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

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Lecture – 13
Waveforms and Design

In this video capsule, we shall look at the wave forms, some critical waveforms of the forward converter. The output portion of the forward converter is like the buck converter and therefore, the inductor current, the capacitor current and output load current parts of the waveforms will be exactly same as that of the buck equivalent, buck converter waveforms that we discussed. What we should now look at is the waveforms of the primary side switch, the secondary side currents and the freewheeling current for core resetting. These are critical waveforms which we will look at and that will give us an idea of how to go about rating the devices and selecting the components.

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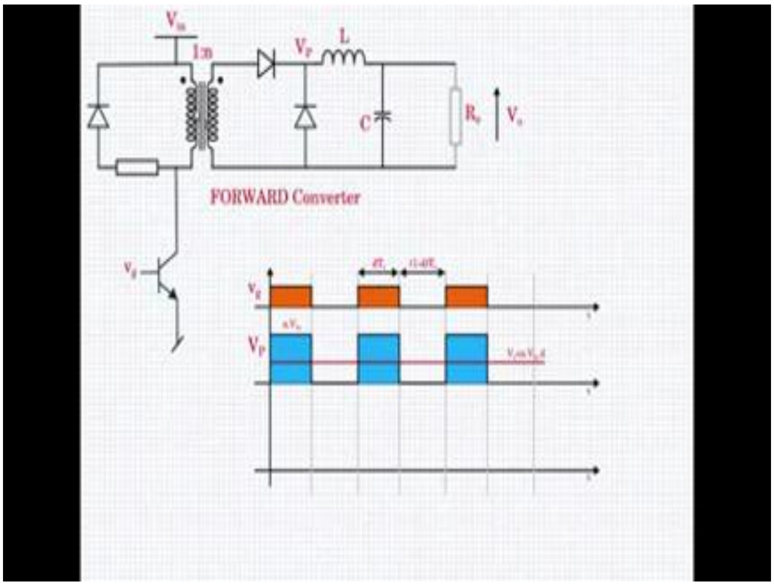

We see here that the forward converter is moved to one corner. So, that I have make some space here to put in the waveforms like before whenever discussing the buck converter i have here the waveform of V g or V g is actually the gate waveform not the wave straight waveform that you would give here. So, this is the signal that you would give here when the signal is high this b j t or the semi conductor switch will turn on. So, this is the period when the switch is on, this is the period when switch is off, this is the d t s period on time 1 minus d t s period off-time.

Now, let us look at some critical wave forms we know the how the buck converter operates and then we know how the pole voltage will be exactly like what we discussed for the buck converter one difference would be the turn ratio m coming into the picture. I would briefly show you that and then we can move on to other waveforms now let us say i will position V a V p here the waveform would look something like this just like before, the only difference would be in the value here which is n V in when the switch is on during that time here you have V in and what gets transfer to the secondary’s n times V in and n time V in will come across at this point.

So, that is what we have shown here and during the time when the switch is off the inductor current is freewheeling in this passion and V p is 0. So, that is what you would get here and the resulting average of that would be the V naught. So, let us say I will position the average somewhere here just an indicating measure and V naught is something like this. So, this is the V naught waveform as. So, as in the buck converter operation is concerned it the buck pole portion that we L and C is exactly same as before.

The inductor current operation is also very similar we will revisit that later on, but there are some few other important waveforms that you need to look at the primary current that is flowing through the switch and the portion of the current that is freewheeling, when the switch is off this is absolute the core reset current the what the current that will reset the flux within the core and makes it ready for operation in the next switching cycle.

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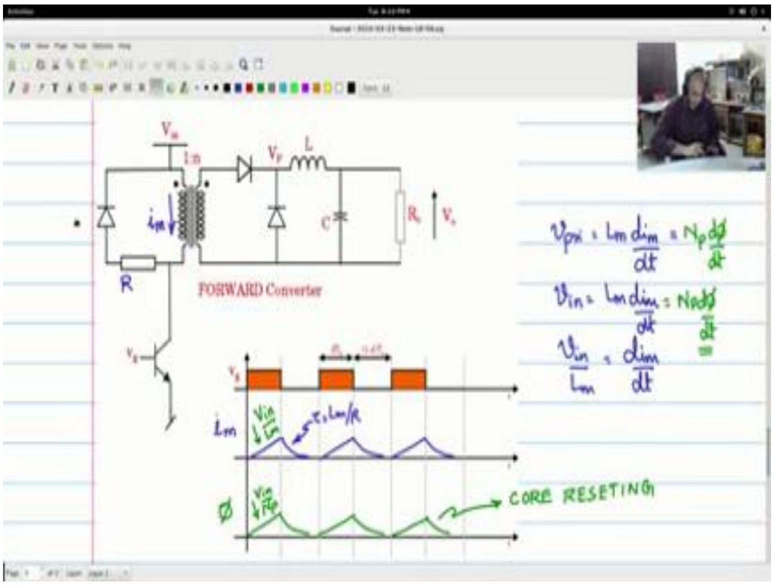

$$V_{pri} = L_m \frac{di_m}{dt} = N_p \frac{d\phi}{dt}$$

$$V_{in} = L_m \frac{di_m}{dt} = N_p \frac{d\phi}{dt}$$

$$\frac{V_{in}}{L_m} = \frac{di_m}{dt}$$

Now, let me draw the magnetizing part for i m that is flowing through the primary of the transformer. So, when the switch is on, there is a voltage V in applied across the primary, which is a constant voltage. So, therefore, the magnetizing part will rise up linearly the reason is that voltage of the primary is equal to L magnetizing d i m by d t. So, as V primary is nothing, but V in which is equal to L m d i m by d t d i m by d t is equal to V in by L m the rate is constant and therefore, the magnetizing current rises up linearly like this.

So, everywhere you will see during the time and it is on, it should go like this and once it is gone the magnetizing current as gone up like that and should also note that by faradays law. There is another fundamental relationship, which is n primary d phi by d t the flux within the core which is more primary relationship.

So, this d phi by d t within the core is also having a similar form like it can be i m by d t and therefore, phi also would increase within the core linearly. So, this is increasing V in by n p primary and this is increasing V in by L m. So, the slope is like that now after having reach the maximum now you are switched off the device, once you are switched off the device you see that the current through the transformer is immediately switched off this will go down to suppose to go down to 0 which is a high d i by d t negative d i by d t very and narrow time and then you are cutting off the current that is a d i by d t and therefore, a negative d i by d t means that the voltage induced here will change polarity.

So, this will become positive and that will become negative. The dotted will become negative, the non-dotted will become positive and this will drive a current through this closed circuit path turning on this drive. So, once it drives the current this is acting now like a generator L by R time constant it will fall exponentially. So, the current the magnetizing current will start falling exponentially like this with the time constant if this is R and L m is the magnetizing this will have a time constant tau is equal to L m by R L by R.

Now, the flux also follows looking at this faradays equation the flux will follow the magnetizing current. So, therefore, the flux shape also will be similar to the flux or the current shape. So, this will also go in this way and this is called resetting the core. So, bringing it back to 0 that phenomenon is called core resetting and it is very, very essential for copper operation of transformers core resetting has to be done whichever be the topology.

So, one is the core is reset at this point here I gave it is ready to begin it is journey in the next cycle. So, this is how the magnetizing part free wheels through this freewheeling circuit. So, what is the current through the switch i q, now let me draw the current through i Q it has, as I said two parts the magnetizing part and load reflected part. So, let me draw also the load reflected part and show you how the primary switch current looks like.

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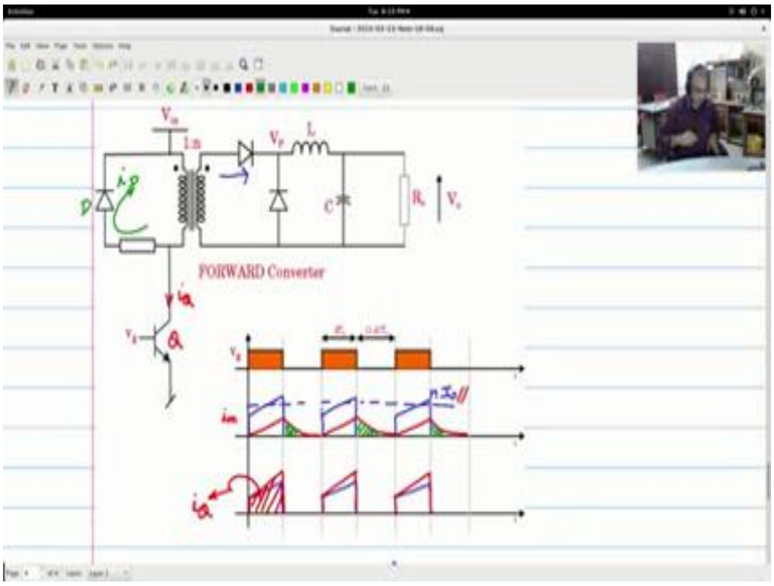

So, the magnetizing current in the primary we saw this like this it had a linear part exponential d k linear part exponential d k so on and so forth keeps going like that. So, this is i m the magnetizing part now we saw the current here this was the inductor current that portion of the inductor current which is flowing through here and it had a waveform which is like this. So, this is the reflected part of the secondary current.

Now, you see that in the secondary inductor current average was i naught and therefore, this value would have been i naught, but recall that when you take it to the primary side it becomes n i naught. So, this value very important gets scaled by n, now the load reflected part plus the part magnetizing part is the current that we flow through the switch.

So, I will draw the low reflected part like this this is the low reflected part and do that let us add the switch part that is this one. So, it gets added like that. So, this would be your switch current. So, this current is i Q which is flowing through the switch Q. So, this part this hash with green part is flowing freewheeling through here i was call, it as i d, and the magnetizing part is the one which is actually included in the i Q part.

So, this is how the current waveforms flow in the primary and the secondary of the forward converter. We will just have a look at the voltage waveforms to understand that is happening to the voltage ratings of the converter consider the switch Q and let us look at the voltage waveform across the switch here V Q.

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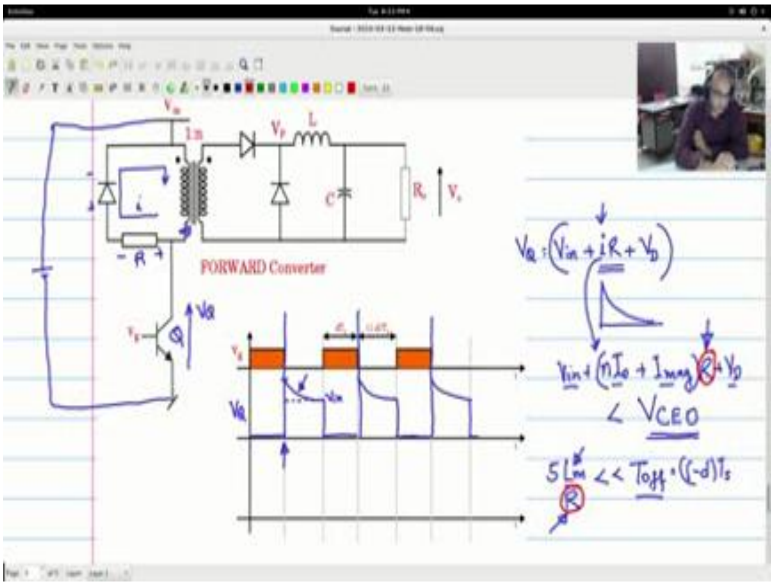

Now, V Q when it is just the on state drop. So, all this will be on state drops when the switch is off you see that there is a preliminary current flowing through in this fashion there is a drop here they will of course, be the divert drop and then V in which completes the circuit here like this. So, if you look at that sketch of slope along this path, the sketch of slope you will see the voltage that you see across this when this is off is this R drop divert drop and the V in value there.

So, what actually will be V Q during the half state would be V in plus i R drop whatever is the current high that flows through here and let say this is R plus V d are the diode on state drop. So, that is what will come here and out of this you will see that this is a varying quantity and we saw that the current here the magnetizing current is going on exponentially or be constant i R drop will also have the shape and ultimately it should when it goes to 0 it should settled to V in.

So, you think the V in value you will see that the voltage will start moving in this fashion the voltage across the device the switch will be like this. So, now, if you look at the rating for this Q the voltage rating should be such that the off state voltage which standing capability should be such that it is greater than this quantity and what is that i, i in general has to be the magnetizing current, but however, you will see in factors there is a leakage component here there will be a leakage; primary leakage in the transformer series with it. So, during the time of the transistor was on this leakage was carrying both the magnetizing plus the load reflected component.

So, n i naught component, n i naught plus i n value will be the value which I will start off at this point at this and then once the leakage energy is decade then the magnetizing energy will decade and formed take this V shape. So, during the instant of switch off you may see in the scope very high spike like this now that is due to the leakage and that is when the leakage energy causes that kick. So, i will actually be n i naught plus i magnetizing peak i magnetizing peak.

So, this into R V in plus V d should be less than V C e o rating of the transistor or the MOSFET. So, based on this you know this you know this by design this can be the value data sheet value chosen from their chosen device knowing all this, this can be estimated, this is one condition. It only says that the value of R. So, chosen should make discussion and there i another constraint the value of the R should not be too low to avoid this pipe because it is too low there is a time constant involved for this d k and five times the time constant should reset the core flux in the available time t off.

So, five times L m by R time constant should be less than the d t off time or which is 1 minus d t s time. So, this is this is known L m is known from design of the transformer this value can be estimated. So, these two values from these two inequalities will give you a higher range and lower range and based on these two higher range and lower range you should pick a value in between this range to satisfy your circuit requirements.

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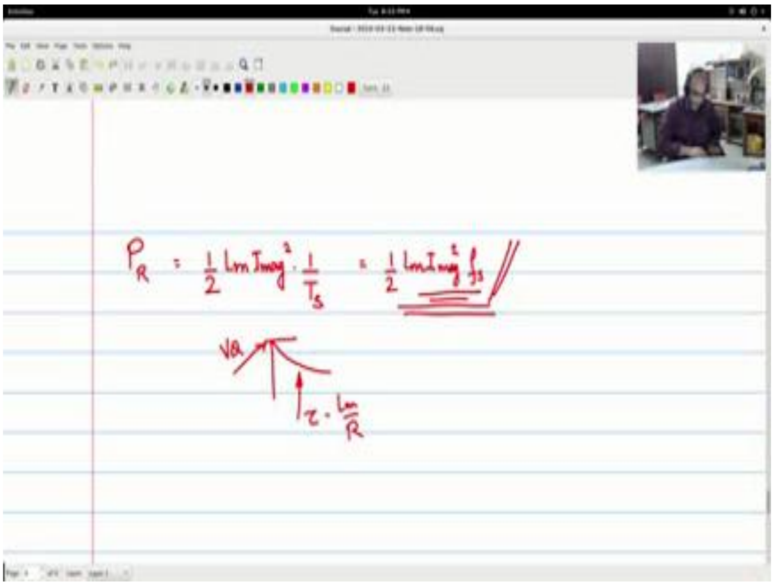

$$P_R = \frac{1}{2} L_m I_{mag}^2 \cdot \frac{1}{T_s} = \underline{\underline{\frac{1}{2} L_m I_{mag}^2 f_s}}$$

Another aspect is that the power dissipation are the power dissipation in R, the energy which is stored in the magnetic in the magnetizing inductance is half L m i max square. Now, this energy has to be dissipated with in R at this cycle. So, into t s this is the energy in joules by t s every cycle this energy has to be dissipated will give you the power dissipation R which is half L m i max, i max square into f s notice that the power dissipation in R is independent of that value of r.

So, whatever may be the value of R the power dissipation is fixed the value of R does two components one is limit the value of this spike voltage here at V Q spike voltage at the switch off time and also determines the time constant tau of the d k of the flux. So, these two are going to decide the value of R and the power dissipation is only by frequency and the inductance in the magnetizing current components. So, this way you can rate the resistance value R.

So, the Q the switch both the current and the voltage ratings are known the voltage rating is basically V in plus i R a drop here and the current rating is whatever value of the current that flows here peak value which is i naught transferred, here n i naught plus delta l. So, n times i naught plus delta i n will flow load reflected plus i magnetizing. These are the two components that flows through here at the current has to be accordingly rated and the diode current here and the diode current here will be rated exactly in the same way as we discussed for the buck converter circuit L and C will be design an exactly the same way as we did for the buck converter circuit because the out portion of the circuit is nothing, but the buck converter.

So, we know how to rate the resistor to rate this transistor switch the diode, here will have a current rating of the magnetizing current average and voltage rating it should be withstand V in when the transistor here is switched on. So, this way you can rate the various components. It is not a good time for you to simulate this circuit and learn more about the various waveforms at various points and get more insides into this circuit.