Introduction to Time - Varying Electrical Networks
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Lecture 49
N-path principle: Multiphase dc-dc converter

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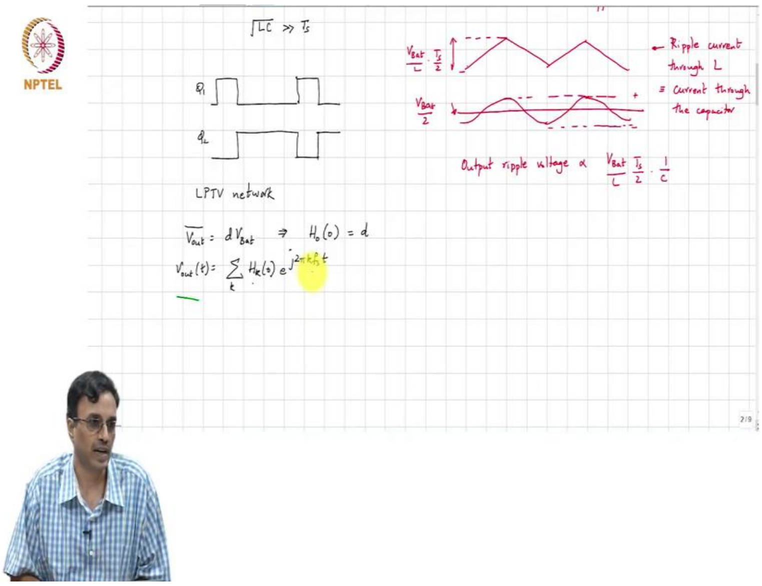

Now, the question is, if we do multi, if we do you apply the N path principle, then as we saw for the last couple of classes, several of these components basically get eliminated because of cancellation. And as a result, you have fewer of these components. And therefore, you should expect the ripple to be smaller. And I am going to take a special case, I mean, for our special case of the dc-dc converter, where we assume that these is half, I am going to just use this as a special case to illustrate the principle, multi-phase dc-dc converter, of course is a vast area in itself and it does not make sense for me to talk about those things in this course.

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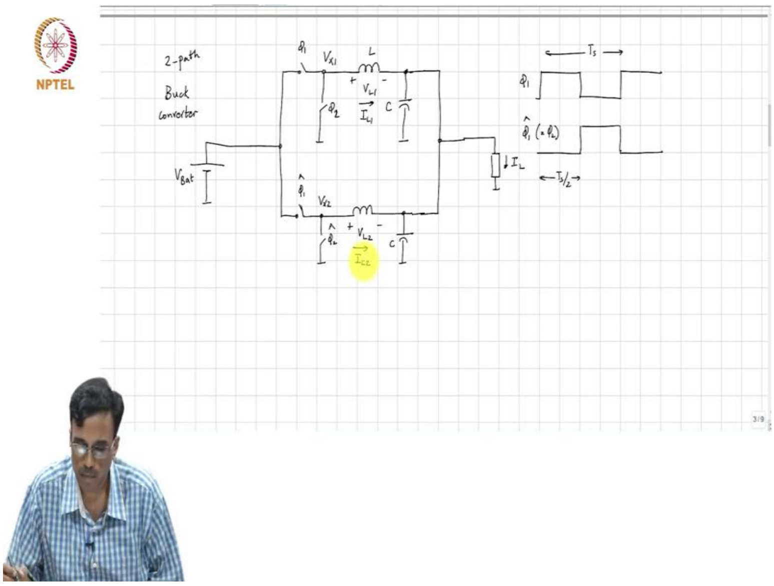

So, let us say I took one dc-dc converter like this. And another one, let us assume a 2-path buck converter. So, we have, of course, the input is the same so, I do not need to have another battery, what I am going to do is have the same converter, now what am I, if I used 2-path principles I mean what am I going to drive? So this is going to be the battery, what are we supposed to, let me call this V x 1, we are going to call this V x 2, this is C and we connect the two outputs together, if you connect two outputs together what happens?

Student: (())(2:25)

Professor: I mean if you think about it, the Thevenin equivalents just basically come in parallel, the Thevenin open circuit voltage is also basically will therefore divided by 2. So, you have to, so the voltage will be the, the DC component of the voltage will remain the same right. And so, this is now I L. So, what should this switch be driven by? Remember, what did we say about the N-path principle? The network is driven with the variation of time is I mean of each component is just shifted in time by Ts over n in this case Ts over n. So, we had phi 1 like this.

Student: This is phi 2 hat.

Professor: Yeah, so if we call this phi 1 hat, this is phi 2 hat, phi 1 hat is simply delayed by Ts 2. So, this is Ts and this is Ts over 2, and similarly for phi 2. And because we have chosen 50 percent duty cycle here phi 1 hat simply happens to be equal to only in this particular case, not if the duty cycle was not 50 percent. So, what comment can we make about the inductor current in, so we call this VL 1. This is VL 2. What comment can we make about IL 1?

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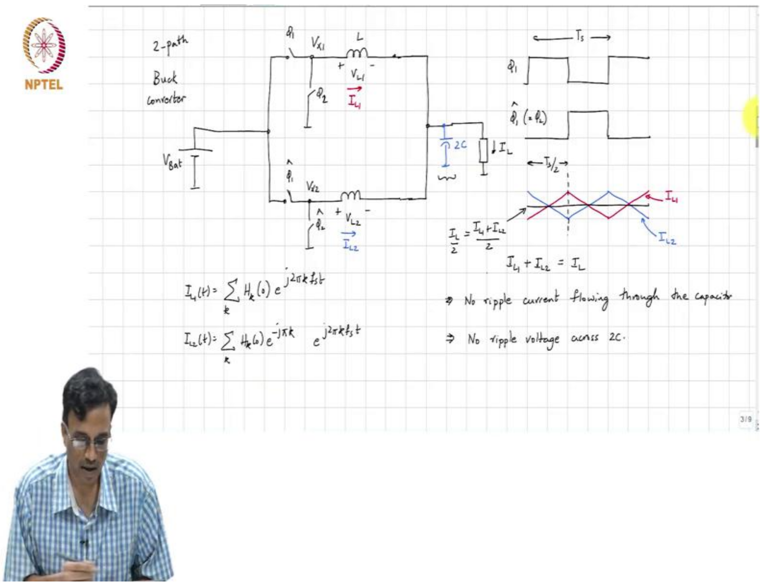

So, in let us see how IL 1, very good. So, let us see what happens in phase phi 1, the IL 1 will basically ramp up during?

Student: Phase 1.

Professor: Phase 1. Why? Because during this phase, let me use a different colour here. So, IL 1 goes up. What comment can we make about IL 2 during that phase? The IL 2 goes down and vice versa. And so this is basically IL 1, this is IL 2 and therefore, when you add these, what IL 1, I mean, you can think of these two capacitors as being a single capacitor here of value 2 C. So, what comment can we make about IL 1 plus IL 2.

Student: Has to be equal to L.

Professor: That of course, but IL 1 plus IL 2 the waveform, it is?

Student: Constant.

Professor: Constant and that constant but I mean must be equal to I. So, this is actually IL 1 plus IL 2 by 2 just so that I want to show you the cancellation of the ripple. I 1 IL 1 plus IL 2 by 2 must be equal to IL by 2, it makes sense if you have two converters, each one is supplying half the load current, and the key point that we have seen here is that the ripple the current flowing through the capacitor 2C, what is the current flowing through the capacitor 2C?

Student: It will be 0.

Professor: It will be 0. And because the voltage across the, because the current to the capacitor is 0 that basically means the voltage across the capacitor is a constant. So, there is no ripple current through the capacitor. And therefore, no ripple voltage across 2C. So, this is how what do you call, the use of 2 paths is completely eliminating ripple.

Whereas, if you had to do this with a single path, the only way that would be possible is if L and C became infinite. And, you know again, as you can see, this ripple becoming 0 is achieved through cancellation. It is whereas increasing L and C is achieved by division. So, of course, in practice, you know the two currents IL 1 and IL 2 will not be exactly the same. So, there will be some residue ripple, but as a principle you can see that the, what do you call the ripple at the output is supposed to be 0.

And how does this work from the LPTV point of view? Well, if you look at the inductor current in the IL 1 of t, if you think of it as sigma k H sub k of 0 e to the j 2 pi fs times t, by the way looking at the waveform of the inductor current, what comment can you make about the Fourier components of the…

Student: At fs.

Professor: There of course at fs, but it is a, you can see that, you know if you assume that this t equal to 0, you can see that it is an even function of time and therefore, only the even components of the…

Student: Fourier series.

Professor: Fourier series will be present. And IL 2 of t is also going to be, it is going to be H k 0 e to the minus j 2 pi fs times Ts by 2 e to the j 2 pi sorry, this must be j 2 pi k fs times t and this is equal to minus 1 to the n, so this is sorry, this goes to the minus j.

Student: Minus 1.

Professor: Minus j pi times k. So, as you can see, there is this cancellation, because this is only true for, I mean, remember that only the even harmonics are present. So, this will go and cancel out all the even harmonics. So, what do you get is only DC will add. So, if you add IL 1 plus IL 2 the only components that will add are DC, all the even harmonics get cancelled because of the…

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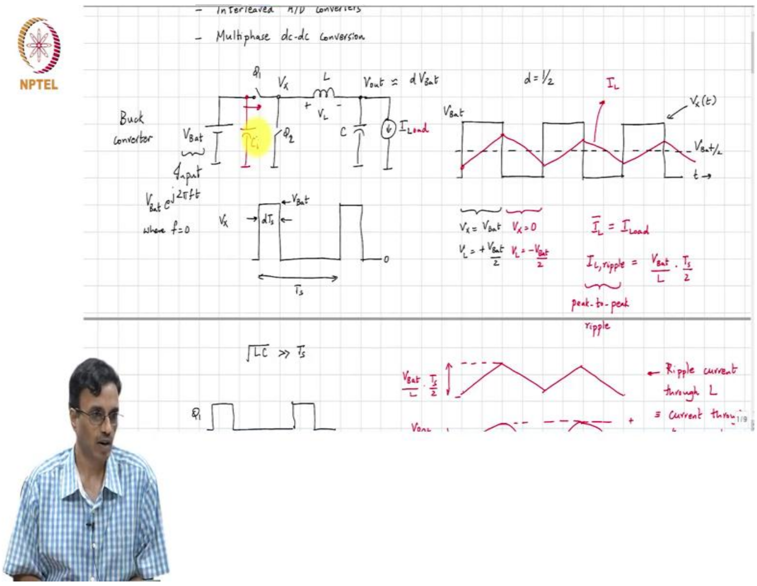

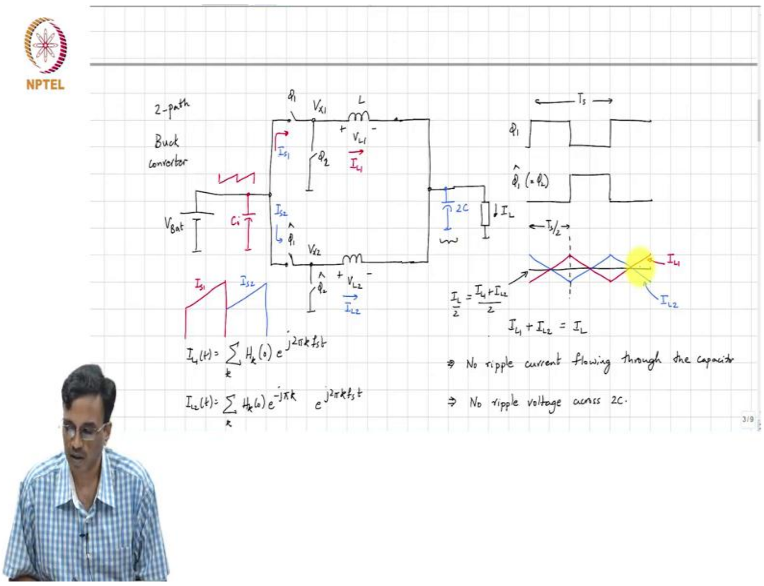

So, and another it turns out that if you look at the current through in the single phase case yet another property I would like to point out is the following, what comment can we make about this current?

Student: (())(13:05)

Professor: Yeah so, it is nothing but during phi 1 it is the same as the inductor current, during phi 2 it is 0. So, the switch current here therefore, is going to be some waveform like that and then what do I, and during the other phase it is going to be 0, what comment can we make about IL2? It is delayed by half clock cycle. So, this is IS 1, this is IS 2. And so, you can therefore see that in the single phase dc-dc converter, what you have is that the current flowing through the battery would be have huge spikes.

So, and that, it turns out that that damages the battery. So, you would actually put in it turns out that in practice, you would also put in a big capacitor CI across the battery. So, that all the high frequency current drawn by the switch is supplied with a capacitor and the battery only supplies a largely a constant current.

Now, what happens with the two phase case? Well, even if you did not put the capacitor Well, all that you are seeing is the small ripple current through the inductor and so, the net current here is going to be a small ripple current, whereas earlier the total current I mean you would jump from 0 to full current during every clock cycle. So, of course, I mean, so therefore, what this means is that the capacitance you can put in to filter out the high frequency current going into the batteries is very small.

So, I mean, we also see that, in this special case of choosing d equal to half the output ripple is 0. Of course, in this it turns out that the output ripple is 0 only at this particular duty cycle. If I change the duty cycle, then the cancellation will obviously not happen, but it anyway turns out that the ripple will be lot smaller than what it would have been in single face case.

So, this is you know one example of the use of the N path principle in multi-phase in dc-dc conversion. And the, in practice, it turns out that it is not uncommon for people to have, you know, maybe four five phases. A large number of phases. And that happens, I mean, you know, one thing that we saw here was that the load current is split into two paths, it is shared among two sets of components.

If you had to drive a large range of currents then you could choose to do something where when the current becomes very large rather than, yeah you basically turn on another phase, so that you not only reduce the ripple because remember that as IL becomes larger and larger, the ripple also becomes higher.

So, when the load increases, then you basically add another phase. So, therefore not only, yeah, so basically the extra load current is shared among a larger number of people and also there is some degree of ripple cancellation, that is possible. The last example I would like to.