Digital Control in Switched Mode Power Converters and FPGA-based Prototyping
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Module - 02
Fixed and Variable Frequency Digital Control Architectures
Lecture - 19
Overview of Digital Hysteresis Control Architectures

Welcome back. So, this is an extension of the previous lecture and this is regarding Digital Hysteresis Control.

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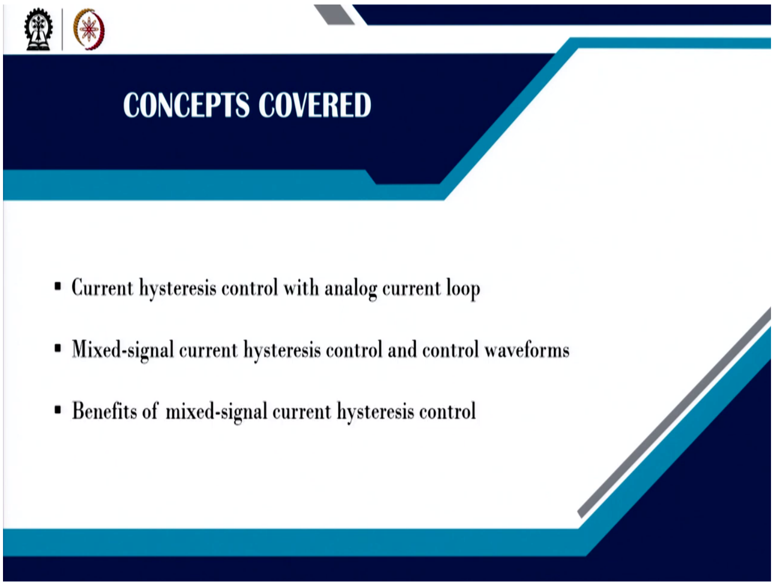

So, in this lecture we will show that you know analog hysteresis current control, then how the mixed-signal hysteresis control looks like, and their control waveform. And finally, what is the architecture of mixed-signal hysteresis control, and then what is the benefit of mixed-signal hysteresis control?

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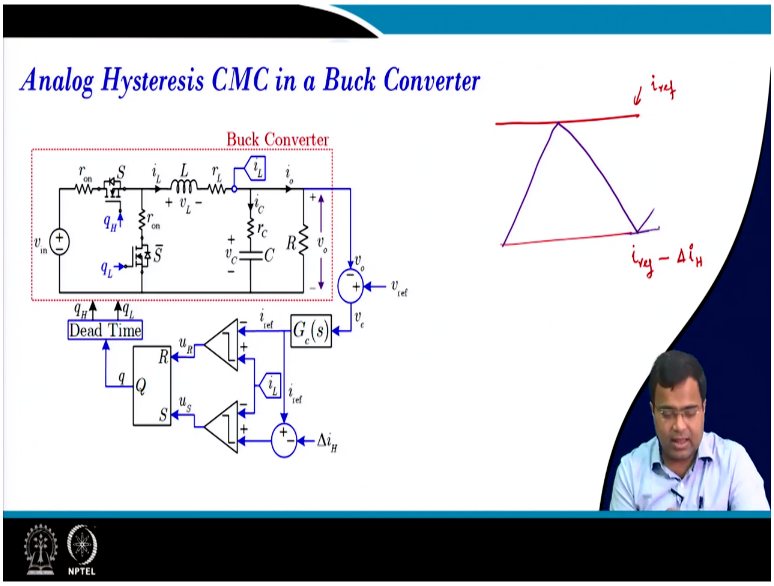

So, we know about the analog hysteresis control, and that we have discussed it in sufficient detail; that means, the inductor current should be retained within some peak and valley. So, in this case, we are talking about the I ref and delta so; which means if this is your I ref. And that means, this is my I ref and this will be my I ref minus delta I H, and what we are going to do inductor current will remain within this band like this yeah. So, this is like this and that we have discussed and it will accordingly generate the gate signal.

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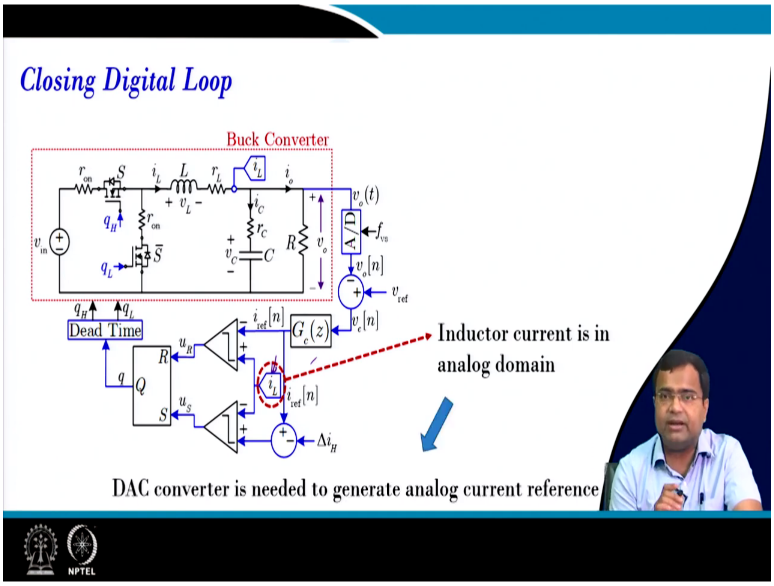

Now, when you close the digital loop, then this inductor is in analog and this is in digital. So, you cannot use a mixed domain thing directly. So, you need to have a D to A converter and which we have also discussed in the previous class.

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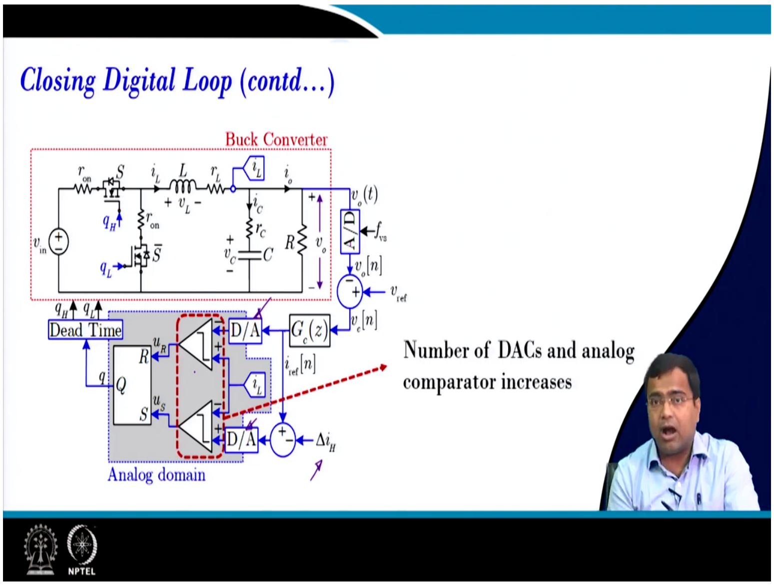

So, when you consider a D to A converter if you straight away replace; that means, you need to insert D to A converter for these two references, but why? Because it is already digital, this is also digital. Because why we kept delta I H in digital because we need to adjust the delta I H because we know this is one of the parameters or degrees of freedom to control the switching frequency.

So, if you want to control the switching frequency you can simply adapt the hysteresis band and which is a very well-known method that can be very easily accommodated in digital control right? But the use of two D to A converters and two analog comparators is practically not acceptable ok. Then what is the way, how can I reduce both DAC and comparator?

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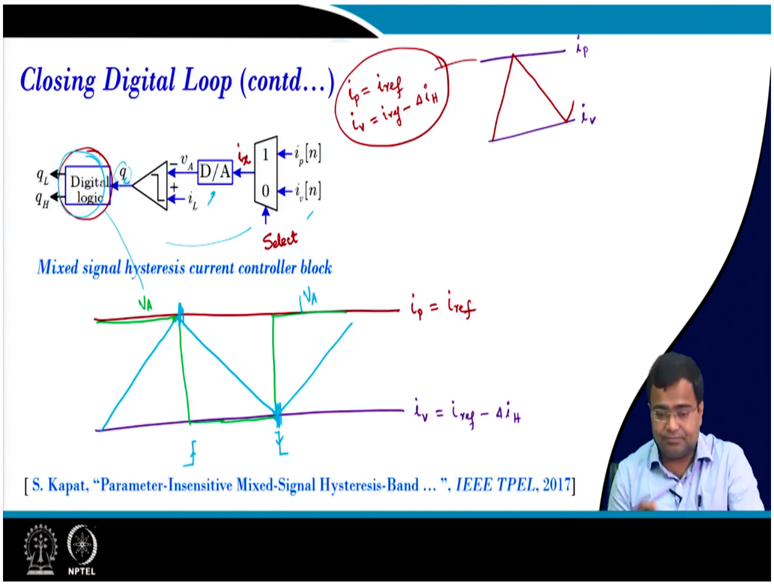

So, you can use a time multiplex operation. That means the peak is the valley because we are talking about the peak and the valley. So, this is my peak and this is my valley and I want to force the inductor current to be within this peak and valley right? And how are you setting peak? That is in your hand.

So, I can set either peak equal to my reference which is the output of the controller; that means, digital voltage controller. Then the valley will be simply I ref minus delta I H and this configuration is the peak control configuration; that means, we are directly controlling the peak current. But if we want to do valley current mode control; that means, you know how do you do that? That means, here remember we need a select line right?

So, this is my select line and the D to A converter will accordingly adjust the output and here the digital logic will be there. So, how does it work ok suppose I am talking about this being my peak. So, let us say this is my some I x ok. So, let us say this is my peak this is my I p let us say which is my I ref I am talking about this.

And let us draw another waveform which is my I valley this is my I valley which is my I ref minus delta I H ok. Now, how does it operate we want to draw the inductor current let us say the inductor current is going up. During this time when the inductor current is rising, I need to compare this inductor current and this is a v A.

That means if I take you to know v A is nothing but is the analog version of the I x. So, what is my v A my v A should ideally represent it should ideally represent my v this is my v A? Whenever there is an intersection then my v A is changed to what I valley, and then the inductor current will start falling because the comparator changes. So, it starts falling sorry.

So, it should start; it should start falling like this and if I continue this structure; that means. If I continue this waveform till this point then again it goes high like this and again the inductor current will continue to follow this path like that. So that means, basically I am changing this v A which is my v A with the muxing operation.

That means we are changing based on how because if the inductor; that means, we have to detect whenever the inductor current tries to cross this v A we will get a positive edge right; that means when it goes from lower to higher we will get a positive edge

Similarly, when it goes from higher to lower we are trying to find a negative edge; which means, a falling edge. So, when the rising has come we will change this mux from v A will now get configured to the valley current and when the falling edge comes to the v A will be configured to the peak current. So, in that way, it will keep on changing, but in the practical comparator, it is not. So, simply because there will be noise in the current each case there will be noise in the current and you need to provide some dead time.

So, as you know from a hardware design point of view this is somewhat complex, but if we can do it then only one D to A converter and one comparator is enough and the digital logic has to be configured in such a way, it will command that how the select line should behave. And what is based on the comparator output is how to take the decision and this is a comparator output it is not the gate signal ok. And this aspect has been discussed in this paper.

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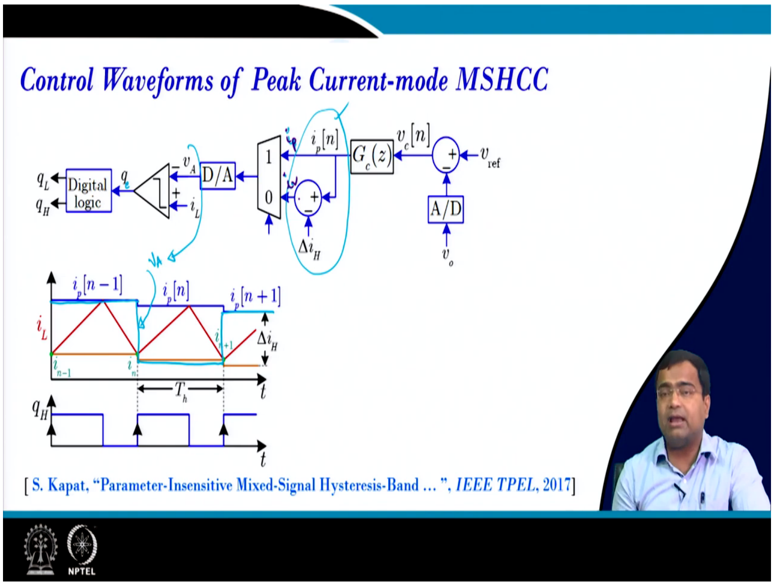

Now, we can set it as a peak current reference as I said. So, this you keep is a reference output of the controller and this is a delta I H I have discussed that you can configure this valley and peak in such a way this v A will change. So that means, if I want to draw v A in this waveform, suppose this is my v A right at this point my v A will change here v A again my v A will go here v A.

So, this waveform is my actual v A which is this signal. And based on this output of this you know comparator output our digital logic will configure, whether it will be turned on or turned off and that accordingly it will select and; that means, using one comparator one DAC you can implement.

So, this is a peak current mode then you can do valley current mode you can do average current mode; that means, here it is just a matter of how are you changing because ultimately this is your peak and this is your valley correct? So, this is a valley sorry yeah this is your I peak and this is your I valley. If you want to change to the valley then I will simply take the compensator output as a valley and the peak will be plus that valley current plus delta I ref delta I H this is exactly what I was showing.

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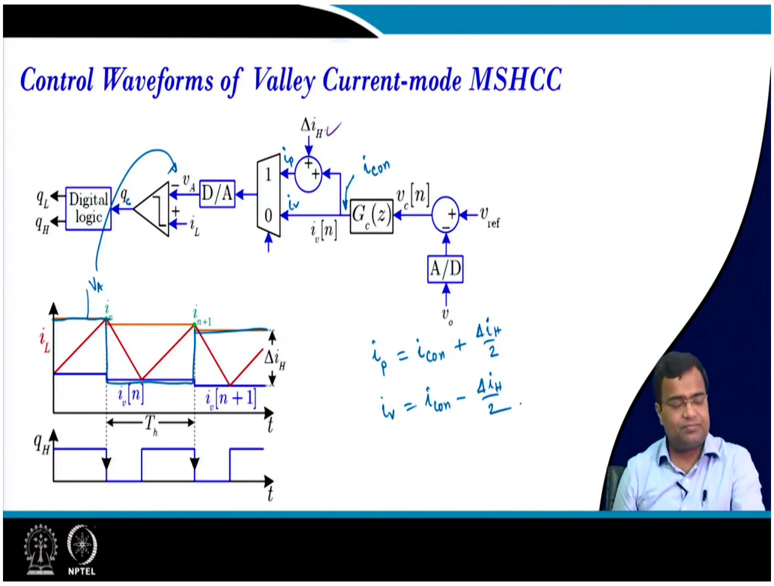

Here also again if you see this logic of v A will remain it is q c and this logic of v A will be again like this. It will configure here, it will change to here, again it will go here, it will go here like this. So, this waveform is my v A waveform which is nothing but here ok. So, because it is a single comparator and the digital logic will accordingly adjust. And if you if I ask you how to do average current mode control. So, this is my peak and this is my valley.

So, what I will do I will simply take a peak equal to if this is my compensator output; that means if this is my this point is mine. Let us say control output, I will set I con plus delta I H by 2 and I valley is I con minus delta I H by 2 that way we can do average current mode control.

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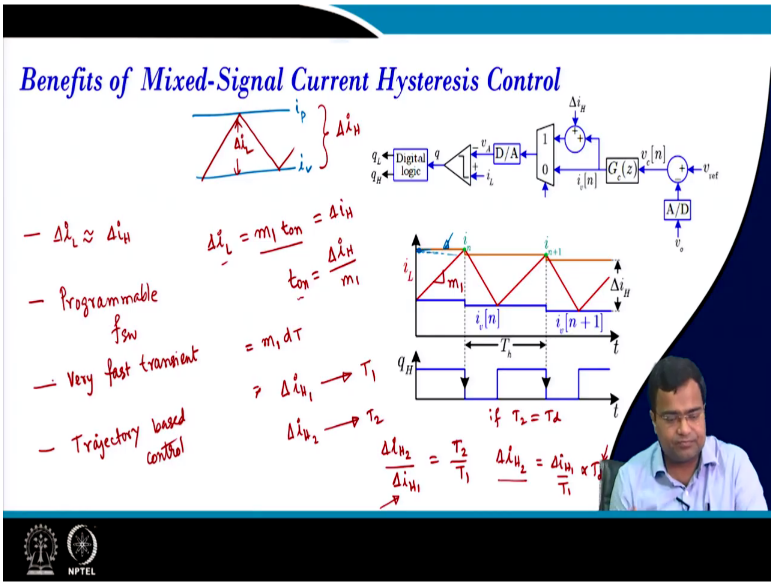

What is the benefit of this we have discussed if we talk about analog hysteresis control? The inductor current ripple was reflected here right sorry the output voltage ripple and as a result, we know that the actual inductor current ripple and the hysteresis bands were different. And that was sensitive to the ESR of the capacitor that was sensitive to the controller parameter.

So, there are many other factors, but in digital mode control if you using event-based sampling we are taking only one sample for the whole cycle. So, even though there can be a ripple in the analog; that means, the actual output voltage, but we are taking just the sample point and holding. So that means, the controller will not see the ripple artifact the in this logic.

So, it will remain constant for the whole cycle. So, your peak and valley will remain constant and the inductor current will simply follow that path. Only the concern is that you have to ensure the cycle-by-cycle stability is retained then at a steady state this two will be fixed. That means, it will look like a peak here and valley here and the current will simply you know follow this path.

So, in that case, the delta I H which is the hysteresis band, and the current ripple which is this particular current ripple delta I L are the same ok. So that means, one of the benefits is that the delta I L is nearly equal to delta I H. So, it is insensitive to the controller parameter it is insensitive to the ripple parameter ESR.

Another peak also if that is true then it makes the design simple because we know what delta I L so; means, what is delta I L? So, delta I L for a buck converter or any DC-DC converter is a rising slope if I keep this rising slope m 1 into the on time. And how do we represent the on time in terms of delta H? Because again the on time is the band so; that means, what is the on time? That t on is equal to; that means, t on into m 1 is equal to delta i. So, it will be delta I H by your m 1 yeah. So, it is delta I H.

So, that we have discussed. So, since the ripple is known now how can we relate the ripple to the switching period? That means, in a buck converter what is this m 1? That means, m 1. If we talk about you know in regular we know that in fixed frequency it is m 1 d T we know right? Next, what is d? It is v 0 minus v 0 divided by v in and so; that means, we have to find out this on time we have to replace and we need to ok.

Let me say if you have delta I H 1 which gives us a period of T 1 then I can set delta I H 2 which will generate my time to T 2. And since, I want to achieve the desired time period. So, what I can do is delta I H 2 by delta I H 1 will be simply T 2 by T 1, and T 2 is my desired time period.

So, if I set T 2 to be my desired time period then I have to find out for what delta I H 2 I am getting, delta H 1 by T 1 into T d. That means, for any arbitrary choice of delta I H 1 you will get a T 1 value that you can measure using a time-to-digital converter, and delta I H 1 you are only setting from the digital controller.

So, then I have to compute just a mathematical computation, what will be my delta I H 2 for my desired time period? So, in one or two iterations you can fix it. So, you can achieve programmable switching frequency and this is very easy because you know that the ripple current and I delta H are more or less close equal because of this they are insensitive to the ripple parameter.

Programmable switching frequency, ok. So, you can configure it to peak valley etcetera, and very fast transient response because it is a hysteresis control right, very fast transient response you can also try other features. So, these are the features you know you can keep on exploring, so ripple is more or less an incentive. So, these are the benefit that you can get. So, very fast transient response and you can do trajectory-based control, because trajectory-based control.

So, to get the very fast transient performance you know you can implement trajectory-based control like hysteresis control and so on, like a sliding mode control also you can implement. Because this is a hysteresis band and then you can generate this current reference from the hysteresis; that means, switching surface.

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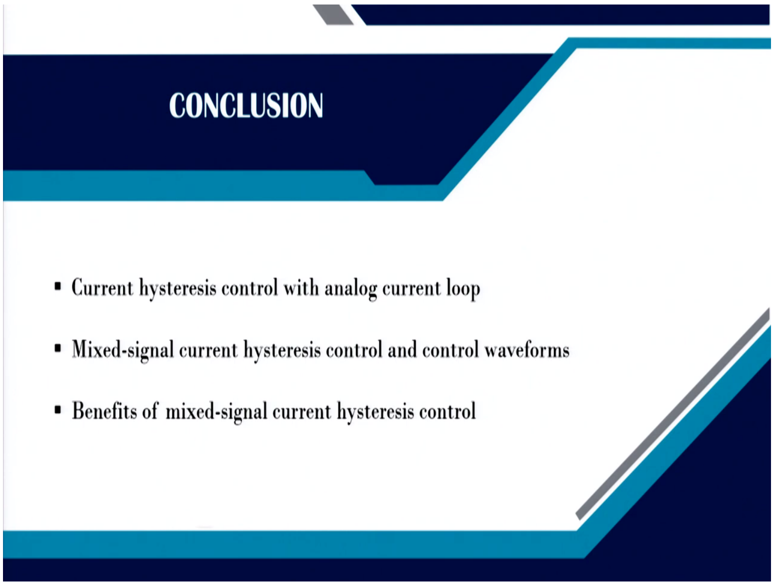

So, in summary, we have discussed current hysteresis control with an analog control loop current loop. Then mixed-signal hysteresis control and the waveform and we have also discussed the benefit of mixed-signal current mode hysteresis control. So, thus we have covered more or less basic fixed frequency as well as the variable frequency basic architecture and we have primarily concentrated on the mixed-signal implementation, but you can do fully digital implementation.

And we have discussed that in the context of fixed frequency control and in the next lecture we want to summarize this control technique. And in the next week subsequent week, we will discuss the MATLAB implementation of this control logic. So, with this, I want to finish it here.

Thank you very much.