Fundamentals of Power Electronics
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Lecture - 55
Core Reset in Forward Converter

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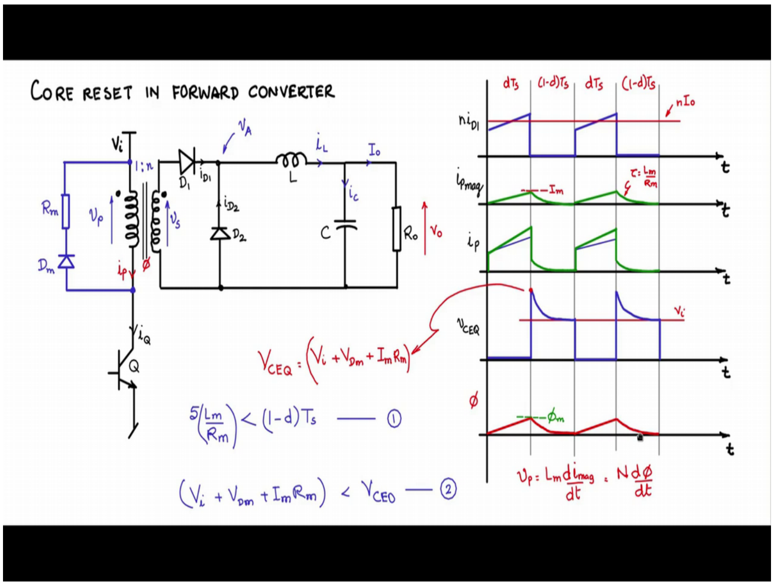

Till now we discussed on the wave forms on the secondary side of the forward converter which was mostly like the buck converter. Now let us look at the primary side, this switcher and the core reset issue. Let us draw the wave from the related to that and then try to understand that. So, I am going to divide the time again into four parts where you have d T s d T s the time during which the switch Q is on 1 minus d T s the time during which switch Q is off d T s again Q is on 1 minus d T s Q is off.

So, let us first consider the voltage wave the current waveform through this diode and that is what will actually get reflected on to the primary. So, let us mark here the primary current i p. Remember that primary current and i Q are same only during the time when Q is on when you how i p and i Q same. The moment Q is off, i Q becomes 0, but ip does not become 0 because there is a freewheeling current that will happen in this direction. So, therefore, ip and i Q are naught strictly same during 1 minus d time ip has some finite current i Q is 0 during that time.

So, what is ip? Ip is the reflected secondary current and at the secondary what is flowing when the transfer Q is on is i D1. So, n times i D1 is what is supposed to be reflected on to the primary the load reflected part. So, let us take n i D1 which is i D1 into the load reflected path flowing through the primary. This is one component. So, we know that the load reflected part during that time inductor current is rising and this is how the current wave shape look like and this we have seen before and if you take the level at this point, you know that that is the n times I naught again load reflected part.

Now, next we should understand that this is a transformer, then there is some current needed to magnetize the transformer and that is the magnetization current. So, a magnetization current also will flow through this primary and that should be added to that to get the total ip. So, what will be the magnetizing current? I will say i p mag when Q is on V i is applied across the primary winding, it is a constant voltage. So, the magnetizing current from the Faradays law V i is equal to L m di by dt. The magnetizing current will have a slope of V i divided by L m. So, it will start from 0 like that it will have a slope of V i by L m, L m being the magnetizing inductance during 1 minus d i will explain later.

For now we will leave this part and again it will start from 0. During this time we have to reset the core. We are to reset the core and bring it to 0, so that it will again start back again. In the meantime let us also draw. Before we draw this portion of the magnetizing current let us draw what will be ip. Ip is the primary current. The primary current will be having two components. One is the load reflected part which is n i D1 and other one is the magnetizing part which is ip mag. These two will add up together to form ip.

So, this part is magnetizing part. I am actually showing this bit zoomed. It will actually be much smaller as compared to the value of n i D1. So, let us say this is the n i D1 part which I am writing down here. This part you can add it up here, starts from this value and then gradually it will go up like that same as this d T s period also.

So, this will be the ip, this green portion will be the total added up ip value during the time when Q is on. When Q is off, you will see that i Q becomes 0, but ip will start freewheeling in this path. So, it will freewheel in this path because inductor current cannot become 0. There is this resistance R m and there is a mutual conductance L m. L m by R m will be the time constant. So, at that time constant exponentially i ip will decay. Likewise here also you will see that it will decay in this fashion.

So, now what will be the ip? we will in the ip waveform the same thing will repeat. You will see a drop because the moment Q is off, the reflected component vanishes i D1 component vanishes that becomes 0 and only the ip mag component will come into the picture and that is what we will find in this.

So, the total ip current we will look like this drawn thick in a thick green line. This will be the ip current that will be flowing through the primary winding. Let us now see also what is the voltage across V across Q V CEQ. So, let us draw on more access here and see V CEQ during the time when Q is on, you know that this is 0 and during the at the moment when Q is turned off, you will see that there will be a sharp rise. What is that value we will see that and then afterwards post that rise, you will see that this is V cc level the V ca will start decaying down to V cc level. Why does this happen?

You see that moment this is switched off, this is prevailing in this fashion. So, there is a drop across the diode forward drop across the diode, there is a drop across this R m ip into R m. Current is flowing in this direction ip into R m and there is V i. So, V i drop across R m and the diode drop will all be reflecting here when it when this shoots up and then ip current is decaying as you see here it is decaying exponentially. So, the drop across R m should also decay exponentially, therefore you see a decay exponentially and once the decay is complete, it will settle at V i because when once this is off, it is only V i that will come at this point.

So, this is how the voltage across the VJT will look like and then, it will repeat again the next cycle and decay in this fashion. So, this point I would like to say is the V CEQ which is equal to V i plus this diode drop V Dm forward diode drop around 0.7 volts plus the current flowing this direction plus minus here you have I m into R m if I say this value I m peek at that point I m that I m into R m will be appearing across. So, this will be the voltage that will come across at this across this transistor Q during the time at the time at the moment when it is being switched off and then further on during the time on minus d T s, it will start decaying down like this because I m is decaying down.

Now this decaying time constant is equal to magnetizing inductors L m by R m. Now what should be the value of R m? So, let us say 5 times time constant 5 times L m by R m, e is the time constant which says that this would have reached steady state, it would have reached 99.9 percent of the final value. So, by that time this would have core would have reset if I m comes down magnetizing, current comes down to 0, then you can say that the core is reset. So, 5 in 5 times time constant the core would have reset, so that it can take up the next cycle. So, this should be less than this time 1 minus d T s. So, before the off time is over, the core would have been reset. So, this is one relation.

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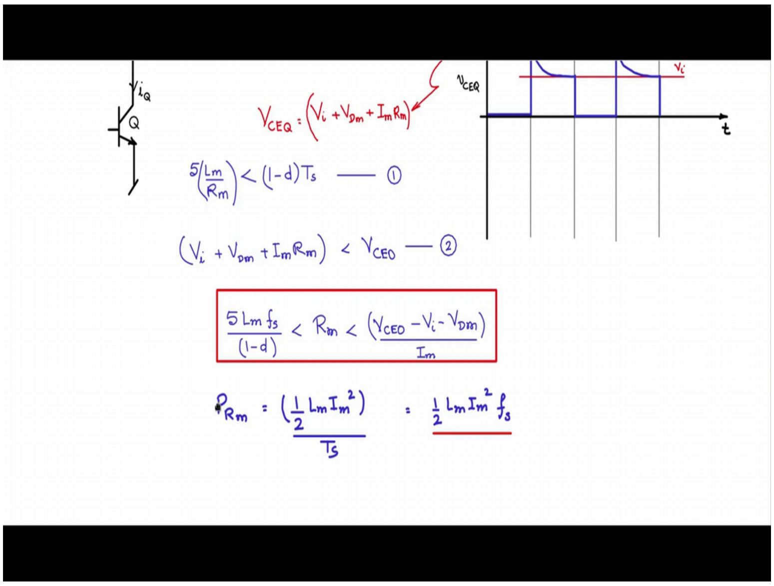

Another relation is the voltage across Q V CEQ. So, the voltage across that is as we saw here V i plus V Dm plus I m Rm. This is the peak voltage that the device will see and that it will see at the point of switch off. Now that should be less than V CEO rating of the device is the second relationship. Now these two inequalities using these two inequalities from this you can see that R m should be greater than 5 L m by 1 1 minus d T s. T s I will replace by switching frequency.

So, I will say 5 L m F s by 1 minus d should be less than R m. R m I have taken to the other side and R m should also be less than. Now if I take this relationship V CEO minus V i minus V Dm by I m should be greater than R m or R m should be less than that; so, V CEO minus V i minus V Dm by I m.

So, this is the value of Rm which will be the upper limit, this is the value of R m which will be lower limit. R m should be a value which is in between in this range. So, this is the design equation for R m selection. Now what is the power rating of R m? To see that when this is switched off, there is a current I m starts freewheeling through R m. The energy in the magnetizing inductance at this point is half L m I m square. Now that much amount of energy has to dissipate, then only the core will reset. So, that has to dissipate only in R m because R m only dissipating element. So, let us say power rating of the R m can be found out from half L m I m square amount of energy has to be dissipated every cycle, every switching cycle.

So, you can say this is equal half L m I m square into F s and this is the power that will get dissipated in R m whatever may be the value of R m which you are chosen in this range because this energy, the energy here is independent of the value of R m. So, this is the power rating choice that you have to do for R m. So, with this you can now say that whole components of this forward converter circuit with core resetting feature can be now implemented in this fashion and also simulated there is one important variable that we will not be able to measure and see on the oscilloscope.

And that is the flux inside this core. We have been talking of core resetting the core in the flux which is to be reset, but we will not be able to see the flux waveform, but indirectly we can know how it looks like. So, let me try to plot an estimate of the flux. See the flux in the core with the symbol phi and let us try to plot that one.

Now, we know from Faraday's equation that V p the voltage across the primary is equal to L m, the magnetizing inductance d L m by dt or demagnetizing current by dt it is also equal to n or np d 5 by dt. So, from this basic fundamental equation we see that L m d I m by dt is equal to n d phi by dt. L m is a constant, n is a constant, V p is fixed for the period of the time and Q is on, therefore d i mag by dt demagnetizing current by dt and d phi by dt will have the same wave shape.

And therefore, same slopes and therefore, I i magnetizing current and flux in the core and also have the same wave shape. Therefore, the flux within the core will take the same wave shape as ip mag that we have drawn here. So, let us draw that the same linear rising and fall because when V p is fixed content when Q is on V p by n V p by n will be the rate at which the flux will rise and it will fall exponentially because the current I m is falling exponentially and again the next cycle it will go in a linear fashion to a max value and then, fall exponentially as maximum value is phi m.

So, this is how the flux wave from within the core may look like if you were able to probe it and see it on the oscilloscope, but we are able to get this wave shape indirectly through the Faradays law. So, you see that the flux rises and then the flux is reset. This is the core resetting action. The flux in the core it is the reset to 0 and it is ready for action. The next cycle when it again rises and then during 1 minus d T s period, the flux is reset again; so, this is core reset in forward converter. We have been discussing about this forward converter with this type of core reset.

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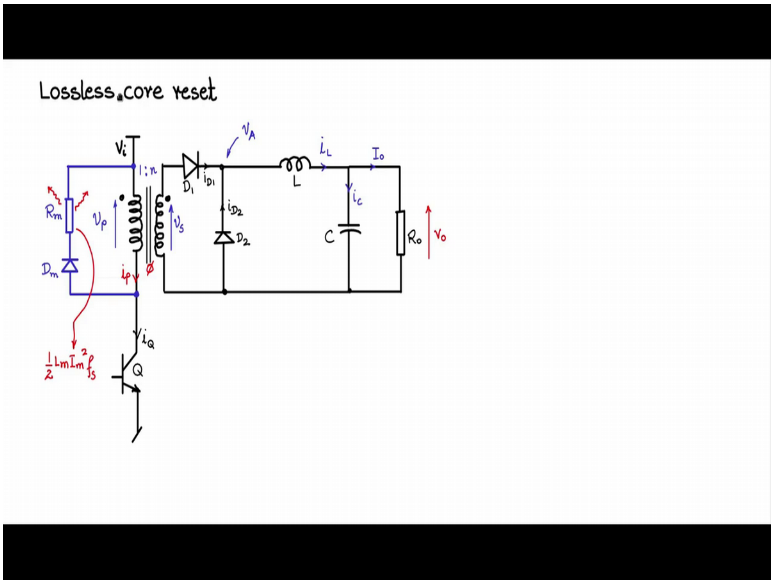

Now, this is a lossless core reset. The reason being that there is some dissipation occurring in R m and we calculated that the dissipation that happens in R m is half L m I m squire into F s meaning half L m by I m square is the energy store stored in the magnetization and that half L m squared must be removed every cycle and therefore, half L m I m square F s is the amount of power dissipation in this R m. So, this will bring down the overall efficiency of the forward converter.

So, let us discuss another method of core reset where it is lossless. So, lossless core reset, so what we do is first we remove this and then let me make some space.

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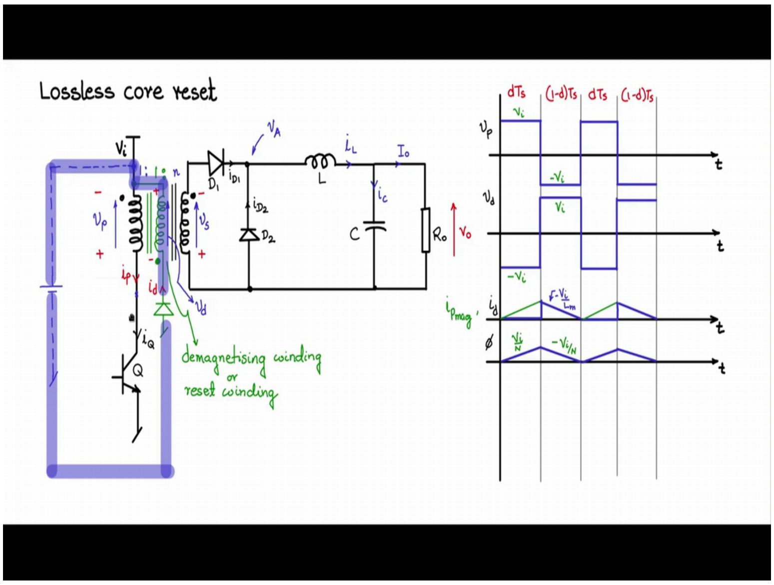

And I will introduce one more winding, one more winding which is tightly wound to the primary 1 is to 1. In fact, bicular wound you take the primary and this winding which I will call as demagnetizing winding because it is used for resetting or reset winding you take them together and wind them, so that there is minimum leakage as possible.

And then you attach a diode like this and other end you connected to V i or V cc and you place the dot polarity in the spanner opposite dot polarity ok, then let me put this as 1 is to 1 and let me push this back here. So, now this is the modified forward converter where you have removed the lossless core reset circuit and you have interposed another winding, no resistance only the winding, but still there is a prevailing diode.

Now, how does this become lossless? Let us see how the core reset action is performed and how it is lossless. So, this winding is normally turn the literature as the demagnetizing winding or simply the reset winding because of the job that it does. Now just like your measuring the voltage V p here in this fashion V s here in this fashion will measure the voltage across the demagnetizing winding and let me call that 1 as V d. So, now it will be appropriate to look at some wave forms to understand the operation of the circuit. Again I am dividing the time into four parts d T s 1 minus d T s d T s and 1 minus d T s two cycles two switching cycles d T s, the time period when Q is on. So, now first let us see the two waveforms V p and V d simultaneously V p and V d.

Now, during the time when during the timed T s during the timed T s Q is on. So, when Q is on the entire V i is coming across the primary coil with dot end positive, non-dot end negative. So, if that is the case in the other winding you will see the dot end positive non-dot end negative for the reading this fashion and dot end positive non-dot end negative in the secondary and the secondary operation we know it is the regular buck convertor operation. We will not be discussing it now. Let us focus only on these two coils the primary and the demagnetizing coil.

So, during that time V i comes across V i comes across V p for that V i and as I am measuring in this fashion the dot end being positive, it will appear minus for V d minus V i. So, because it is minus V i, the diode is reversed biased because there is a minus V i and there is also V i of the supply. So, minus 2 V i comes across the diode. Diode is reversed biased no current flows through it, but it is also interesting for us to look at what is this diode current id.

So, let us also look how one access here for the diode current id I would also like to look at the magnetizing part of the ip. We will come to that later. So, the diode current id because the diode is reversed biased, it will be zero current at that moment of time. Now if I take the magnetizing part of ip remember recall that ip is consisting of two parts. One is the load reflected part that is the n times i D1 and the magnetizing part ip mag together that form ip. So, consider only the magnetizing part ip mag which is a kind of a ramp in this fashion which is having a slope of V i by L m the slope.

Now during 1 minus d T s Q is switched off the moment, Q is switched off. The current here is immediately brought to 0. So, there is a large di by dt negative d i by dt and therefore, they will be reversal of potential across the coils. So, let us mark that reversal of potential non-dot end becomes positive dot end is negative, non-naught end is positive; dot end is negative likewise on the secondary side the secondary side now here inductor is freewheeling. This is plus and minus in this fashion this there is a reverse biased. So, the entire secondary is like open circuited. We will not talk about that. We will talk about these two.

Now here if you look at the non-dot end is positive and this will keep this will become as positive as it can pump against this V i and make this diode forward biased, so that the diode is conducting for freewheeling action. So, if I draw the voltage source V i portion also, here you will see that there will be conduction of current in this path like that and comes through this against the source V i and reaches here from this plus it goes in against the source. So, if the diode is ideal, the drop just a bit more than V i is what this will be needed to pump current into the pump current for resetting the core. So, there is freewheeling action that will happen.

So, what are the voltage across V d and V p? So, across V d because it is this a diode clumping plus and minus this is coming directly across V i, it will be V i in this measured in this direction nor non-dot end positive. So, in the case of V p you will see that it is negative minus V i because this is 1 is to 1 times ratio, this is 1 is to 1 and what happens to id see that ip had charged the flux up to that point and now it will take over from there and discharge during that time with a slope of minus V i by L m. This charged with V i by L m, this will discharge with minus V i by L m.

So, therefore if this is taken x seconds, this should also take x seconds. That is why we say that if this has taken T s by 2, this would be T s by 2. You should give the same amount of time for it to reset. Therefore, you cannot have a duty cycle greater than 50 percent in these type of converters, but is not a disadvantage because you have n has a degree of freedom whichever you can adjust the voltage.

So, next again next cycle next cycle behaves in the same way. You have the repeat and during this portion there is no id. There will be ip mag and then id comes down in this fashion. So, ip ip mag magnetizing close only during d T s portions; id flows doing 1 minus d T s portion as the freewheeling path. If you look at the flux within the core, the flux within the core will have the same profile as id and ip mag. It will take the profile of ip mag during the d T s period because that is a magnetizing current that is flowing and during the 1 minus d T s period. The magnetizing part is flowing in the freewheeling portion of the demagnetizing winding and that will be this part.

So, this is V i by n, this is also is V i by n negative because it is falling. So, this repeats. So, this will be the nature of the Flux. The flux builds up and the flux resets during 1 minus d flux builds up, flux resets during 1 minus d period because the slopes are same. You need to at least that much same amount of time for it to reset therefore, limiting the duty cycle for this type of converter max to 50 percent.

So, this is the way the core reset functions in this. Note two points this windings here the primary winding and the demagnetizing winding should be 1 is to 1 and they are to be tightly woven together, wind them together. That is called bifilar winding, so that the leakage inductions is minimized. The reason is that if there is a leakage here that portion is not covered for mutual inductance for demagnetizing, so that can cause a large spike across the device.

When it is switching off that can also be avoided by having this number circuit which I will discuss later when I am discussing devices. But, I could also provide you with a quick solution provide even the leakage inductance shortly when I am talking of using dual switch or two switches for the forward converter and remove this magnetizing portion, then we can still get lossless core reset and avoid the leakage inductance issues also.

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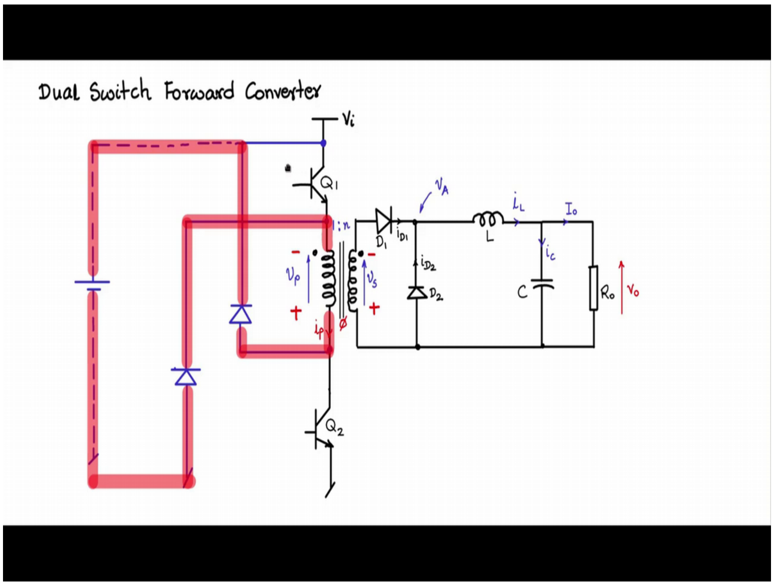

We can do lossless core reset with dual switch forward converter also. So, let me briefly describe the dual switch forward converter and explain to you how this lossless demagnetizing can be done. So, this is the circuit of a forward converter without any demagnetizing; without any core reset and let us introduce core reset now. So, let I remove the V cc for now and then here I will introduce another switch another BJT this is V i. Let me call this Q 1 and this is Q 2 ok.

Now, these two switches are switched on simultaneously ok. Now I will add two freewheeling diodes; one diode freewheeling from here to V i to V cc and another diode from here down to ground in this fashion. I will explain to you how the current flows. Let us also visualize that there is a supply here. So, let us place that supply because we have placed the label. So, let us visualize to understand the current flow.

Now, let us consider the situation d T s when Q 1 and Q 2 are both on together. So, they are both on together. You will see that this will be this is on. So, V i this is plus and this is minus, on the secondary side this is plus and minus, secondary side operation we know is buck converter operation, but let us see how the current flows here on the primary. So, it starts from here, goes in this direction, comes like that through the ground and back again to the power supply. So, this is the path of the current flow during the period d T s and where the voltage across the primary is plus minus dot and positive V s dot end positive buck operation follows.

Now, what happens when you switch off Q 1 and Q 2? So, when you switch off Q 1 and Q 2 there is a cut in the primary current meaning the primary current is cut off to 0, but we cannot allow cut off to 0. There will be a reversal of polarity. So, first these polarities will reverse because of the minus di by dt and there has to be a path for ip current flow in the same direction in the coil.

So, let us start from here ip flows here now as Q 2 is off current flow in this direction through this diode and then into the supply. So, I am indicating the supply here goes into the supply and this comes in this direction through this diode up there again and then, down and maintaining the same direction of current flow in the primary only. Now the dot end is negative; non dot end is positive. So, it is demagnetizing.

So, this is this coil is acting like a demagnetizing winding during the 1 minus d period because the secondary side is open, this diode is off. So, this because the same winding is operating as a demagnetizing winding, there is no leakage inductance problem because everything is included here and primary reflected and you will not have leakage inductance spikes due to due to the leakage inductance spikes on the two switches when they are off. So, this is the path the this is the path where the demagnetizing current will flow and if you will consider diodes as ideal, this whole V i is coming across the primary plus minus in this direction.

So, you have to allow the same time because again it is 1 is to 1. The magnetizing is happening at V i by n the demagnetizing is also happening at the rate V i by n. Therefore, you have to allow the same amount of time for the magnetizing as you are allowed for magnetizing and therefore, this is also limited to 50 max duty cycle. This is not actually a serious limitation because of the n here, you cannot just the value of the n to get whatever required output voltage. So, this is the dual switch forward converter. You have removed the windings, but you have included one extra diode and one extra switch and an extra controls switch means extra get right for that.