Design of Power Electronic Converters

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Lecture 03

Choosing L and C

Last lecture, we discussed the analysis of buck converter, we saw the different equivalent circuits and we also saw some of the waveforms. How do you choose the values of inductors and capacitors? The waveforms we saw that that it is dependent on the value of L and C, but how do you choose the value of L and C that is what we are going to see in this lecture.

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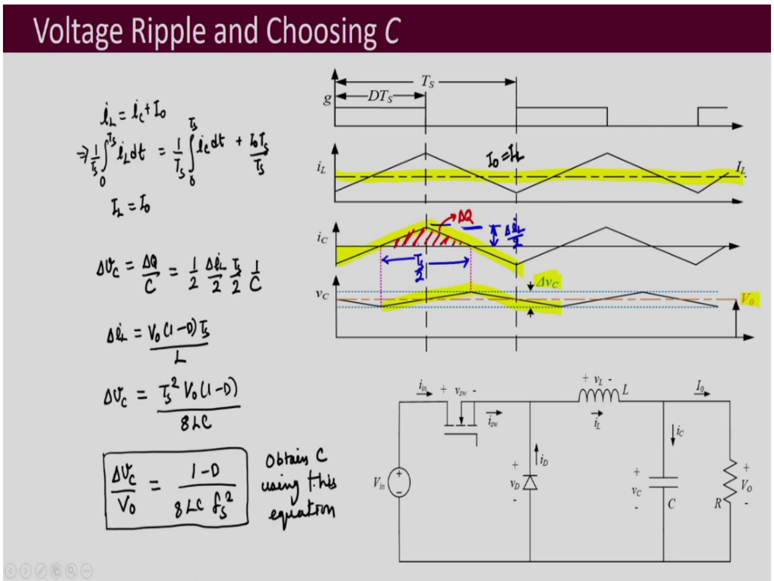

So, to do that first let us see this inductor current i_L. Now, here at this point if we apply KCL then what you can write it is that

$$i_L = i_c + i_0$$

. Now, we have said before that the average current through the capacitor is going to be equal to 0. So, that means, if we take the average over one switching time period for this entire equation, so what we will be getting from this is that

$$I_L = I_0$$

because the average current through the capacitor is equal to 0. Now, using it if we have to draw the capacitor current waveform. So, what we see here this is the inductor current waveform and then we subtract the average inductor current this is the average inductor current I_L which is same as equal to I_O the load current, this is I_O which is equal to I_L. So, then when we subtract this, what we will be getting is this capacitor current i_C.

Now, we can see that that here the average is equal to 0, the current through this capacitor. And then here in this part the capacitor current is negative and here the capacitor current is positive. So, while the capacitor current is positive what will happen the voltage across the capacitor will increase and then when the capacitive current becomes negative here, the voltage to the capacitor will decrease that means, the capacitor will discharge at that time.

So, that is what leads to a smaller ripple in the capacitor voltage and that is what which is denoted by this Δv_c, the ripple across the capacitor voltage. And if we take the average of it, then that average is given by this V_O, which is the output voltage V_O and which is what we had assumed to be constant initially, but this is not really constant, this is equal to this voltage V_O which is average of this ripple voltage.

So, now, let us write some equations for this capacitor voltage.

$$\Delta V_c = \frac{\Delta Q}{C}$$

ΔQ is the change in the charge to the capacitor and you can write it as shown above. Now, from where are we getting it?

You can see here that that if you integrate this area that means basically find out the area when the capacitive current is positive, that is what is going to be equal to this ΔQ. So, that is what is written and this is equal to Ts/2 this time interval. So, that is why it can be written as

$$\Delta V_c = \frac{\Delta Q}{C} = \frac{1}{2}\Delta i_L \frac{T_s}{2}\frac{1}{C}$$

So, before what we have derived

$$\Delta i_L = \frac{V_O(1-D)T_s}{8LC}$$

So, therefore, substituting it ΔV_c can be written as

$$\frac{\Delta V_c}{V_O} = \frac{V_O(1-D)T_s^2}{8LC}$$

$$\frac{\Delta V_c}{V_O} = \frac{V_O(1-D)}{8LCf_s^2}$$

This is the expression which can be used for obtaining the value of capacitance. So, using the voltage across the ripple, how much is the ripple that is allowed for the capacitor when we can specify a limit on it and using it, we can find out the capacitance value. Now, next, let us see how do we obtain L. Now, to obtain L we have to understand something else which is called as the boundary condition.

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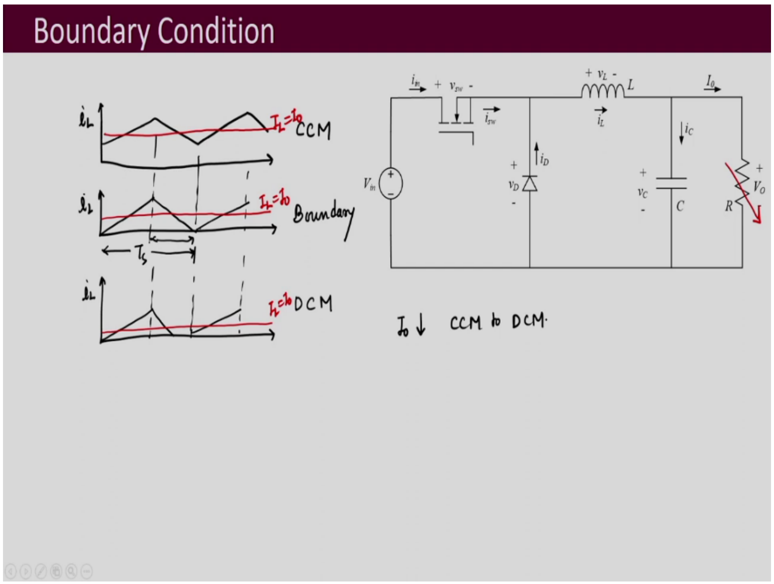

Now, we saw this inductor current waveform it was like this. So, this is continuous, this is not becoming 0 at any time and that is called as the current is in CCM continuous conduction mode. Now, it may so happen that there may be situation where it may start exactly from 0 this inductor current and come back to the exact 0 when the switch is turned off. So, this is the total T_s period, this is the on time and this is the off time. So, it may exactly start from 0 come back to 0.

And it is also possible that, that it may start from 0 but it becomes 0 before the switch is turned on again. So, this current then becomes discontinuous, the inductor current. So, this is called as this continuous conduction mode and this is the boundary between the two where the current is still continuous, but it exactly begins from 0 and at T_s it exactly reaches 0. So, this is called as the boundary condition.

And how this happens? This happens because this average I_L which is equal to I_O. Now, as we change this load, this resistance changes this I_O may decrease. So, here if you see that this I_O, or I_L this is going to be lesser than when it is in CCM and similarly here it is going to be further reduced this I_L. Then as our I_O decreases, the converter goes from CCM to DCM. Now, what is the role of this boundary condition?

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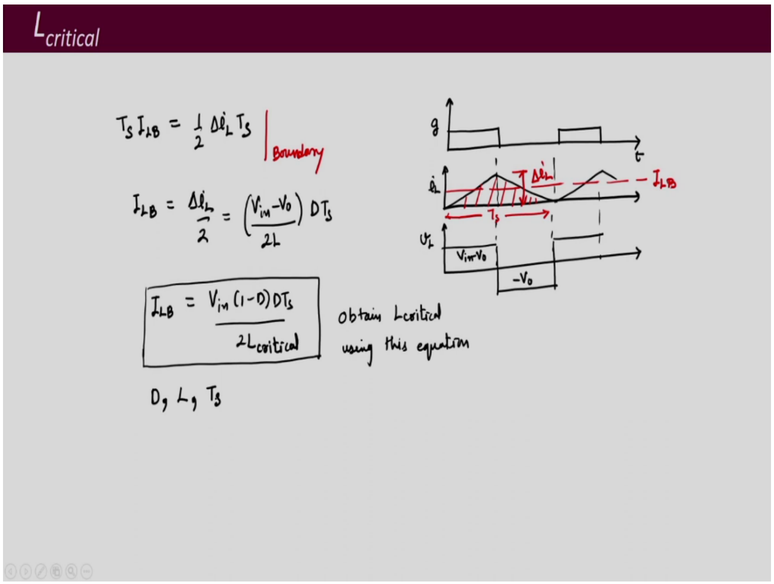

Let us look into some of the equations related to boundary conditions. For that, let me draw this gate pulse g and then this is the inductor current. So, at boundary it will be like this and the voltage across the inductor v_L. So, this is

V_{in} - V_o = -V_o.

So, at boundary if we find out the average this is T_sI_{LB}.

And what is this I_{LB}? I L B is this average current boundary current I_{LB}. So, if we equate the averages that means T_sI_{LB}. So, this is T_s, this T_sI_{LB} will be equal to the area under this triangle. So,

$$T_s I_{LB} = \frac{1}{2}\Delta i_L$$

And what is delta i L? Delta i_L is shown on the graph. Note that that this is only at boundary we can write it otherwise you cannot write it.

$$\Delta i_L = \frac{(V_{in} - V_o)DT_s}{2L}$$

$$\Delta i_L = \frac{V_{in}(1-D)}{2L}DT_s$$

Now, this is also called as L critical, we will denote it by $L_{critical}$, the L that is associated with boundary condition. And this is, this $L_{critical}$ is important because, when we decide that at a certain particular value of I_O, we want the boundary condition then for that particular value of I_O you can calculate the value of L and we denote that as $L_{critical}$.

If the inductance goes below that, then what will happen is that the same current converter will go into DCM which is not what we want. So, obtain $L_{critical}$ using this equation. So, then what we see is that this boundary condition depends on the duty ratio, it depends on the value of L and it also depends on the switching frequency or the switching time period.

If we change any one of these then the boundary condition will change and then accordingly the $L_{critical}$ value you should change for to obtain the boundary at a particular value of load current. So, from here what is the importance of these boundary, why we did this boundary condition.

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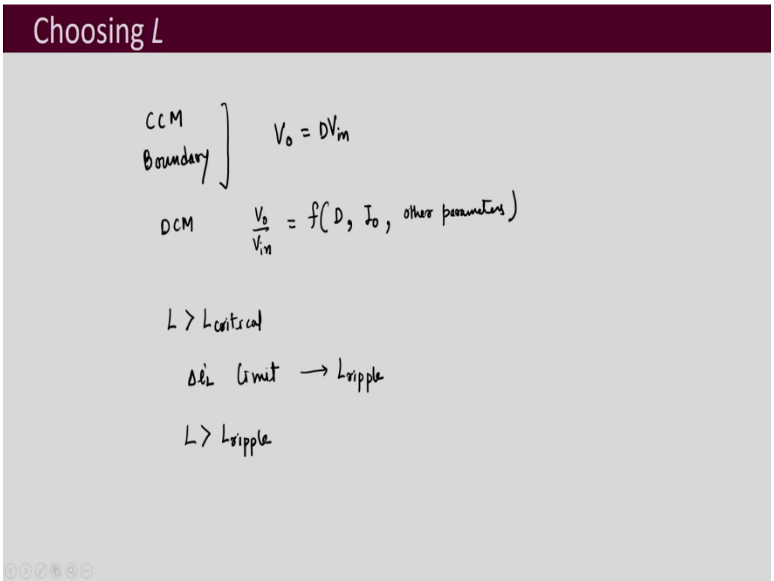

So, what happens is that when the converter is in CCM or it is in boundary, at that time, this output to input voltage relationship remains Vo as equal to DV_{in}. And here in this case, this load current we do not need to know this the ratio is independent of the value of load current. Whereas when the converter goes into DCM at that time what happens is that this Vo/Vin this becomes a function of your duty ratio as well as the load current and of course, other parameters.

So, then that means what the control does not remain simple, the control becomes more complicated in DCM. So, we want simple control. And so, we want the converter to operate in CCM and in or up to boundary. So, that is why boundary condition has to be specified for most of the load range for which your buck converter is going to operate, you would want it to be in CCM.

And so, that is why your inductance value has to be greater than the $L_{critical}$ that you obtain from your expressions for boundary condition that we just derived now. So, L has to be greater than $L_{critical}$ that is how we will be choosing it. And further, you should also note down that we had obtain this expression for Δi_L as well. Now, we can put a limit on this Δi_L.

In certain application, we may not want the inductor current ripple to be very high, we may want it to be small enough. So, using that expression also you can obtain another value of L. So, let us call that as L_{ripple}. So, your L whatever you choose, that should be also greater than L_{ripple}. So, this is how you choose your value of inductance.

Now, there is no specific concept that this is going to evaluate, it is a choice depending on many things your how big inductor you want to design or how small inductor one wants to design because the size of the inductor also matters. So, and the cost of the inductor all that is a factor. So, but theoretically, it has to be greater than this $L_{critical}$ and also it should be greater than the L_{ripple}.

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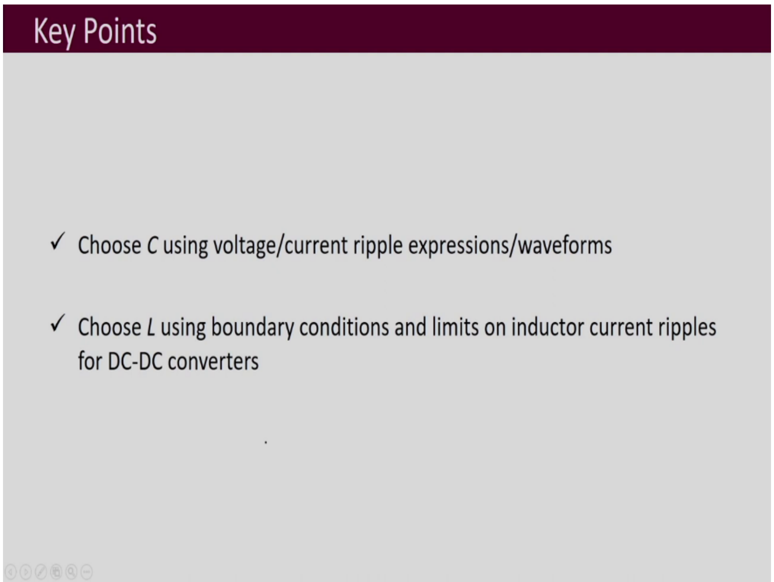

So, the key points of this lecture are what that we can choose the value of C depending on the voltage ripple expression of the current ripple expressions. And second, you can choose L using boundary conditions and the limits on the inductor current ripples for DC-to-DC converters. Thank you.