Fundamentals of Power Electronics
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Lecture – 97
Single phase inverter with sinusoidal PWM

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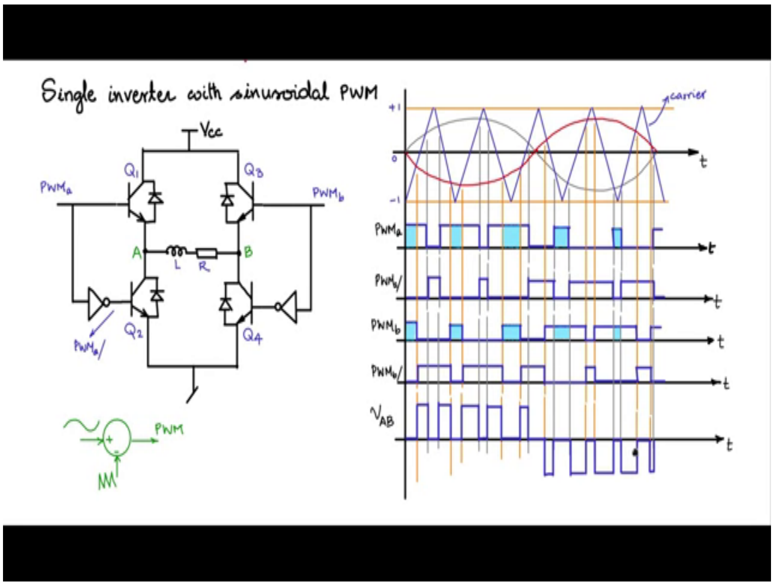

Let us discuss now a single phase inverter with sinusoidal PWM. You have already studied the full bridge circuit while studying the DC-DC converter the full bridge DC-DC converter. So, let me draw the full bridge circuit. So, this is one arm of the full bridge circuit you have a top switch semiconductor switch bottom semiconductor switch it could be either BJT or MOSFET, if there is an internal body diode for the MOSFET and for the BJT if there is no internal body diode you have to put externally this freewheeling diode.

So, you also put another arm just like this arm. So, you have another BJT set of BJT, top BJT and a bottom switch in this fashion this is V cc this is ground. So, let us call this Q 1 we will call this is Q 2 this is Q 3 this is Q 4 and in between here we will have the load. So, we will have an RLload let us say L and R. So, this is our full bridge converter. This full bridge converter depending upon the way you modulate it, it could provide DC-DC converter. If you put a transformer at center with center tap secondary or in this case you are putting LR the voltage across the centres or center points of the bridge will be AC voltage.

Now, we want to get a special quality of the AC voltage we want to get the AC voltage which is having a fundamental of a sinusoidal 50 Hertz sinusoidal. So, that when you filter it out you get back your fundamental sinusoidal PWM. So, you get your sinusoidal wave shape. So, we need to modulate the switching pattern of the switches in such a way that when you filter out the voltage waveform which is occurring here, you will get the fundamental sinusoidal wave shape. So, let us see how we go about doing this.

Now the switches Q 1 and Q 2 should be mutually exclusive when Q 1 is on Q 2 is off so, that there is no direct shoot through current. And when Q 2 is on Q 1 should be off, likewise Q 3 and Q 4 should be mutually exclusive Q 3 is on Q 4 is off Q 4 is on Q 3 should be off. Now, therefore, we can say that if this is A and B and if you are giving a PWM here what you give here is through a NOT gate.

So, it will be the inverted signal likewise. So, if we call that once PWM a likewise on this side also you have to give to Q 4 the inverted signal. So, you can say this is PWM b. So, now, how do we get this PWM a and PWM b and how do we get the sinusoidal PWM pattern across the center arms of the bridge voltage vab. So, let us have a look at that.

So, now let us draw some waveforms and try to understand how sinusoidal PWM can be established. Now, let us take a time waveform and let me draw the modulating signal this is suppose to be the sine wave modulating signal and it could be a 50 Hertz sine wave if it is for a 50 hertz application. Now, across A B after filtering we would like to have a sine wave shape like that. So, let us compare this sine wave with a carrier. So, the carrier is a triangular carrier which is between these two limits. So, let us draw that carrier wave form. So, the triangular carrier is in this fashion, it is between these two limits and let us say these limits this is the triangular carrier and it is between the limits of minus 1 to plus 1 this is 0.

So, in general you choose a carrier wave waveform frequency, which is greater than 20 times the frequency of this fundamental modulating signal. So, keep that in mind when you are choosing the carrier frequency. So, the carrier frequency if you choose 1 kilohertz at least 1 kilohertz for a 50 hertz waveform, then it is exactly 20 times. So, anything greater than 1 kilohertz is a good choice so, but normally the frequency of switching of these switches are much higher. So, it will be carrier frequency will be of the order of 20 kilohertz or 50 kilo hertz and the fundamental frequency is the order of 50 hertz. So, there is a sufficient ratio much greater than 20.

So, next let us plot the waveform that you get PWM a. So, we will plot PWM a. So, these are the intersection points, critical points where the modulating signal is cutting intersecting with the carrier signal. So, let us mark that points and pull that down in this fashion. So, the PWM a is generated in this fashion. So, you have a comparator plus minus. So, you are having the modulating signal sine wave given to the plus carrier given to the minus and the output of that is the PWM signal. So, which means that whenever the modulating signal is higher than the carrier, you will get a high and whenever the modulating signal is lower than the carrier you will get a low.

So, let us draw that. So, we get a low here then it goes high because modulating signal is higher than the carrier, then in this time period you see that the modulating signal is lower than the carrier let us mark that here the modulating signal is higher than the carrier. So, on you can plot draw the waveform PWM a in this fashion using this logic here.

Now, here this at the bottom Q 2 switch, we have let us say PWM a bar. So, we can plot PWM a bar which is let me drag down these critical time lines and invert PWM a to obtain the PWM a bar in this fashion. So, this is PWM a bar. So, we have the switching pattern for the arm 1 the A arm Q 1 and Q 2 given in these two fashion likewise we should generate Q 3 and Q 4 also.

Now, for that do not use the same modulating signal, see if you are giving a modulating signal to the A like this then for B you give the modulating signal which is 180 degrees phase shifted so that when this is positive peak high this will be negative peak high so, there will be voltage difference across A and B.

So, you do the following to generate PWM b and PWM b bar so PWM b. So, let us give a 180 degrees modulating signal, the same modulating signal 180 degrees pass it through a 180 degree inverter and use that compared with the same triangle do not change the triangle with the same triangle, and plot draw the PWM waveforms. So, let me mark the critical time points there is a critical time point here with the red waveform. So, 180 degrees phase shifted waveform there another critical point here; critical point here so, on you mark the points of intersections.

Now, after having mark the points of intersections use the same logic as here whenever the modulating signal is higher than the carrier you have a high at PWM b and whenever the a modulating signal is lower than the carrier, you have a low. So, we have a high here low high here a low high and low in this fashion you see PWM b.

Compared PWM a and PWM b, PWM a you have more pulses more wider pulses during the time when this is positive likewise PWM b has more wider pulses when the 180 degrees phase shifted is more positive. So, PWM b in like manner can be obtained by basic inversion. So, let us invert PWM b to obtain PWM b bar. So, this is a simple. So, now, you have PWM b and PWM b bar. So, all the switches Q 1 Q 2 Q 3 Q 4 have the pulses in this fashion.

Now, let us plot v AB let us plot v a b and across that should be the pulse width modulated waveform it should be the sinusoidal pulse width modulated waveform because it should contain within it the fundamental sinusoid that is this fundamental sinusoid which we should be able to extract by filtering. So, how does that wave shape look like? So, if you look at the waveform if you look at the potential at A it is if Q 1 is on this is Vcc connected here if Q 2 is on A is connected to ground. So, this potential v a with respect to ground swings Vcc to 0 so which will be something like the PWM waveform itself, but only the amplitude will be Vcc.

Likewise potential at B with respect to ground will swing from Vcc to 0 it will be like PWM b only the amplitude will be Vcc. So, the difference between PWM a scaled with Vcc and PWM b scaled with Vcc the difference between those two waveform should give you the voltage waveform v AB. So, let us draw that v AB and let me draw down all the critical points so that we it will be easy for us to draw the waveform.

So, now take this first part PWM a PWM b. So, PWM a the A part and the potential at b they are similar this is also at Vcc; at Vcc they will cancel and you will have 0 here. And then here PWM a is having a pulse PWM b is not having a pulse. So, you will have a positive pulse in this fashion where this is Vcc going after amplitude of Vcc. Then PWM b is 0 PWM a is 0 v AB is also 0 PWM a is having a positive pulse PWM b is 0. So, therefore, AB it will be having a positive.

Now, here you have PWM a is positive pulse, PWM b is also having a positive pulse. So, it will be 0 at the output v AB. And here PWM a is having a positive pulse PWM b is 0 you have a positive v AB and both are 0 PWM a and b are 0 at that point. So, here it will be 0 again PWM a goes high PWM b being 0 here PWM a and PWM b are same cancelled and become 0 and here you have PWM a, both are 0 here and at this point you have PWM b which is positive PWM a is 0. So, it goes negative here and you have PWM a and PWM b coming in together. So, 0 PWM b is positive PWM a is 0. So, you have negative v AB is negative and 0 here again it is negative 0 because these two cancel negative 0 so on.

So, in this fashion you get v AB which is having pulse width modulation and the this is the pulse width modulated waveform, the widths are varying according to the sign pattern, and this will have within it the fundamental sinusoid which was which was used for modulating the carrier. So, when you filter it you will get a sinusoidal wave shape out of that filtering out the high frequency carrier.

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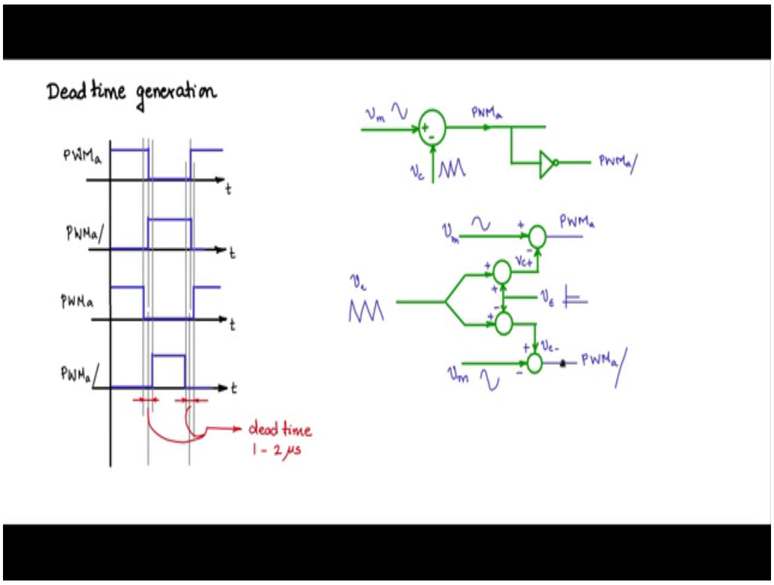

In the generation of the PWM signals for the various semiconductor switches Q 1 Q 2 Q 3 Q 4, there is a practical problem and to solve that problem there is dead time that we need to generate called the dead time generation. If you look at these waveforms here you take PWM a and PWM a bar or PWM b in PWM b bar they are mutually exclusive

180 degrees out of phase. So, when Q 1 is on Q 2 is off Q 2 is on Q 1 is off look at these two waveforms.

They definitely are inverted 180 degrees out of phase; however, the problem occurs at the transition look at this transition which is indicated as an instantaneous transition, and at the instant when p Q 1 is going off Q 2 is going on at the same instant. However, in practice in reality things do not happen the switching on and off does not happen instantaneously there is a finite time.

So, you know finite time you will see that Q 1 is going from the on state to the off state and in a finite time Q 2 will be going from the off state to the on state and in between they will be in the active region for some period of time when both will be conducting. During that time there will be a shoot through directly from Vcc Q 1 Q 2 to the ground. So, that is called the shoot through current. This is not desirable because that will cause Q 1 and Q 2 to deteriorate or you may have to overrate the devices which is not actually a good thing to do because it can be very costly.

So, in order not to have these shoot through current stresses, we provide dead time that is we turn on this a bit earlier and we turn off this a bit earlier and we turn on Q 2 a bit later so that you can fix a period for period of time call the red time period when both Q 1 Q 2 are off that you are insured Q 1 is off and Q 2 is still not started on. So, this is a problem that we need to solve. So, we are solving this by this dead time generation and let me explain to you that let me take just only PWM a and PWM b, but it is valid for PWM b and PWM b bar.

So, the PWM a and PWM a bar how do they look like? Let me just draw for one period, one switching period PWM a bar is inverted in this fashion like this. So, this is the problem this point of switchover transition PWM a is falling low PWM a bar is going high and also during these times and what is it that we expect let me make some space here. So, what is the new PWM a and PWM a bar that it should look like.

So, let me create a dead band zone let me create a dead band zone and during this zone, both PWM a and PWM a bar should be low, which means both the associated switches Q 1 and Q 2 should be off. So, which means that PWM a should go low earlier and come up later in this fashion, going down should be earlier say likewise PWM a bar should go up later and come down earlier in this fashion. So, in this fashion you have a dead band here and that is called the dead time and this can be a fix at time and it is normally very very small percentage of the on times and this is the order of 1 to 2 microseconds.

So, how do we implement that? So, normally if you take the PWM generation scheme, you have v m that the modulating signal which is the low frequency sine wave v c which is the carrier signals the high frequency triangular carrier compared in this fashion plus and minus and you get the PWM output. And that PWM a is that is inverted and you will get PWM a bar. So, this is the normal way of generating we discussed, but let us now generate with which will give you this dead time generation inherently.

So, let us first have this carrier, now this carrier this is now translated. So, let me have this v epsilon a very small DC voltage v epsilon which is added and subtracted to this carrier. So, this carrier plus and plus and plus and minus here. So, if you see this is v c plus which is small epsilon DC bias is added to the carrier here, and to this v m, v m is now compared with v c plus and that will generate PWM a.

And in another case you how v epsilon subtracted from the carrier which means it is brought down a bit translate at level translated towards the negative side average, and we that is called v c minus and that is actually added that is plus sign and v m is minus subtracted and you will get the PWM a bar. So, this is the scheme that we will use for generating PWM a and PWM a bar and if it is for the other phase PWM b and PWM b bar similar such thing. Let us just have a look at the wave shapes to understand this a bit.

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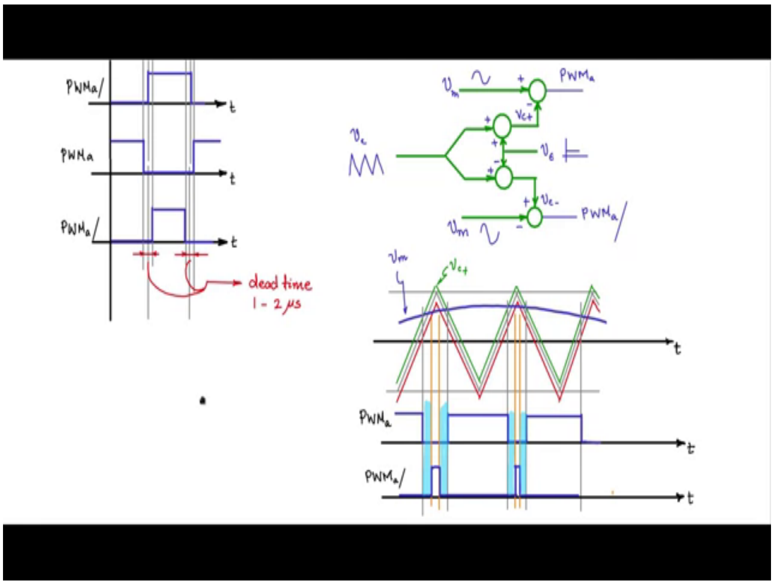

So, let me have between these two limits, what is supposed to be the actual carrier? But this is not the carrier that we will use, we will add a small epsilon to this carrier and get v c plus and v c minus. So, when you add a small epsilon v c plus will look like this, it is shifted up by a small epsilon. So, it is going to give me the epsilon is converted as a time shift here and if I subtract it v c v epsilon is subtracted from v c you will get v c minus. So, it is in this fashion it is now slightly lower.

So, you use v c plus and v c minus for comparison v c minus and v c plus is used for comparison. So, with v c plus we are doing the regular comparison of the modulating signal to the plus terminal of the comparator v c plus is given to the minus terminal PWM a is obtained. So, let us get that. So, this is the modulating signal now let me draw the crucial points here these are the crucial points where the modulating signal is intersecting with v c plus waveform the green modulating signal intersecting with v c plus modulating signal intersecting with vc plus so on.

Now, let us draw the PWM a waveform PWM a; what is PWM a? Whenever the modulating signal is greater than v c plus it will be a high. So, here it is greater than v c plus high, here v c plus is higher you get a low at PWM a then high here at this point. So, in this fashion you get the PWM a waveform what is PWM a bar waveform? v c plus is given to the plus terminals and modulate signal the minus terminals. So, whenever v c minus is greater than v m you get a high, whenever v c minus the now let me draw the waveform for v it PWM a bar and let me mark the critical points of intersection of v m with v c minus that is a red triangle.

So, whenever vc minus is higher than v m it is having positive like this. So, you see that you have this dead band a fixed set dead band as determined by v epsilon. So, v epsilon will determine what is this fixed dead band irrespective of the pulse width this fixed dead band will be given between PWM a and PWM minus. So, this is the dead band that will be used to protect or avoid any shoot through currents in the arms of the full bridge circuit.

So, in this way you can implement a sinusoidal PWM with dead band generation or a dead time generation to obtain single phase sinusoidal pulse width modulated inverter.