Fundamentals of Power Electronics
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Lecture – 71
Pushpull converter

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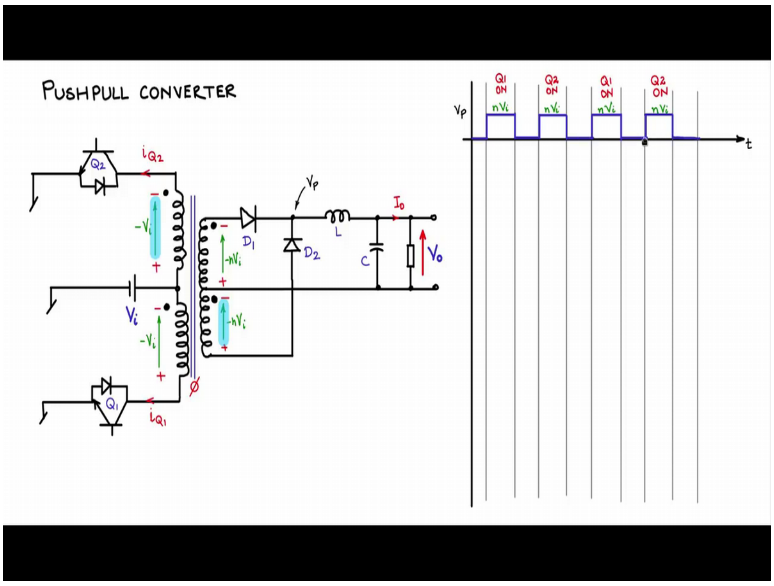

In this session station we shall talk on a 3 important converters. The Pushpull converter which I have written here, the second one is the half bridge converter and the third one is the full bridge converter.

This three converters are generally used for higher powers in order in which I told push pull converter, then followed by half bridge converters still higher power followed by full bridge converter is for still further higher powers all very high power converters are generally the full bridge converter.

Now these three converters are also buck derived converters only thing is that it is special in the sense that, they have a kind of an oring mechanism where during the 1 minus dts period also power can be delivered to the load, I will explain to that how this oring mechanism comes into play.

This is done by having a centre tap on the secondary side. So, all these three converters have secondary as centre tap. So, let us these three very important converters which are very very popular and used in many applications.

So, let us now consider the push pull converter. Let us begin by writing down the typical forward converter with demagnetizing winding; this is the forward converter forward converter primary is vi or vcc. This is the demagnetizing winding which we discussed, the diode which is used during the de magnetizing time. The de magnetizing diode and then you have the secondary.

The secondary you have the secondary blocking diode. And then you have the secondary side, the freewheeling diode where the inductor free wheels during the time when this bjt primary side bjt is off. Now we will see and the load r not connected in this fashion.

So, this is our typical forward converter, let me place the dot polarities on the primary side I have placed the dot here. Remember that the dot polarity is down below here for the de magnetizing winding. Well we want this de magnetized winding to come during the time and this switch is off.

The secondary side will have similar kind of a dot polarity like the primary, because we want the power to flow to the secondary at the time when the bjt is on. This regular forward converter which we know and you know how it operates. So, let me put a diode here, this is actually not an extra component, most of the switches the MOSFETs, IGBTs will have this internal body diode coming to the picture.

So, I have drawn this for the sake of completeness and also symmetry. Now this diode is there, let me also make that into a controlled switch. So, an IGBT and this diode is actually the body diode of an IGBT. So, imagine it in that fashion, so now you have two controlled switches. So, let us play around placing of the switches to see how the push pull converter evolves.

Now the concept is that during the time when the bjt is on the primary is energized and it will pump power to the secondary and then so on by buck converter action to the load. And during that time when the switch is off the flux in the core demagnetizes by a current flow through this diode through this demonetizing winding and into the supply.

Now, instead of pumping this power into the supply, let us pump the power into another winding and then root it in some manner into the output. So, then we can have this we can have an output which is having a higher power than as compared to the one where is oring effect does not come into picture.

Now, how to bring about this oring effect? Let us see that. And this de magnetizing winding in the forward converter is a very low power winding, it has very very thin wires and it can handle only the magnetizing current cannot handle the power currents, like the primary and the secondary. So, that is one change that you have to do, you will have to change this de magnetizing winding into a power winding and then reposition.

So, let us see how we can bring about using this demagnetizing as a power winding, and also try to steer the power through another winding into the output, rather than putting the power back into the source. So, let us first mark this, this is Q 1, this is Q 2 and this Q 1 let me shift the position in this fashion without altering the circuit in any way.

So, this is I am instead of putting it down vertical down a vertically down to ground here, I am going to place this transistor Q 1 in this fashion horizontal and make space here. So, next let me make space and let me bring the supply v i again in a horizontal fashion like this here, remove that, and now I have made space here.

Now this winding is de magnetizing winding what was supposed to be de magnetizing winding I am going to flip and pull it up like this from this common points. So, from this common point first the non dot end and then after the non dot end the dot end will come at the remote side here.

So, from that you see this diode and transistor combination switch coming in here the diode and this is Q 2 and I place the dot here. So, now I can remove this winding and this part yes. So, now it is that same forward converter transformer with de magnetizing winding by play the windings place in such a fashion that it now looks like the primary is a centre tapped common winding.

Both are on the same coarse, 1 is to 1. Now, let me for rooting power to the secondary I will replace this with another winding here, I am centre taping the secondary. And the dot I will place the dot here, and on the non dot end the diode. So, let me erase this, the non dot end diode I am not going to use any extra diode; I will use the freewheeling diode. And connect it to the non dot end, and then I will make this connection.

Now, this would be the secondary side all these winding the secondary two winding centre tap, primary two windings centre tap all will reside on the same core. So, all this is one single core, now this is called the push pull transformer, Now this power supply, I can complete it and ground that one.

So, now we will call this, name the parts this is V i, this is V naught as we have normally named V naught measured in this fashion. Then let us push it to one side because we need to draw some wave forms here to understand the operation of the circuit. Let us call this D 1, let us call this D 2 L C and this is I naught this is IQ 1. And here current flowing in through this switch Q2 is i Q2 ok.

Now to understand the operation of the circuit, let us draw the waveforms alongside here and get more inside into this operation ok. Let, me now draw series of these lines I will explain to you what these time divisions are.

Now, during this time I will say this during this time only Q1 is ON and I leave this space. I will tell you what this other spaces are Q2 is ON only during this time, Q1 is ON only during this time and again Q2 is ON only during this time.

And all other times Q1 and Q2 both are off. So, during this time when I say Q1 is on Q2 is off during the time when I say Q2 is ON Q1 is off, but in all the places where I have not written anything it means both Q1 and Q2 are off. So, that is the meaning of these thing ok. Now, let me draw one axis time and this is the pole voltage Vp and let us start by looking at the pole voltage V p.

Consider the period when Q1 is ON only Q1 is ON. So, when this bjt transistor Q1 is ON this is connected to the ground here. The dot end is connected to the plus of V i. So, Vi comes directly across this coil. So, you are having plus minus across the coil like this.

So, because all the coils are coupled on the same core, you will see that all the dot ends are positive non dot end is negative. On the secondary side also dot end is positive, non dot end is negative, the other coil plus on the dot end, minus on the non dot end.

So, let us see what is the voltage, the voltage measured in the fashion from non dot end keeping the common and the measuring probe on the dot end, you will measure Vi across this coil and by induction it is Vi across the other coil, even though Q2 is off by induction.

In the secondary side if you take a turns ratio 1 is to n, you will have n times Vi. And the other coil also we will have n times V i. Now this will be the way the voltage will be appearing across each of the coils. Now Q1 is ON, Q2 is off there is no iQ2 current, only iQ1 current is flowing.

So, the only active portion on the primary side is this, what I am showing through this cursor moment. So, this coil of the primary is active giving you a positive dot end positive V i. On the secondary side dot end positive diode D1 is forward biased. The moment D1 is conducting D2 is reverse biased, because you see that this is positive and the other end of the D2 is negative at the reverse bias over to the picture.

So, only this coil, the top portion of the centre tap secondary is active, because D1 is forward biased D2 out of the picture. So, D1 forward bias will charge up the inductor and this portion will act like a regular buck converter. So, what is the voltage at Vp; nVi will appear at Vp with respect to the centre tap.

So, it will be nVi, likewise whenever Q1 is ON; you will have a same voltage appearing nvi here. So, now consider the situation when Q1 is off only Q2 is ON only Q2 is on.

So, let us write down when Q2 is ON, the dot end is now connected through Q2 to ground dot end is ground, non dot end is positive V i. Likewise non dot end of the other coil is plus dot end minus and the secondary side non dot end plus, dot end minus; non dot end plus, dot end minus.

And the voltages that you would see measured the same direction in minus Vi on the primary side across each of the coils. And on the secondary side the n times minus nVi and minus nVi. And now, you see that D2 forward biased, D2 is forward biased D1 is reverse biased.

So, there will be a current flow through D2 through the inductor charge up and there will be buck converter operation with respect to this portion of the coil. So, you will see that this is the active coil, on the secondary side this is the active coil; there will be power transfer in through this coil to the output.

So, on at the pole you will see when Q2 is ON, you will have plus coming in here Vp nVi. We have nVi, and it will repeat for all Q2 on periods. So, if I draw in this fashion complete the waveform, this is how Vp will look like. Why do we say it is 0, why do Vp is 0 during the time when Q1 and Q2 both are off.

So, during that time you will see that the inductor is freewheeling; the freewheeling path will go through like that. Look at the curser it reaches the centre tap and then at the centre tap it equally divides into this path and this path. And back again through the diode ors up at this point and comes.

So, because the current is going one entering the non dot end, the same equal current entering that dot end in the core they are all coupled one is having ni mmf in one direction. In the other ni mmf in the opposite direction equal and opposite, because the currents are getting divided by 2 exactly. So, the mmf in the core cancels, there is no induction the voltage across the coil is 0. Therefore, potential at Vp both the diode are conducting potential at Vp is 0, therefore, I have indicated as 0 here.

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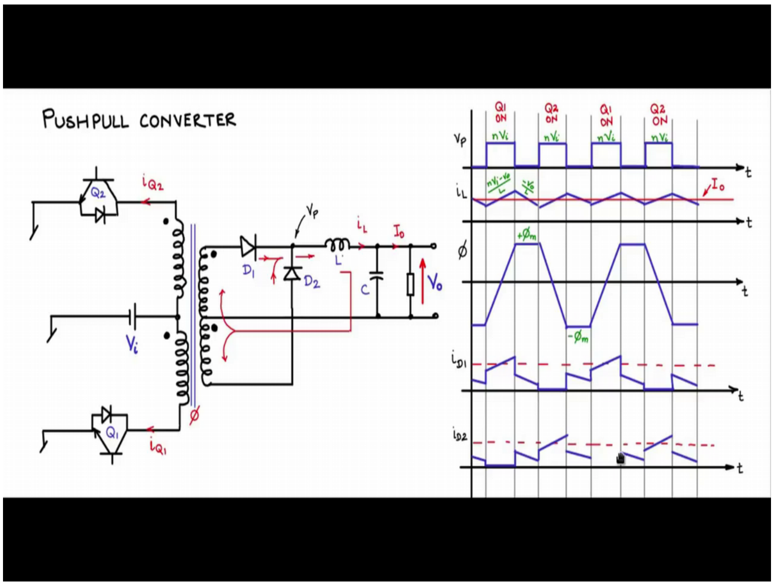

Let us now discuss how the inductor current waveform looks like? Let me mark the inductor current waveform here, iL and let us draw its waveform. This is the time axis and let me mark this label this as iL. Now, let us take this interval when we say that Q1 is ON.

So, when Q1 is ON we saw that this winding was active, this winding was active on the secondary side, D1 is conducting Vp is at nVi. And we have marked that here in the Vp wave form. So, what is appearing across the inductance? On one side you have Vp which is it at nVi, on the other side you have V naught voltage across inductor is nVi minus V naught.

And at the rate of nVi minus V naught by L you will have a current rise, because V naught is lesser than nVi you have a current rise inductance e is charging, inductor is charging. Let me mark the slope nVi minus V naught by L.

Now, during this period both Q1 and Q2 are off. So, when both Q1 and Q2 are off inductor current is freewheeling, it free wheels fast passes through capacitance and the load, goes through this line through the centre tap. And at the centre tap it divides equally into 2 half's, one going in the direction, other going in this direction they are or up at the pole point and then go through the inductor.

So, because exactly half the current is flowing through one part of the coil which is going through the non dot end, and another parts of the coil which is the dot end. The mmfs and nice cancel each other and their the flux remains at wherever it was. And there is no D phi by D t. As a consequence there is no voltage induced across any of the coils; and then therefore, Vp is 0 and we have indicated Vp 0.

But, there is V naught on the other end of the inductor coil; and therefore, the voltage across the inductor is minus V naught. So, it will have a falling slope of minus V naught by L. And then, during this period Q2 is ON and when Q2 is ON this coil is active and on the secondary side this coil is active, D2 is active Vp we saw is again nVi.

So, consequence inductance will charge up again at nVi minus V naught by L rate, and it will fall down at minus V naught by L and this repeats. So, if you take the average of this, draw an average right through is the D C part. And this D C part is nothing but I naught, the reason is that I naught is the part that is going through the load and it is the average part.

The part that is going through the capacitance is the 0 average part, there is no average current through C; and therefore, the entire average has to go through the output load. Therefore, we have indicated is it as I naught. To get a better inside of the operation of the push pull converter, we need to look at the flux within the core, how does it look like?

So, let us deduce the wave form of the flux within the core, you cannot see the flux waveform on the oscilloscope, but, let us deduce it using the Faraday's law. So, let us draw an axis time axis t and we would like to draw waveform of the flux; flux within the core. Now, let us say during this period, when Q1 is supposed to be ON; when Q1 is supposed to be ON this point is grounded this point of the coil is grounded. The dot end is connected to Vi, so the dot end is more positive with respect to the non dot end..

So, therefore you can expect the flux to increase, you have the positive mmf being applied flux will increase. So, in this period the flux will go from minus 2 plus from minus phi m to plus phi m at a rate, what rate? It will go at the rate of this voltage whatever the voltage which is being applied; divided by the that number of turns of that particular winding. So, if I take the primary winding half this from the centre tap to this end the voltage across this coil is Vi, that is the np is the number of turns, then Vi by np is the rate at which it will rise.

If I take the secondary winding, ns is the number of turns and the voltage across the secondary winding is nVi. And therefore, the rate at which the flux will change is n Vi by ns, but because ns is a related to n, you see that both these rate of same. So, me write that let down, this will be the way the flux will change, constant rate voltage divided by n. Because we are using V is equal to nd phi by d t is the d phi by d t rate.

Now, importantly during this time this period when Q1 and Q2 both are off, when both Q1 and Q2 are off, I said that the inductor current is freewheeling, how does it feel wheel? It goes in this path this path I am just shown as a short as a short path but actually it will go through the capacitance and it will also go through the load and then or up at this point.

So, I am just indicating it that it goes through these two impudences, and it comes in this direction. And then it splits here equally exactly half because this windings are exactly equal.

So, whatever the inductor current iL by 2 will go there iL by 2 will go in this direction and then you have iL by 2 coming from this diode D1 and D2 also iL by 2, both these will or up and then flow through inductor again. But importantly if you take this part here iL by 2 flowing into the dot in the lower half of the secondary centre tap winding. And here iL by 2 flowing into the non dot end part into the upper half the centre tap winding.

So, the upper half and the bottom half they are having a opposing mmfs and then mmfs cancel there is no magneto motive potential. And therefore, flux wherever it is will not change, it will remain. So, the flux was here and it will remain at that point.

So, if it remains at that point what is d phi by dt during this period, d phi by dt is 0, there is no scope. So, if d phi by dt is 0 all the coils coupled to the core. The primary top, primary bottom, secondary top, secondary bottom, all will see 0 voltage. Because d phi by dt is 0 and because this voltages are 0 Vp will also be 0.

So, therefore you do you see the voltage Vp 0. Next during Q2 ON, when the Q2 is ON dot end is negative, non dot end is positive. And therefore, you have a negative magneto motive force, and it will start falling like this. And then during this period both Q1 and Q2 are off flux wherever it is will stay.

So, it will stay there, and then from there again it has a positive rise Q1 ON stays and then Q2 negative, negative rate falls and stays so on. So, you will have this plus phi m this is minus phi m, you will see the flux swinging from minus phi m to plus phi m and in between and go to switches are off. The flux just remains d phi by dt is 0 and voltages across all the coils are connected all the coils on the same core will be 0.

Let us now look at two other important waveforms in the push pull topology. One is the current is flowing through D1 and the another one is the current that is flowing through D2. These two currents are pretty unique in shape you would not have seen this current waveforms, this type of current waveforms in other buck derived converter like the forward converter and the non isolated buck converter. In the push pull half bridge and full bridge, you will see this type of currents flowing through the diodes.

So, let us have a look at them, let us draw the t axis and look at the iD1 current here, and another axis another t axis and let us look at the iD2 current here. Let us first draw the level because it is the inductor current that has flows through iD1 and iD 2 parts of the inductor current. We will see which part of the inductor currents will flow through.

But, first let us mark this average level of the inductor current which is i naught like that, and for iD2 also I will mark the level. Now, when I take iD1, when is iD1 active? Whenever Q1 is ON this winding on the primary side is active dot end. Whenever the dot end is positive you have the dot end positive and this portion of the winding top half of the secondary will be active and D1 will be active during the time when Q1 is on.

So, it will just follow the inductor current whatever the inductor current was will be iD1 during that time and we can write that down. And you see Q1 is ON again here, here also it would be the same thing. Now what is happening during the time, when both Q1 and Q2 are off? Here also Q1 Q2 off here also Q1 Q2 off here so on.

Now, during the time when both Q1 Q2 are off, the inductor current is freewheeling and we see that at the centre tap point it is dividing into two exactly two halfs iL by 2 and iL by 2 through D2. So, D1 will be carrying iL by 2 during the period when Q1 and Q2 are off.

So, this is the iL wave form by 2 half of that will flow through iD1. So, like this half of that, the you see that it is having a down slope and negative rate. So, you full wave the iL wave form would have been like that, but half of that would be like this.

So, like that we can draw there also and the other side here also you see that it is both Q1 and Q2 are off. The inductor current divides exactly into half and that is how it would look. So, this is the type of waveform that you would see for the D1 current. And for the D2 current also similar during Q2, you will see that the D2 is active during the time when Q2 is on.

So, D2 is active and you will see during this time it is exactly the same as the same as inductor current during this time also it is exactly same as the inductor current, and during the time when both the switches are off, half of the inductor current. So, half is flowing for iD1, half flowing through iD2. And here also you see that half flowing through iD1, half flowing through iD2 likewise here also, so, completing the wave shape you will see that.

So, during this time only iD1 is flowing iD2 is 0, during this time only iD2 is flowing iD1 is 0. So, you will see that the diode currents on the secondary side will be like this. And if you actually probe the currents in an actual circuit with the help of an oscilloscope, you will be able to see currents like this.

Let me remove the wave from iD2 and make some space, and in this space I will include another wave from another very important waveform the voltage across the switch. The voltage across the switch Q1 and Q2 very important we will be discussing that now. Ah The voltage across both these switches are very very similar accept that they are phase shifted. I will look at only one of the voltage waveform across the switch either Q1 or Q2 I will take Q1 for now.

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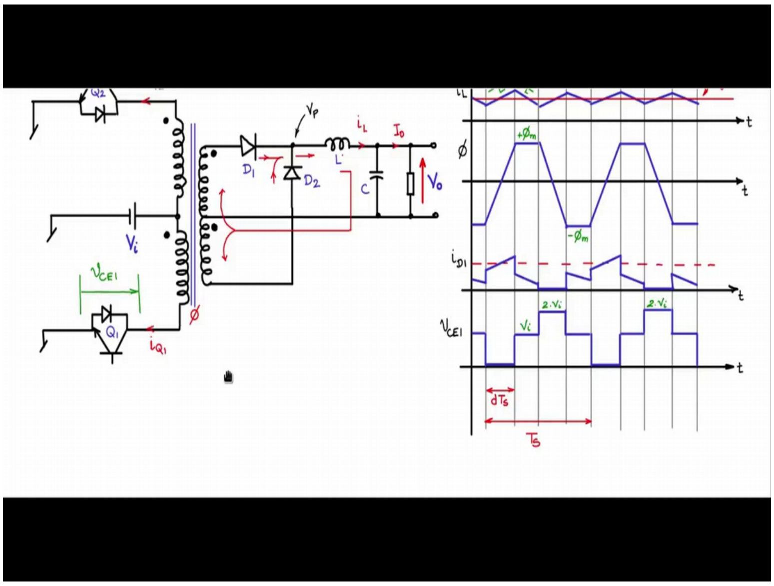

And let me mark the way I am going to measure in this fashion vCE1 is the label. And let us bring that label down here and see look at the wave from here of vCE 1 across switch Q1. We know that when the switch Q1 is ON during periods and during the period, the voltage across the switch Q1 vCE1 will be 0 almost 0, and we will put that down.

Now, the another state is when Q2 is ON. So, when Q2 is on Q1 is off, when Q2 is ON, this dot end here is at ground potential. And this point here at the non dot end see that each coil is having Vi with the positive side on the non dot end, Vi here also positive side the on non dot end.

So, overall from this point to this point you have two Vi coming across the switch. So, therefore, when the switch Q1 is off and Q2 is ON, Q2 is ON, these two periods here. We will see two times Vi coming across the switch Q1, because of the voltage induced across both these coils.

Now during the time when both Q1 and Q2 are off, we saw that the inductor current is freewheeling in the secondary side and the inductor current is splitting into two equal halfs. And you have opposing mmfs mmfs ni on one side in the top due to the current flowing in the top of the secondary centre tap into the non dot end. And due to another equal and opposite current flowing through that dot end of the bottom half of the secondary centre half causing mmf cancellation and no flux.

And therefore, the voltage across all the coils is 0 as we see here even across Vp. And therefore, if this voltage is 0; this centre tap point which is at Vi will come directly to the collector point of Q1. And therefore, they will all be at Vi in between this. So, this Vi this is the voltage waveform that you can expect to see on the oscilloscope across switch Q1 vCE1.

Similarly, you would see across the switch Q2 vCE2, only thing is phase shifted with the 0s or the low voltage 0 almost 0 voltage occurring during this period Q2 period. So, now let us try to calculate the voltage equation input output relationship, first let us see what is the time period.

Now you see that this is the time and this switch Q1 is turning on and it is on for this period. I will call this one as dTs. This whole period is Ts till again the cycle repeats. And this period when the switch Q1 is on, we call that one as dTs as the duty cycle of the switch Q1. Likewise the duty cycle switch Q2 also is dTs only it is turning on here during this period.

So, now this is the switching pattern for the device, but what is the duty cycle for the voltage profile at Vp? You see that the voltage profile at Vp is slightly different, in the sense that it is having double double pulse in that same Ts period.

So, Vp is actually having double the frequency as compared to the switching frequency of these two devices. So, therefore, this arrow or dimensioning that I have indicated here will be the frequency of Vp and this time is Ts by 2.

So, therefore, what is the duty cycle for the Vp, the Vp duty cycle will be this period which is dTs, we know its dTs divided by Ts by 2. So, this is nothing, but 2 times D. So, the duty cycle for the Vp or the pole voltage waveform is 2 times the switching duty cycle of the individual switches off the push pull converter.

So, therefore V naught, V naught here is nothing about Vp into the duty cycle and duty cycle is 2 d. And Vp we know is n times Vi we have marked it here, we saw how that came about. Therefore, we can use nVi for Vp into 2d.

So, if you write it down here, 2 to n into Vi into d d here is the switching duty cycle of the independence switches and this is the input output relationship for the push pull converter.