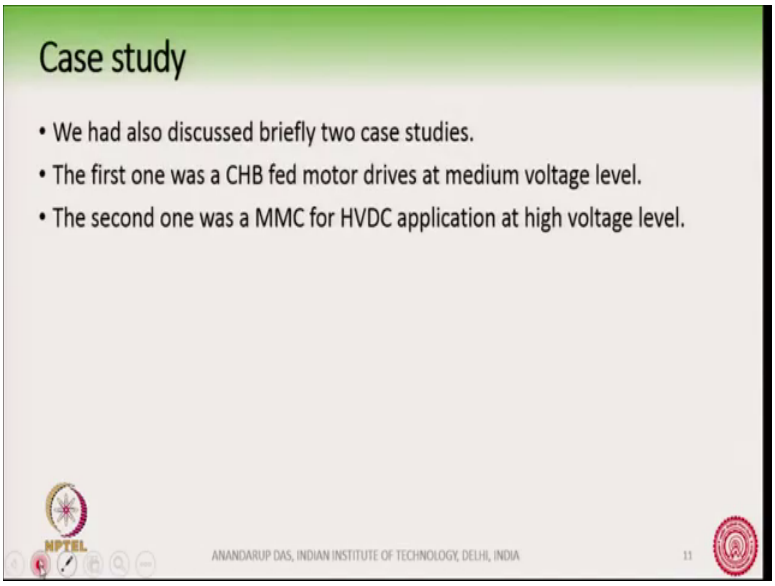

We studied briefly two case studies, one with was a CHB fed motor drives at mode medium voltage level and the second one was a MMC for HVDC application at high voltage levels.

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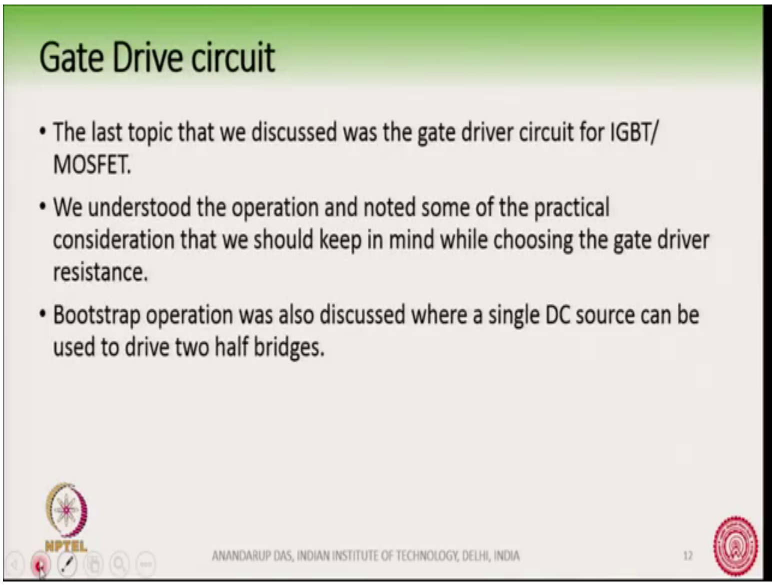

And lastly we covered the gate drive circuit ok. And we saw that the gate drive circuit for IGBT and MOSFET are very similar. We understood some of the operations like how the IGBT is turning on what are the sequence of events happening, while it is turning on and while it is turning off. Based on this understanding of the sequence of operation, we can choose the components and one of the most important component is the gate resistance of IGBT or MOSFET which we apply.

And there are several consequences and we must keep all these consequences in mind while choosing the gate driver resistance. Not only will it impact the switching losses, but also it will impact all this parasitic phenomenon. Like oscillation on the gate emitter voltage or even parasitic turn on when the device is supposed to turn off. And all these have an all these parasitic effect will be influenced by the choice of the gate resistance.

Apart from that we also need to choose a proper value of the steady state gate emitter or gate source voltage of MOSFETS, because it will determine what is the loss during the conduction period of the device ok. So, apart from this we also have seen bootstrap operation and the bootstrap operation is used when you want to have a single DC source and you want to drive 2 half bridges.

So, with one source you are temporarily we are temporarily charging up the capacitor, a charging up one bootstrap capacitor which is again utilized to drive the high side or the upper side of the half bridge ok. So, we have seen this operation also. We also studied briefly few other types of topologies which are interesting some of them have been commercially manufactured for example, flying capacitor and some of these topologies like alternate arm converter is also very promising a very promising multilevel converters ok.

So, I hope you have gained some knowledge out of this course and I hope you have enjoyed. You will get a lot of information apart from these lecture slides you will get a lot of information in the internet or in the web and information is now readily available. So, you can go through additional material, books like that and some articles application notes, where you can gain more understanding into the operation of different types of multilevel converters.

So, with this remark I will now conclude the course and you can access my website where you can get some additional information or you can email me in my email ID.

Thank you and have a wonderful time ahead.