Flexible AC Transmission Systems (FACTS) Devices
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Lecture - 08
Multi Level Inverter - II

Welcome to our 8th lectures of Flexible AC Transmission System Devices. We shall continue with the second lecture on the multilevel inverter. Now, we are discussing about the multilevel inverter to and we have started we are discussing with the capacitor clamped multilevel inverter. Now, we shall start after that so, this is the realization of the capacitor clamped multilevel inverter.

Same way here we have a this diodes, you can see that there was a diode and these diodes were replaced with the capacitor and you required to actively charge and discharge this capacitor.

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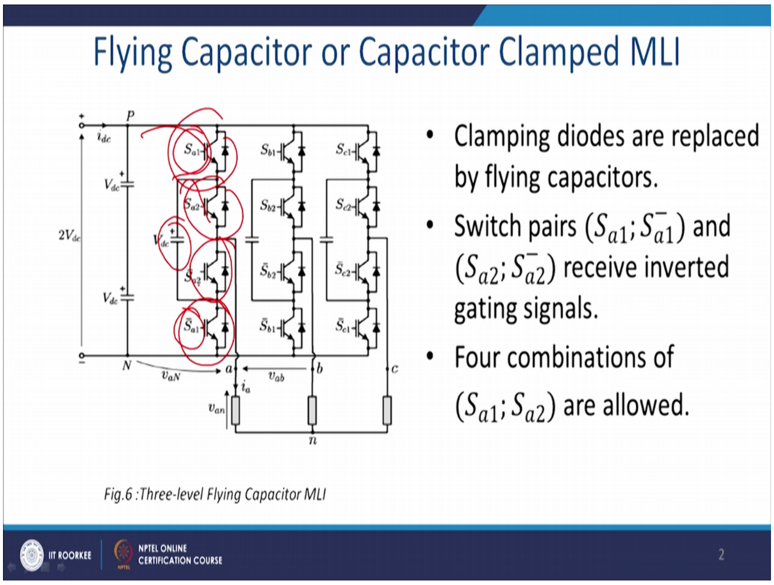

Fig.6 :Three-level Flying Capacitor MLI

So, this is the one of the requirement. So, it should charge from this or it should discharge from it similarly. Thus what is the condition? We can see here also you know if this switch is on then this switch will be off, there is a little difference in the logic here. Previously we had S 1 S 2 is simultaneously on and we generally find S 1 and this one as complementary logic here load switch will have a complementary logic.

Similarly, your these 2 switch will be complementary. So, this is the basic difference. So, here this switch upper switch this one and the lower switch will be complementary and this middle switch and this switch will be complementary. And, we can have a 4 combinations of the states and we required to charge the capacitor and so, that a different level voltage can be can we get so, see that.

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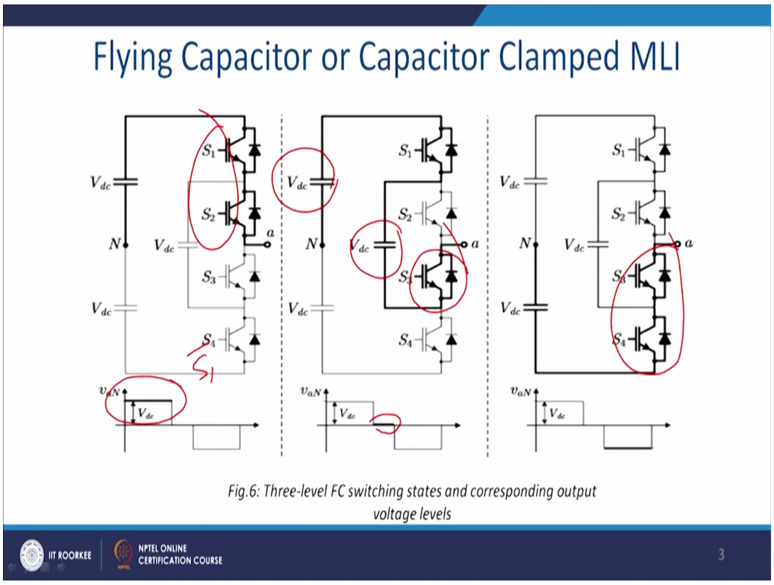

When both the capacitors when actually want to connect this point a to the high higher end of the DC bus voltage, then both S 1 and S 2 should be on and S 3 S 4 should be off. And thus you get this voltage so, later we will find it out this 1 is S 1 bar.

Similarly, if you wish to generate this 0 so, you will connect this S 1 and S 3 should be on. So, you will actually then this is the realisation ultimately this is the path and this voltage comes into the picture. So, this voltage is V dc and this voltage is V dc by 2 and since this voltage also V dc by 2. So, you are getting 0 voltages.

Similarly, if you wish it is quite simple, this voltage you get minus V dc by 2 now there is a beauty of it. Generally what we do when are 2 lower switch connect is closed and you want to generate a positive voltage 0 voltage then instead of this 3 S 2 can be turn on. So, thus this is the logic you can see that S 1 S 2 and this one is S 2 prime and S 3 and S 1 prime. So, this is the way of generating voltage.

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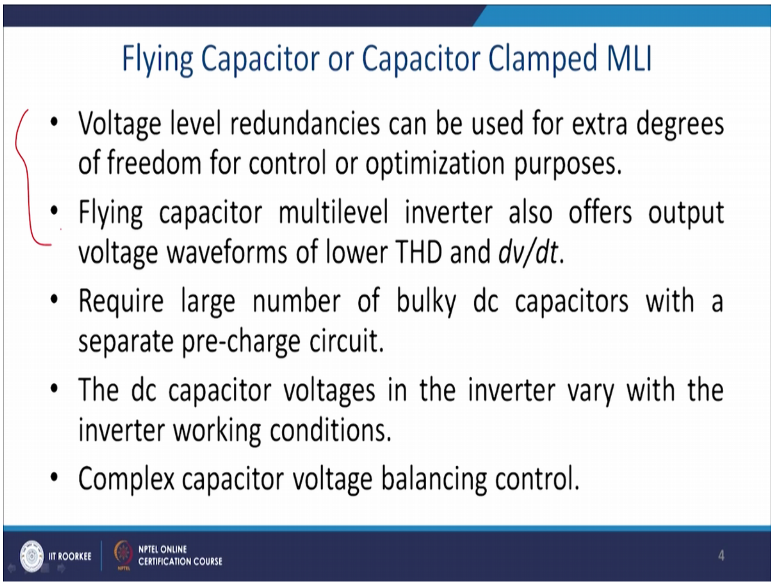

So, what are the take away of this inverter voltage driven redundancies can be used for having extra degree of freedom. Why? Because, we have realized 0 by these 2 switches, S 1 and S 3 we can also realise the switches S 2 and S 4. So, or S 2 and S 1 prime. So, depending on which switching state is having a lower you have some kind of redundancy in switching and thus it gives more reliability, and you can reduce the switching losses.

Flying capacitors, flying capacitor multilevel inverter also offers output voltage waveform with the lower it is same because number of level is high. So, instantaneous error voltage is less as same in case of the diode clamp inverter, but these are the 2 advantages and thereafter we come to the disadvantage.

We require large number of bulky capacitor diodes are basically sleek devices bulky capacitor and we require a separate pre charging circuits and the controller required to be operate in such a way is charges and discharges quite effectively; And with the first charging and discharging in every builder or time required very confident control circuits also.

The DC capacitor voltages of the inverter vary with the inverter working conditions. And depending on the which switches will on and we required to balance the capacitor voltage always, since we have assume that the that this flying capacitor got an voltage of V dc by 2 if it is not actually then operation will hamper, but since you used the close manner. So, you will ensure that this voltage gets this value. Now, another multilevel inverter is the cascade H- Bridge.

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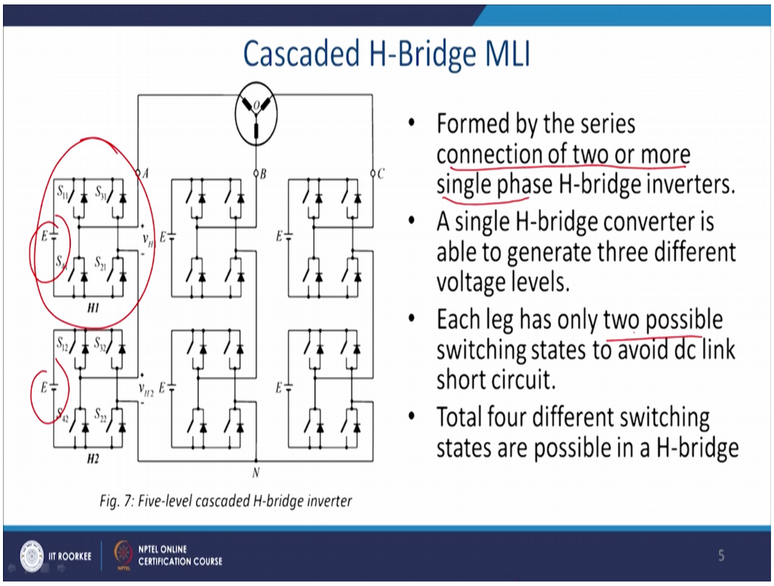

You have a you have a H-Bridge and you cascade them as many and you wish and thus you get a cascade H-Bridge inverter. Multilevel inverter we have discussed till now it is require a single source, but in this case we require a separate DC sources. So, all this DC sources required to be separate. Otherwise line short wills takes place operation will hamper.

So, what are the actually features of it is form by series connection of two and more single phase multilevel single phase bridge inverter H-Bridge inverter. Single H-Bridge converter is able to generate see different voltage level that we will see little later in next slide. Each voltage leg has only two possible switching state to avoid shorting of the DC link voltage. And so, we required to restrict it; 4 total 4 different switching is possible for these 2 inverter. So, you can get the number of states.

So, see that how does it work?

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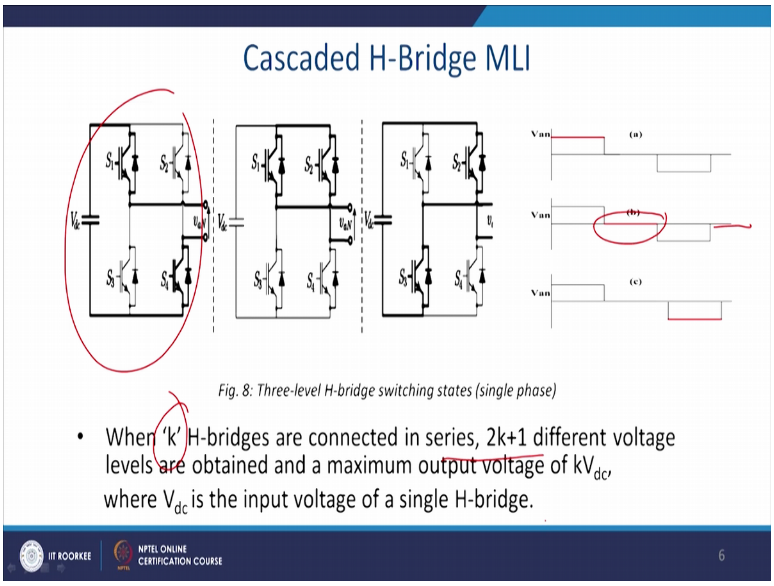

You have this switches and when S 1 and S 4 is the typical conventional single phase H-bridge inverter. So, you get van and when you close this to upper switch in this configuration you get 0. And, similarly you can have a S 2 S 3 been shorted you get minus DC bus voltage here and same way you can short that is to lower switch again you get 0 here.

And, we required to cascade both of them. So, we get a number of levels. So, for kth H-bridge if it is connected. So, you will get 2 k plus one different voltage levels. So, thus this can gives us 5 level and where V dc is the input voltage of the single bridge configuration.

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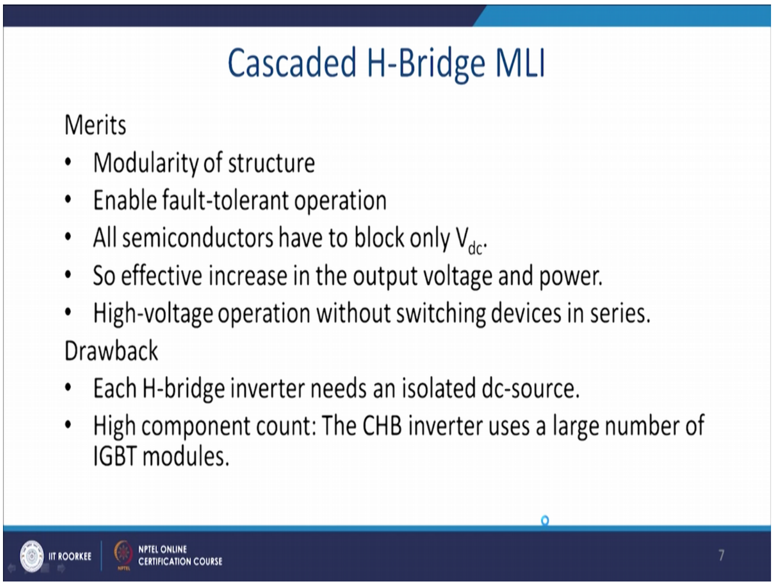

So, merits you can have a such a high degree of freedom, it is modular in structures you can add on and you can get it unable enable fault tolerant operations, because you can introduce a short circuit contradictions any of the devices all semiconductor will have a same blocking capability thus uniformity. It is so, effective leg you know it is a very much retrofittable you just increase the number of level and when voltage level change. So, you can have a same inverter configured and put into the applications.

So, increase the so, effective to increase the output voltage level and the power high voltage operation without switching, without switching devices in series this is one of the these are the few advantages of this cascade multilevel inverter.

What is drawback H-H bridge inverter requires a separate DC voltage source. Otherwise it will short the DC link voltage and it would not be able to operate properly. And high component count because you have a 4 H- 4 switches require to count. So, you have a huge number of components comes into the picture, the H- bridge uses lots number of IGBT or IGCT, whatever the switches module it is been used in practice.

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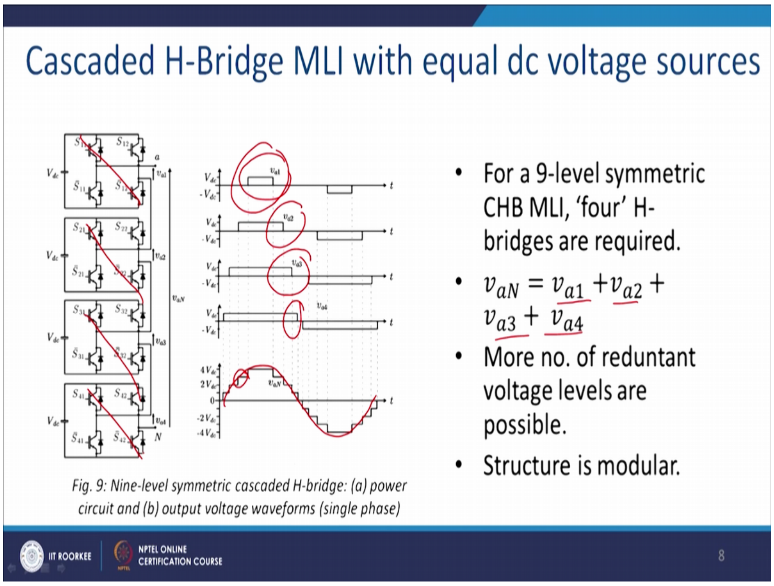

So, see that this is the applications of the 9 level multilevel inverter and so, it is simple to realised. So, you have 4 blocks. So, 2 k plus 1 it is nine-level.

So, essentially you can switch it on like that v a 1 v a v a 3 v a 4 you add them in series and ultimately you get this is the wave very close to the sine wave thus instantaneous voltage is very low, THD contain is very low, and it has got a modularity. So, 4 H- bridge is required ultimately you add on this 4 voltages you get nine-level, no number of redundant voltage level also possible and structures is modular.

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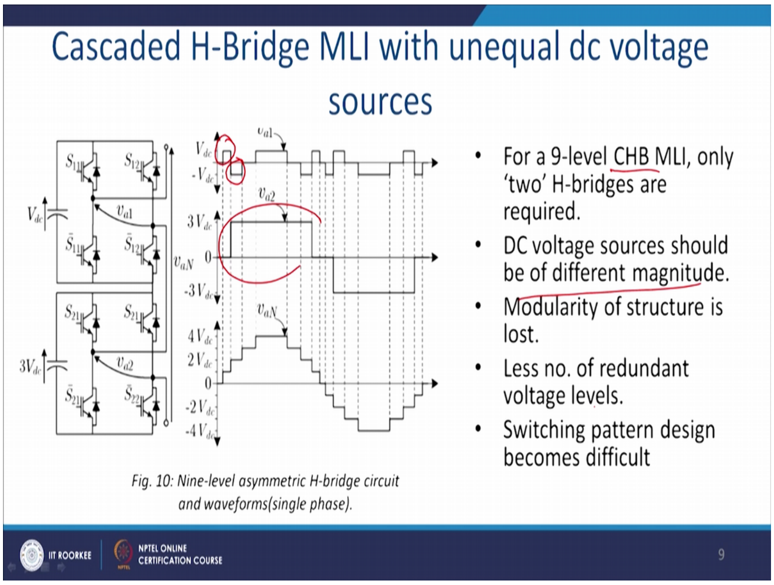

So, this is the case of for nine-level cascade multilevel inverter here is the special case we can switch in a such a way, if it is allowed a plus and minus previous case you will see that you have applied only positive voltages. Thus one combination of switching is been used, and we can generate negative voltages by it and we can increase the number of switching state by it by simple is the change is the controller pattern.

So, you can see that you can generate plus V dc and minus V dc. So, in that way you can generate different lined voltage level. So, this is the another voltage level ultimately this gives you by this by these 2 multilevel inverter can give you a nine-level.

So, DC voltage sources should be have a different magnitude modularity of the structure in this case it is lost because more handling capability of the switches will be different. So, and less number of redundant voltages, because you do not you do not have a it is problematic to have a redundancy here, but and designing the switching pattern is also little difficult, but what it helps it helps to increase the level with less number of cascade multilevel inverter. And, it is found very many applications in case of the solar inverter.

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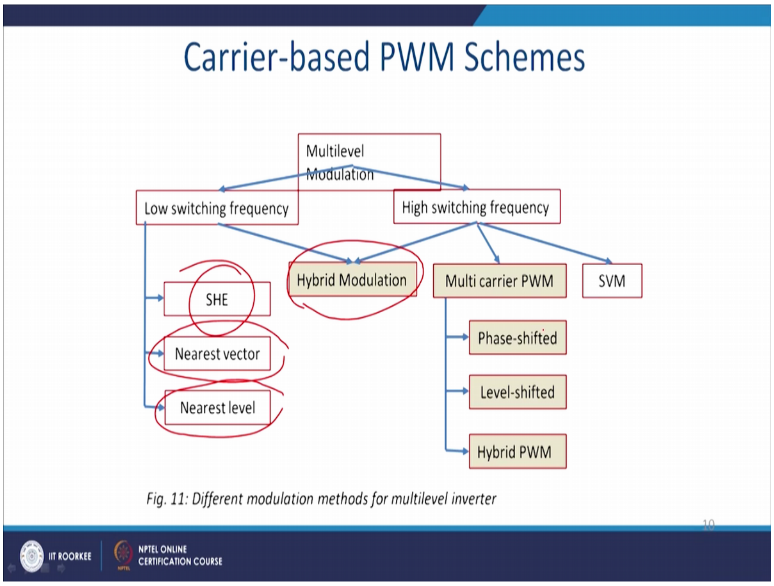

So, now, let us see we have seen the topologies, now we required to control this topology by PWM and while doing it we required to find it out. So, what are the different kind of PWM technique to what we have studied is a bipolar or the unipolar and what else here it is available extra. So, that it can effectively generate the voltage required by the application specific voltages that will required to be generated.

So, if it is a low voltage low switching frequency. So, we can go for the selective harmonic elimination it is same what we have discussed into the 2 level inverter and I it can go for the nearest level and the nearest vector. So, this kind of application we can go and we can combine both of them we shall see in our in our discussions that is hybrid modulations, we can combine she and PWM thus we can have a hybrid modulation. And we can have a career based PWM, which we have studied in 2 level inverter bipolar and unipolar. You have phase shifted level shifted and hybrid PWM. We shall see the different kind of it and of course, you have a we have already discussed 2 level SBM now we will discuss about 3 level phase vector modulation.

So, one typical example is the phase shifted PWM, where this sine will be we know that in case of the bipolar PWM we require only one V sine omega t and in case of the unipolar PWM you require V m sine omega t and minus V m sine omega t. And here it is also essentially a bipolar PW unipolar PWM is you can termed as a phase shifted PWM where phase shifting is 180 degree, but here it will be different and this is the actually the phase shift equation.

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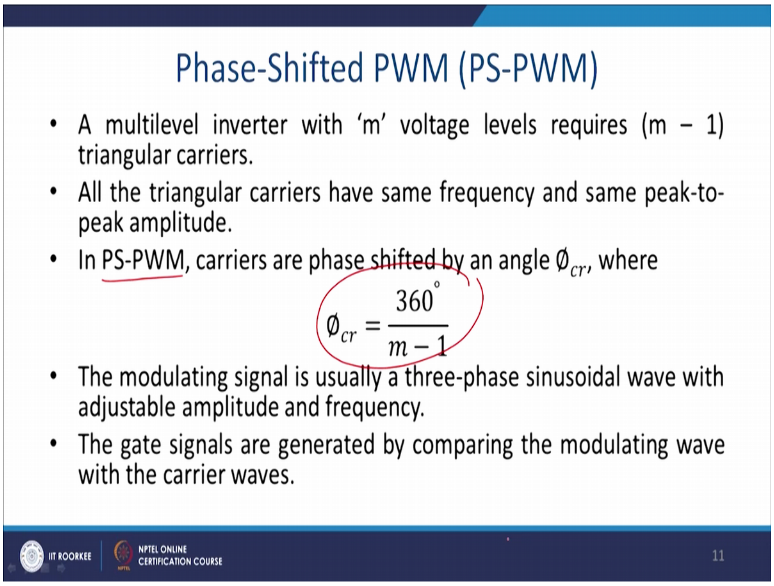

Multilevel inverter with m level requires m minus 1 triangular wave you have a 2 level inverter. So, you require 1 1 triangular carrier wave, all the triangular carrier wave have a same frequency and same peak and amplitude then relate this on a uniform magnitude of 1. And this phase shifted carrier wave is phase shifted by this angle phi cr it is given by 360 minus 1, 360 by m minus 1 is the 5 level. So, basically it will be 5 minus 1 that is 4 and so, it will be 90 degree phase shift something like that.

The modulating signal is usually a three-phase signal wave with adjustable frequency and amplitude depending on the requirement of the voltage stable and it will change. So, you have a same modulating signal and where carrier wave will be phase shifted depending on the number of level. And gate singles are generated by comparing modulating wave with the carrier wave. So, this is see the application of it.

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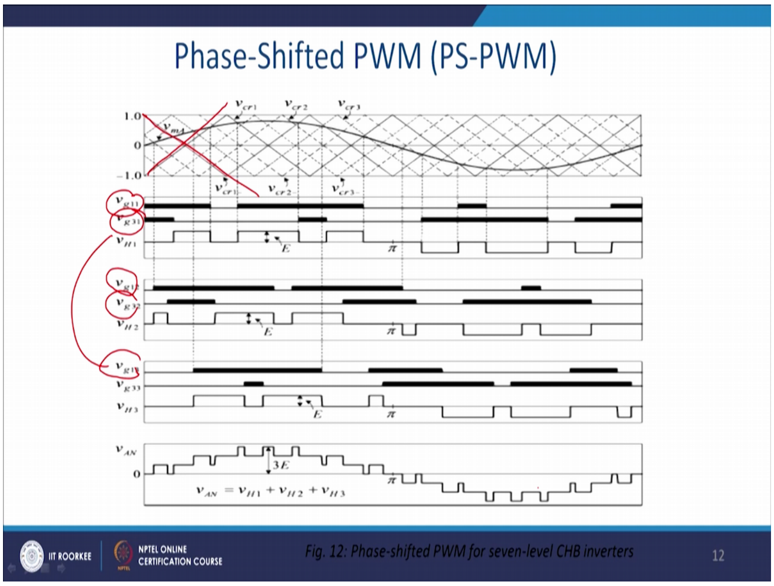

So, this is it comparisons of you can see there are many triangular waveform. So, this one it is when considered for the 3 level inverter and thus you have a 2 carrier wave. So, m is basically here these 3. So, m minus 1 is 2. So, it is 180 degree phase shifted carrier 2 carrier wave it is been actually put into the operation with a same carrier wave.

So, this stands for actually this is this will be the gate signal for v g 1 and v g 1 3. So, this will be the positive signals same way v g 1 2 and 2 3 will be given by the this gate signals. Where this carrier wave are actually 180 degree phase shifted. This will start from here and that will start from here logic is same when v sine or the v modulating is greater than the v tri upper switch will be on otherwise lower switch will be on.

So, similarly you get v 3 1 and this one and this one is complimentary and say you get v g 3 and ultimately you get the voltage v AN something like this 3 level inverter.

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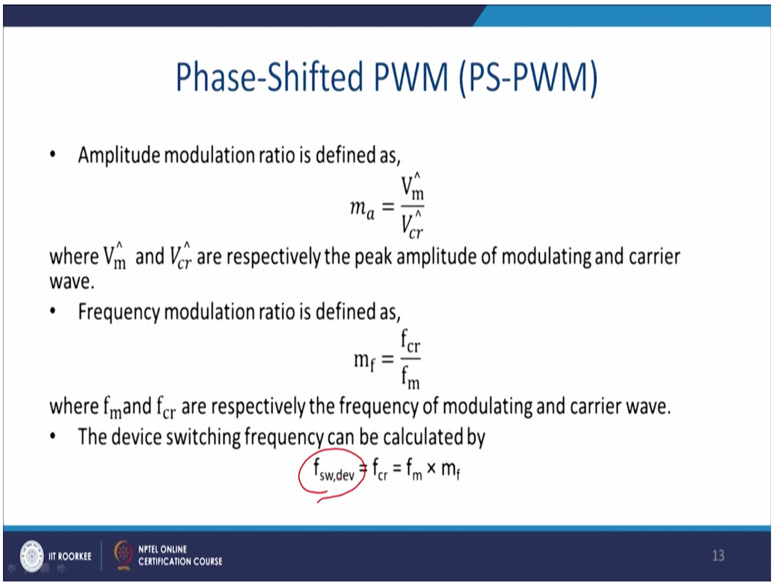

Now, what is the amplitude modulation receiver is same in case of it will be V m by V cr, and it is same for the 2 level inverter and V m and V cr the respective the peak amplitude of the modulating and the carrier wave.

Similarly, what is m f m f will be same f cr by m f and this will be the ratio and device switching frequency will be given by f cr equal to mf into f m. So, this is the multilevel here afterward. So, when you are choosing a device you should ensure that this device can sustain this switching frequency.

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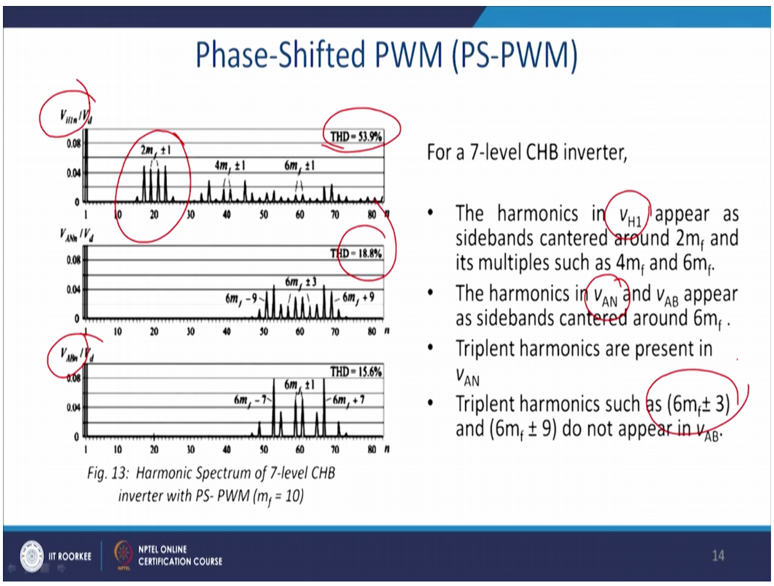

So, what spectrum you will get? You can see that voltage spectrum in line this quite high and it is it is for the 7-level cascade multilevel inverter. So, assume that actually m m f to be 20 m f to be 20. So, you have this kind of spectrum and following that. So, the harmonics of V H 1 will appear as a sidebands and concentred at 2 m f and multiple of the 6 m f this is a HI n. And, harmonics in actually face like AN and AB with appear in the sideband, you can see that this will be cancelled ultimately van will have a frequency at 6 harmonic.

So, THD will be drastically reduced to the 18.8 percent. Similarly so, ratio if you take it. So, you will find V van that is the line voltage. So, it will be further shifted and it will be it will be again it will be available in 6 f. So, you require a very small inductor essentially to eliminate this noise or eliminate this high frequency harmonics and this will be you know 15 percent.

And, this harmonic content will be actually 6 m f plus minus 3. This is the beauty of the multilevel inverter compared to this normal 2 f inverter in unipolar inverter you know that it is actually line voltage is here in 2 f. So, here it is 6 m f. So, it is actually 3 times higher the cut actually lower cut off frequencies available. So, what are the advantage of the phase shifted PWM.

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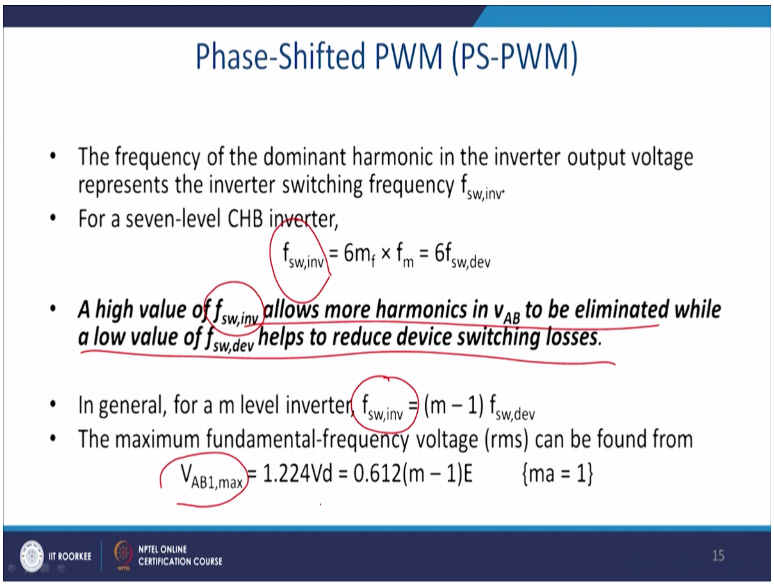

The frequency of the dominating harmonic in the inverter output voltage represents the inverter switching frequency. So, this is one of the constraint and inverter switching frequency is required to be quite high. So, for the several level multilevel inverter. So, switching frequency of the inverter is 6 f into f m and due to that high value of this value inverter switching frequency allows more harmonic in AB to be eliminated, while low value of this help you to reduce the device switching losses.

So, this is the major advantage of multilevel inverter. So, for this reason it finds more application and in FACTS device we cannot do anything we required to choose a multilevel inverter of high value, but moreover you get this add ons.

In general for a m level multilevel inverter you can generalize that switching frequency of the inverter will be m minus 1 into switching frequency of the device. So, maximum fundamental frequency and RMS can be found. So, that is basically this much max. So, it will be 1.2 2 V d d and that becomes you know assuming that it actually V d d is basically V dc by 2. So, essentially you get half of it 0.612 m minus 1 into E. So, this is the level of voltage stress available across a switch.

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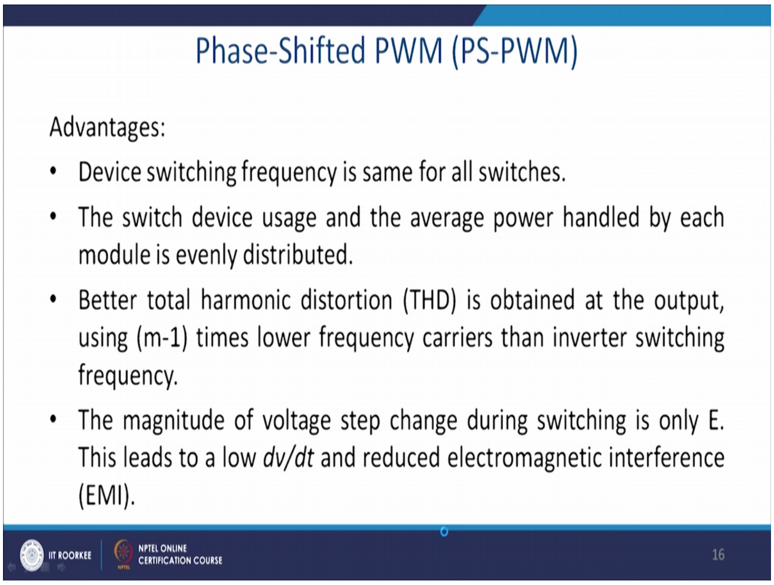

So, what are the advantage of this phase shifted PWM device switching frequency is same for the all, switch device uses and the average power handle by the each switch is same. So, there would not be any local hotspots if some switch conducts more and some switch conduct less then it will generate a local hotspots.

Better total harmonic distortion we have seen in the previous slides and is obtained at a output using m minus 1 times lower the frequency carrier than the inverter switching frequency. So, it will use effectively the more switching frequency you can say magnitude of the voltage changes in step and during this switch only E and that leads to less timidity and that also reduces the EMI MC problem.

Now, level shifted PWM. Another PWM technique now I will discuss. So, it is the level shifted PWM in case of the level shifted PWM triangular carrier waves are vertically shifted.

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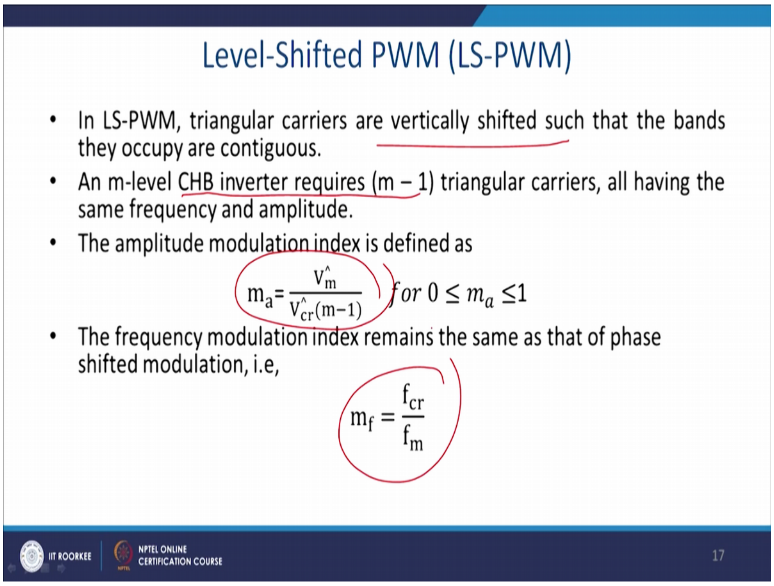

And, that band occupies a continuous one and what is how it is been occupied and m level cascade multilevel inverter require m minus 1. So, if you have a several level you require 6 triangular carrier, all having same frequency and amplitude and automatically the phase shifted by 60 degree and amplitude modulus index is defined in this case is by this. So, m a will be equal to V m by cr minus 1 where is a level.

The frequency of the modulation index remain same as that of the phase shifted modulation that will be the same basically it is just phase shifted so, m f by f cr by f m. Now this is the case so, you have 5 level so, for this reason you have a 4 carrier wave.

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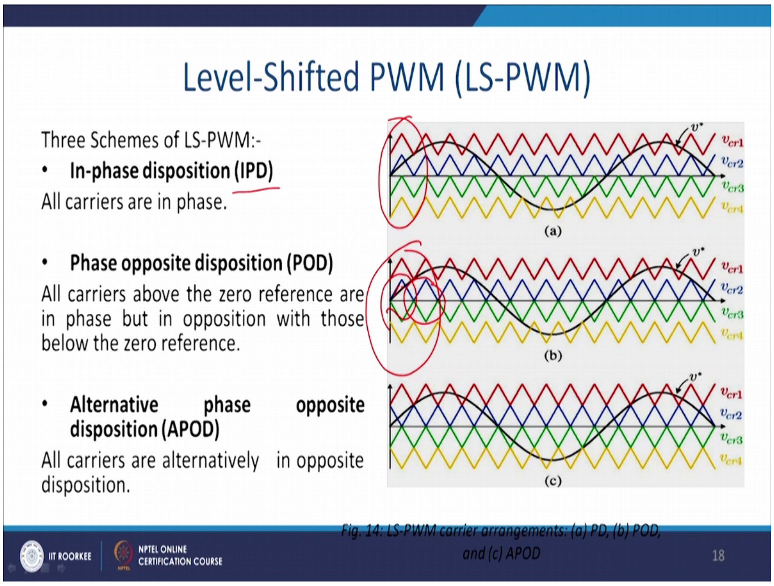

So, you can see that you can therefore, for phase shifted by pi by 2. So, there are different kind of phase shifted technique one is in phase disposition or PID all carrier wave are in same phase opposition disposition POD. So, you will find that there is a phase opposition disposition here this is actually IPD here you will find that POD, essentially this one and this one are the mirror image of it. And, this is the shifted and there is another method that is called alternative phase opposition disposition are APOD.

So, all those has it is advantage and disadvantage that required to be discuss in great details. So, that to appreciate that the PWM control technique for the 3 level inverter. So, let us see and I will give the some assignment based on it.

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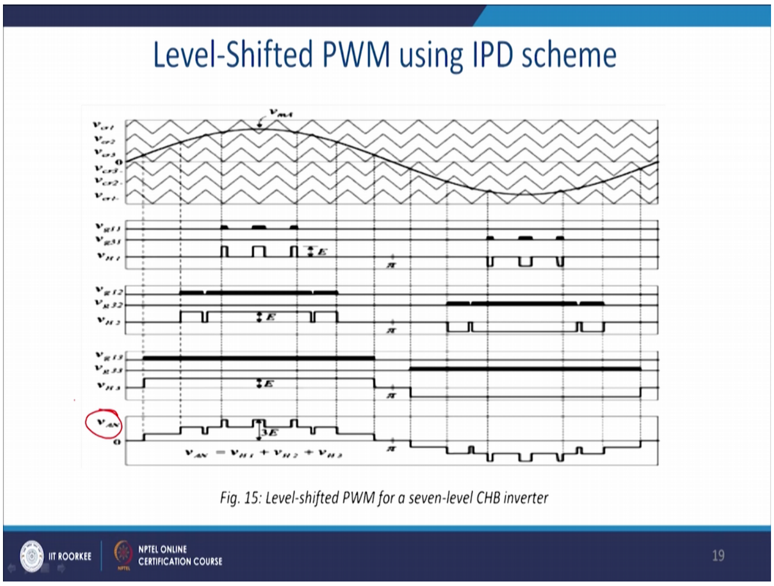

This is the modulating signal and this is the carrier wave ultimately you will get the different voltages depending on the when it crosses. So, when crosses the triangular wave. So, when triangular wave is less than the modulating wave that particular switch will be on in that logic you are having a sequence of modulating voltages and essentially this is you get a pole to the neutral voltages.

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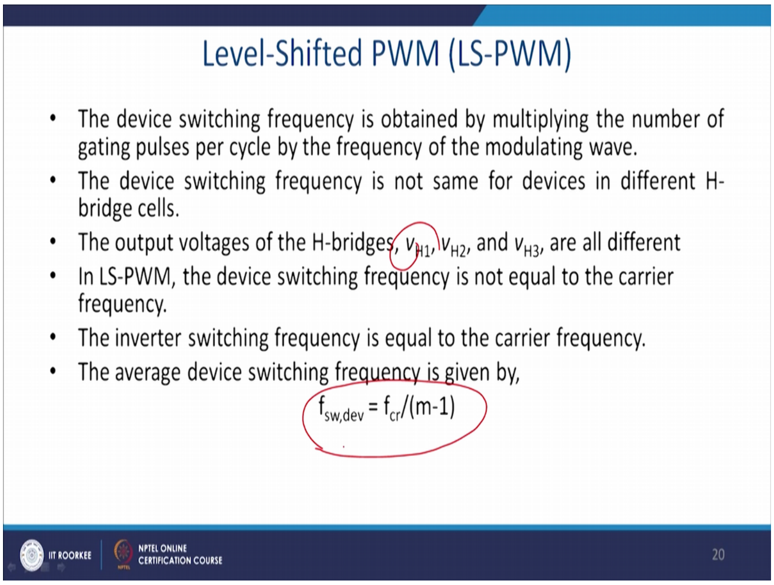

Now, in this configuration the device switching frequencies obtained by multiplying the number of getting pulses per cycle by the frequency of the modulating wave a duration of the each switches get reduced. The device switching frequency is not same in different

H-bridge this is one of the disadvantages. And output of the voltages of this H-bridge H 1 H 2 H 3 all will different. In case of the this level shifted PWM the device switching frequency is not equal to the carrier waveform. And inverter switching frequency is equal to the carrier frequency the voltage device of the switching frequency will be described here will be given by S W, dev f c r m minus 1 ok.

Now, we are coming to the conclusions for our 8 lectures; we shall continue to the different kind of PWM technique, we have discussed only the I POD. So, you have to discuss POD and APOD this kind of control technique and advantage of it and with the with our next class. And this is something we require to study from next class onward, what is the advantage of this and the level shifted PWM.

Thank you.