DC Microgrid and Control System
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Lecture - 10
Power Electronic Converters in Microgrid Applications
(Converter Modulation Techniques)

Welcome to our lectures on the DC microgrid and the control. So we shall continue our discussion in power electronics converters, application of the power electronics converters in DC microgrid. So, today we will discuss about the pulse width, different kind of pulse width modulation technique that is useful and it will be used in the DC to DC converter or DC to AC converter.

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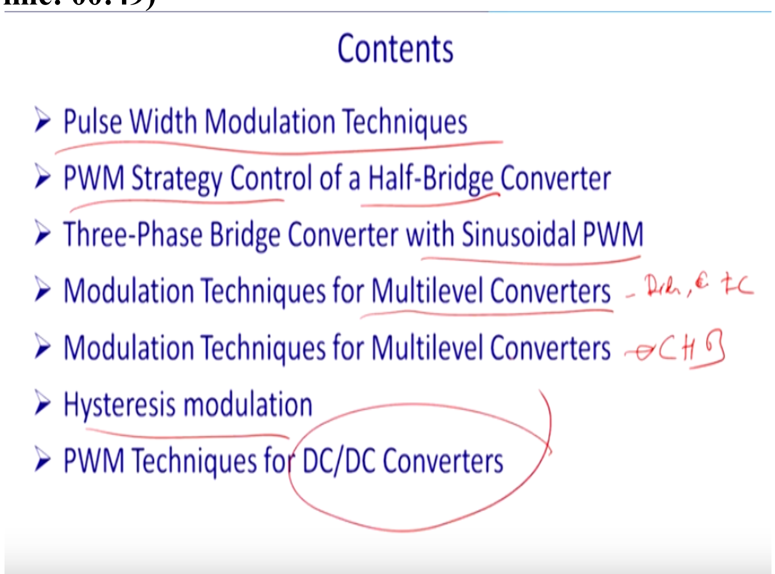

And PWM strategy for, first we will check for the half-bridge converter followed by three phase bridge converter with sinusoidal PWM modulation technique for the multilevel converter that we require to understand. And nowadays you are simulating maybe the DC microgrid and we require to understand that how you use the different kind of multilevel inverter and how you can fit it to this power electronics module to be integrated into the DC microgrid.

And apart from that modulation technique for the different kind of multilevel inverter, so that is basically diode clamp and flying capacitor FC and this one mostly will be discussed about the cascade H-bridge CHB. So these are the two changes you will make it, we will do it. Thereafter we shall see that hysteresis modulation.

And PWM technique also for the not only AC to DC converter and DC to DC converter or rectifier inverter operation, also DC to DC operation. So in order to improve the quality of the output voltage PWM technique is used.

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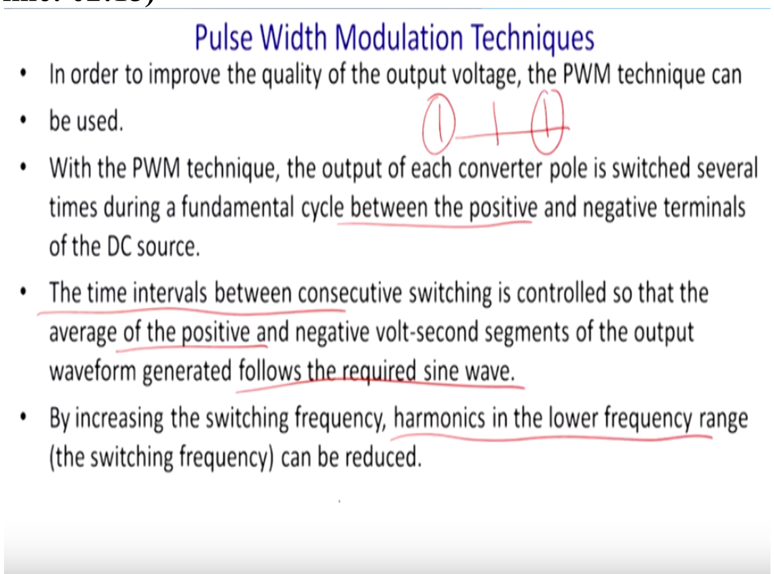

What essentially PWM does you know it shift the harmonic to the higher frequency range for the voltage as well as the current. And then since current has to since our power system is essentially a low pass filter, so this high frequency voltages you know will be reduced with the effect of this low pass filtering effect and thus you get the better THD.

So PWM technique the output of the each converter pole is switched several times during the fundamental cycle between the positive and the negative terminal of the DC link voltage. So it will switch over, for the to two level inverter it will switch over to the plus V dc to the minus V dc. If it is a multilevel inverter in different level it can be switched on.

So different kind of modulation technique require for multilevel inverter or two level inverter. The time interval between consecutive switching is controlled so that the average of the positive and the negative voltage per second segment of the output voltage is matched and thus you do not have any DC offset. Otherwise, if it is positive area and the negative media does not match you will have a DC offset.

Moreover the bolt are that you generate by the PWM should match your proper sine wave. So the waveform follows the required sine wave. By increasing frequencies, harmonics in the lower order frequency range can be reduced. Essentially it is transferred to the higher frequency range and ultimately voltage harmonic remain same, but current harmonic is been reduced drastically with the effect of the filtering effect of the power system or the size of the inductor or the filter becomes lower. So how it will be done? It is done very simple way.

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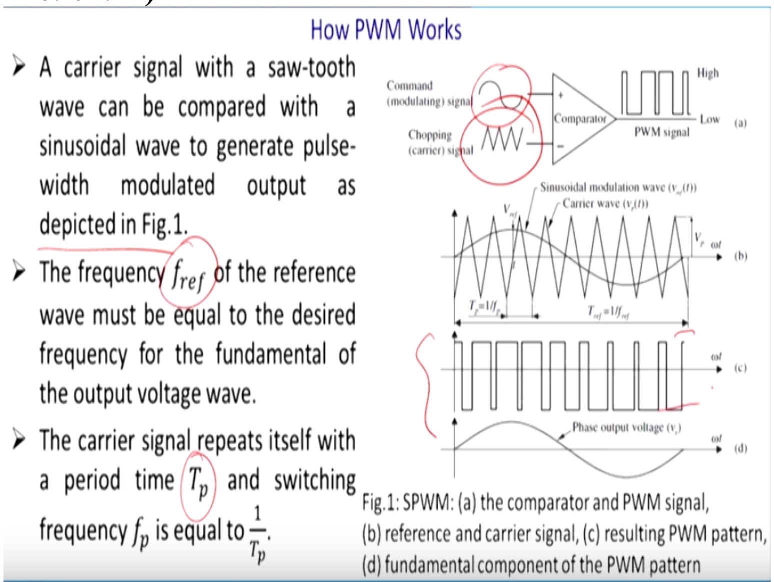

You have a sine wave and you have a different kind of modulation technique which has been discussed in the different books also by NPTEL courses of the advanced power electronics, you can refer. So this has to be compared with the triangle wave and ultimately you generate a bidirectional pulses. You can have a unipolar pulses, you can have a bipolar pulses.

This is a bipolar pulses, but we prefer to the unipolar pulses. A carrier signal with a saw-tooth waveform can be compared with the sinusoidal wave to generate the pulse-width modulated output voltage as shown in figure 1. The frequency reference of the frequency or the reference frequency RF must be equal to the desired frequency of the fundamental of the output voltage.

In case of the line operation, you require the 50 year supply. The carrier signal repeat itself with a period T p and the switching frequency f p = 1/T p. So you can have this as a reference and you are comparing with a simple, compare it in a open loop thus you are generating and ultimately inverter essentially amplify this voltages to the plus V dc and minus V dc. And when you filter it out, then you get this kind of sinusoidal waveform.

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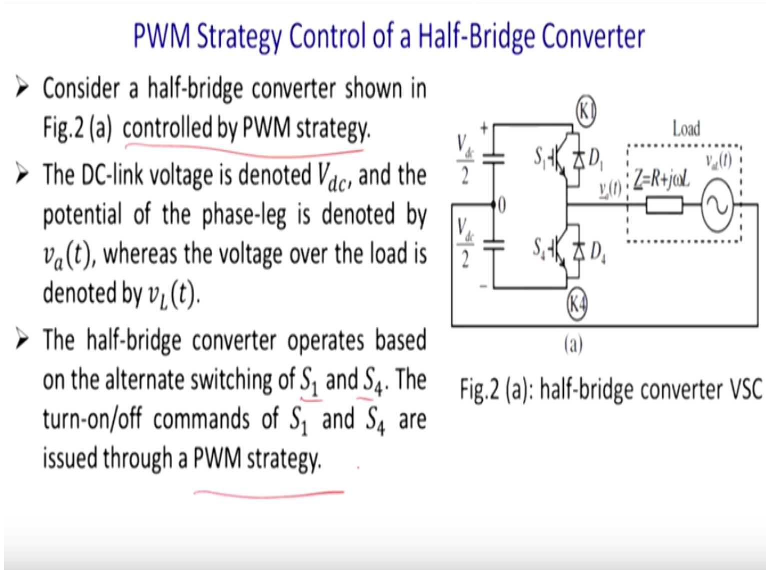

Now consider a half-bridge topology where voltage will be reduced here. Consider a half-bridge converter shown in the figure controlled by PWM strategy. The DC link voltage is denoted by V dc and the potential of the phase leg is denoted by V at, whereas the voltage is denoted by the v l. So half-bridge converter operate based on the alternate switching S 1 and S 4. The turn off or turn off comments of S1 and S 4 are used through the PWM strategy. So this is S1 and S 4.

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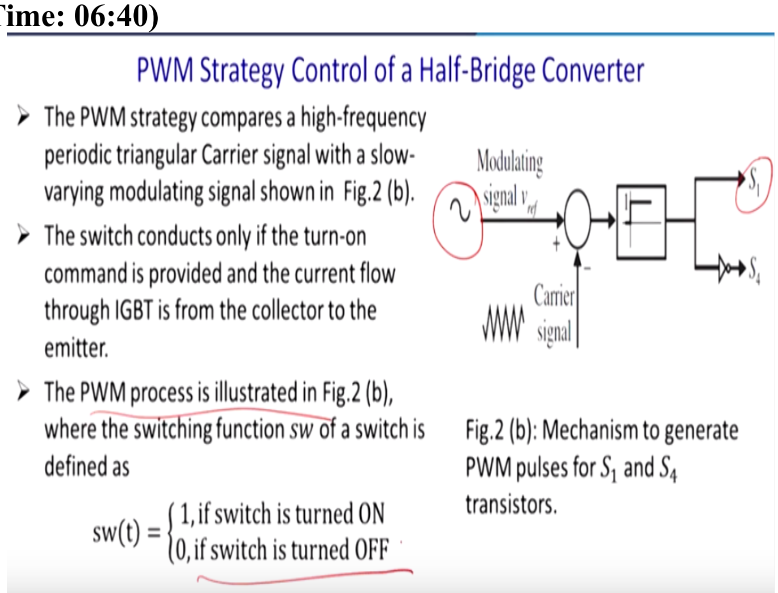

The PWM strategy compares a high frequency periodic triangular carrier signal with a slow varying modulating signal as this is around 20 times higher than the carrier signal. And if it is higher then it will be one S 1 will be on and otherwise if you not get then S 4 will be on, very simple thing. The switch conducts only if the turn on command is provided to the current flow through the IGBT or the MOSFET from the collector to the emitter.

The PWM process is illustrated in figure 2 b and whereas the switching function sw of a switch is denotes as 1, if switch is turned on and zero if switch is turned off. So this is a simple logic.

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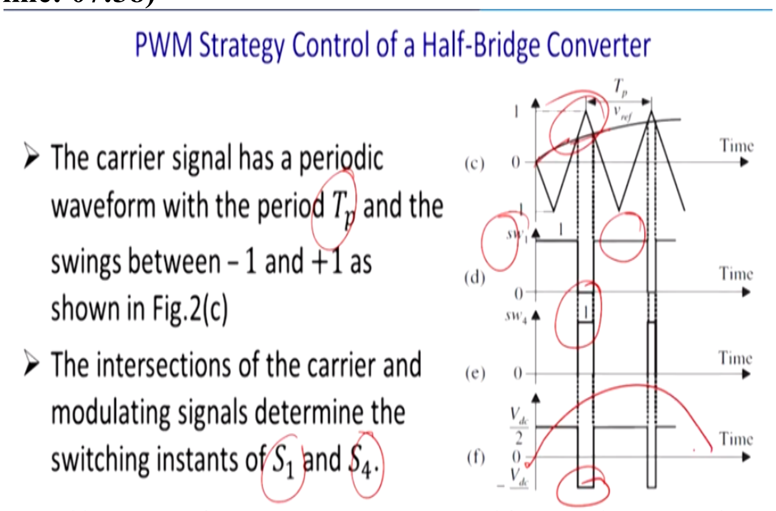

Fig.2: (c) comparison of the carrier and modulating signals; (d) switching function sw_1 of the S_1 switch; (e) switching function sw_4 of the S_4 switch; (f) phase a output voltage v_{a0}.

So PWM strategy for the control of the half-bridge converter. The carrier signal has a periodic waveform with the period T p and the swing between – 1 and + 1 as shown in figure 2 c. The intersection, so this is the intersection. This part you can see that triangle is more than the carrier and in this part totally the signal is more than the carrier. The intersection of the carrier and the modulating signal is determined in the switching instants S 1 and S 4.

So see that it is S 1 and it is on till the carrier waveform is less than the signal. Once this happens, carrier waveform will be, a carrier waveform is more than the signal waveform, thus S 1 will be switched off. And thus what happen you know, S 4 will be turned on for the small duration of time. Similarly, for this duration again T 1 will be turned on and here for this small duration of the time this will be turned on.

So what you can get essentially a bipolar voltage. So here you get plus V dc by 2 and for this reason you get minus V dc by 2 and so on and since the average is positive, so you will get you try to encircle the sine wave. This is the operation of the half bridge.

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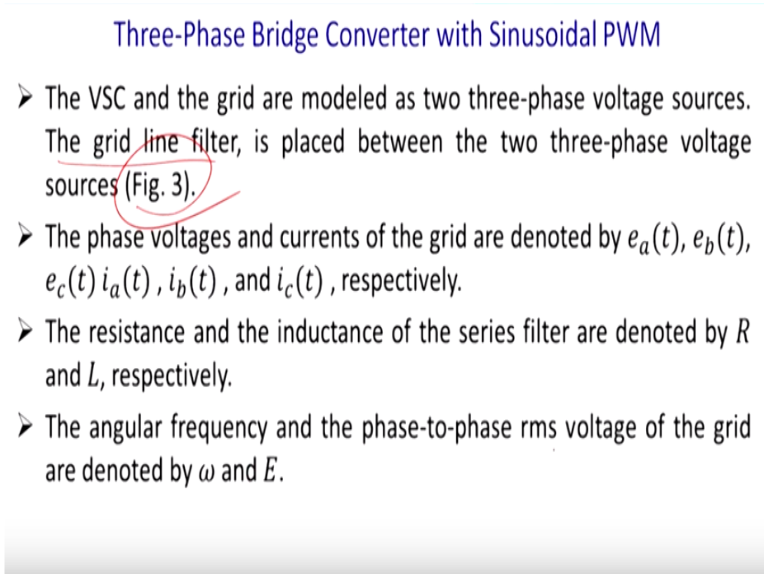

Similarly, the VSC and grid are modeled as two three-phase sources. And the grid line filter is pressed between the two phases of the voltage. We will see it in figure number 3. The phase voltages and the current of the grid are denoted by e a, e b, and e c and current cell i, i b, and i c respectively. The resistance and the inductance of the filters are denoted by R and L respectively. The angular frequency and the phase to phase rms voltage of the grid is denoted by the omega and E respectively.

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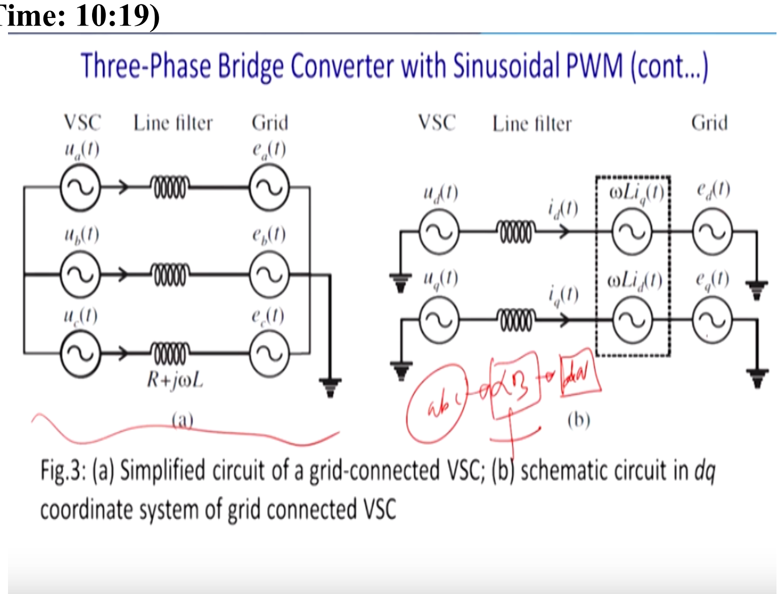

So you can consider, this is the simplified circuit for the grid connected voltage source converter. And B is essentially its dq equivalent. So what essentially we require to transform that abc parameter to alpha beta to this is called stationary reference frame of and it will have two excess and when this dq when this alpha beta is rotated in a synchronous frame then the quantities in 50 hertz become stationary.

This is a advantage of it and it is by the Clarke transformation and ultimately you get the dq. So this is for the, this is the three phase model and this parameter essentially become dc here and this is your e d and e q.

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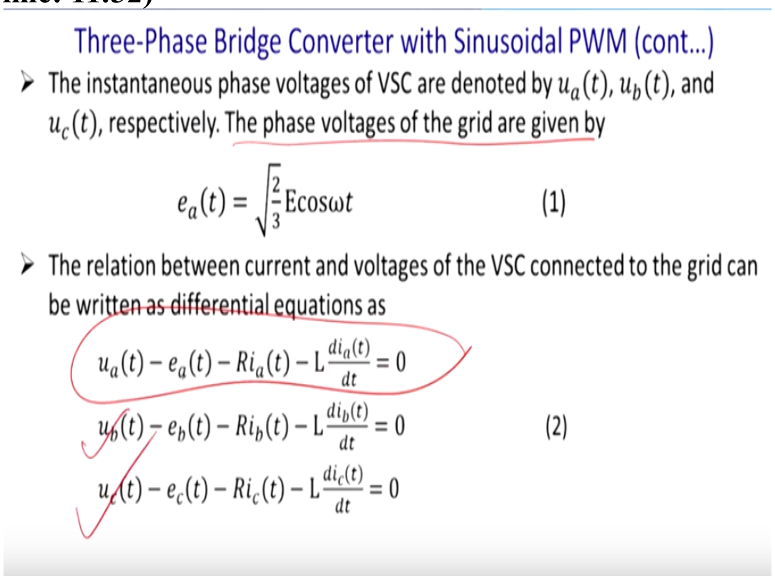

So the instantaneous phase voltage of VSC is denoted by u a and u b and u c respectively. The phase voltage of the grid are given by definitely this e a under root of 3 by 2 e cos omega t. The relation between the current and the voltage of the VSC connect to the grid in the different phases can be retained as it is. So it is u a minus that is the (()) (12:04) if it is generating. Thereafter minus i R a minus L di a t equal to zero. Similarly, for the b as well as the c phase.

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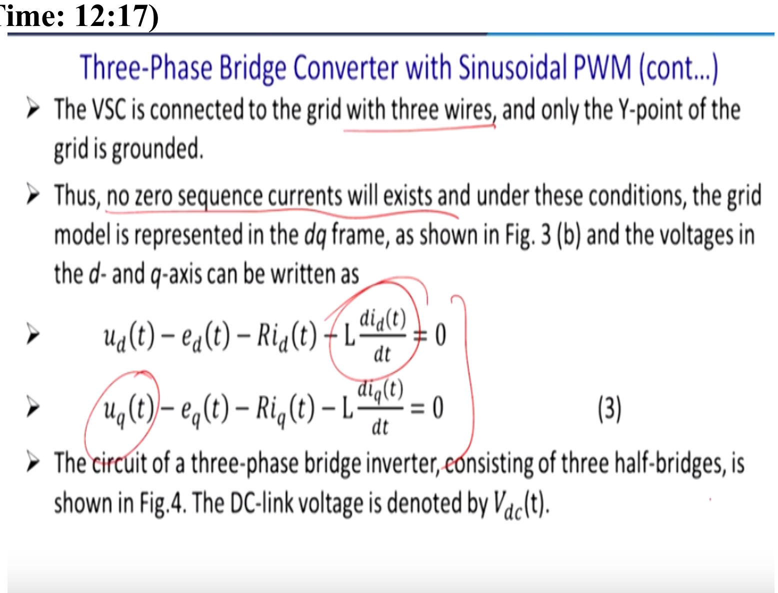

In case of the three phase bridge converter let us see the sinusoidal PW how does it work? The voltage source converter is connected to the grid with three wires and only Y point is grounded. Thus no zero sequence current exists under this condition. And grid is represented by in a dq frame as shown in the previous figure 3 b and this is the equation governing this equation. So u a - e d – i d – L di d t = 0.

So you may confuse I just told you that this parameter looks dc then this terms come. So you know actually it is reference from itself is moving in a 50 years. So thus this term will exist. So similarly, this is for the quadrature axis and this is for the direct axis. The circuits of the three phase bridge converter consisting of the three phase half bridge is shown, will be shown in the next figure 4 and let us see that figure.

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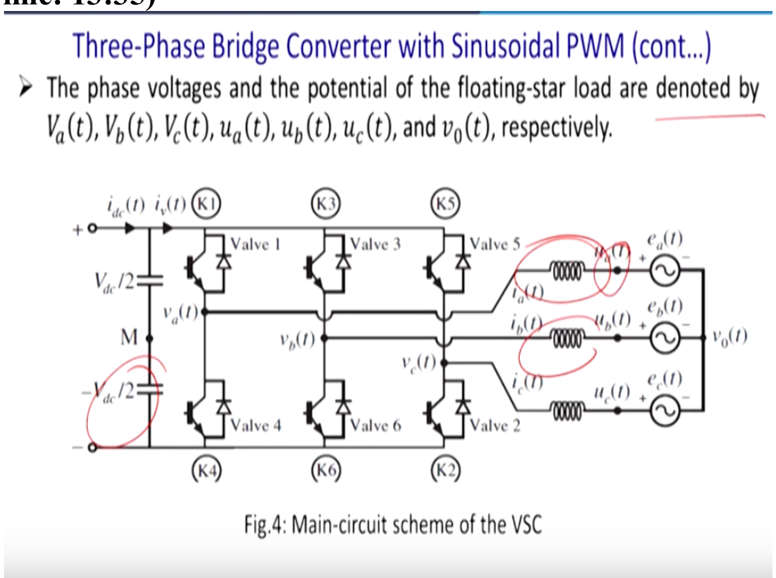

Fig.4: Main-circuit scheme of the VSC

So this is V dc by 2 and this is V dc by 2 and it can handle the bidirectional power flow. This is essentially the e a and from there, there is a source inductance or you will put some amount of inductance to have a active filter operation. And so power can be flown to this point to the DC and i c bus. If it is flown through AC to DC side it is rectifications and otherwise it is the inversion.

The phase voltage and the potential of the floating stars loads are denoted by v a, v b, v c and u a, u b, u c and v o respectively, that you can see what are the different parameter indicated. This is u a, this is V dc and all those things and this point is the terminal voltage of the output.

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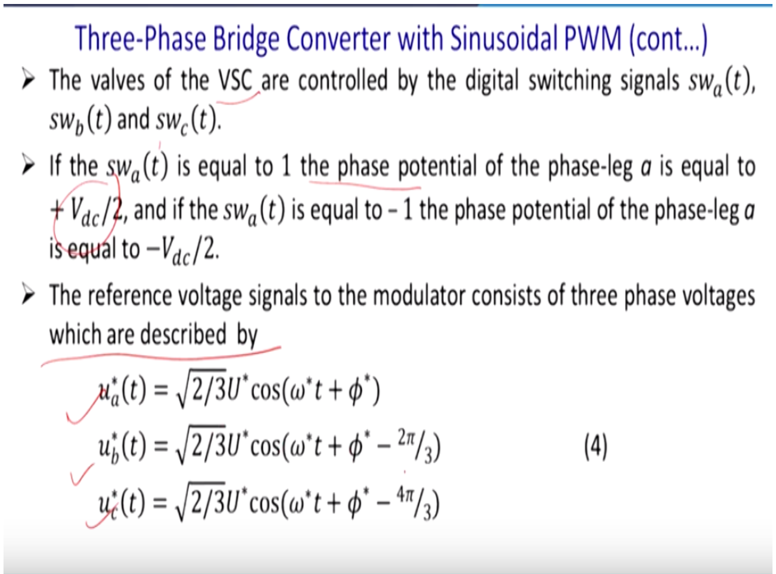

The valves or the switches, nowadays we do not use valves, of the VSC are controlled by the digital switching signal sw a and sw b and sw c respectively. If the sw a is equal to 1 then the phase voltage, then the phase potential and the phase leg actually it is V dc/2 and if sw a t is equal to – 1, then the phase potential of the phase leg a equal to – V dc./2. The reference voltage signal to the modulator consist of three phase voltages, which are can be described by u a, u b, u c and have root 2/3U cos omega t + phi, root 2/3U cos omega t + phi – 2/3 and 4/3 and so on.

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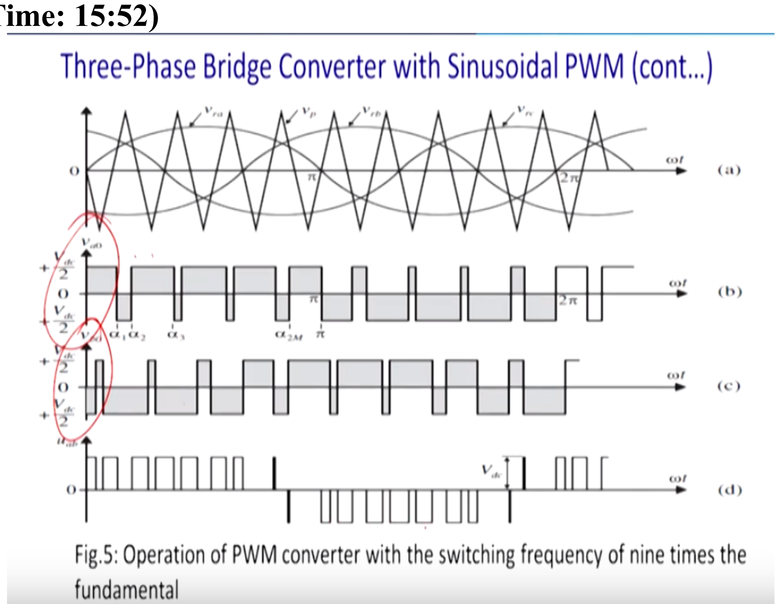

Fig.5: Operation of PWM converter with the switching frequency of nine times the fundamental

So you can see the different kind of voltage. This is the three 120 degree phase shifter 3 sinusoidal voltages. This is actually for the V ao and this is for the V o and ultimately if you subtract this and this essentially you get the line current. Thus you know negative term will cancel and you will have a unipolar voltages in case of the line voltages.

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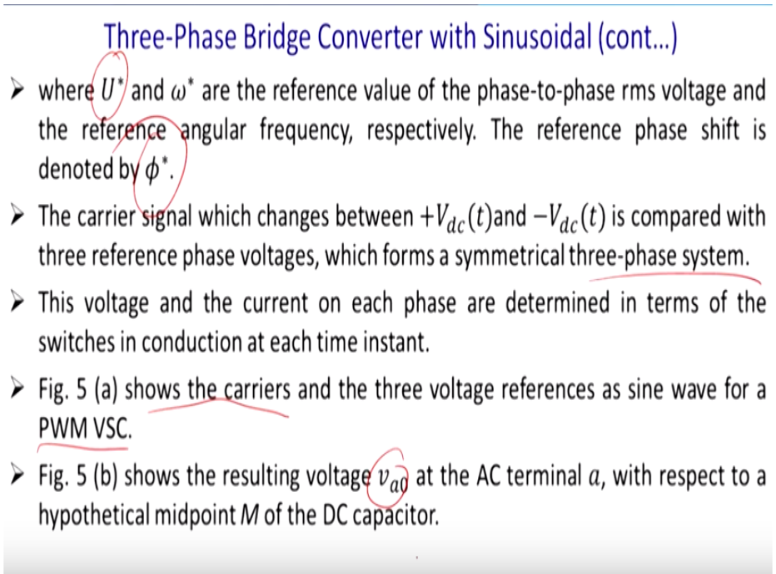

So where U * and the omega are the reference value of the phase to phase rms voltage and the reference angular frequency, the reference phase shift is denoted by phi. The carrier signal changes between +V dc to –V dc and is compared with the carrier three reference phase voltages which forms a symmetrical three phase system.

This voltage and the current on each phase are determined in terms of switches in conduction at each time instead. Figure 5 we will show little later. That the carries shows the carrier and the three voltage reference or the sine wave for this PWM voltage source converter and figure 5 b shows that v ao and the AC terminal voltage with respect to the modulation index.

So this is the phase voltages and this is respect to that. This is the pole voltages rather and this is the line voltage.

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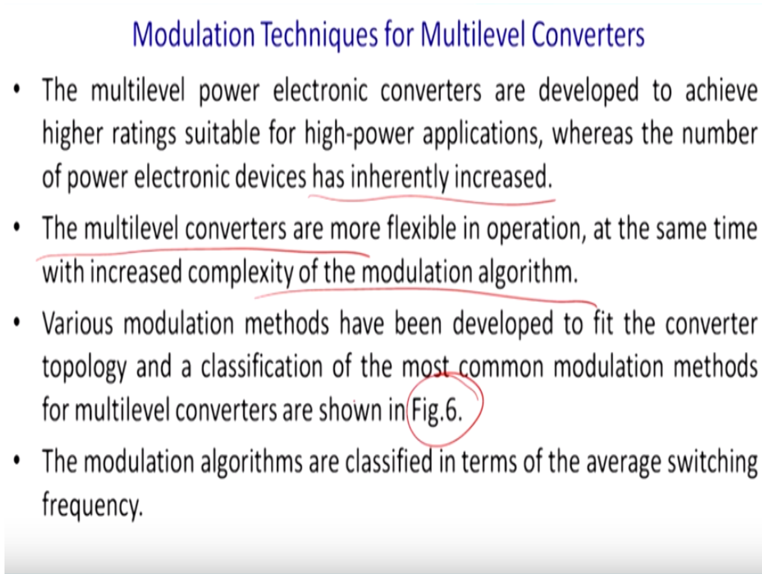

Now, let us go into the multilevel, modulation technique for the multilevel inverter. You have a different, you have a more than two levels. So multilevel inverter power electronics converter are developed to achieve higher rating suitable for high power application whereas the number of power electronics devices are increased. That is one of the disadvantage you got. But power rating of these devices is lower.

The multilevel converter are more flexible in operation because of the you can have a redundancy in the switching states. At the same time with increased complexity of the modulation algorithm, algorithm required to be more complex. Various modulating methods are developed to feed the converter topology and the classification of the most common modulation methods of multilevel converter are shown in figure 6.

The modulation algorithms are classified in terms of the average switching frequencies.

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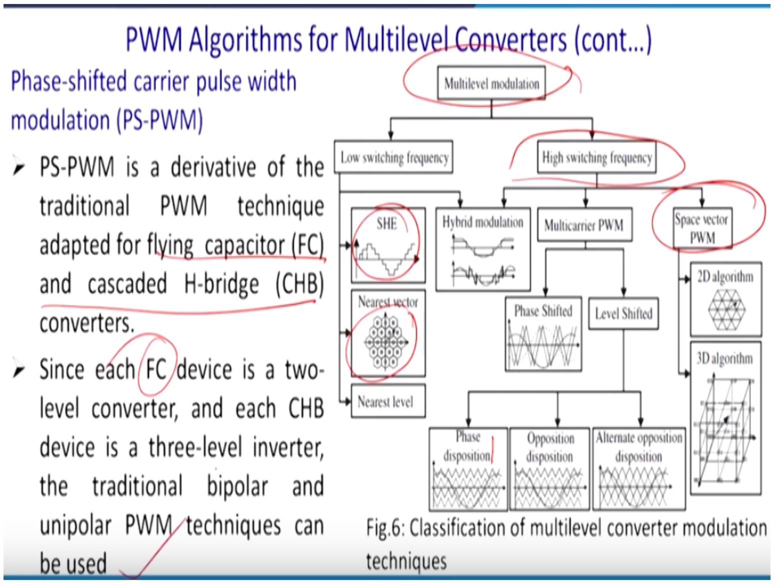

So this is the block diagram of it. So we will show the different kind of switching strategies. So we can have the multilevel modulation technique. One is, if it is a low frequency you made by the GTOs or even ACS, so you can use selective harmonic illumination and you can have a nearest vector phenomena and also nearest level. And you can have a high frequency switching pattern. One is hybrid modulation.

So that is basically you can use the SHE and both combined. Thereafter you can have a multicarrier PWM. These are phase shifted PWM, it is phase shifted by 60 degree or something or whatever the level. So and you may have a level shifted PWM. So the level shifted PWM, one is actually phase disposition. So this carrier are in a same phase. Phase opposition disposition.

So these are anti-phase and alternate phase opposition disposition. All the permutation combination is possible and all has its own advantages and disadvantages even at a different kind of modulation index. And you may use space vector modulation that is properly used now. This is the 2D algorithm and this is a 3D algorithm. So what happened here based on this hexagon will increase based on the level and we have a different switching pattern here.

And of course, this hexagon can have a many states. Space vector modulation has one of the advantage that it utilizes the better DC link voltage and for this reason and switching stress is less. Of course, same can be done by the (()) (20:57) injection. But instead of doing that you can achieve that same features in case of the space vector modulation.

Thus PS-PWM or phase shifted carrier PWM is a derivative of the traditional PWM technique and update for the flying capacitor and cascaded CHB application. Since the each flying capacitor device is a two-level converters and each CHB devices is a three-level inverter, so the traditional bipolar and the unipolar PWM techniques are used. So this is the catch here.

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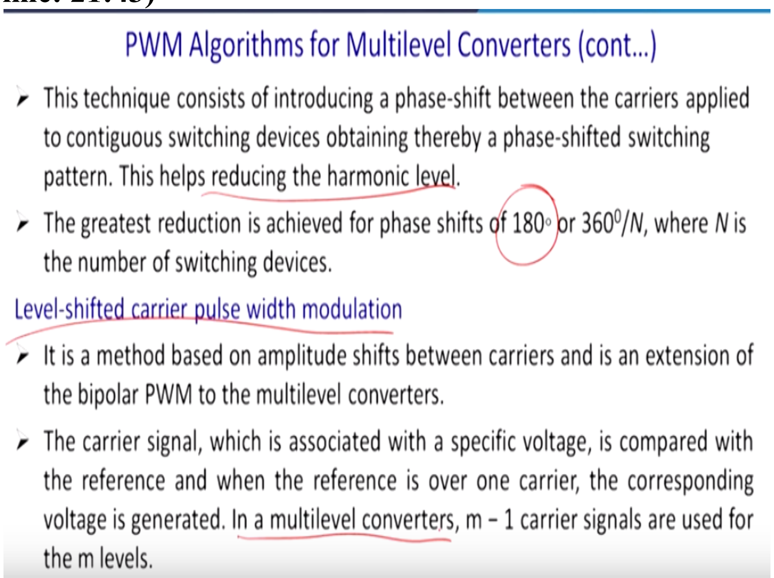

And apart from that this technique consists of introducing a phase shift between the carrier applied to the contiguous switching devices obtaining hereby a phase shifted switching pattern helps to reducing the harmonic level. The greatest reduction is achieved for the phase shift is 180 degree or 360 /N where N is the number of level, number of switching devices.

And phase shifted carrier pulse width modulation, this is the method based on the multiple shift between carrier and is an extension of the bipolar PWM to the multilevel converter. The carrier signal which is associated with the specific voltage is compared with the reference and when reference is over one carrier the corresponding voltage is generated. In a multilevel converter m 1 carrier signals are used for the m levels.

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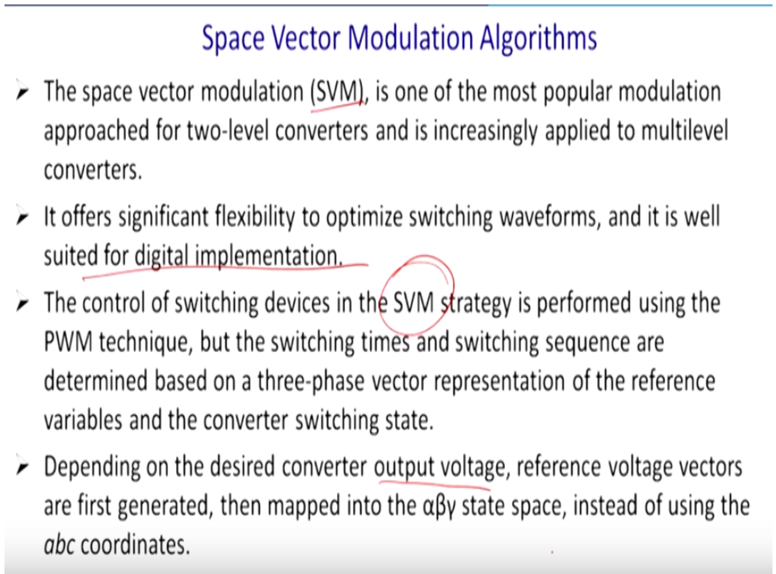

The phase vector modulation or SVM is one of the most popular modulation approach for the two-level converter and increasingly applied to the multilevel converter. It offers significant flexibility to optimize switching waveform and it is well suited for the digital implementation because it is a one and zero format.

The control of the switching devices in space vector modulation strategy, this is the space vector modulation, is performed using the PWM technique, but the switching times and the switching sequence are determined based on the three phase vector representation of the three phase vector representation of the reference variables and the vector switching states.

It has been discussed into the advanced power electronics courses. You can refer to the YouTube or you can refer to the books of Ben Hur and other this thing has been covered in detail. Depending on the desired converter output voltage reference voltage vectors are first generated then mapped into alpha, beta if it is a three dimensional space, alpha, beta, and gamma state space instead of using the abc coordinate.

Now next come to the, is a very important topic the space vector modulation, is a different kind of algorithm. The number of states depend on the number of switching devices in the converter.

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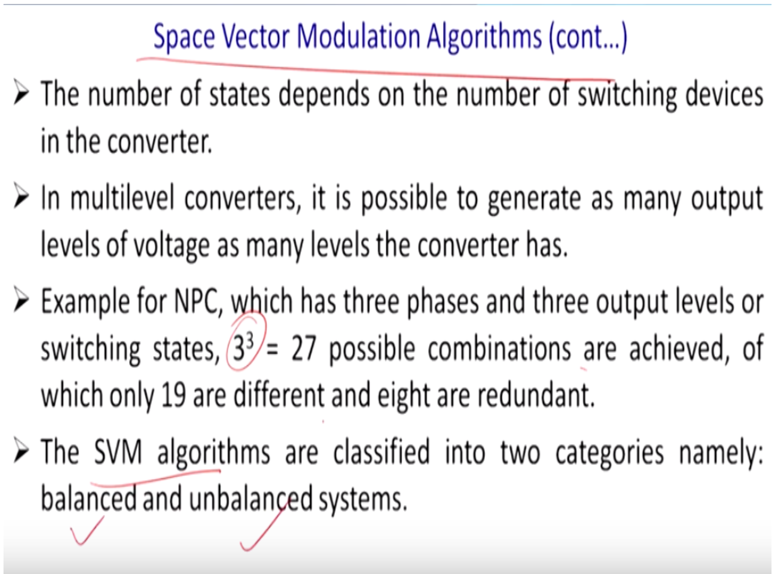

The multilevel converters is possible to generate as many output levels of the voltage as many level in the converter has. Example of NPC which has three phases and three output levels or switching states are 2 to the power 3 equal to 17 possible combinations are achieved of which only 19 are different and eights are redundant. The SVM algorithms are classified into the two categories namely balanced and unbalanced system.

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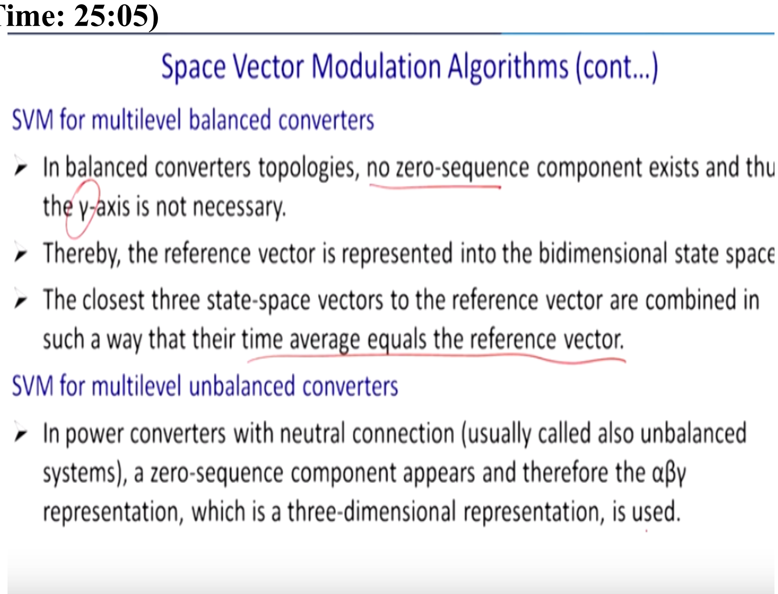

SVM for the multilevel balanced converter that is for the balanced converter topologies non zero sequence or you have if you have a three phase COS system with non zero sequence component exists thus you have another axis instead of the alpha beta. Thereby, the reference vector is represented into the bidimensional state space. The closest three phase three state space vectors to the reference vectors are combined in such a way that their time average equals to the reference vector.

In power converter with neutral connection, usually called also unbalanced system, a zero sequence component appears and therefore, the alpha, beta, lambda representation which is the three dimensional representation is used. Now come about the hysteresis modulation technique. This is a nonlinear modulation. We shall discuss little later into the class.

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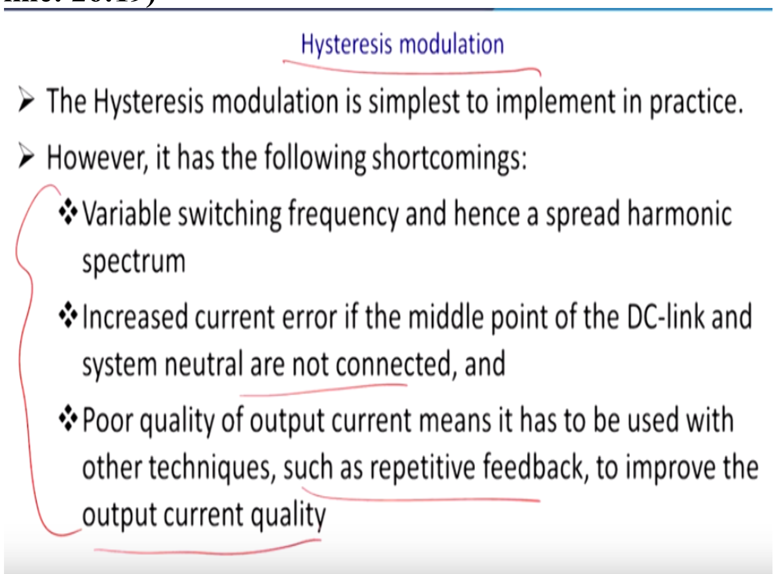

Hysteresis modulation technique is the simplest to implement and in practice. However, this has these shortcomings. Variable switching frequency enhance spread harmonic spectrum increasing current if the middle point of the DC link and the system neutral are not connected. And thereafter also poor quality of output current means it has to be used for other techniques such as repetitive feedback to improve the output current quality.

And moreover the designing challenge since it is a variable frequency operation, so we require to put a inductor as you have seen in the rectifier, active rectifier. So designing inductor is becoming challenging and other issues.

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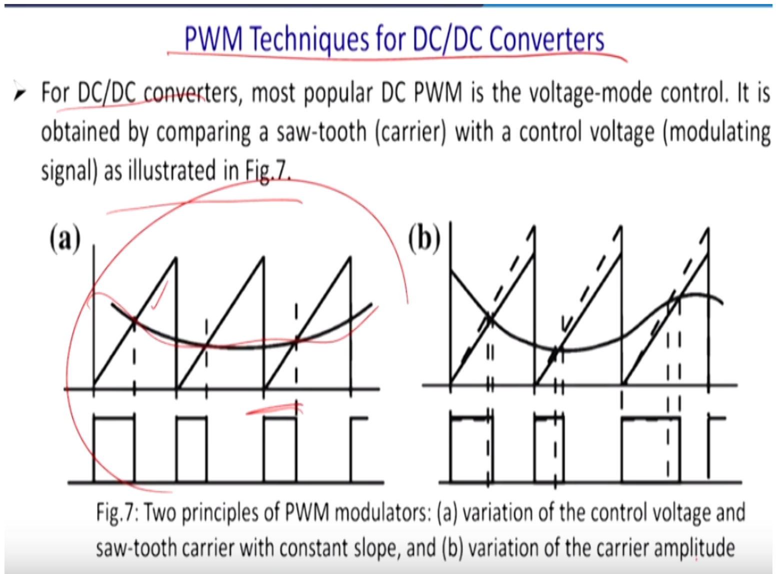

So now we will touch upon that PWM technique for the DC to DC converter. Now we will have a DC that is let us consider that non isolated DC to DC converter. So DC to DC converter most popular PWM techniques also used. It is obtained by comparing the saw-tooth waveform. There you had a triangular waveform Here you use a saw-tooth waveform with control voltage signals as illustrated in the figure 7.

So this is the your saw-tooth waveform and this is your maybe the capacitor output voltage and it is swinging like this. Ultimately what will happen? You can see that this is the duration and this duration changes. And you will have a different kind of switching pattern based on that you will be switching on. Generally what happen here, you can see that there is a error, since we will compare it.

So here this much of error was more here and thus, you will have a different off time. So switchovers maybe on here. Thereafter, you can see that this has been reduced. So ultimately switch will be off for the more time. Again here error has been increased. So you will change the duration of the switching. Another aspect is that the b type, you can also ferry the carrier wave, depending the error.

So it is called a variation of the carrier wave amplitude, that is also possible. Mostly we use this pattern. This is a simplified version and easy to operate.

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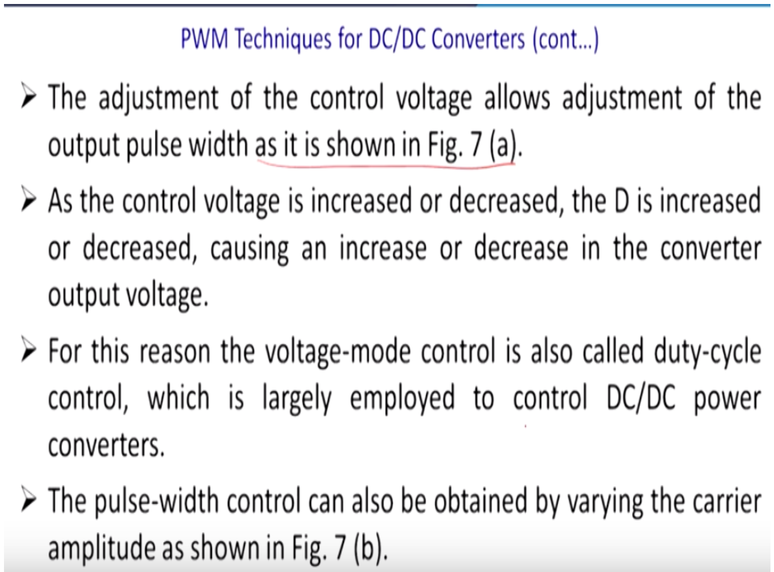

The adjustment of the control voltage allows the adjustment of the output pulse with as shown in the figure 7 a. As the control voltages increase or decrease, the duty ratio is increased and decreased causing an increase or decrease in the converter output voltage. For this reason the voltage mode control is used is called duty cycle control, which is largely employed in a DC to DC converter.

But we will have a faster current loop to compensate. We will see in detail in the future courses. The pulse rate control can also obtained by varying the carrier amplitude as shown in figure 7 b. So we shall carry our discussion with DC to DC converter in our next class also and little bit of the control modulations. Thanks. Thanks for your attention.