Fundamentals of Power Electronics
Prof. L. Umanand
Department of Electronics System Engineering
Indian Institute of Science, Bengaluru

Lecture - 72
Flux Walking in pushpull

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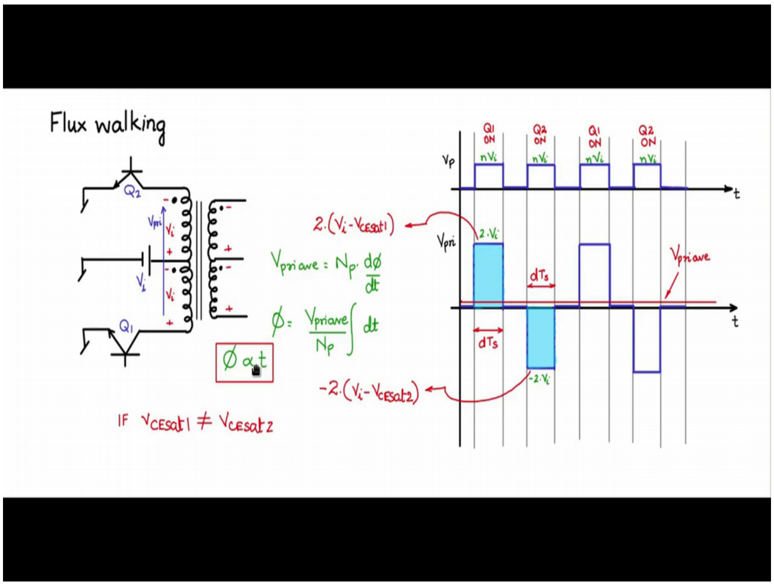

In a practical push pull converter there is one issue called the flux walking. We will try to discuss and try to understand what flux for walking means and how to take care of this. Let me first draw the push pull circuit, I am going to focus myself only in the primary side.

So, you have the two transistors, the battery here on the common core you have the secondary, and a secondary stand centre tap and you have the further portions of the circuits here that is the two diode the inductor capacitor the buck converter complete buck converter. But I am not going to draw this here we know that, because I want to restrict myself to this portion of the circuit here on the primary side and see what is this flux walking.

It is a serious problem in practical circuits and which can cause damage to the topology itself. It could blow up the transistors and it could cause saturation of the transformer. So, let us see how this happens and how we can solve this problem.

So, let me mark these dot polarities here for the transformer, this is Q1 this is Q2. Let me mark V i here and let me also put in this waveform that we need to understand. And here I am going to draw only 1 waveform and that is the primary voltage here V primary.

I am taking; I am picking the entire primary coil, one could pick any one of the coils either a primary or secondary it does not matter, because the flux inside is the common one linking all the coils. But it is easier to draw the waveform for the primary. So, therefore, I will draw that all the waveforms are similar, but easier to understand just with a complete primary.

So, let me draw the time axis, and let me mark the label here V primary the voltage across this entire primary. Now, we know that during the time periods when Q1 and Q2 are off the voltage across the coils are 0, because the output side inductor the buck converter inductor is freewheeling and it is splitting across the secondary centre tap, secondary coils and causing opposing mmfs to come up.

And therefore, d phi by d t is 0 no voltage during the time when Q1 and Q2 are both off together. Therefore, during all those periods you will see zero voltage across the coils. So, that is what I am marking here and during the time when Q1 is ON, when Q1 is ON you will see that the non dot end will be connected to the ground zero potential. The dot end is connected to V i and therefore, the voltage here would be V i with dot end positive.

So, all the dot ends will be positive with respect to its non dot end, here also dot end will be positive with respect to the non dot end even on the secondary side. So, this we know, the voltage will be V i and V i this is what will be induced across the primary coils. So, therefore, if I take the entire primary coil it is V i plus V i which is 2 V i.

So, let us mark that here during the time when Q1 is ON the primary voltage with the dot ends being positive you will see a voltage of 2 times V i. And during the time when Q2 is ON, during the time when the Q2 is ON the dot end is actually grounded the non dot end is plus V i and this minus V i is induced on all the coils.

So, therefore, let me place the polarities in this fashion non dot end is positive with respect to the dot end, same with all the other coils too. And on the primary side you are seeing V i with the non dot end positive. So, it is a minus voltage that you will see across the primary and that will be minus 2 times V i. So, this will repeat cycle by cycle second cycle it is 2 V i positive, minus 2 V i negative when Q2 is ON so on.

So, if we connect the mall together you see a waveform like this and this is the type the waveform that you would see on a oscilloscope when you probe the entire primary. You will see that it is also you will get similar waveforms across each of these secondarys, but they will be scaled by the turns ratios.

Now, let us see the problem what is the problem? Now in a practical circuit in a; when all the devices are consider ideal; we are expecting that the voltage positive voltage the area here volt second and the negative voltage second here these two should exactly balance so that there is no average. So, this is the physical nature the a fundamental physical nature of the coil where you cannot have an average voltage across the coil..Now in the case of a practical situation if you look at this voltage here, this is the time during which Q1 is ON. Now Q1 when Q1 is ON an ideal case we say that the ground is connected to this point which means that VCE sat is equal to 0. But in a practical case the VCE sat is not 0. So, therefore, it will be V i minus VCE sat 1 which will appear across this, and that is what will be induced with proper scale.

So, V i minus VCE sat 1 is appearing across Q; is appearing across the primary coil connected to Q1 and 2 times that will be appearing across the entire primary coil. Likewise during the time when Q2 is ON, you will see 2 times V i minus VCE sat 2 coming across the primary coil.

So, if you look at this there is volt second balance, perfect volt second balance only when VCE sat 1 and VCE sat 2 or equal same. But in a practical situation it will not be you should also understand that the time period is d T s when Q1 is ON you would also be given control signal d T s for Q2 to be on during the same time period.

So, a VCE sat 1 and VCE sat 2 are miss matched you can have a difference in the area. So, if VCE sat 1 is not equal to VCE sat 2, then there can be a small average here, can be a very small average we will call that one as V primary average, it could be as much as a micro volt, but does not matter.

So, even if it is a micro volt you will have a problem, that is because from the Faraday's equation V primary average which is equal to N p. If I consider the number of turns N p for the whole primary d phi by dt, this is Faraday's law. So, what is flux? Flux is V primary average which is a constant d c divided by N p integral d t, which means that phi is proportional to t. This constant, this is constant integral of d t is t, phi becomes proportional to t which means that the flux is increasing continuously with time.

Whatever may be the scaling V primary average may be 1 micro seconds which means that phi will continuously increase and probably reach saturation after few months. But still you will have a problem which means that initially these circuit will be working and after a few months, after the flux saturates. You will see misbehaviour, it maybe catastrophically damage by blowing up some of the components.

So, what happens is that the operating point keeps drifting depending upon whether V primary average is positive or negative, it will drift to plus phi m or minus phi m and ultimately saturate the core in one direction. So, once the core saturates when you give a duty cycle t on there will not be induction and the current will increase and blow up the switches.

So, this is the problem in a practical case, you cannot make the transistors perfectly matched it is not possible. So, you will land up with VCE sat 1 not equal to VCE sat 2 and you will have this problem of flux working. So, how to solve this problem electronically, so that is what we will be looking at next.

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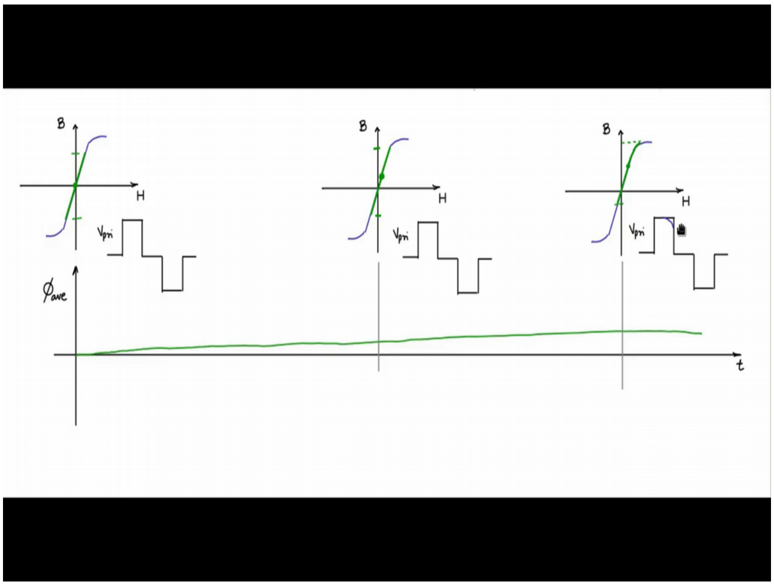

Let us now try to visualise the effect of flux walking on the primary voltage waveform. So, let me draw this B H curve, here a typical B H curve of the core using the push pull transformer. And normally the operating point the average flux value operating point will be in the centre here, average flux would be 0. And about that average flux you will have the swing going plus and minus phi m.

Now, if you look at the average flux in a practical push pull converter, we saw just know that the flux average flux was proportional to time t which means that it starts growing. It grows from 0 in this fashion, and at somewhere here you will see that the average flux point will be somewhere at this point away from 0. I have shown it positive of course, it could also be negative you could have the flux decreasing.

So, you see that the swing will still be about that average up flux operating point. And you see that it is near the at the top end at the positive side you will see that it is near the knee of the B H curve, still there is no damage done as at.

Now, as time progresses somewhere here, let us say at this point in time you have still the much higher average flux somewhere here. And when you take the swing about the average flux operating point you see that a portion of the curve on the positive side is moving on the knee which means d phi by d t there is lower and because the d phi by d t there is lower. You will see that the induced voltage at the back e m f across a primary winding will be lower, and as a result there will be a drop in the voltage.

So, let us have a look at that, voltage across the primary. So, the voltage across the primary is like this we just now saw this, V primary and as it is swinging in the linear region there is no change the d phi by d t rate here or even in this case there is no change the d phi by d t rate. So, the primary voltage waveform will look essentially like this.

Now, in the case of in this last case where a portion of the flux operating row region is moving towards the knee the d phi by d t there is decreasing. And you will see a drop in the induced voltage across the primary. So, this drop in the induced voltage primary can cause a high inrush current because V i is fixed constant applied as a input.

The primary is showing a lower back e m f and the difference in the voltage V i minus this lower back emf will cause a large inrush current and which can blow up the devices and it is against this problem that we have to protect.

So, as the flux working continues you will see that there is a drop in the induced emf across the primary due to loss of induction, and as a result a high inrush current and damage to the transistors. So, these is the problem of the flux working, and let us see how we can avoid that.

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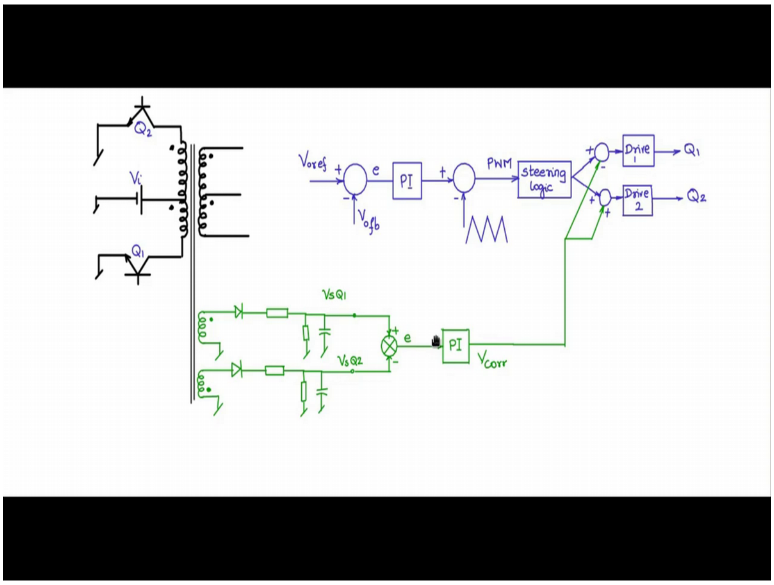

Let us now see if we can have a solution for the flux working problem. So, let me again draw the pushpull circuit topology, and I am focusing mainly on the primary side, because we have to control the pulse widths of Q1 and Q two. So, let me draw that portion of the circuit and bringing your attention to Q1 Q2 switches.

And we have a common core on which we have the centre tap secondary, let me draw the dot polarities like this. Now here we have the diodes, o ring, inductance, capacitance, load. So, the buck portion is there and we know the how that works. Now, I am going to put on the same core, on the same core two more windings one winding these are all very low power windings very thin wire gauge they are use only for sensing.

So, dot polarity like this note that I am going to put another winding there dot polarity in the other direction. So, this is going to sense this dot polarity would be positive when Q1 is ON, when Q1 is ON the dot is positive, so, this will be positive. And when Q2 is ON the dot is negative the non dot end is positive, so, the non dot end. So, I am basically trying to use sense coils and sensing the dot side and the non dot side positive under different switch on condition.

So, let me go further in the circuit, I will put a diode. So, which means that I just need to have the positive it is a clipping circuit, it clips and takes only the positive part of the pulse across the primary and finds an average. So, basically I am trying to find the volt second. So, this will find the average; this is an average in circuit r c, I am putting a simple averager, I could also use an op amp averager to get better precision.

And then for the other winding also I am clipping and then putting the r c averaging circuit. This is just to indicate conceptually that I am trying to take the positive part of this pulse, V primary pulse and then averaging it to get the volt second. And the non dot end during the time and Q2 is ON that part I am taking it out and finding the average. So, that I have the volt second of the positive part of the voltage V primary voltage and the negative part of the V primary voltage.

So, this I will call volt second of Q1 volt second of Q2 during the time Q2 ON, volt second when Q1 is ON volt second Q2 is ON. So, these 2 should in actuality be same under normal operating conditions. But if they are not same we have to do corrective action. So, let us say I subtract them plus and minus and take the error. So, the error if both are same should be zero, but if one is saturating and the other is not saturating then this error would be finite the error can swing positive or negative. So, you pass it through a PI controller.

So, the job the PI controller is to make the error zero by giving a correct corrective voltage V correction. This correction voltage should be added to the duty cycle patterns of Q1 and Q2 in such a manner that error here become zero. Error here become zero means Vs volt second of Q1 then Q1 ON and volt second and Q2 ON will both match.

So, this will take care of the differential VCE sats of the devices, now where do you go and give the correction. So, normally under normal condition you will have a control a scheme like this where you have a V naught reference and you have a V naught feedback coming from the output of the converter. Then the error is given to a PI controller and the output to the PI controller is compared with a triangular carrier plus minus in this fashion.

So, the after the comparison of the control voltage the triangular carrier you will get a PWM voltage here. And this PWM is steered alternatively to go and switch Q1 and then Q2 Q1 and Q2 Q1 and Q2. So, this steering logic will act in such a way that Q1 and Q2 are mutually exclusive when they are on a turning on. So, you will have the drive for Q1 and the drive for Q2 and goes to the base drives or the gate drives of Q1 and Q 2.

So, this is how the normal e w m switching pattern will work, I will discuss this in greater detail shortly, but for now we will consider it as a block scheme like this. Now we need to add somewhere here this correction, because Q1 is getting a drive pulse d T s for a d T s period of time Q1 is ON for mutually exclusive d T s period of time Q2 is ON.

So, let us say here I introduce something there and then take this correction and then the correction is passed through some logic. Let us say, and then it is connected to this points basically to in; let us say it subtracts from one and adds with other the pulse widths.

So, which means that here in this case, let us say if the volt second when Q1 is ON that that part is increasing that part is saturating. Now you need to decrease that volt second, so, you are subtracting some amount of pulse width from here and then adding some amount of pulse width to the Q2 drive. So, that Q1 is turned on for slightly lesser time than Q2 and then there will be a balance achieved e will go to zero.

Now, this is the nature of the correction logic that we would use for correcting the flux walking. So, as the flux tends to walk positive, let us say; then Q when our Q1 is ON there will be a tendency for the tendency for the vacuum of induced when Q1 is ON to reduce slightly when it reaches the knee and that will be detected.

So, you will see that that value will be lesser than this value and then the correction value will go will go positive in a way such that you can add and subtract here such that Q1 and Q2 will automatically correct each other. So, they will not be given same d T s in the earlier case open loop case the d T s of both would have been same.

But d T s will get corrected by the PI controller in such in such a fashion that Q1 will be again brought back below the knee and the average flux will tend towards the 0 point. So, this is the effect of the closed loop which will be happening continuously and then prevent the flux walking. Of course, I have shown all this in a kind of a block schematic way, I will in detail show what is actually the logic, so that you will understand that.