Design and Simulation of DC-DC converters using open source tools

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Lecture -19
Pushpull Converter

This week we shall extend our discussion on isolated converters. We have studied till now the forward converter and fly back converter. In the isolated class, the forward converter is derived from the buck converter and the fly back converter as you know has been derived from the buck boost converter. The forward converter has few more derived forms the push pull topology, the half bridge topology and the forward topology. These three topologies we will look at the additional stages of the lectures and see what are their advantages and where they will be used.

Generally, you will see that these three topologies will lead to more compact transformers because they utilize the flux swing much better in the forward in the fly back we saw that the flux swing was always from 0 to 5 m, but in the case of the push pull half bridge and the full bridge topologies the flux swing will be from minus 5 m to plus 5 m and therefore, the transformer core is better utilized and for a given power the size will be smaller.

The full bridge topology which is the one, which co which could the lead to the most compact form and the most popular especially at the higher vantage levels will also be looked at. Then after that we will study bit on the multiple output converters, actually it will be the same forward in the fly back topologies with multiple secondary windings and when you have multiple secondary winding, how will you get regulation from all the outputs. So, before that we should also know how to do close looking of a particular output. So, we shall briefly study the close looking aspect of the converters and then later extend our discussion to multiple outputs and see how they will get regulated and then if time permits we can look at some advance control aspects.

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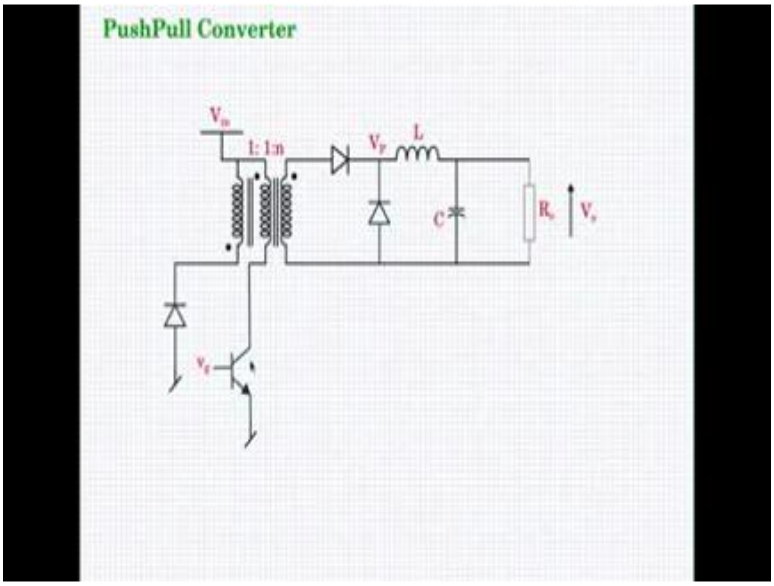

So, this is enhancing summary of what will be covered in this week's course. You see that this circuit is that of a forward converter, you recognize that this is the forward converter and this is the demagnetising winding. Now, I am going to describe the revolution of the push pull converter using the forward converter. So, first step let us look at the primary sign, we have the demagnetizing winding the main function of the demagnetizing winding is when the switch is off, the energy in the core is put through the demagnetizing winding into the supply.

Now, let us enhance the concept a bit further during the time when this primary winding is off, instead of putting the energy into the supply, let us put the energy into the output. So, that is the concept which will come in push pull. So, instead of calling this as a demagnetizing winding, we will be calling it as another alternate primary which will go into the output instead of putting into the input.

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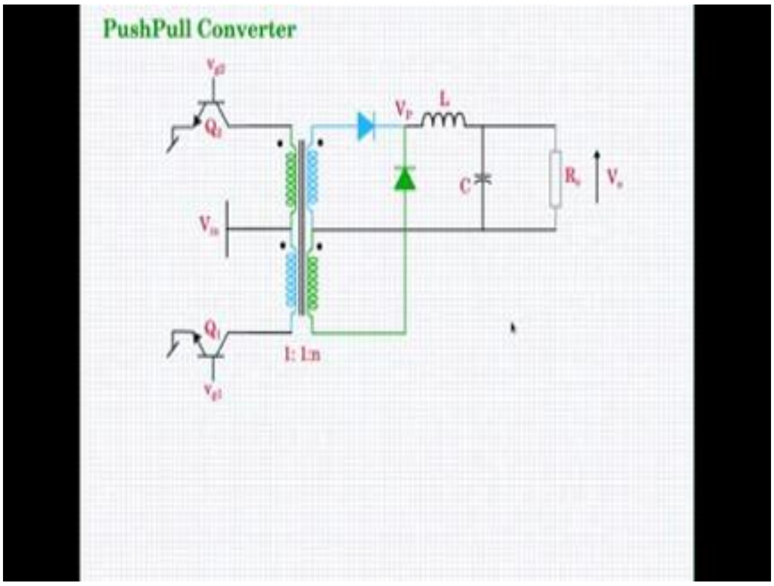

So, how is this going to come about? So, we shall use the same winding, we will call it as another primary, this 2 are having the same terms ratio. So, I will put this I will flip this and put this winding on top above here like this, now let us move this whole converter bit down. So, that some space of there then I move it every to the right side. So, we make some space next I will clear up some here and now connect this, now this portion is diode portion is actually connected here and instead of connecting a diode, I will connect 1 more switch in the place of the diode to this as follows.

So, I will connect this transistor like this at this point, this end you already have the transistor I do not want this diode because instead of this diode which is connected here, I connected the transistor there this ground can come up here and remove this conductor piece and remove this and let me switch over and flip this up like this and then I will connect this transistor here and we have something like this, Now, this is push pull circuit. So, what I will do, I will move this down and extend these 2 here to indicate that is coupled this way is not needed and this would be the push pull as for the primary side is concerned.

So, in this primary portion, you will see that we will name this b j t as Q 1 it has a drive V g 1 and then you have Q 2 which has a drive V g 2 and V g 1 and V g 2 are never applied. Simultaneously, they are mutually exclusive. Now to understand the circuit better we should know that when Q 1 is on this winding this primary winding is the 1 which is 1 action. Let me give it a different colour. So, when this winding is action this dot polarity this is the secondary winding that is in action. Let us mark that also in blue colour so that you it is easy for understood that when Q 1 is on this blue winding is in action.

Accordingly the blue secondary winding is also in action which delivers the energy to inductor and then the output box circuit in a way which you have familiar with when the transfer Q 1 is off, this is the blue winding this blue winding is out of the picture, but there is energy stored in the core of the transformer. So, we would have expected that in the absence of Q 2 we had earlier put a diode and the diode will allow the freewheeling to happen through the wheel.

Now, what we expect to we will let us say for now, that there is no change in the flux we will energies the core in the opposite direction by turning on Q 2, which will because the dot polarity is now towards the switch here. The dot polarity is away from the switch it is another polarity and when you analyse this switch, it is trying to make the magnetizing current flow into the non dot end and out of the dot end, when Q 1 is on magnetising is flowing into the dot end out to the non dot end. So, when Q 2 is on magnetising current flow into the non dot end and out of the dot end.

So, this we will try to pull the core to 0 and go pass 0 into the negative region and during that time when this is off, we would want this to supply energy to the output rather than do the input. So, let me mark this 1 in another colour and let us say this is this and to handle that we need one more winding at the secondary side which will have similar kind of dot polarity to pump into the output. So, what we shall do is try to make the following changes, I will make this some changes from and I explain to you.

Now, you see that I have made for this primary an appropriate secondary with an appropriate dot polarity and they are connected in the secondary like this. So, this should also charge up this. So, what will do we will connect the diode in this fashion, I will connect the diode like this should understand this; this is not a junction point the diode is flowing in this fashion and let me probably give a different colour for this diode. So, that to indicate that this is the path flow for this let me also change appropriately then this would be the other like this.

Now, it comes much more clearer, you see that you have 2 possible circuits to charge the inductor let me explain that to you in a moment. So, you see here when Q 1 is on the dot end is positive all the dot ends are positive. So, the blue dot end is the only is the only co the only coil the portion of the coil which can pump energy into the inductance in this fashion there is no other circuit which can do that though which can possibly pump energy during that time let us consider the green portion of the circuit dot end is positive the there cannot be a flow of current in this fashion. So, this is out of the picture this is reverse biased and because the dot end here is positive this is positive on this reverse biased.

So, therefore, the only possibility or energy flow is through the blue and through this blue circuit into the output capacitors and now when the switch Q 1 is off let us say for those, for some time both Q 1 and Q 2 are off. During that time there will be a freewheeling of the inductor and it will freewheel through this or it put also freewheel in this path as we have seen and now, some time let us say we are switching on Q 2, the moment we switch on Q 2 the dot end is connected to the ground and the non dot end is connected to the positive. So, the non dot end is positive which means the non dot ends are positive. In this case the green, the non dot end which is this green has capability to pump energy into the inductor in this fashion follow the arrow way in which I am moving this arrow. So, that will indicate given indication of the current flow through the circuit during the time when Q 2 is on.

So, in this way you see that whether Q 1 is on or Q 2 is on there is energy pump into the inductor the magnetising circuit. So, the inductor energy increases and then during the time when both Q 2 and Q 1 are off the inductor is freewheeling both through the green path and the blue path. So, this is how the push pull converter will operate recognize here this output portion output segment is essentially a buck converter there are 2 parts basically happening basically due to the 2 primaries and the 2 secondary’s with common buck converter output. So, this is called push pull push and pull basically because of the circuit of the topology when Q 1 is on the flukes is push to one side and when Q 2 is on the flux is push to the other side. Now, this is the push pull circuit operation.

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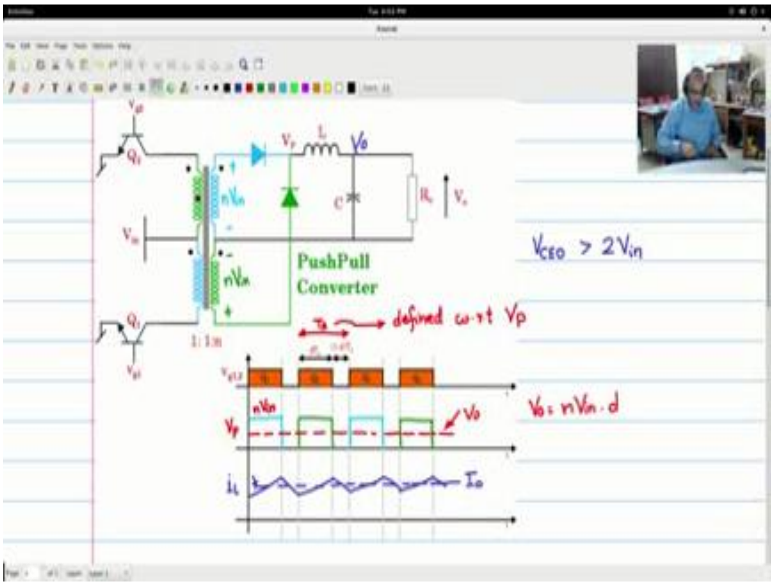

So, you see that this is the push pull converter that we have discussed. We will get a bit more inside if you look at the waveforms. Now, to the waveforms I have here template of writing the waveforms, now this first line here indicates the drive that we have giving to the 2 switches Q 1 and Q 2. V g 1 comma 2 is what I have indicated means both V g 1 and V g 2 are given on the same time line. Right now, I will not discuss, explain this for the moment just leave at what is this d t s and 1 minus d t s, I will explain it later, for now the important point for you to focus on is that Q 1 is on loading this period.

Then there is a period of time where neither Q 1 nor Q 2 is on in this period of time where I am showing this row both Q 1 and Q 2 are off then doing this time I said that Q 1 Q 2 should be on the mutual exclusively Q 2 is on and Q 1 is off and again you have a period of time and both are off and then Q 1 again is on both are off Q 2 is on. So, in this fashion you have alternately Q 1, Q 2, Q 1, Q 2 being on and in between there is a period of time when both are off.

This is the pattern in which we will give the gate drive for V g 1 and V g 2 and accordingly Q 1 and Q 2. Now, giving this pattern let us see how the waveforms will appear at the V p the pole and then off course the inductor currents. So, considering the discussion that we had earlier when Q 1 is on we see that the blue portion of the circuit is end. So, when Q 1 is on the dot side is positive this dot with respective of the ground is V in and this dot with respect to the centre of point midpoint would be a times V in. If we have terms ratio of 1 is to 1, this is 1 is to 1 this is 2 are same and these 2 are also same and the secondary side it is n times dots ratio.

So, here we are having n times V in which appears at V p. So, at V p you will have n times V in here and that will charge up the inductor and we will indicate that portion of the waveform in blue here. So, let me indicate that, as the blue waveform. So, whenever Q 1 is on you will have this kind of ethic here Q 2 is on and again Q 1 is on here. So, let me indicate this now, this is what will appear at which point it will appear at V p the pole voltage point and then when Q 2 is on the green portion is active and you will see pole voltage will get the same V in during this time.

So, during the time when Q 1 is on I am going to write here n times V in will appear here and during the time when green portion is active Q 2 is on, you will get n times V in here, but remember that this will be plus with respect to the dot here. In the case of the blue this would have been plus with respect to this maintaining the dot polarity convention. So, if you look at this wave shape here, you are having at the V p the blue portion which is high then a low then again high and then low.

Now, if you take the switching frequency of Q 1, Q 1 is switched here then nothing up to this point here you have the switching of Q 1, I will take the pole voltage frequency for the switching frequency of Q 1 or Q 2 the frequency that appears at the pole voltage is double because of the effect of the green and the blue portions of the circuits, because of the orange effect at the pole voltage there is a doubling of the frequency and therefore, we now define this d t s and 1 minus d t s with the respect to the pole voltage wave shape.

So, the pole voltage wave from; if you take from this point to this point will be considered as t s then the portion when it is high is considered as d t s and the portion when it is low is considered as 1 minus d t s. Now, that is what I have indicated here, the portion for which either Q 2 or Q 1 is on is called d t s and the portion when neither of them is on is called 1 minus d t s.

So, this buck converter operation is based on this kind of a definition and we can use this kind of a definition to find the V naught. Now, what would be V naught? V naught would be the average value of this. So, let me now draw the average value. So, average value of V p will be V naught and I know that the high time is d t s and the low time is 1 minus d t s and the average is given by n times V in into d. Now, this is n times V in now d as defined here, where the t s is one period of the pole voltage t s is defined with respect to pole voltage V p that is important because the switching frequency is half the pole voltage frequency.

The inductor will be designed at a frequency which is double the switching frequency of Q 1 and Q 2 because the inductor is of the effect, inductor increasing the double the frequency. This is the very key point which you have to note in all the three topologies; which is push pull converter, the half bridge converter and the full bridge converter where all these three converters the output side or the secondary side is exactly like this exactly similar only the primary side will change in the half bridge and the whole bridge converters.

So, the inductor will see an effect of the 2 components and therefore, the frequency of the voltage across the inductor will be double the switching frequency on the primary side. So, that is 1 aspect which you have to consider and the d is always defined with respect to the pole voltage. This is the important aspect in the case of those push pull operation for bridge trampolines. Let us look at the current through the inductor i n. So, during the time when Q 1 is on we see the blue portion of the circuit is active and at the pole you have n V in.

So, n V in minus V naught by l will be rate at which the current will increase in the inductor. So, this rate is n V in minus V naught here, we know it is V naught by l. So, that is the rate at which it will increase then it will come back in during the time, when the inductor is prevailing and during the time when both Q 1 and Q naught are on the Q 1 and Q 2 are off then again Q 2 is on the green portion of the circuit is active and V in is applied at the pole V p, and it will again rise up with the rate of n V in minus V naught by l then it will fall down and when it is falling down it is at V naught by l rate and this keeps happening.

So, this is how the inductor current will look like and the average of that is i naught. So, all these are just like the buck converter because output portion of the circuit is exactly like the buck converter. Now, if you look at the rating for Q 1 or Q 2 see the V C e o rating or either Q 1 or Q 2 is should be it is greater than 2 times V in how does this come about. So, you see here when Q 1 is on this is V in dot is positive V in and the non dot end is connected to the ground now assume Q 1 now switches off the movement Q 1 switches off there is a reversal of polarity this will be having plus and here it is minus V in and there is a V in here connected in the circuit. So, you are having V in and another V in due to the reversal of the polarity appearing across Q 1.

So, Q 1 should withstand at least 2 times V in, likewise when the 2 Q 2 goes off when Q 1 is on let us say dot end is positive V in this is V in plus this V in. So, in this portion of the circuit you will see that Q 2 has to stand 2 times V in. So, the rating for Q 2 and Q 1 is as come down here, likewise the diode when, let us say this diode is conducting this diode is off 1 end of the diode is at n V in and the other end other end of the diode, here if you see during the time when this is conducting is having another n V in. So, this n V in plus this n V in this conducting diode is coming across this. So, the diode overall should withstanding 2 times n V in. So, that would be the rating of this.

Deciding the ratings of the inductance and C is exactly same as we had discussed in the buck converter circuit. Now, there is one small aspect which I want to discuss that is the freewhelling aspect and the flux within the core then the discussion of the push pole will be more complete, let us look at that.

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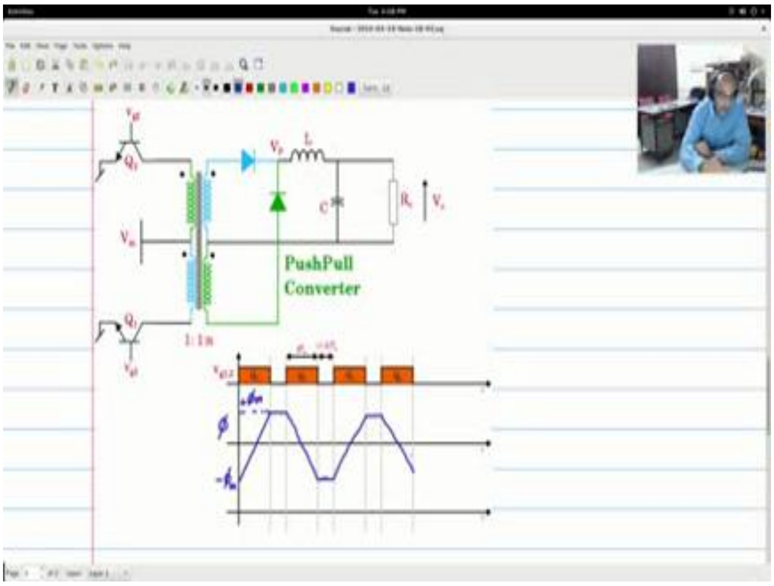

Now, consider the flux waveform within the core. Now, let us say the flux is in the steady state it had the point of starting it is at one side of the core. Let us say it is at minus phi m and during the time when Q 1 is on that is magnetising current which is flowing through and it is magnetizing the core from minus phi m to plus phi m. So, let us say this is plus phi and then during the time when both Q 1 and Q 2 are off. So, when both Q 1 and Q 2 are off the inductor current goes in this fashion at this point it equally divides in this way and in this way.

So, the inductor current of the l will divide into i l by 2 on this side i l by 2 in this side become join and then again become i l and so if you look at the magnetics there is an i l by 2 entering the non dot end coming out to the dot end and moves in this way there is i n by 2 entering the dot end. Here, coming out of the non dot end and then joining up and here joining up at this V p point core point and then going as i l into the inductor. So, you see that in the secondary of the coil there is i l by 2 entering the non dot end there is i l by 2 entering the dot end.

So, n into i l by 2 is the which is generated inside in the core and in on one side, it is in one direction and due to this current flow in the other coils in the other direction. They will cancel each other out and effectively there will not be any voltage here or the flux or flux will not change d phi by d e t, it will be 0 because of the cancellation effect of the equal currents flowing through this in an opposite magnetic sense.

So, therefore, once there is no change in flux, there is no d phi by d t voltage is 0, d phi by d t is 0, flux continuous to be wherever it was and then again there is a dissymmetric Q 2 is turned on and now in an opposite sense magnetizing current is flowing and then this will go down up to minus phi m from plus phi m and at the other end when the both Q 1 and Q 2 are off and again inductor current is freewheeling in such a manner that the current flows in the opposite sense and both are windings, there is no change in the flux and the whole operation keeps continue. So, this is how you would look if there is a possibility or a chance to look at flux. This is how would it look like within the core of the push pull converter.

This would give you some insight when you are making the push pull transformer along similar lines which you did for the converter. Now, I would like to see the currents that are flowing through this diode and this diode. So, these 2 currents are actually the once that are flowing through the inductor. They are basically the inductor current during the time when this particular diode is on or the inductor current during the time when this particular diode is on.

So, during the key Q 1 period inductor current and this blue diode will be the same. During the time Q 2 period inductor current and the green diode will be having the same current. During the period when Q 1 and Q 2 are off inductor current will equally divide between the 2 diode currents. So, using the principle we can write the diode currents. So, let me now go about drawing the diode currents.

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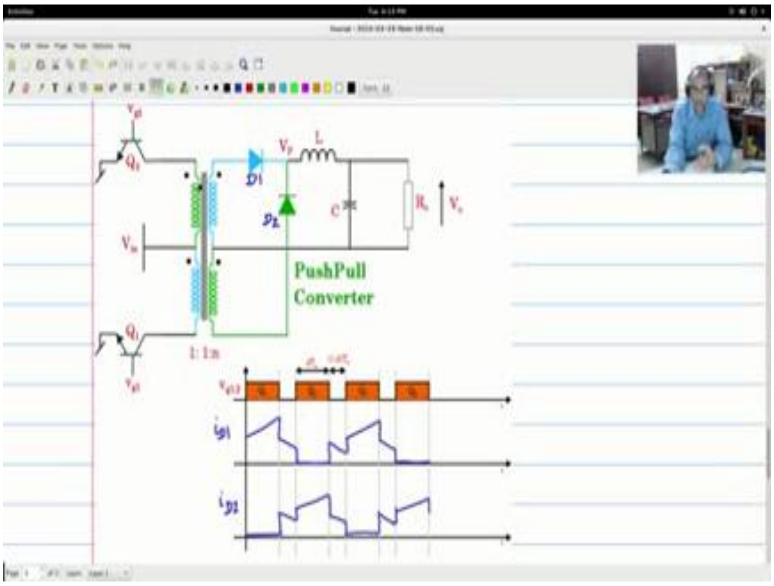

So, first let me take the diode current d 1 I will call this 1 as d 1. So, i d 1, during the time when Q 1 is on the diode d 1 will be conducting. So, it will take the same wave shape as the inductor current then the inductor current will actually, I will know going to put it dotted will go in this shape and then during the time when Q 2 is conducting actually the i d 1 current will not be flowing. So, I can safely say that it will be 0 during this time.

And again during the time when Q 1 and Q 2 are off there will be some sharing of the current which we will come to and then again when Q 1 is on, it will take the shape and cut it. Now, I am showing the dotted because that is not the way that is not the profile of the current flowing through the diode. Now, when both Q 1, Q 2 are off, its half of this falling current which will flow through the d 1 other half will flow through i d 2. So, let us say half of that is, this and the remaining half I will say equal which will flow through i d 2, this is d 2.

Likewise at this point also at, the diode current will look something like this. It goes and during the time when Q 2 is on you see that the current goes like this and half of it only will flow through this other half will flow through the other half, will flow through i d 1 diode. So, half of the half will be shared during the time when both are off. So, you will see on the scope a pattern of the diode current which is like this and likewise for the other diode too, you will see the pattern of the diode current which flows in this fashion and jumps up and then goes like that. So, this is how the diode currents will flow and this is what you would actually see. Let me remove this dotted portion and this is what you would actually see on a scope for the diode currents.

So, this is how the push pull converter will operate. Now, you will see that it is very easy to understand the half bridge and the full bridge. The secondary part, the whole of the secondary part is exactly same there will not be any change in a secondary part to the converter, whether it is push pull, half bridge or full bridge. The operation is also exactly same, this diode currents will be exactly same and the input output relationship, the inductor currents and voltage across the inductor in frequency with which the d t s and 1 by d t s that we say, the pole voltages will be very, very similar. What will change is the primary part and that is what I am going to change and then point of the difference to you and this will give an idea for the half bridge and the full bridge circuits will work.