Digital Control in Switched Mode Power Converters and FPGA-based Prototyping

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Module - 03
MATLAB Custom Model Development under Digital Control
Lecture - 29
MATLAB Model Development for Constant-Off Time Control

Welcome. So, in this lecture, we are going to talk about Constant Off-Time Mixed Signal Current Mode Control.

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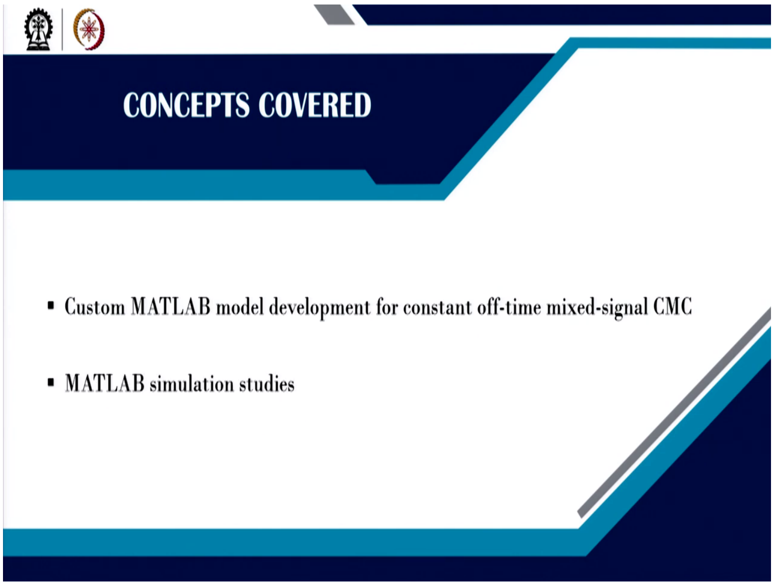

So, this is what you know this lecture is somewhat similar to our previous lecture where we have considered constant on-time mixed-signal current mode control. Here we are talking about constant off-time. The only difference here is the modulator; that means, your constant on-time is replaced by constant off-time as well as the sampling edge; that means, you know the point of sampling is different. Otherwise, it uses event-based sampling and the fundamental architecture point of view, many things are common. And we will also talk will consider a few simulation case studies.

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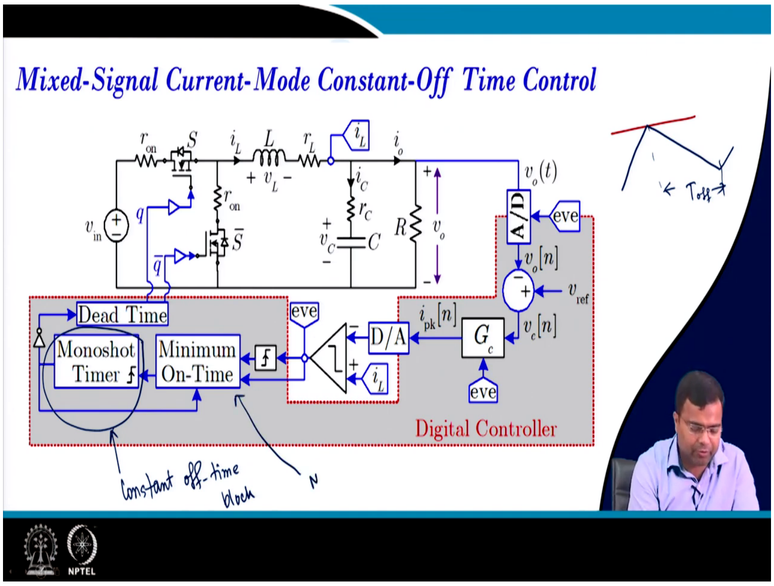

So, if you talk about mixed signal current mode control constant off-time control is analogous to peak current mode control. And we know that if we take any peak current mode control here, so in this particular case the current will rise and then fall like this. So, here our off-time is fixed. So, off-time is fixed. So, that is why it is analogous to peak current mode control. The only difference here it is a variable time control where the off-time is constant, but the time period can vary.

So, this block is using the same, only we are replacing the monoshot timer. Now, this will act like a constant on the off-time model, a constant of a time block. And this is a minimum on-time. It is written already. So, it is a minimum on-time block, ok.

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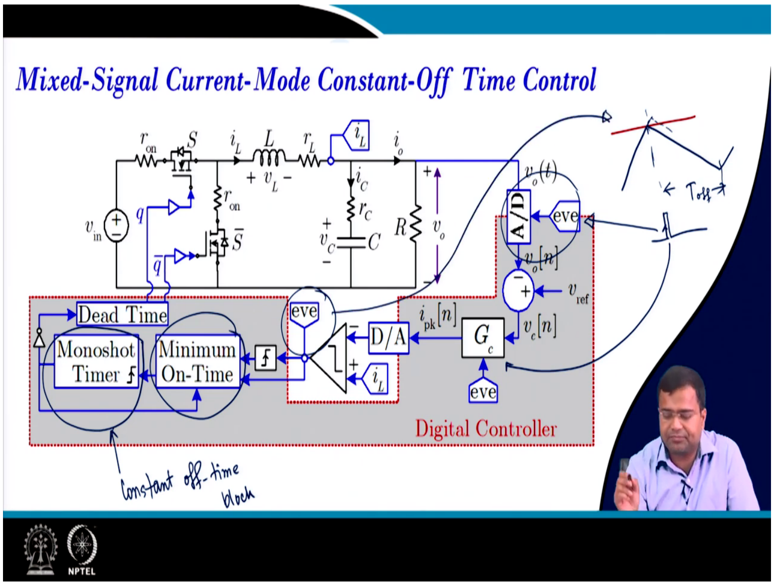

So, this block is the minimum on-time. Then, the same we need an A-to-D converter which should be sampled using an event clock. So, here event again is a comparator. So, what is the event? Here the event is this is the event; that means, whenever the inductor current hit the peak current that is the event. But in the practical circuit, even if it hit the inductor current will hit, the peak current may turn off a little later because there will be some delay due to the comparator, and driver.

So, we can capture the sample at this point, so that we can capture the clean inductor current or clean output voltage. Because we want to avoid we should not sample at the point of switching as well as just immediately after switching because that will be noisy data. Because of the delay, you can capture the clean sample, ok. So, you can see this is the edge. So, this will be the clock, even a clock which will be used even for computing this controller as well as the sample.

Because we are not considering additional delay just to you know initially to introduce the concept. And this event clock is generated from this comparator which is shown here, ok.

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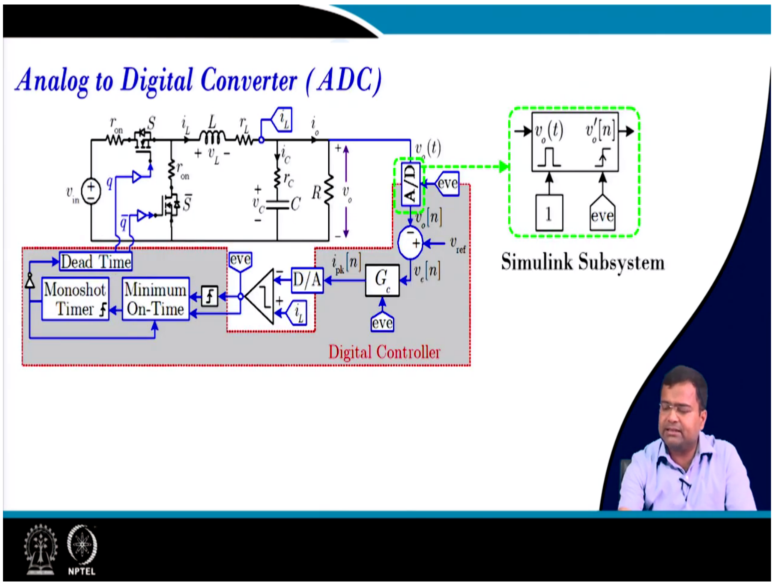

Here again, it is an event triggered by ADC. We have discussed this.

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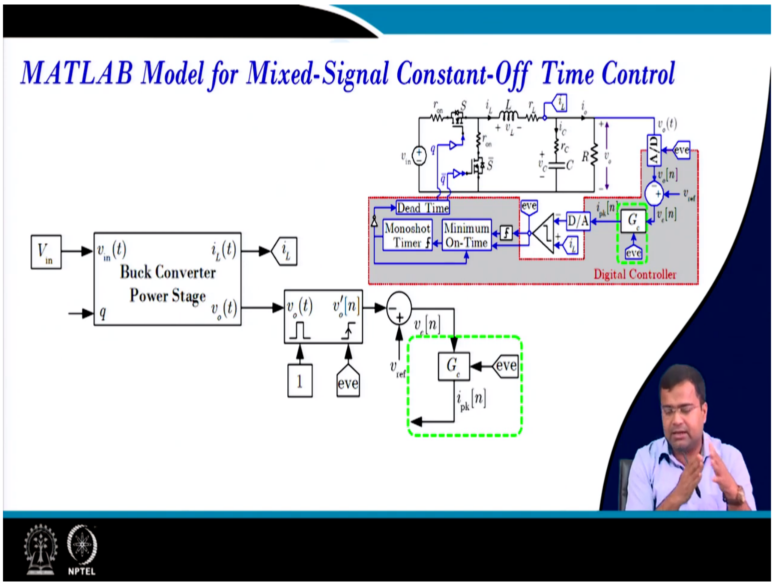

Then, power stage we can easily develop. We have discussed this in MATLAB.

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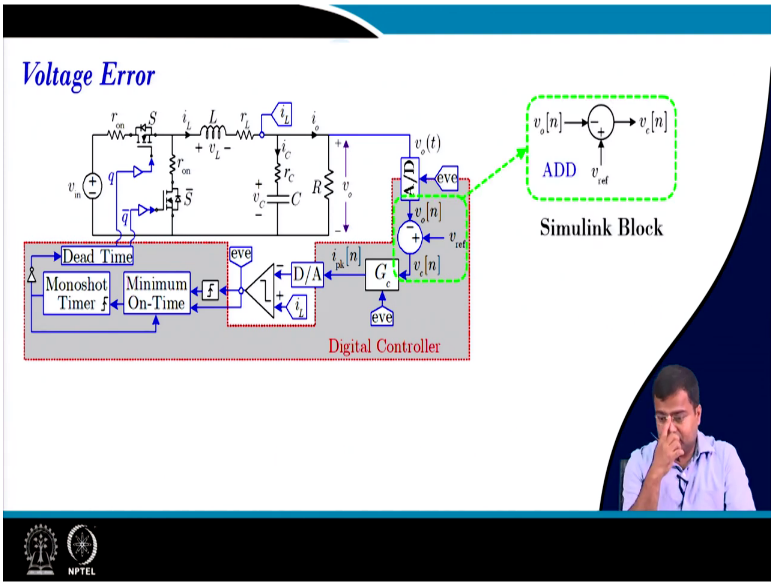

We can just drag and drop that block.

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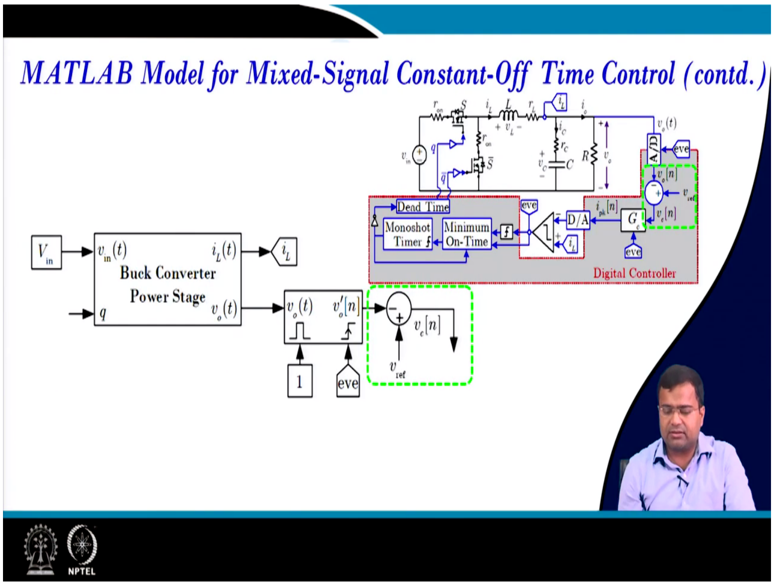

Then, we can put an adder block, which is a subtractor.

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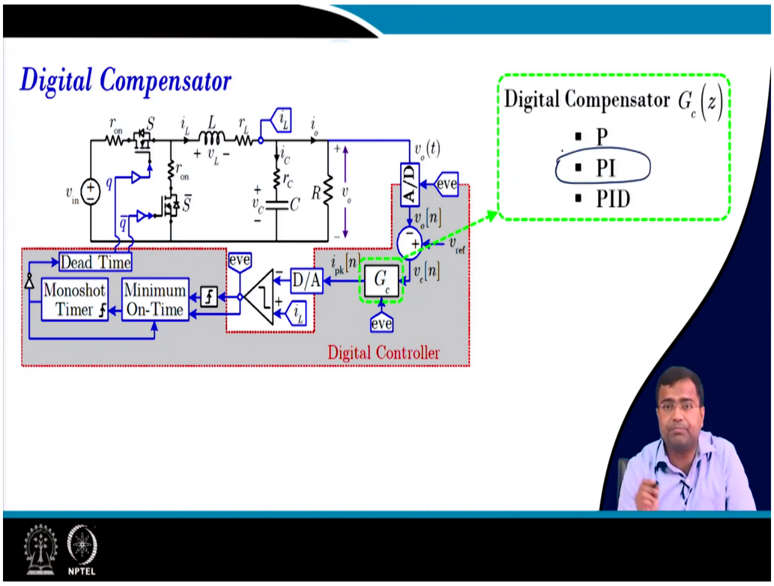

Then, after that, it will go to the compensator. Since you are talking about the PI controller's current mode control, will consider the PI controller.

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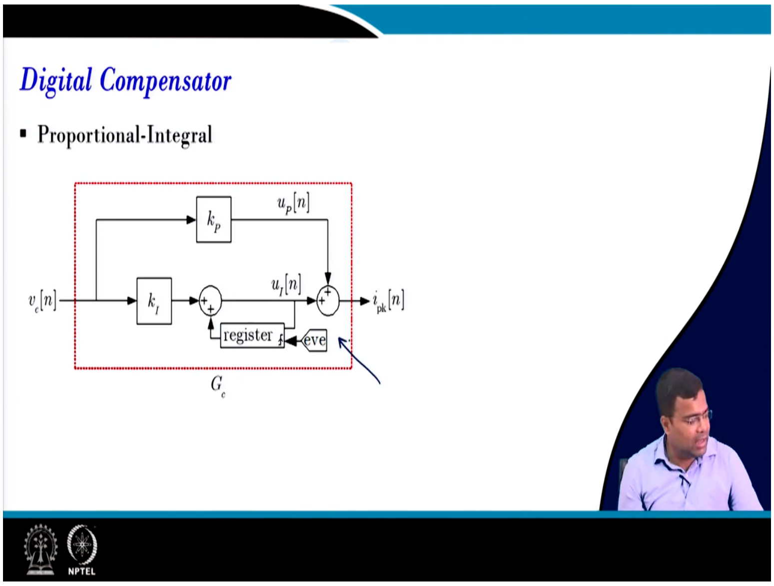

And this PI controller will be realized using an event clock. So, this exact representation we have already discussed.

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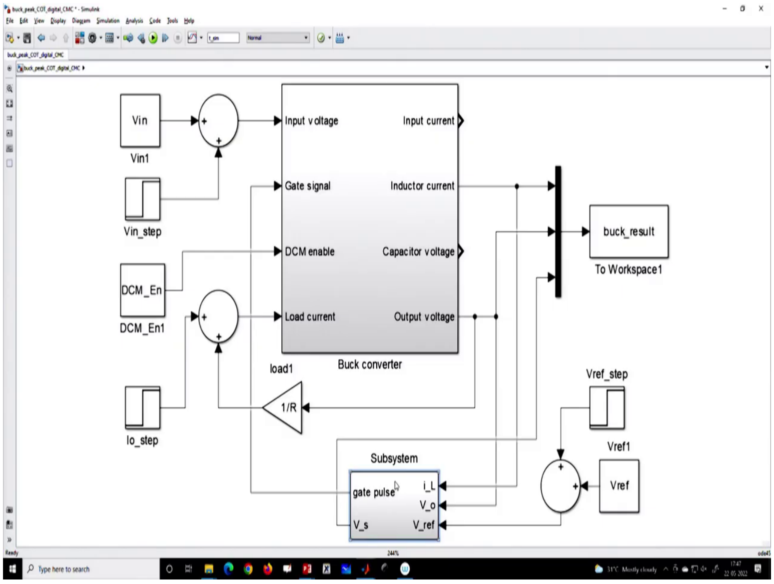

And if you go to the Simulink diagram here; if you go inside this block.

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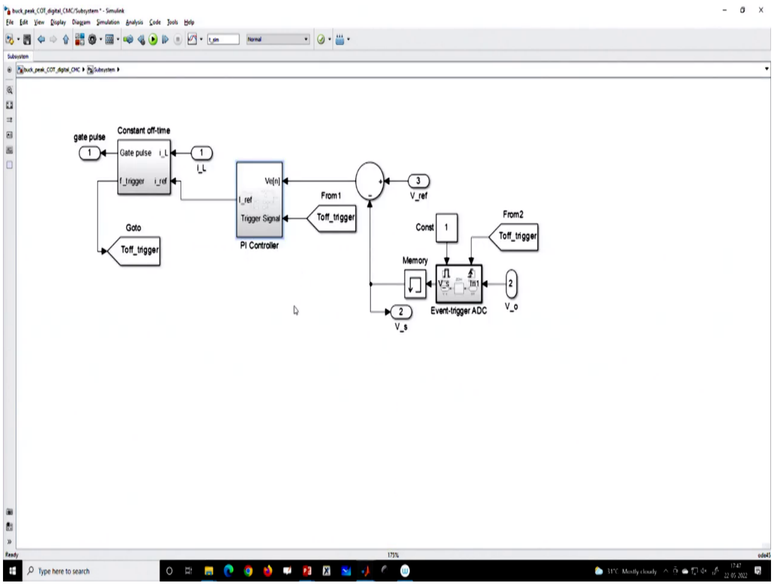

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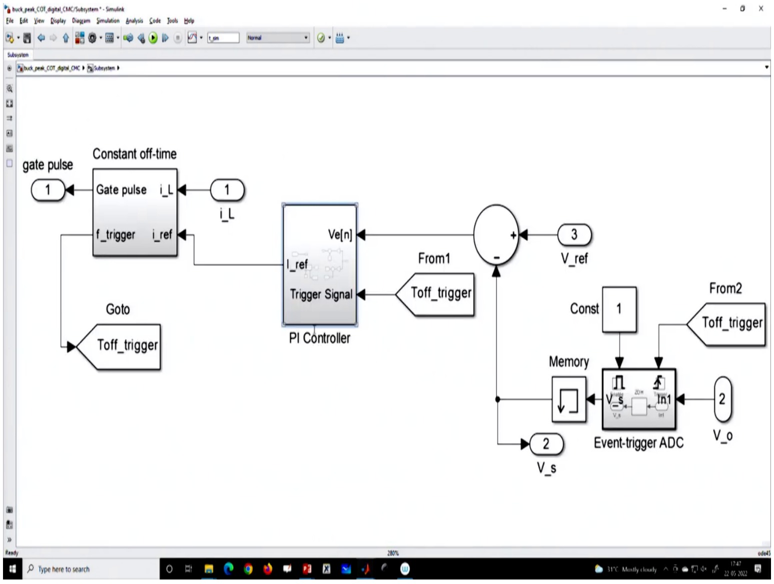

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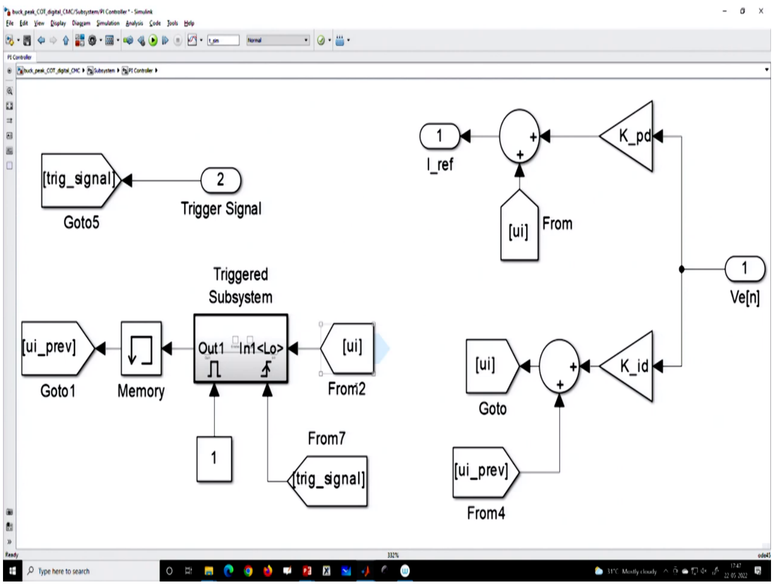

So, this is a PI controller. And we have discussed this block. The same as constant on-time as well as fixed frequency control. Only the clock is different here. We are using a different clock. And here we are using non-uniform sampling or event base sampling. So, it is different from the uniform sampling. Next; that means, we can realize the PI controller using a difference equation and using a clock-triggered operation.

Then, once we implement this the output of the controller will generate the peak current, and then we can give a D to A converter. But in MATLAB, we do not need a separate D to A converter. But in the actual circuit, the output of the control will be digital and that will pass through a D to A converter and that output of the D to A converter is the peak reference current.

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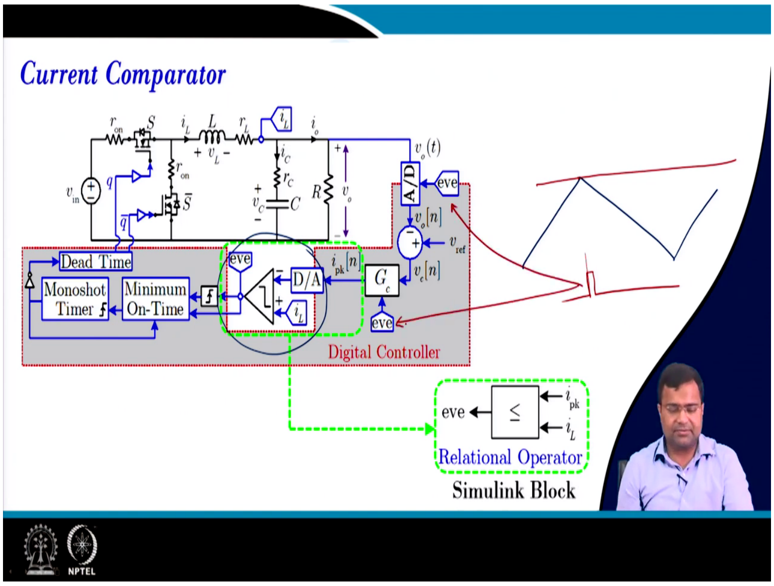

And that will be compared with the actual sense inductor current and that is the comparator that is in the analog domain that we have discussed. Whenever it hit the peak current; means, whenever the inductor current hit the peak current; that means if you draw the peak current reference and that is the point we are taking this event. So, this event is passed through this. It is generated, ok.

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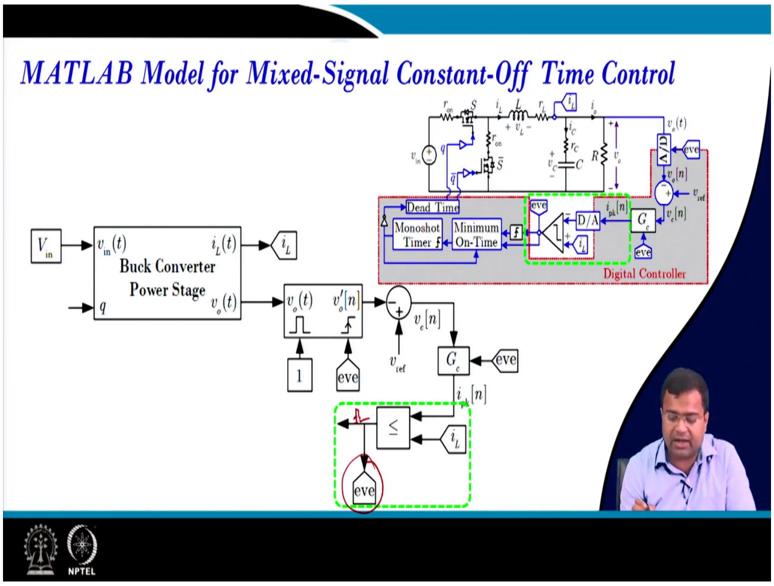

And that means we have this event created from this comparator output when it is just triggered and this rising trigger actually will generate them, enabling the monoshot timer because you have to turn on the constant off-time block.

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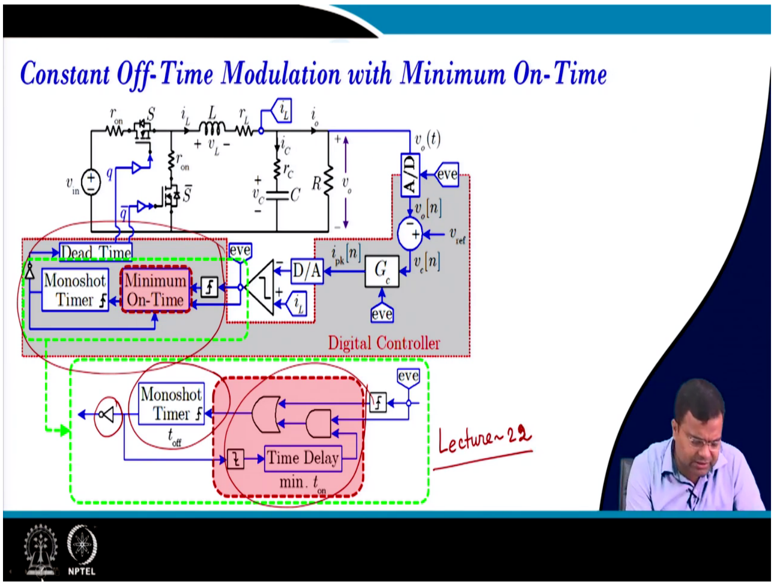

When the inductor current hit the peak current then your monoshot timer is enabled and as long as the monoshot timer enables the switch will remain off. And that is the monoshot timer. And you can see when it is enabled, it is a NOT gate, so it will be off. And this operation also requires a minimum on time that we know because all commercial products will have minimum off-time for constant off-time control; on-time minimum on-time for constant off-time control.

So, here is the minimum on time. And this thing we have discussed in our previous NPTEL course is the control and tuning method in the switch mode power converter. And I think we have discussed in lecture number, I think lecture number 23, the constant off time 22. 22 lecture we discussed constant off-time.

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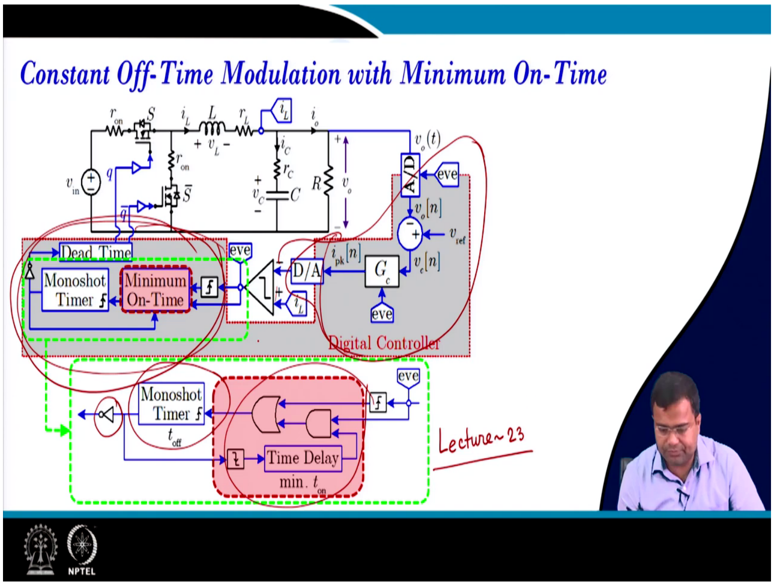

We have discussed the 23 also, we have discussed 23 as well where we have compared various things. So, this is in our past lecture on control and tuning method in switch mode power converters. So, all these blocks are common. This block is common for analog control as well as this mixed signal control, but this block is different up; that means, this block is different including this DAC. Remaining this analog comparator everything else is common.

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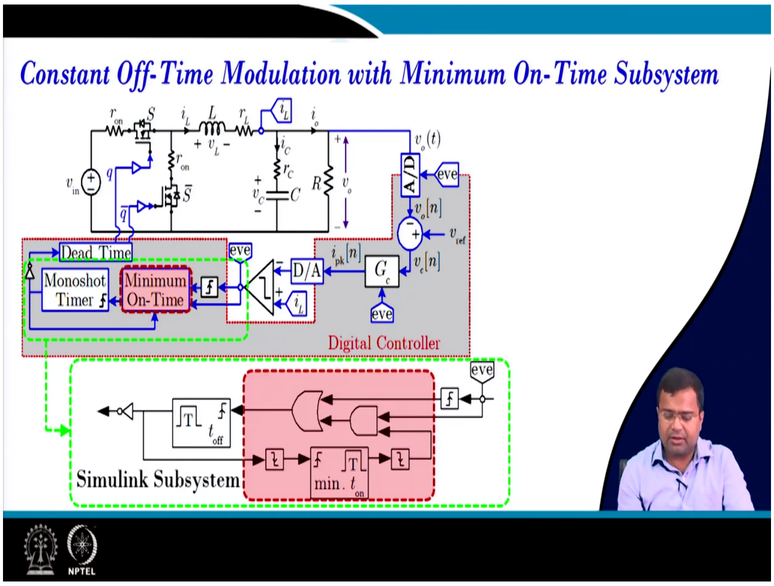

So, here as I said this is common and I will go to the MATLAB Simulink block, and we have to incorporate the minimum time.

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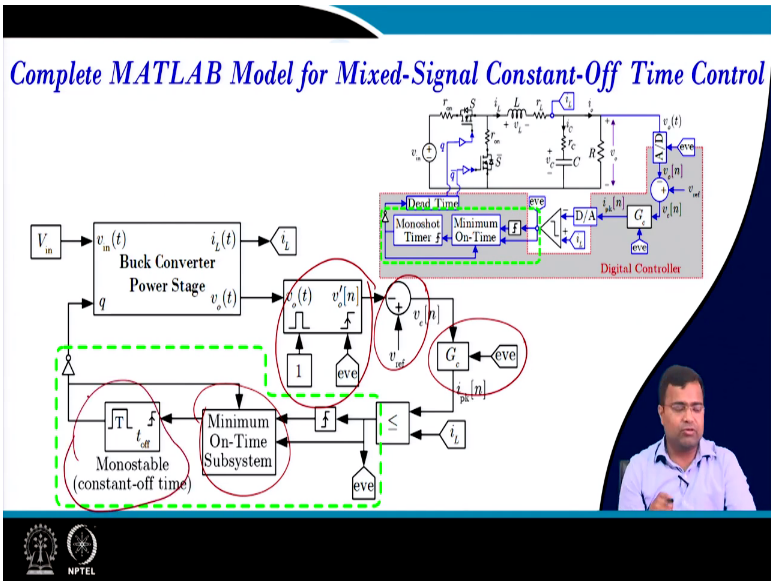

Then, we will go for custom the complete MATLAB model. You know this will be the event trigger ADC, error voltage, then controller, event trigger compensator using difference equation, minimum on-time, and then this is the constant off-time modulator.

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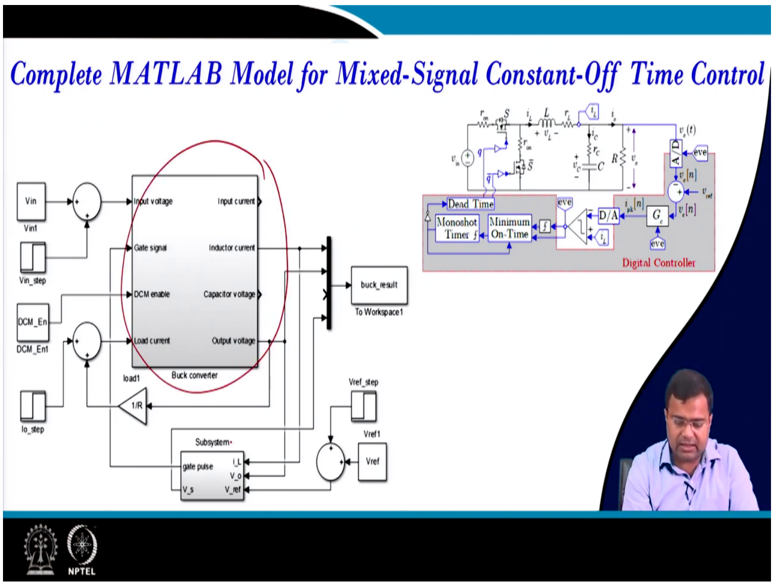

And this is a complete block diagram, we are going to MATLAB. So, this is the power state that we know and this is the controller.

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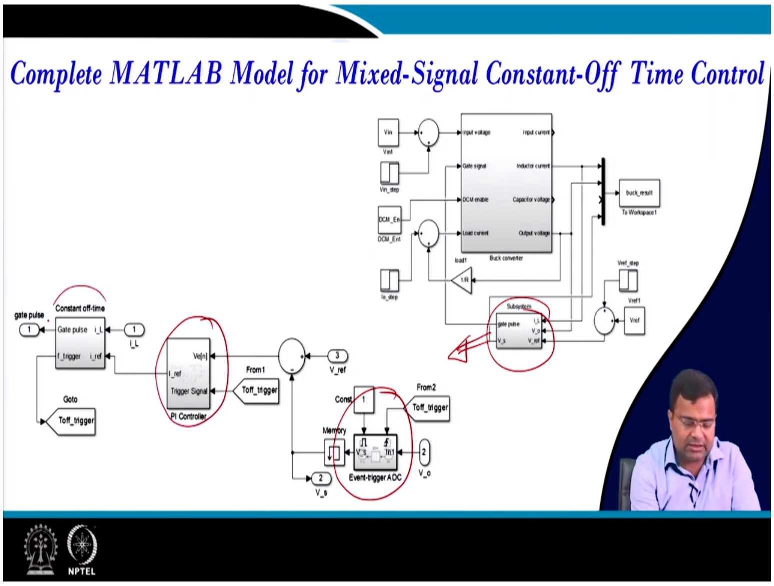

Then if you go inside the controller here, if you emphasize, what we will get? This is your event trigger ADC, and this is your controller, PI controller, and this block is a constant off-time modulator.

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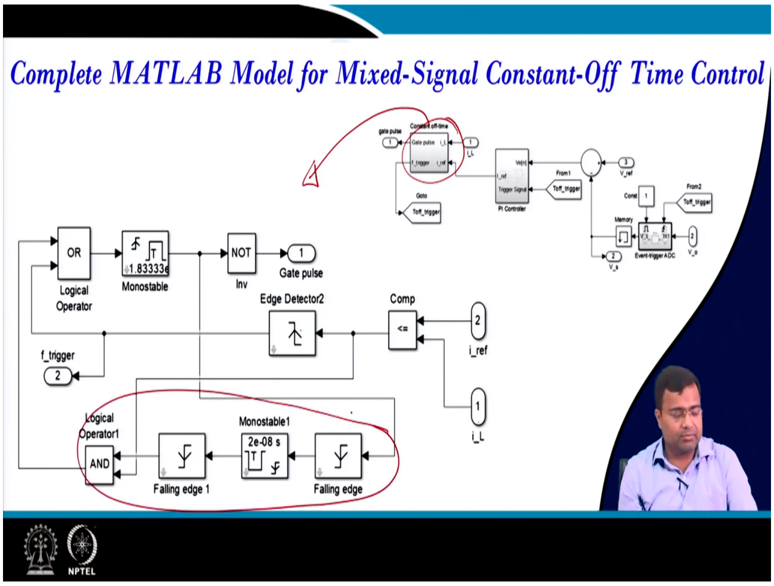

And if you go inside the constant off-time modulator then you will see this block. So, this block takes I ref and I L. So, whenever the inductor current hit the peak current, the rising edge comes and that will trigger the monoshot timer. And this is the additional block that is used to minimum off-time, and minimum on-time because it requires a minimum on-time.

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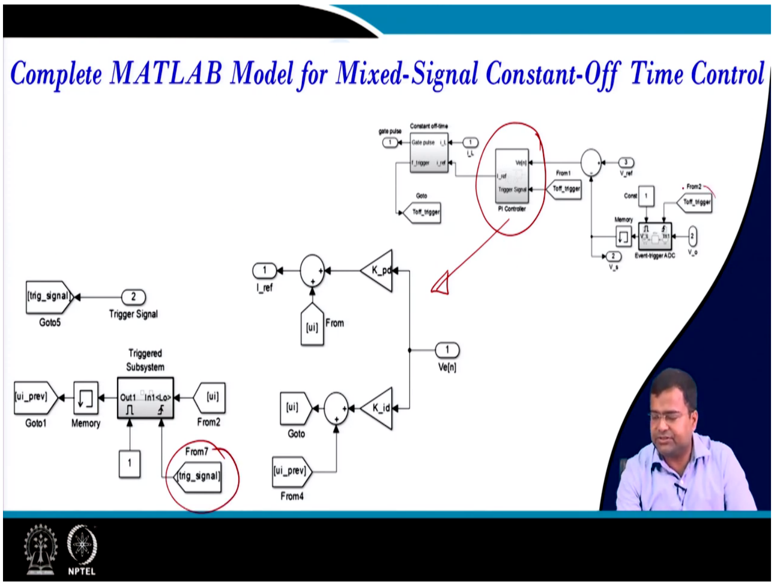

And if you explore this block, this block we have discussed multiple times, the only difference is the trigger pulse is different here. That means, we are using this trigger pulse and this is created from the comparator output.

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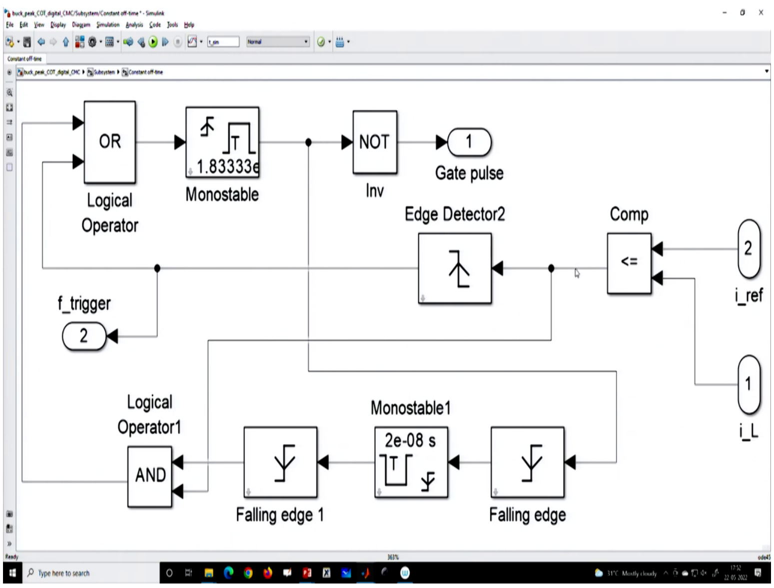

So, if we go to MATLAB. So, let us go to MATLAB. So, this is the complete representation of this circuit, buck converter, and whatever we have discussed. And the trigger pulse is generated from here; that means if you go to this monoshot timer sorry; the comparator output you can see that whenever the inductor current hit the peak current that is the edge is detected and that is the trigger pulse.

And The trigger pulse you are using is the trigger pulse, and that is going to go to the goto block. And this trigger pulse is used for the controller computation, this trigger pulse is used as well as this is used for ADC, ok. So, if you go further up now we are running a case study.

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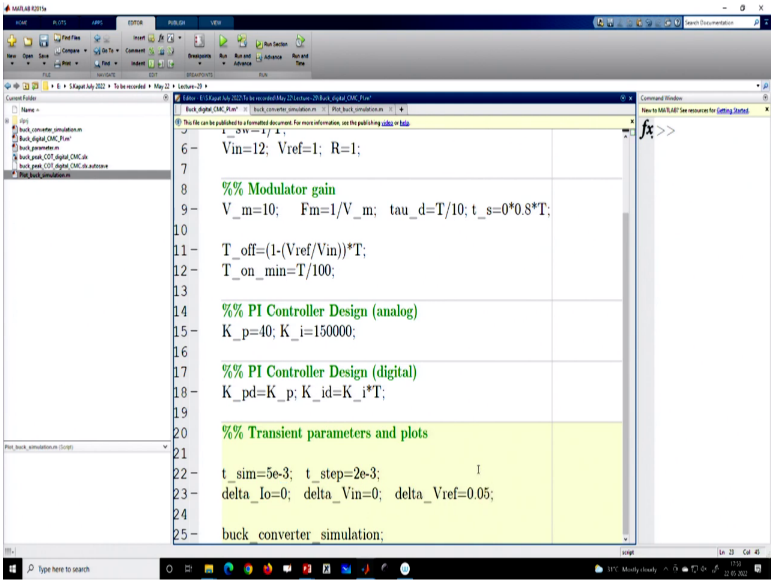

So, we want to show a first reference transient response. So, let us say we are using a reference transient response, and let us run a simulation case study.

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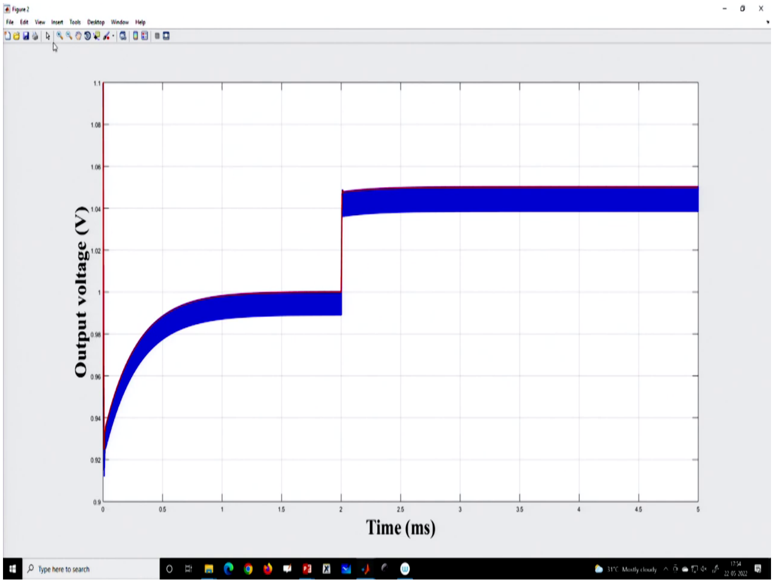

So, now this shows the reference transient case study.

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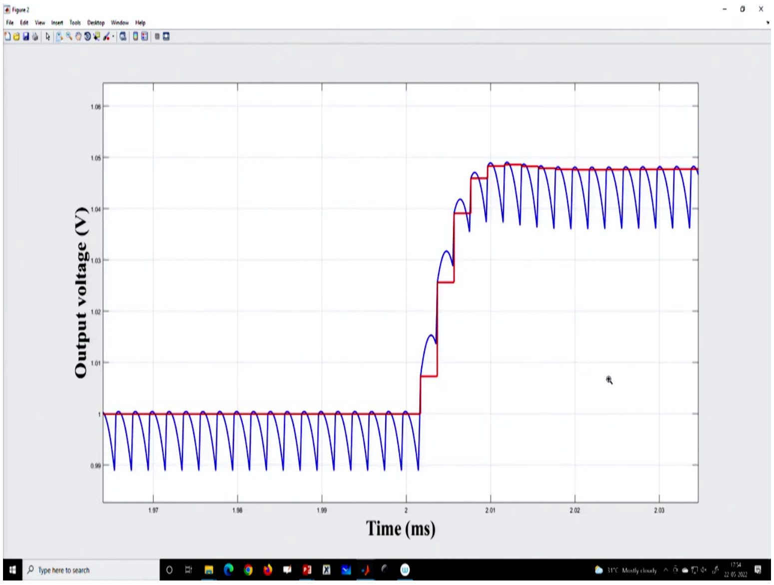

So, if you see that the output voltage is changing from 1 volt to 1.05 volt.

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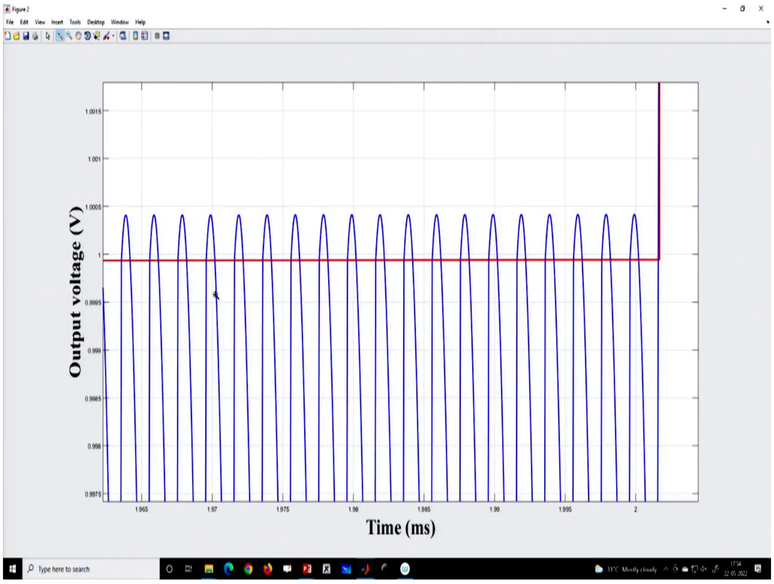

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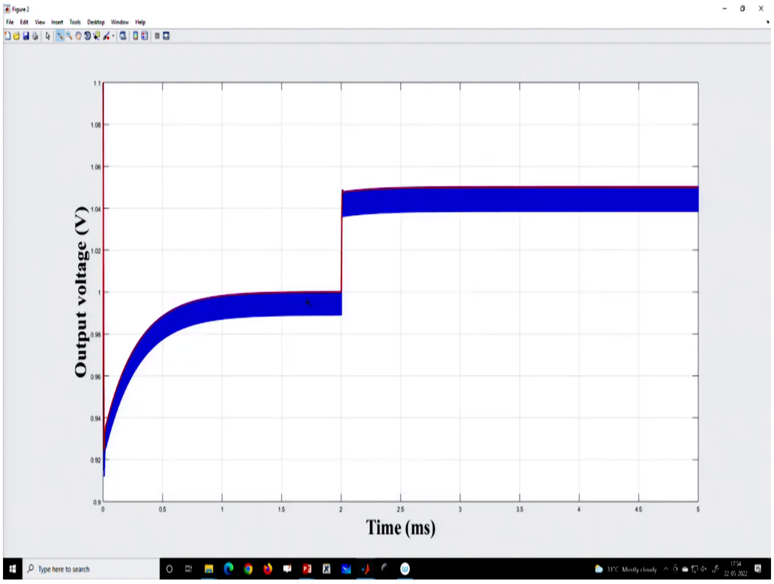

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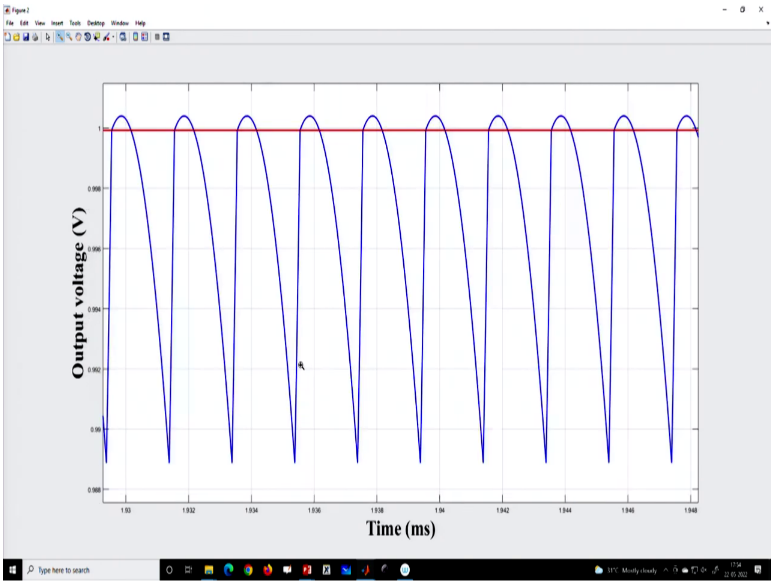

Interestingly, you will find, since you are sampling here, that means, we are sampling whenever the inductor can hit the peak current. That means we are almost sampling at the peak voltage.

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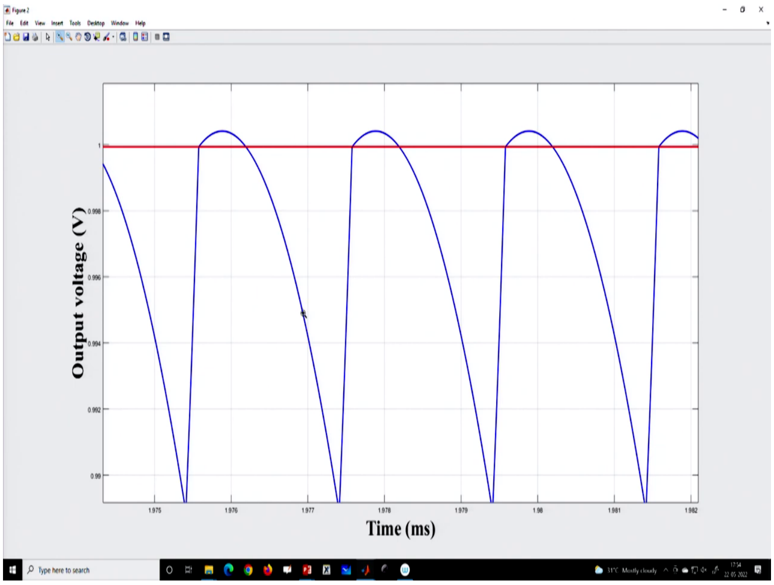

So, that is why your peak voltage is regulated at 1 volt, but not the average voltage. So, to solve this regulation problem, we may have to shift the clock edge a little bit. That means if we take to let us say we sample somewhere in between; that means because during this time your switch will remain off and when the switch remains off; that means, your monoshot timer is enabled. So, we can take the midway point as an event clock; that means, we can sample at the middle of the off-time, ok.

May not be just the beginning of the off-time because if you sample the beginning of time there may be a voltage regulation issue, so that can be addressed. But here I am not showing all this because this can be an advanced study, but you can get the reference transient response from here.

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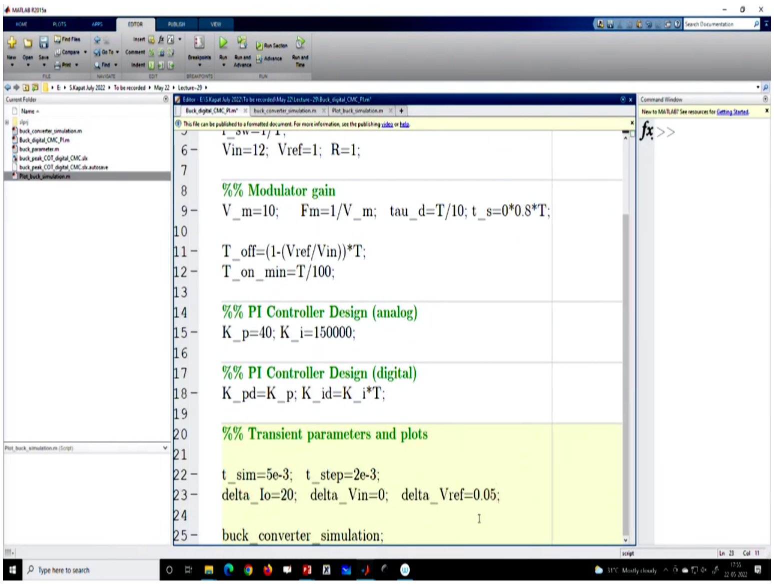

Similarly, we want to run a load transient case study. Now, we want to go for the r 20-ampere load step and the reference voltage is now cha, need let us run a simulation case study.

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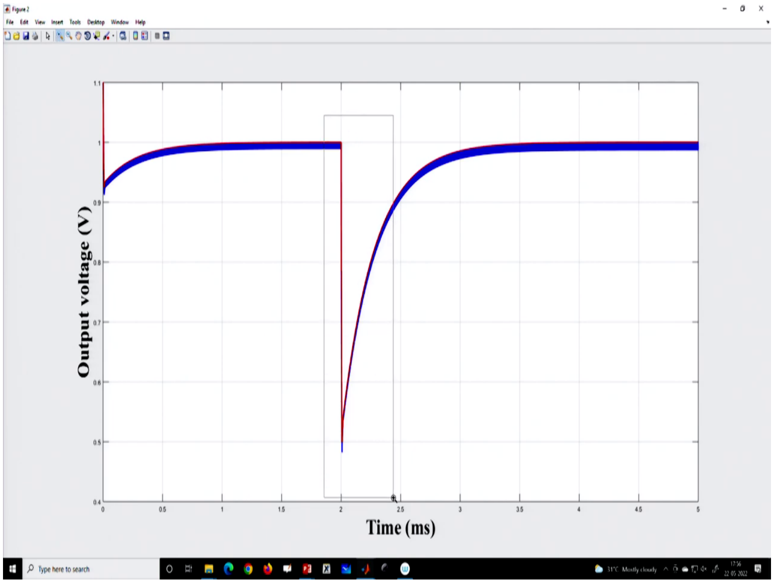

So, now, this shows the load transient, the load step of the transient case study.

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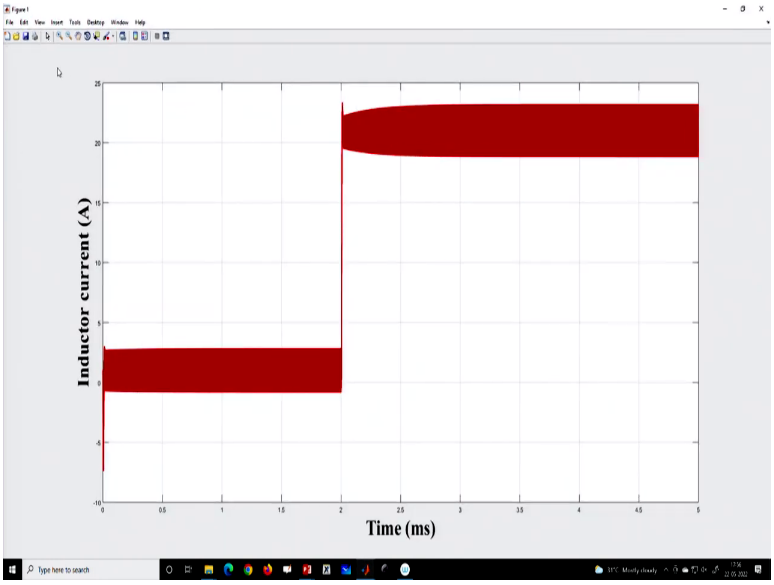

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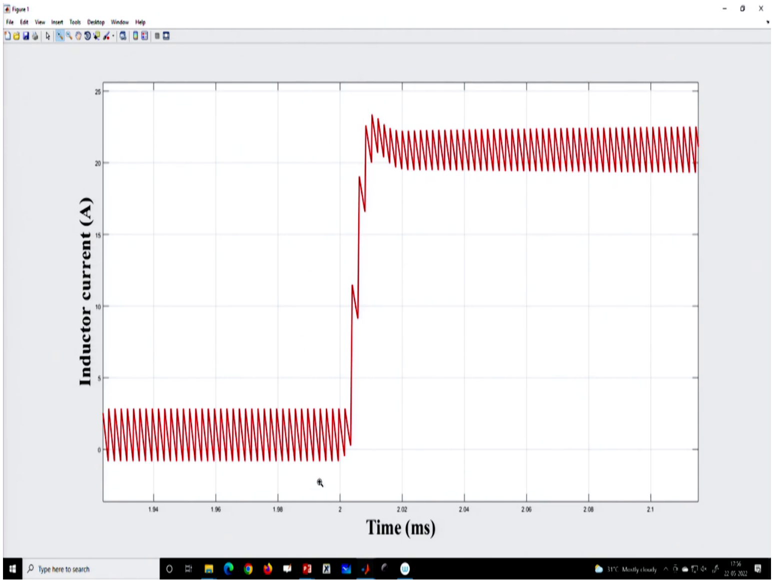

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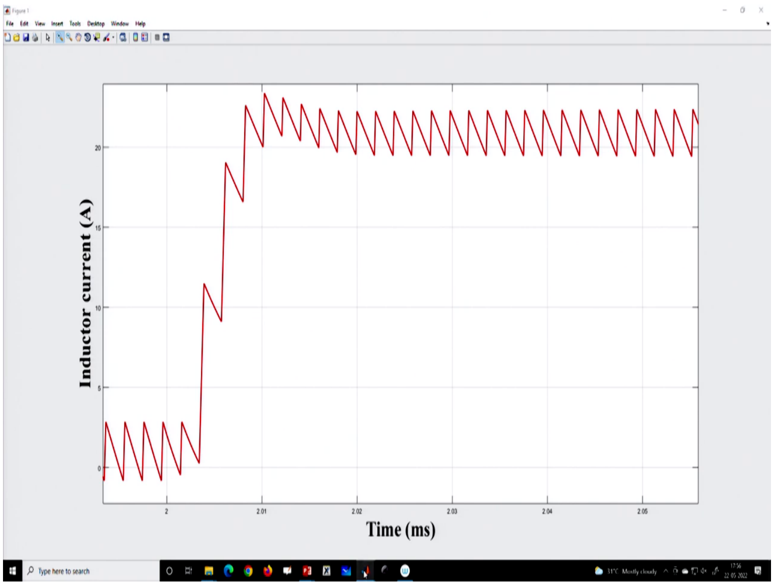

So, where if you go to the inductor current, the inductor current is changing from you know initially it was 1 ampere average current, now it is changing to 21. So, a 20 ampere load step size, ok. So, this is the output voltage response. It is a sluggish response, but we have not discussed about the compensator design. So, what I am saying here? Here we have considered T by 100 as the minimum on-time, but you can customize it. So, you can customize the other parameter.

So, in that way, we can implement the constant off-time modulator. And we have discussed the overall diagram simulation and how to implement it in Simulink. That means, we have discussed the complete block diagram realization using MATLAB Simulink.

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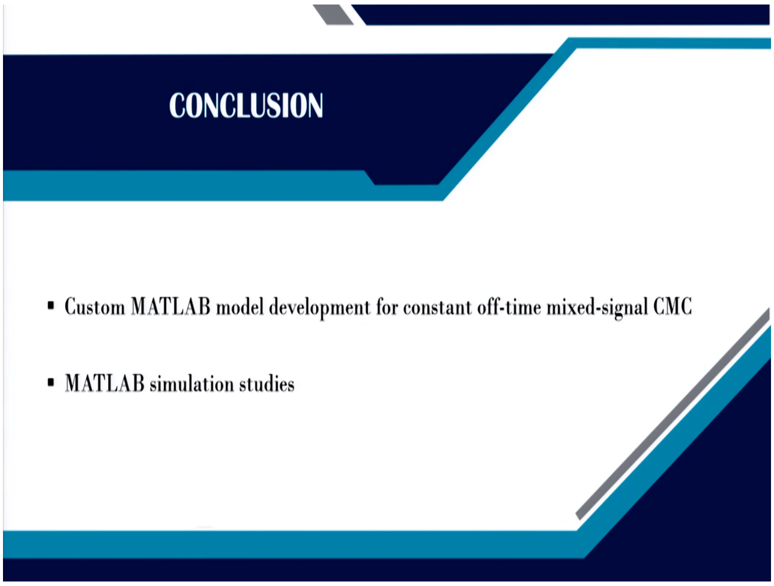

So, in summary, we have discussed custom MATLAB model development for constant off-time mixed signal current mode control and we have also discussed some MATLAB simulation case studies. So, in the next lecture, we are going to talk about digital hysteresis current control technique. That is it for today.

Thank you very much.