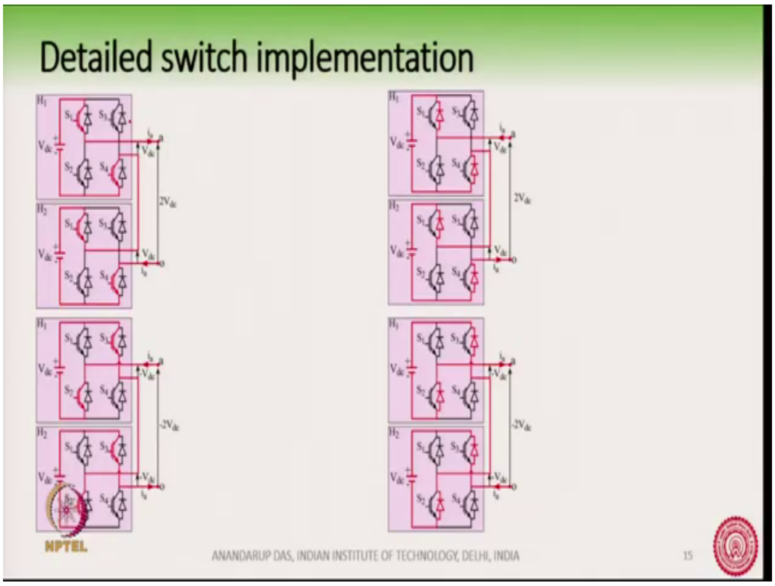
**High Power Multilevel Converters - Analysis, Design and Operational Issues**
**Dr. Anandarup Das**
**Department of Electrical Engineering**
**Indian Institute of Technology, Delhi**

**Lecture - 13**
# Output Voltage Waveform Synthesis in CHB Converter and Basics of Asymmetrical CHB Converter

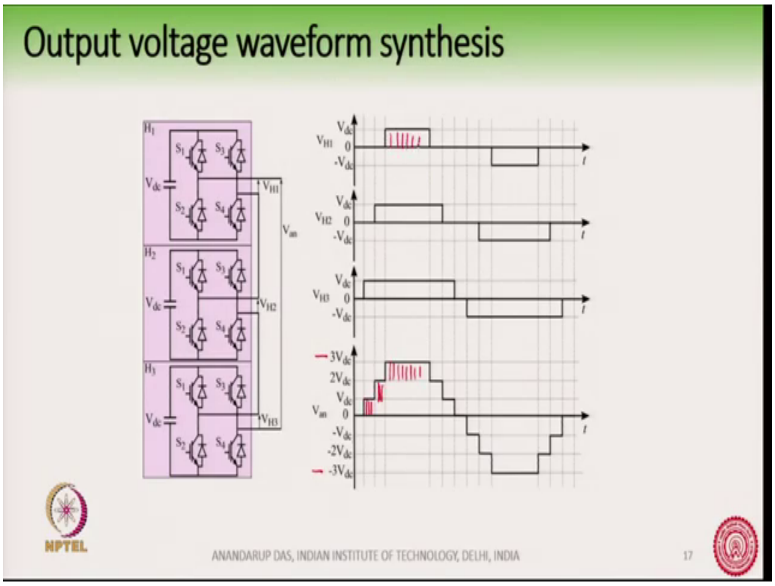
(Refer Slide Time: 00:21)




Now, we see the detailed switch implementation here. I am not going to talk about it in details because we have already covered it earlier, where you can see how the depending on the direction of current, how the switches are conducting.

So, for example, if this current is i a which is going like this then this transistor will be conducting and this transistor will be conducting here and it will produce a voltage of plus V dc ok. So, we have seen that this operation of 1 H bridge earlier in the lecture series. So, we will not go into the details, you can follow it up.

(Refer Slide Time: 01:09)



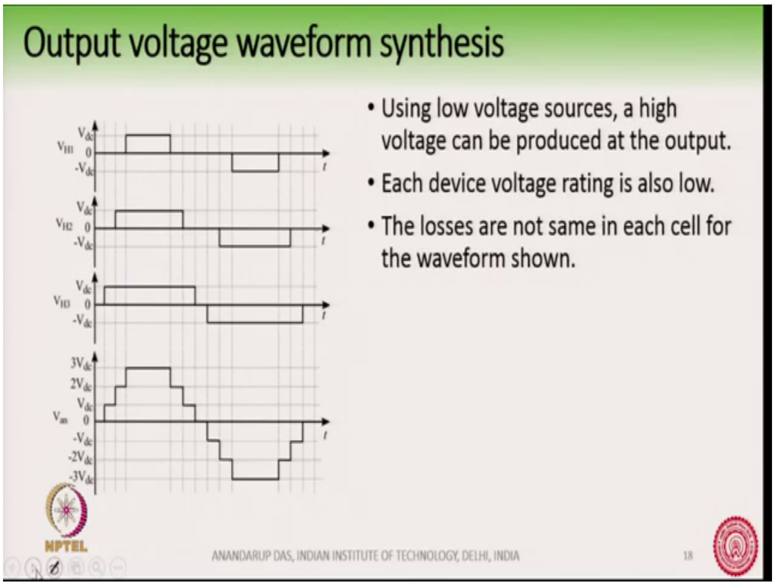

Now, so, we have understood that fine it is possible to cascade the output voltages of this H bridge. So, how do we get; so the how do we get a higher voltage waveform? This higher voltage waveform that we get is shown in these three cells a CHB version ok. So, in this case you can see that this V an is nothing, but V H 1 plus V H 2 plus V H 3 ok, sum of these three.

Now, suppose V H 1 that is the voltage produced from CHB 1 or the upper CHB is this quasi square wave like this. If V H 2, the voltage produced by the second cell is this waveform and the voltage produced by the third cell is like this waveform and since V an is sum. So, we add these three waveforms and we get to this waveform which is the total waveform V an. If you observe this V an waveform we see that the peak to peak magnitude of this V an is three times the peak to peak magnitude of V H 1.

So, it is like three V dc 2 minus 3 V dc whereas, V H 1 is V dc 2 minus V dc. So, therefore, we see by using low voltage rated igbts in each cell we are now able to produce a high voltage ok, because the transistors or igbts in this each cell is rated for only V dc ok, they are only rated for V dc like this here ok. This it is this is the rating for each igbt, but now the peak to peak magnitude of voltage that is produced at the output is considerably larger than the rating of an individual device, if we have more number of cells the peak to peak voltage in V an will also increase further.

So, this is one of the advantage of using the H bridge, cascaded H bridge that by using low voltage identical low voltage more reliable transistor igbts or transistor or switches we can get to a high voltage ok. Of course, we have not shown the PWM here ok, there is a PWM here like this we will come to that later. There is a PWM here, here, here. And so it will come here like this, we will show it later yes.

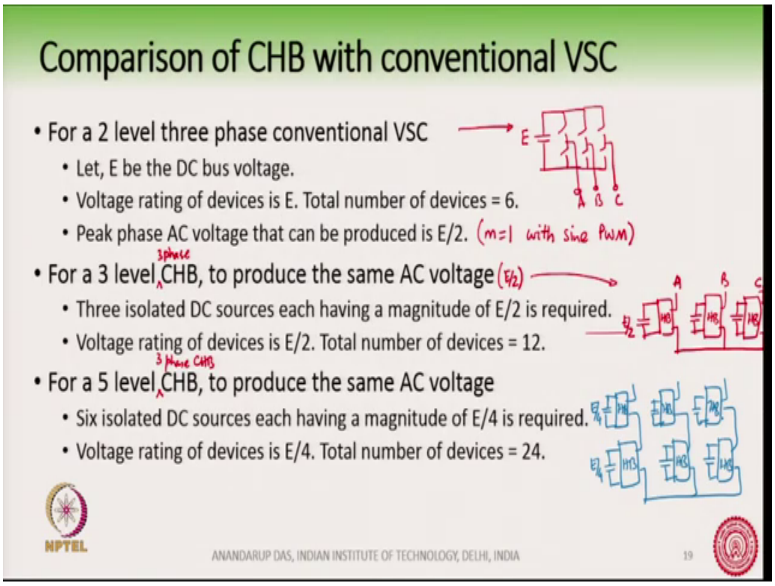
(Refer Slide Time: 04:43)




So, this is what I was talking about; using low voltage sources a high voltage source high voltage can be produced at the output where each device voltage rating is low. The one more important thing to observe is that from this waveform for this particular waveform which I have shown you can see that the losses are not same in each cell, in particular the conduction loss. Why? Because the first cell is only operating for this duration, the rest of the time it is 0. Whereas, the second cell is this and third cell is like this.

So, the switches which are operating have they are working for unequal duty ratios, in cell 1, cell 2, and cell 3 which is evident from this waveform. And so the losses which are incurred in each cell are different. And, so we have to make some special arrangement. So, as to make this losses same ok, we will see this PWM technique in particular level shifted PWM.

(Refer Slide Time: 06:13)




Suppose we make a comparison of the CHB with a conventional 2-level voltage; source convertor how do they compare with each other? So, this slide talks about that. So, suppose for a 2 level three phase conventional VSC which is this one ok, ABC here suppose. For this conventional VSC suppose if the DC bus voltage is E, that is this voltage is E then the voltage rating of all these devices are E and the total number of devices we require is 6 ok.

Now, what is the peak phase AC voltage that can be produced? We have seen earlier that suppose we use sin PWM then it is m times the DC bus divided by 2. So, the peak phase AC voltage that can be produced is for m equal to 1, that is I will say that m equal to 1 with sine PWM; which therefore, the peak voltage that can you can produce is E by 2.

Now, let us compare this with a 3 level three phase CHB. So, for a 3 level I should write here three phase CHB and for also a 5 level three phase a CHB. So, for a 3 level 3 phase CHB, if we want to produce the same AC voltage then we need 3 isolated DC sources each having a magnitude of E by 2 ok.

So, how does this look? This looks like this. So, this is one H bridge, this is one H bridge, then one another H bridge and this is the another H bridge. And then we connect them and this is the A B and C phases ok. So, for this is the 3 level three phase CHB and then we need a DC bus voltage of E by 2 why because we know that it produces 3 levels. So, it will be producing plus E by 2 0 and minus E by 2 which means that the peak voltage that it can produce peak to peak the magnitude is E and it if this is same as this E here ok.

So, if this E and that E which can be produced here are same, then the AC voltage also will be same. So, that can be produces E by 2. So, this CHB here can produce the same AC voltage of peak value of E by 2 ok. So, the same CHB, if we are if this A B phase is the peak AC voltage that can be produced at A B or C, if they are same all both in both cases with conventional VSC and with three level three phase CHB then we require the DC bus magnitude E here and the DC bus magnitude of E by 2 here ok.

But now, we require three isolated three isolated DC bus, which is not required for the conventional VSC, but again this is the disadvantage, but there is an advantage and the advantage is that the voltage rating of device is equal to E by 2 the voltage rating of all the devices in this is E by 2, but we require 12 devices because each H bridge has 4 devices, 4 transistors. So, we require 12, 4 4 4 12 devices here whereas, we require 6 devices in this converter ok.

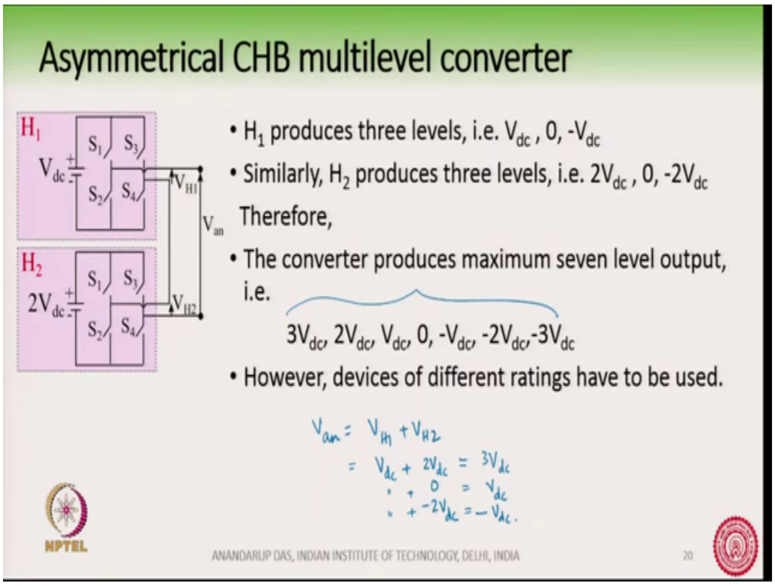
So, there is something we gain something we lose. What we gain is that we get lower rated devices of magnitude E by 2, but we require more number of such devices and of course, one major drawback is that we require three isolated DC sources in this converter. For this 5 level

CHB; for this 5 level CHB we will require two such H bridges connected together, we will have one H bridge second H bridge and third H bridge and then also another set here and we will connect it like this.

So, this is the five level three phase CHB. So, how many devices do we require now? We require 4 into 6, that is 24 number of devices here, but to produce the same AC voltage now this will be now E by 4 all voltages must be E by 4. But again the major challenge is that we require 6 isolated DC source that is a major challenge, but the advantage is we will use low voltage devices or we can say it in a converse or in a reverse fashion that if we use the same devices like a conventional VSC and a 5 level CHB then we can get more AC voltage in a 5 level CHB as compared to a conventional VSC ok.

So, these are the some pros and cons of using this converter. Now, so far we have been talking with cells having identical rating or identical DC bus. What happens if we make the voltages unequal in the 2 H bridges?

(Refer Slide Time: 14:25)



For example, we can make the voltage of H 1 V dc and that of H 2 of 2 V dc we can make it. So, then the how will V an voltage be; So, H 1 the first cell produces 3 levels which are V dc 0 and minus VDC.

Similarly, and independently H 2 will produce three levels which are 2 V dc 0 and minus 2 V dc from here, 2 V dc 0 and minus 2 V dc and 0 V dc and minus V dc from here. Therefore, what is V an? V an is V H 1, plus V H 2 and for each V H 1 we can go on adding. So, this plus this say V an is equal to V H 1 plus V H 2.

So, you take first V H 1 as V dc and then you can have V H 2 as 2 V dc you can have V H 2 as 0 you can have minus 2 V dc and this plus this is 3 V dc, this plus this is V dc and this plus this is minus V dc. So, in this way if you go on doing we will see that we get actually seven levels of voltage like this. Spanning from plus 3 vdc to minus 3 V dc with a 0 in between. So, 3 V dc, 2 V dc, V dc, 0 minus V dc minus 2 V dc and minus 3 V dc.

So, it seems to be attractive, with such asymmetrical CHB because now we are producing more number of levels and more number of levels from some discussion earlier we can conclude that if the levels are more then we will be probably going closer and closer to the ideal sine wave. So, this is seems to be an attractive solution. However, the major disadvantage of having an asymmetrical CHB is that we lose the modularity; we lose the modularity of the cells.

So, for this we need for this H 1 we will need devices of voltage rating V dc and for H 2 we need devices of double the voltage rating. So, we lose the modularity, we lose the repeatability we have to have two sets of cells available to us. So, this is not very attractive to the industry ok, because they would like to go for this mass scale production.

And remember that whenever we have double the voltage rating so we need a different gate driver board we require. So, for most likely there will be the loss distribution will most likely be different and we required a different heatsink, we probably will require a separate isolation barrier between the bus parts because the voltage ratings are different.

So, several changes in the design has to be made when this we use two types of, two types of cells. And also if you have; if you want to have a fault tolerant where you want to suppose one of the cells has been damaged and you want to quickly replace that cell then you must have two types of cells spare. For example, in this case we must have two types of devices a spare, one with V dc rating and one with 2 V dc rating.

So, losing the modularity and using different voltage rating devices is not very attractive and so although we get some advantage of having this asymmetrical CHB, but it has not been success commercially. And so we will we will not discuss this in further and we will stick to the CHB with equal ratings for further discussion.