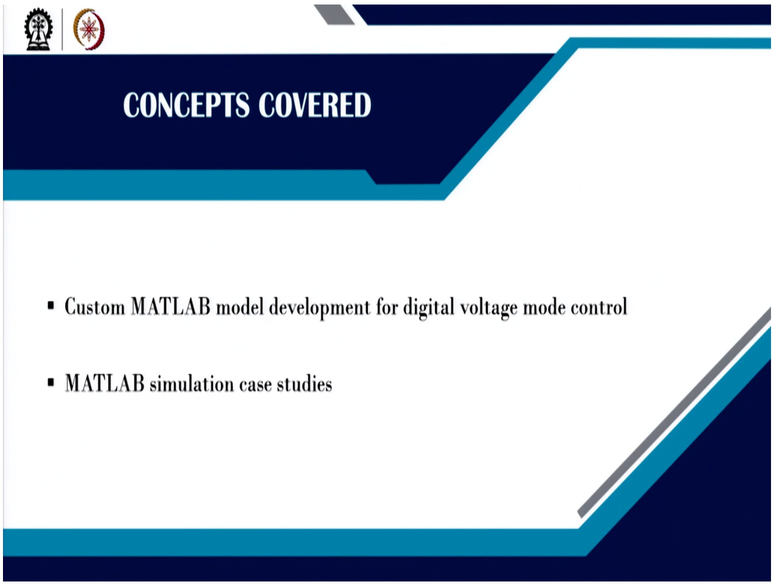
Digital Control in Switched Mode Power Converters and FPGA-based Prototyping
Prof. Santanu Kapat
Department of Electrical Engineering
Indian Institute of Technology, Kharagpur

Module - 03
MATLAB Custom Model Development under Digital Control
Lecture - 25
MATLAB Model Development for Digital Voltage Mode Control

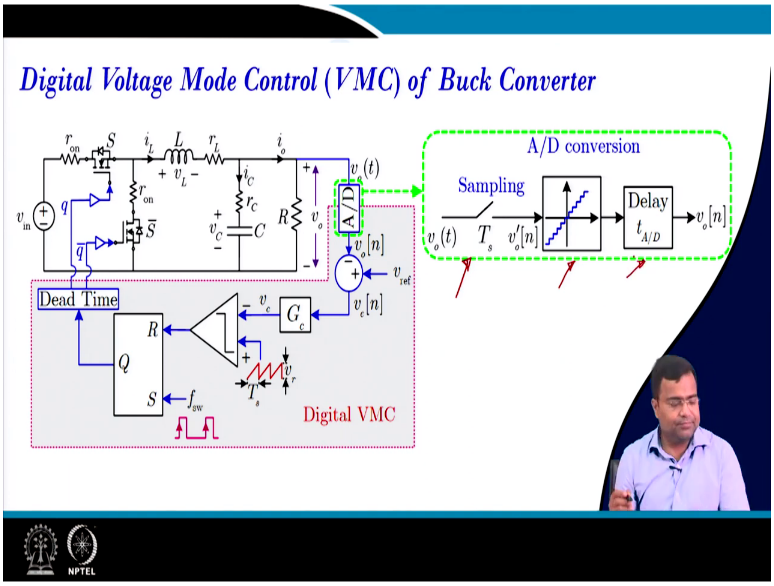
Welcome back. So, today we are going to talk about the MATLAB Model Development for Digital Voltage Mode Control.

(Refer Slide Time: 00:31)



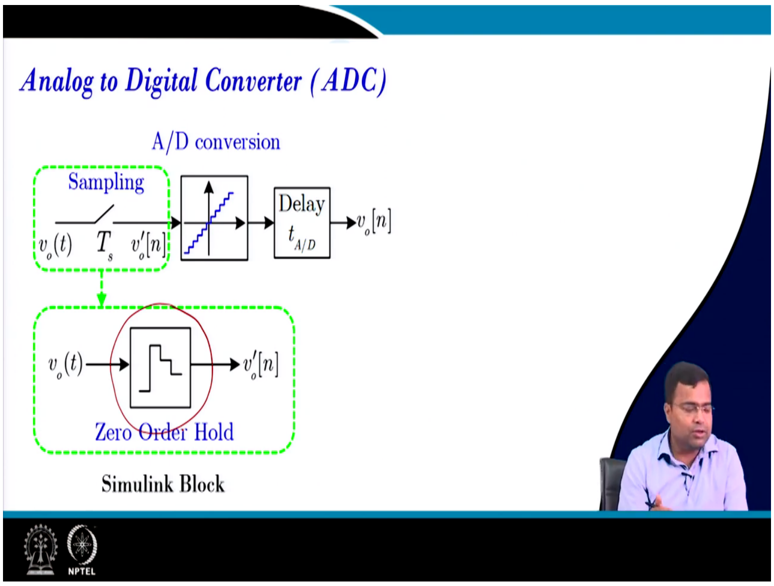
This is the continuation of the previous lecture, in this lecture we will continue you know using our difference equation for digital control implementation. And I want to summarize what are the step overall for overall digital voltage mode control implementation and I want to show a few case studies.

(Refer Slide Time: 00:48)



So, here this is the block diagram of the digital voltage mode control that we have learned and we have already discussed A to D converter, the first requirement is a sampling block, which is a sampler, then you can use a quantizer block and we can use also a delay ok.

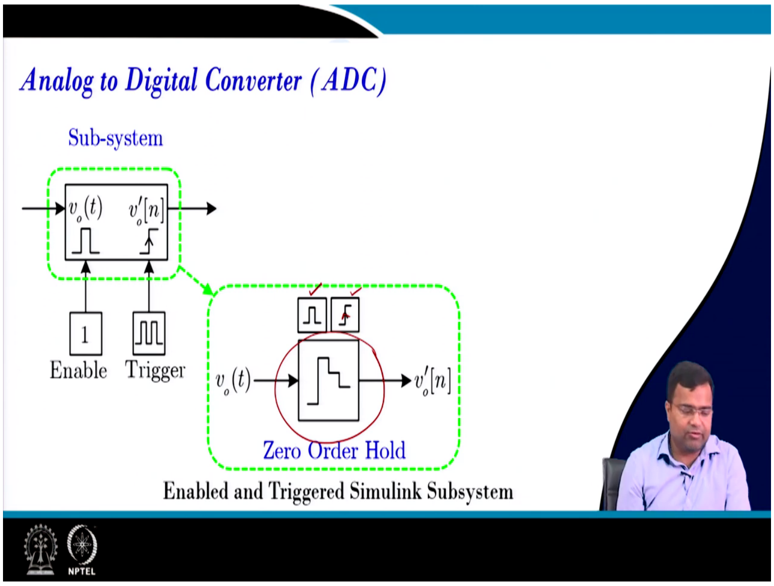
(Refer Slide Time: 01:04)



So, to start with the sampling block, the basic block is a zero-order hold that we have learned and you know this zero-order hold is used to take the sample.

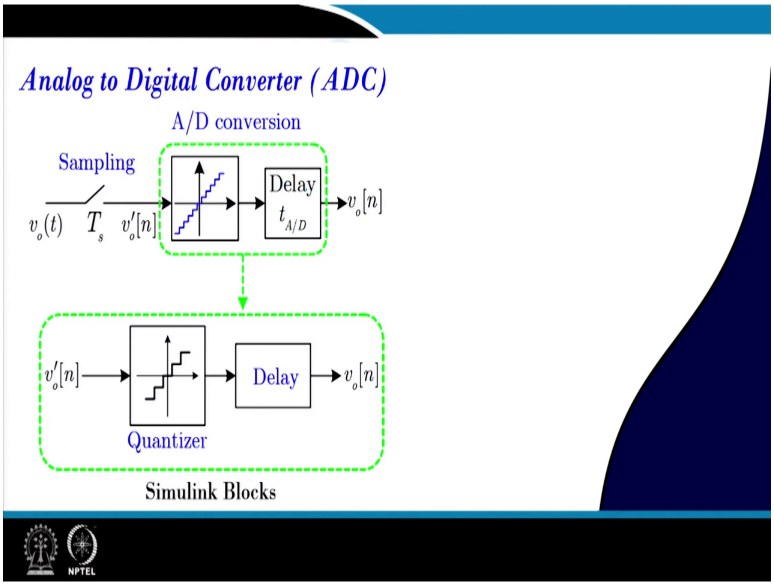
But this whole process you have if you enter go the zero-order hold you need to provide the sampling time. But if you provide sampling time, it will sample with respect to the simulation time and that with the capital T; that means, it will start from the start of the simulation and after every T time it will sample. But we want to customize the edge as well as we want to use an even base clock.

(Refer Slide Time: 01:37)



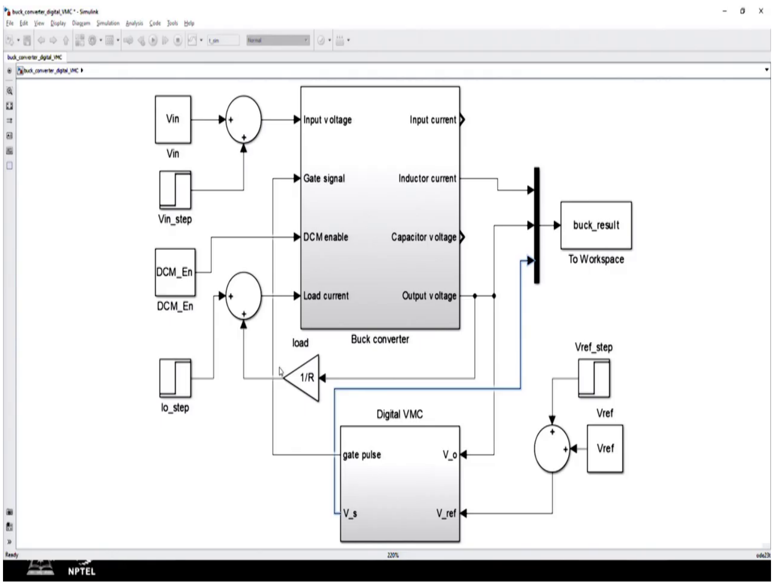
So, we need even trigger the A to D converter, and this is the block that we have discussed. Inside the event trigger, we have a zero-order hold block as well as the enable block as well as the event block. So, whenever this edge comes the rising edge comes then only take the sample ok. So, that means, this is now the even clock, I mean you know even trigger A to D converter.

(Refer Slide Time: 01:58)



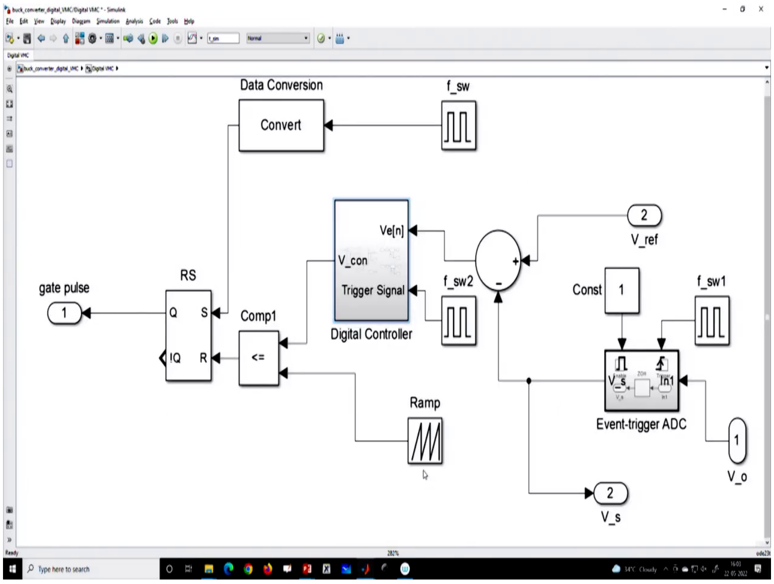
The next part is the quantization, so we can add a quantizer and we can as a delay and delay we can add I will go to MATLAB and show.

(Refer Slide Time: 02:09)



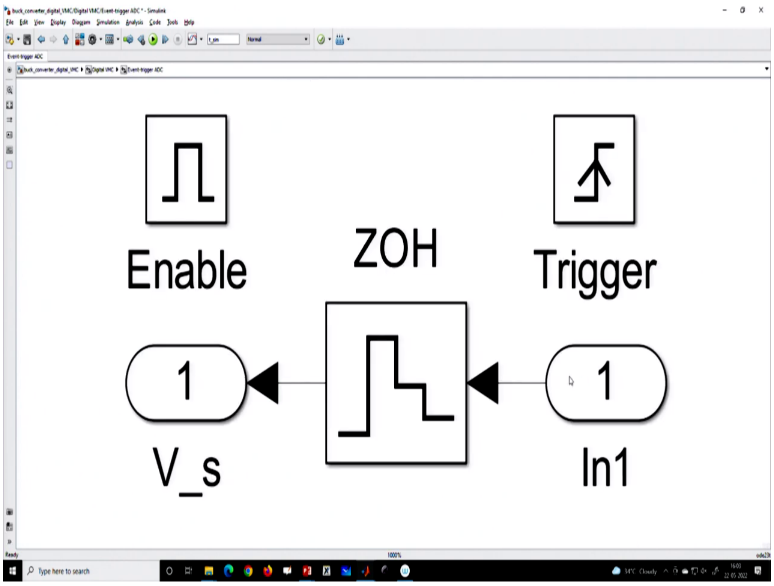
So, let us go to the MATLAB because if you go side by side it will be easy.

(Refer Slide Time: 02:12)

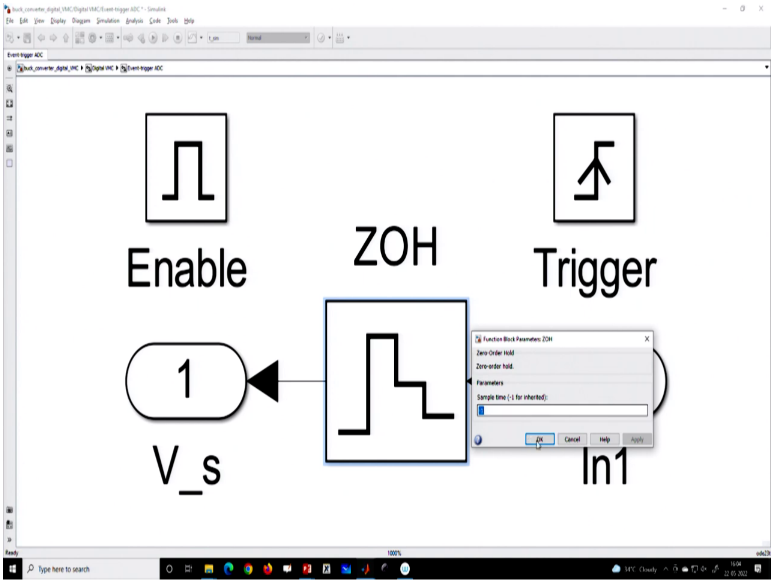


So, this is the block I am talking about, even trigger A to D converter.

(Refer Slide Time: 02:18)



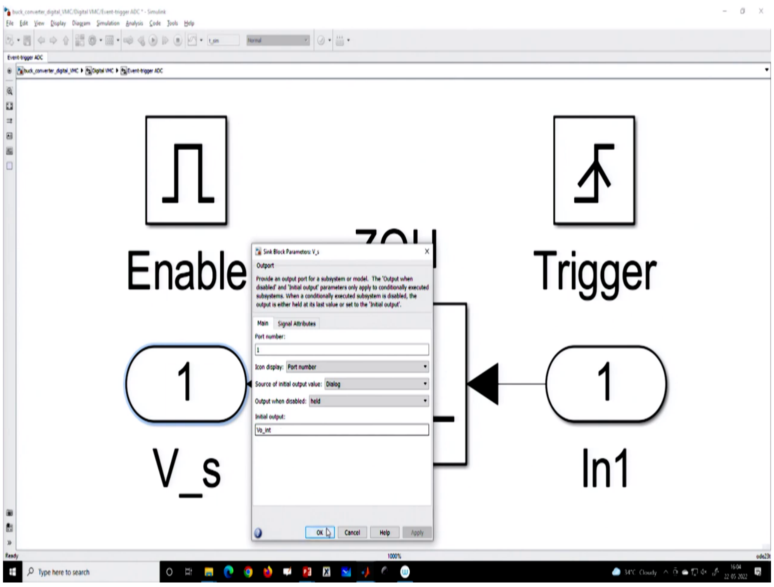
(Refer Slide Time: 02:22)



And if you go inside that block you can see inside this block, there is a zero-order hold. Since you are using inside an enable and trigger. So, there is no need to specify sample time. You can use a default zero-order hold which is there in the library.

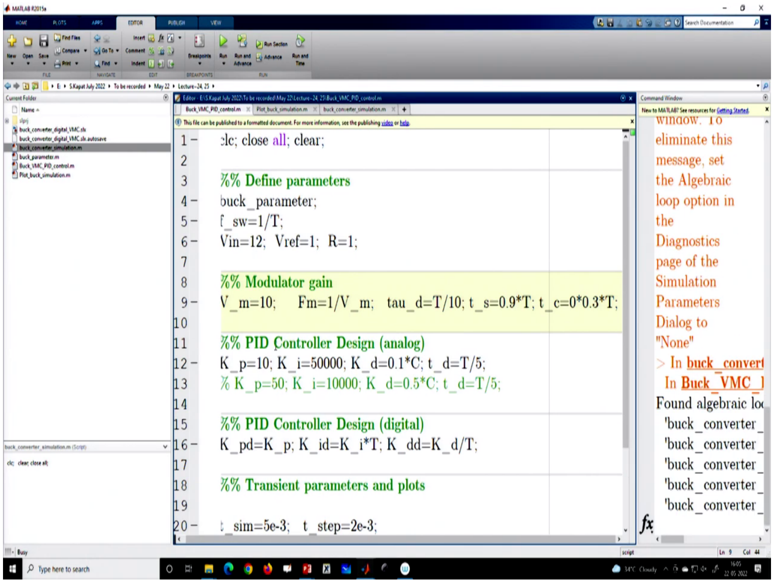
But whenever this enable goes high, then only it will sample and this trigger will actually sorry enable will enable this block ADC will be enabled if it is 0 the ADC will never be enabled. And then when it is enabled we have to send the trigger pulse when it will sample.

(Refer Slide Time: 02:51)



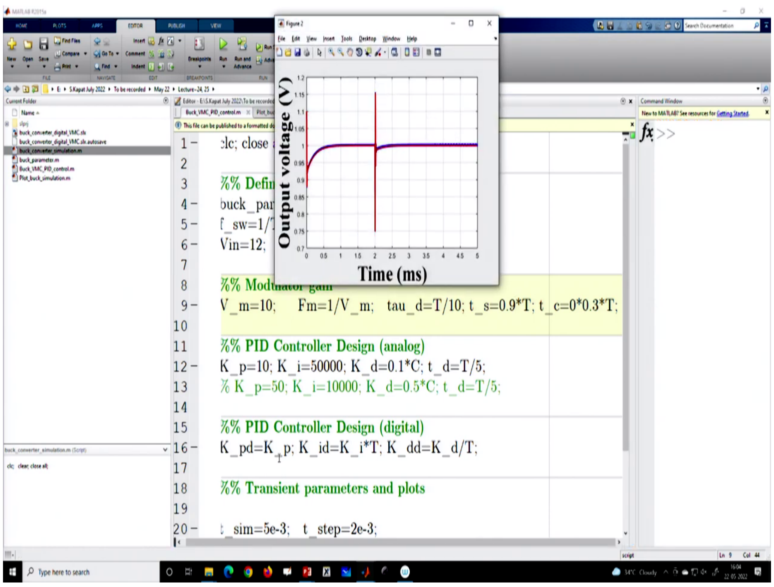
And in this block, if you go inside it has a by default hold circuit; that means, it is like a register where it will store, we need to initialize the register V 0 initialization ok. So, it is possible, then if you want to incorporate a quantization. So, let us first run without quantization without this delay.

(Refer Slide Time: 03:11)



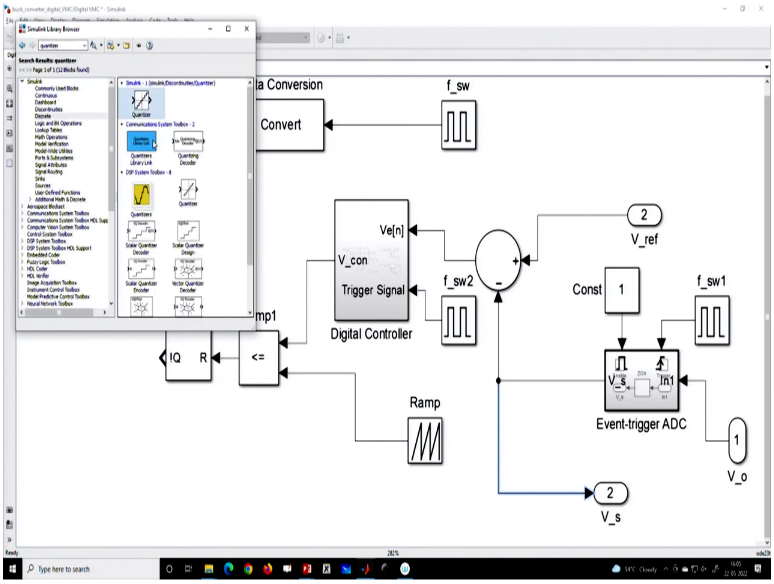
So, what will happen? If we go to this you know MATLAB block and if we run it there we are not using any quantization.

(Refer Slide Time: 03:21)



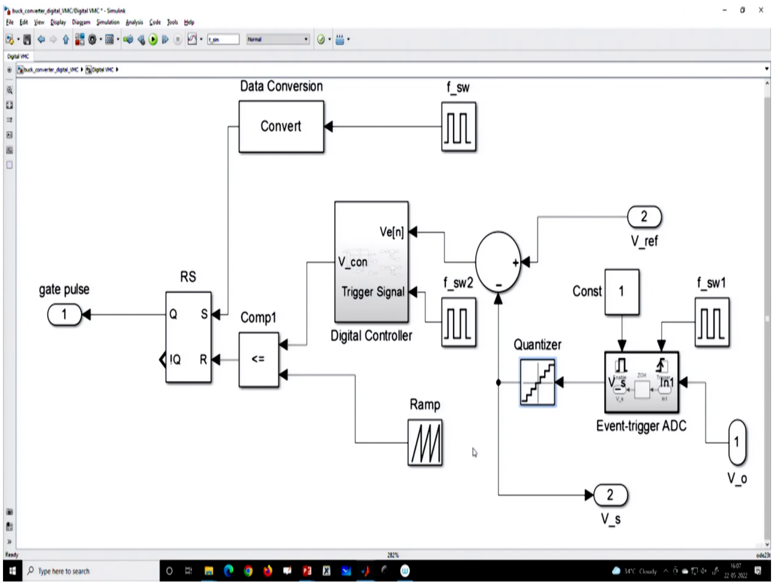
So, let us see if we use a quantization block and this is with some delay.

(Refer Slide Time: 03:32)



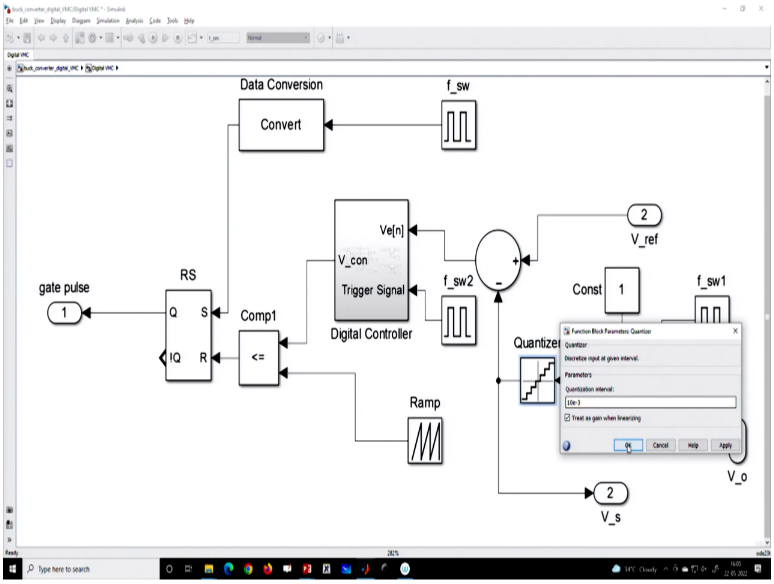
Now, we are going to use this quantization block; that means, let us use a quantizer. So, we can go to the library and we can use a quantizer here.

(Refer Slide Time: 03:48)



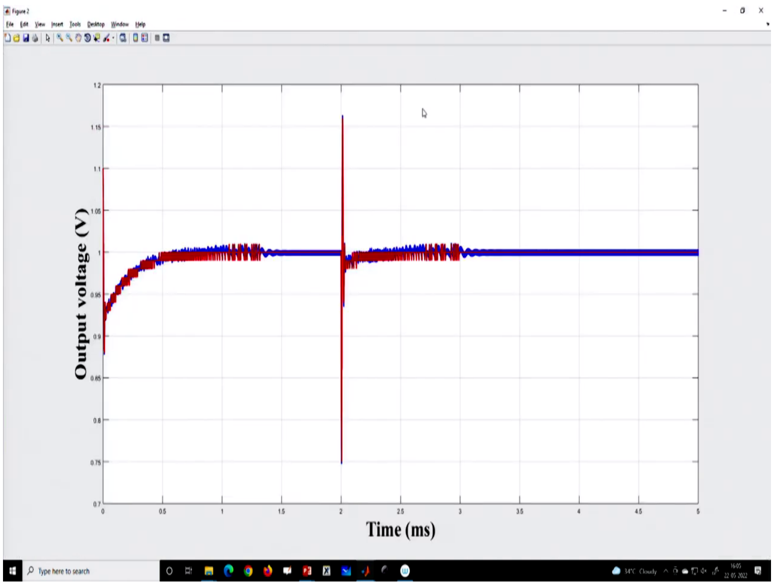
So, let us see a quantizer. So, this is a quantizer, and if you ok. So, you can just use this quantizer.

(Refer Slide Time: 03:58)

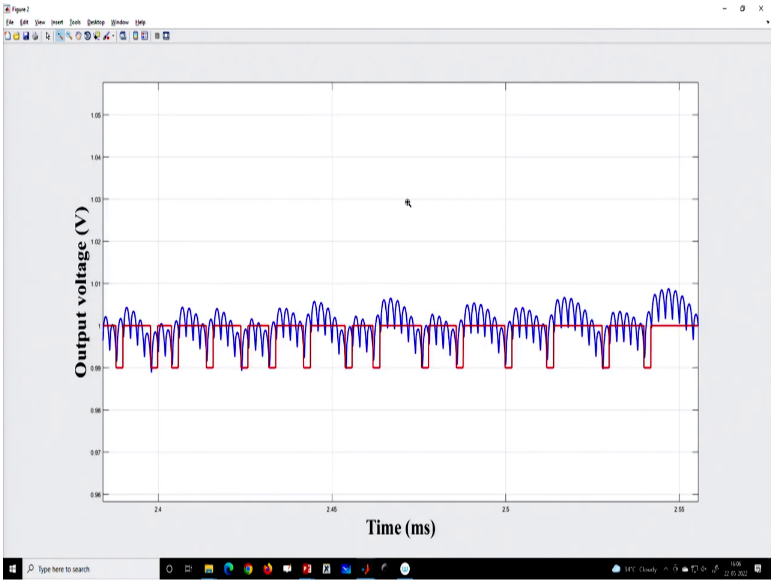


Now, the quantizer interval, it is like a voltage interval. So, we need to provide you know maybe we can give 10 millivolt 10 millivolt or maybe yeah 10 millivolt. So, you can provide a 10-millivolt quantizer and we want to see what happens after this quantization block. So, earlier simulation there was no quantization, now we have added a quantization and see what happens.

(Refer Slide Time: 04:23)

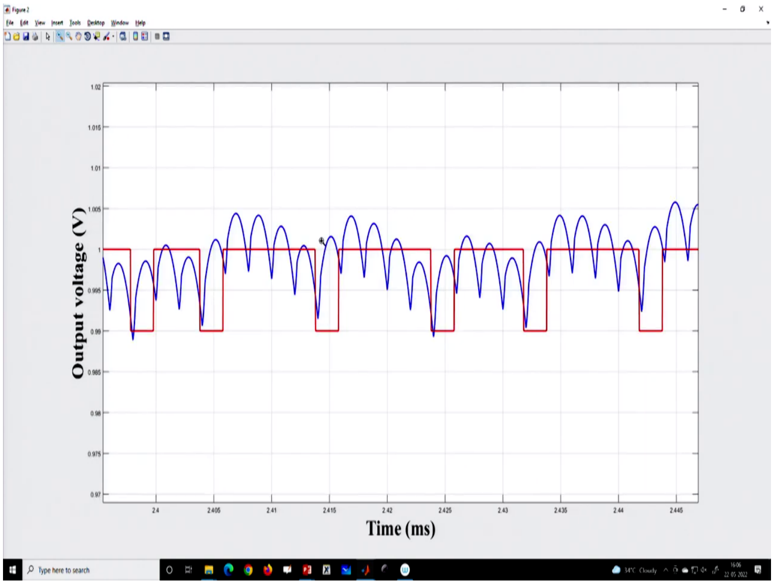


(Refer Slide Time: 04:28)

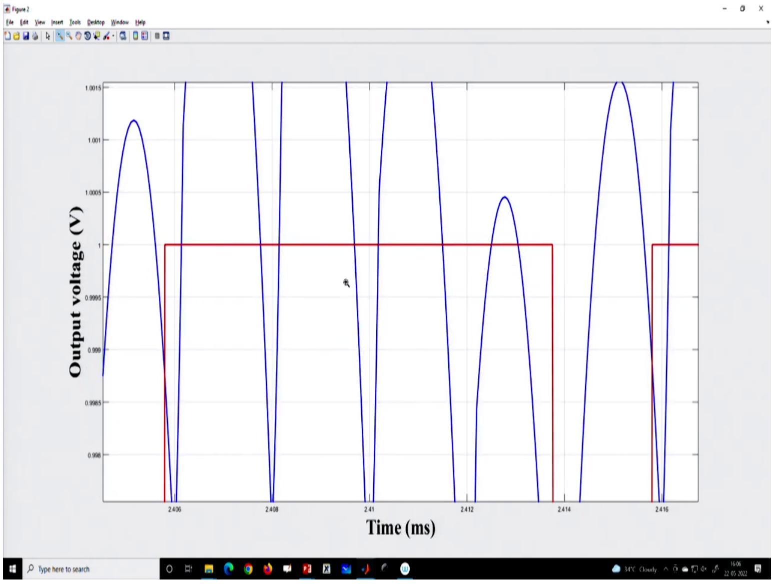


So, now you can see because this is the quantized data.

(Refer Slide Time: 04:29)

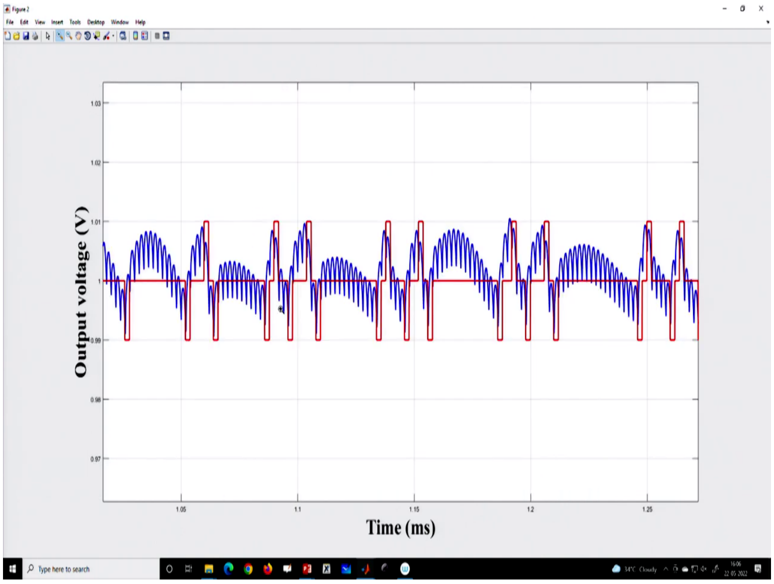


(Refer Slide Time: 04:35)



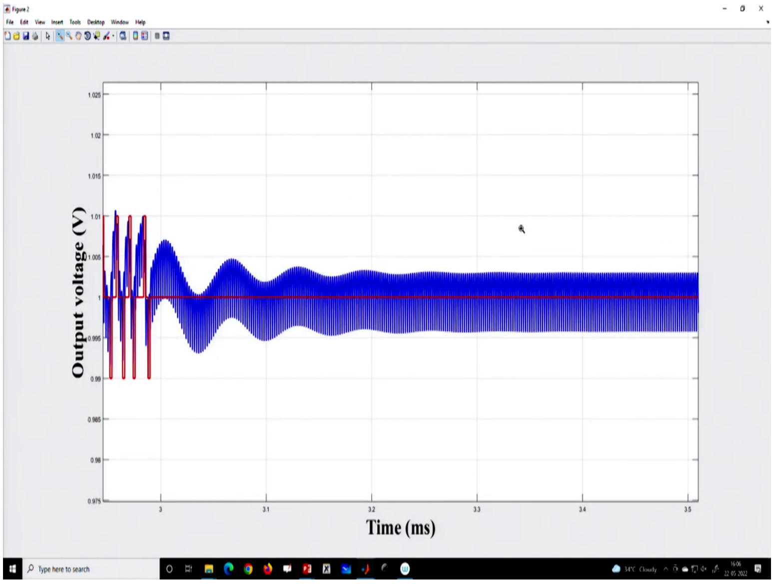
You can see that because of the quantization level, it is unable to differentiate the close values ok.

(Refer Slide Time: 04:39)

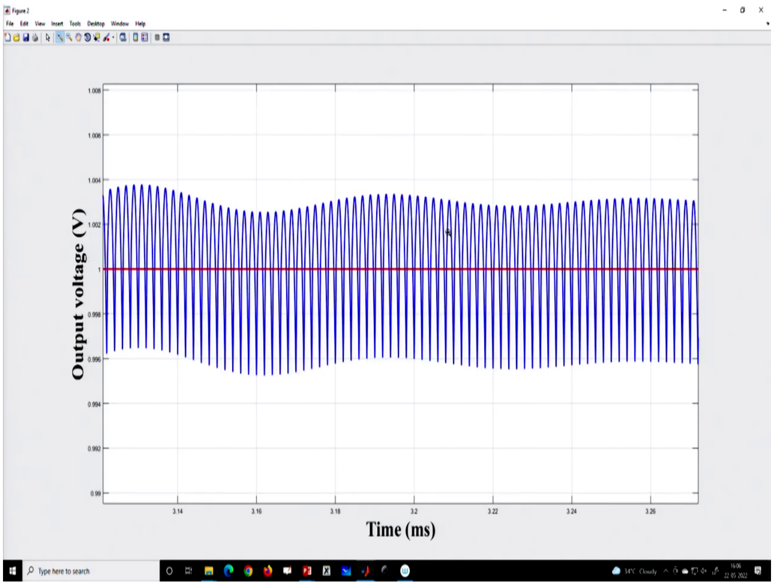


So, that is why quantization induces some instability is coming.

(Refer Slide Time: 04:45)

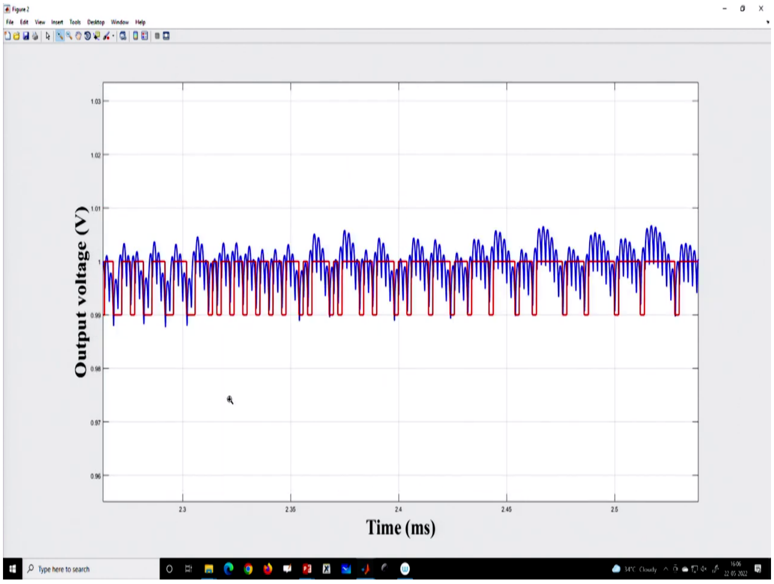


(Refer Slide Time: 04:48)



But once you can ensure the dynamically it is stable, then here the quantization level is reached and there is no stability problem.

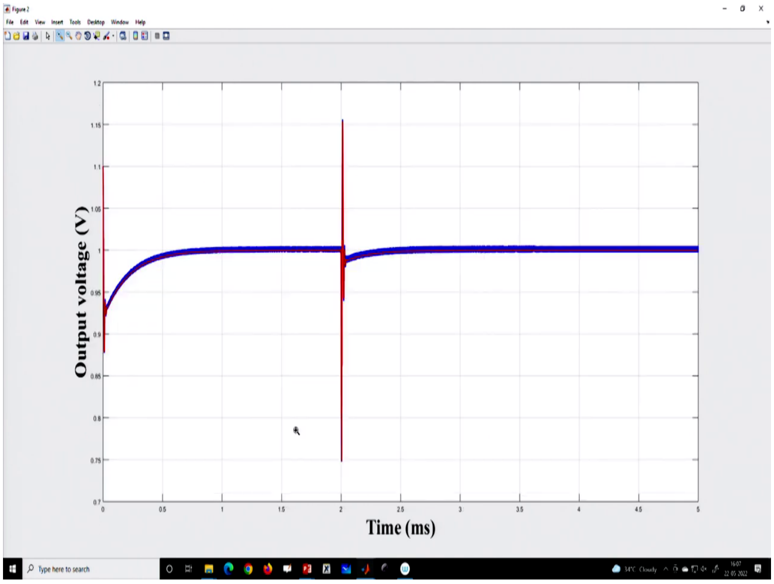
(Refer Slide Time: 04:55)



But due to quantization, there can be some sort of instability and we will discuss also this in the analysis case.

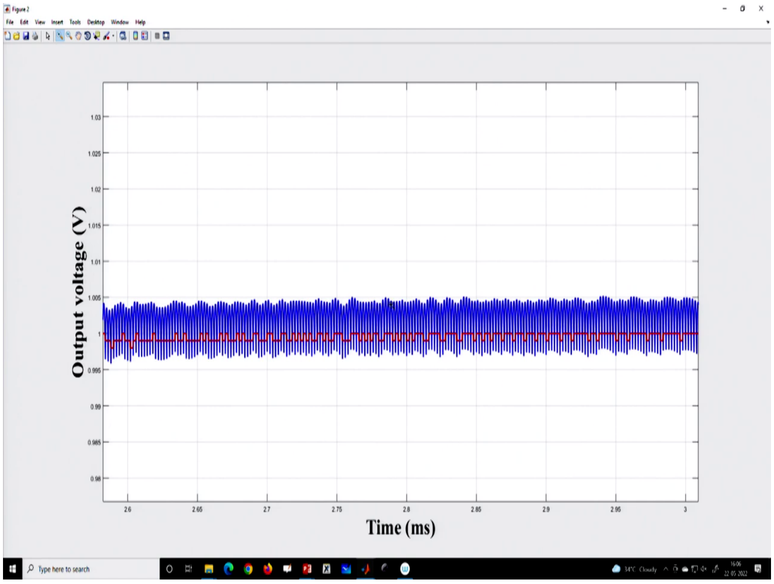
Now, if you reduce this quantization level; that means, if you reduce to let us say 1 millivolt, then you can improve this response; that means you can make the, you can somewhat improve the stability status.

(Refer Slide Time: 05:18)

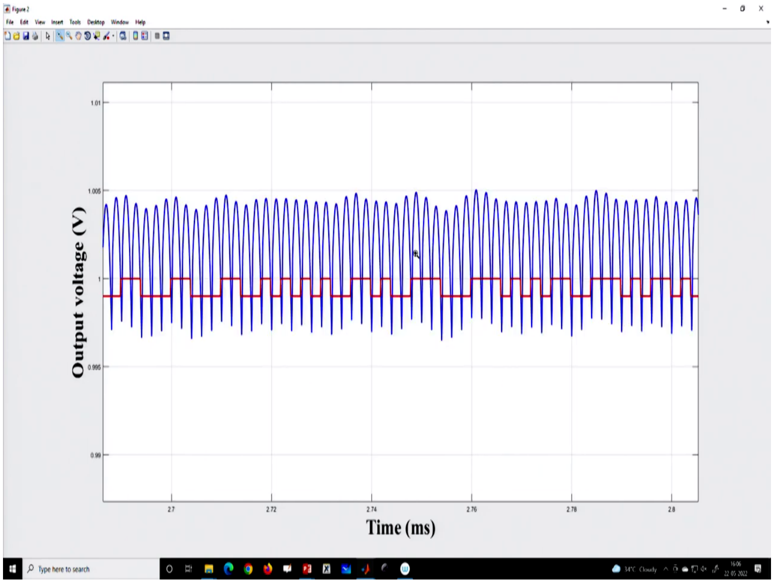


So, you can see how the effect is substantially reduced

(Refer Slide Time: 05:22)

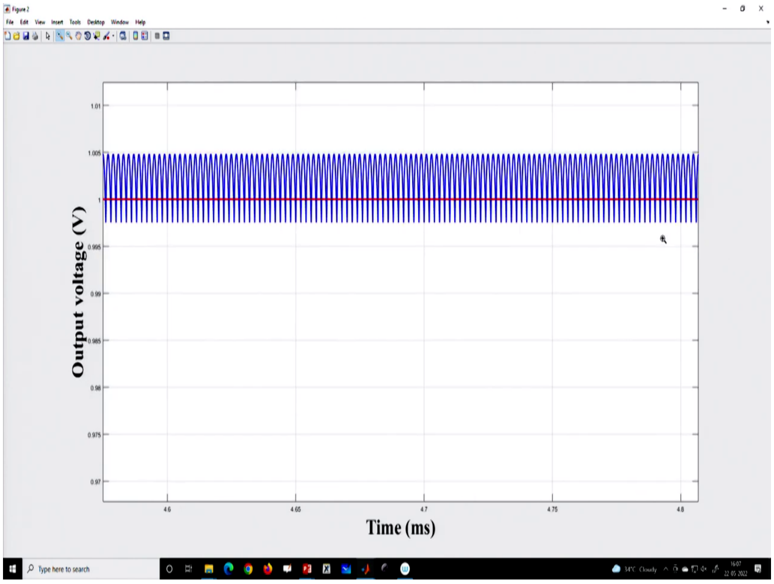


(Refer Slide Time: 05:24)

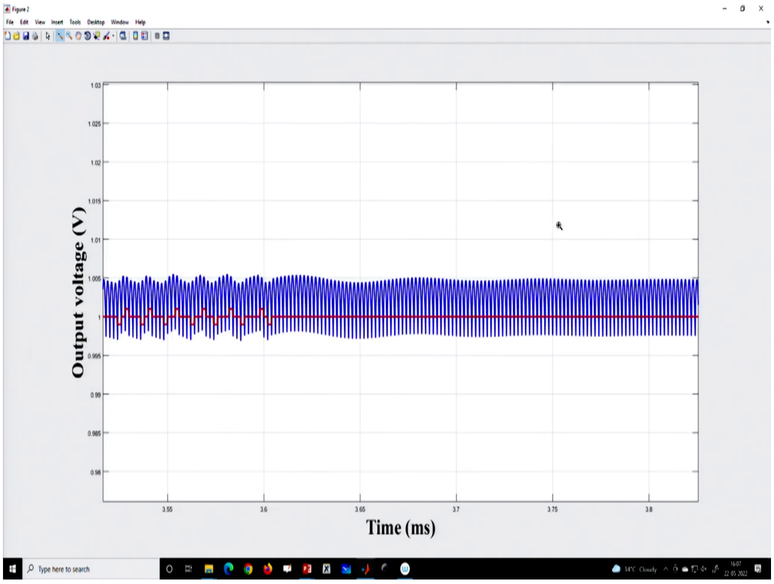


It is there, but it is substantially reduced.

(Refer Slide Time: 05:29)

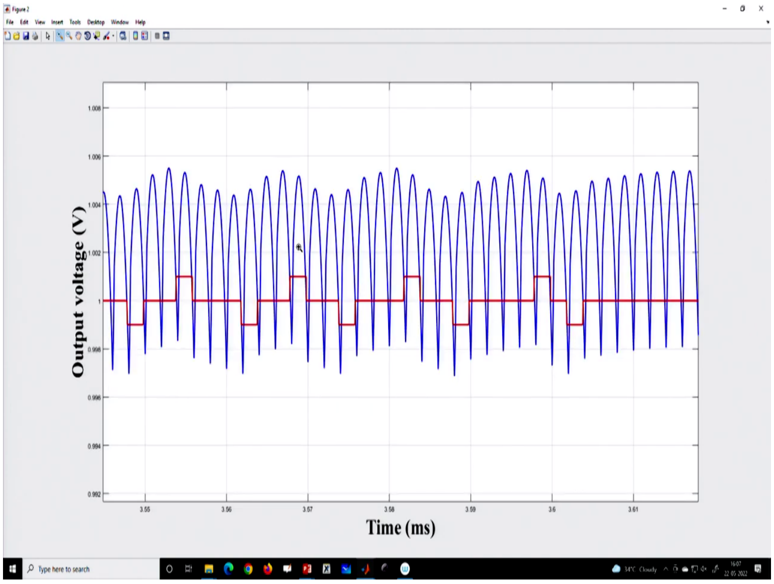


(Refer Slide Time: 05:33)



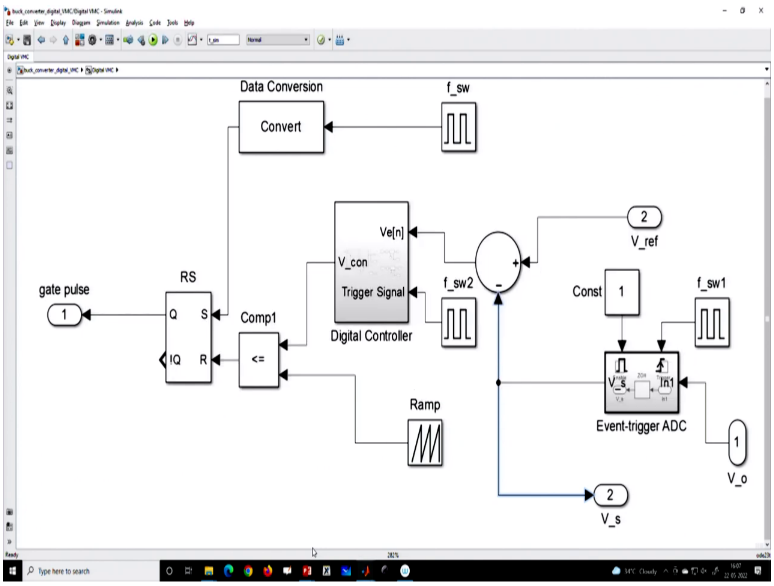
So; that means, as if under steady state also there is a small kind of after long time like you know, then only this effect is gone.

(Refer Slide Time: 05:35)



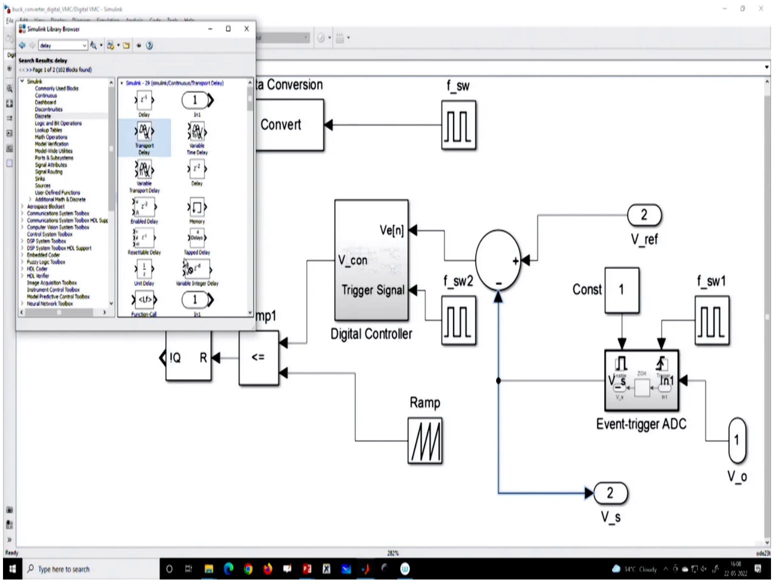
But due to this quantization effect, you will have some slow scale oscillation ok. And we will talk about this quantization effect, which may lead to limited cycle oscillation. Or in fact, it may lead to high periodic behavior, but if we do not incorporate for the time being, this quantization effect then we can simply discard this block and you can continue with our earlier block ok.

(Refer Slide Time: 05:55)



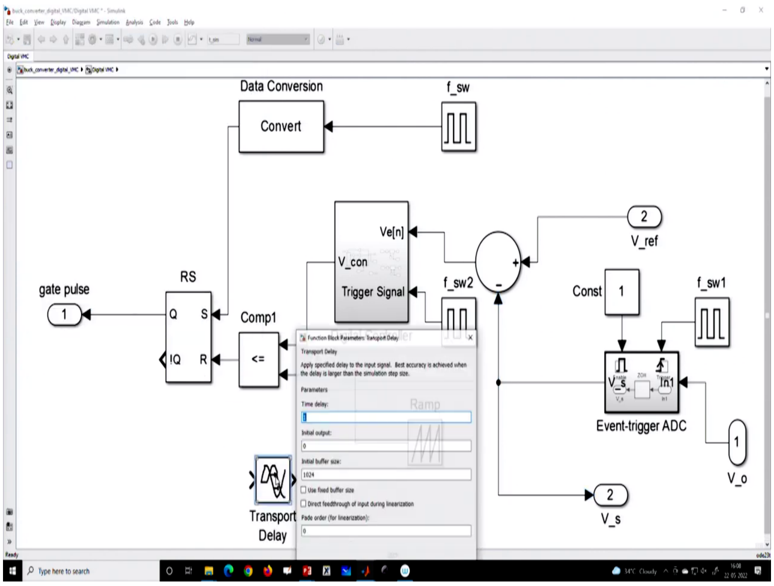
So that means, we can incorporate this block and let us go to our presentation ok, yeah. So, that means, we can add this quantization block; we can add a delay that we have already discussed that how to delete the clock. So, everything can then you can physically can add a delay in this MATLAB. So, if you go you can use a delay block, there will be a transport delay.

(Refer Slide Time: 06:28)



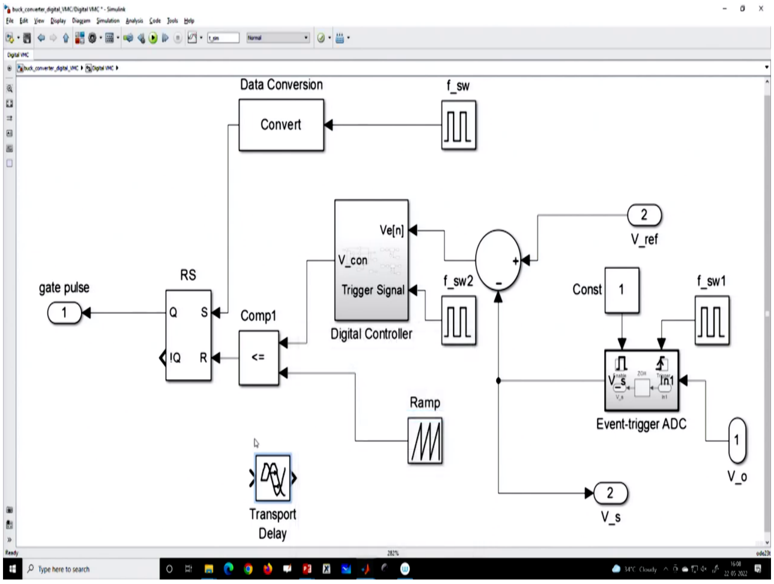
So, you can simply take a transport delay here ok.

(Refer Slide Time: 06:31)



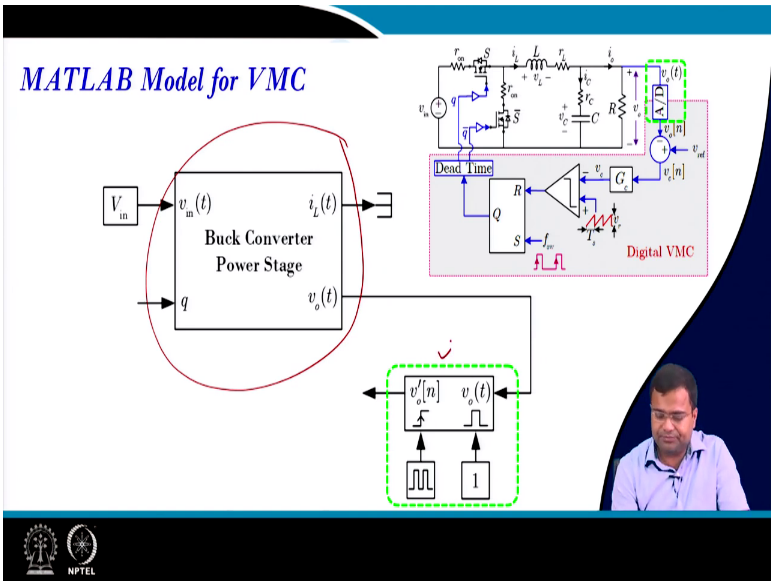
And here you can specify what is the delay amount.

(Refer Slide Time: 06:35)



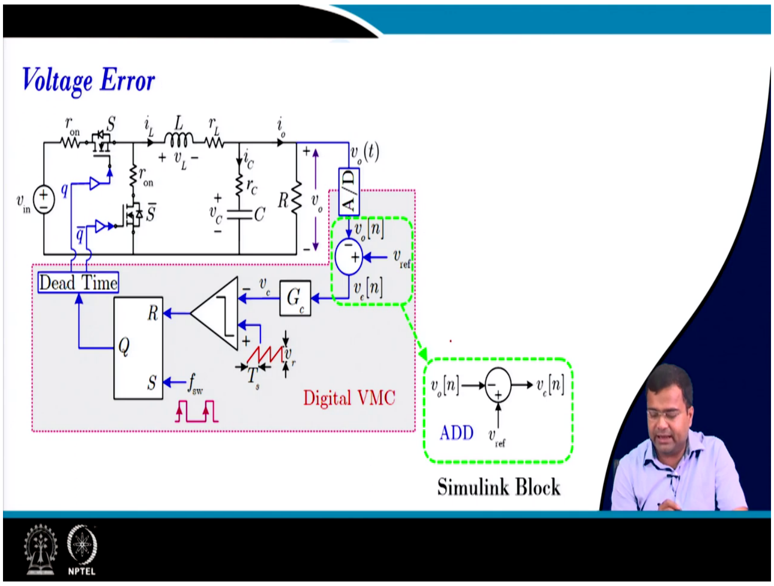
So, these are the possibility, I am not going through all this, but I am just showing these are you know you can all, of course, make the simulation more realistic ok.

(Refer Slide Time: 06:43)



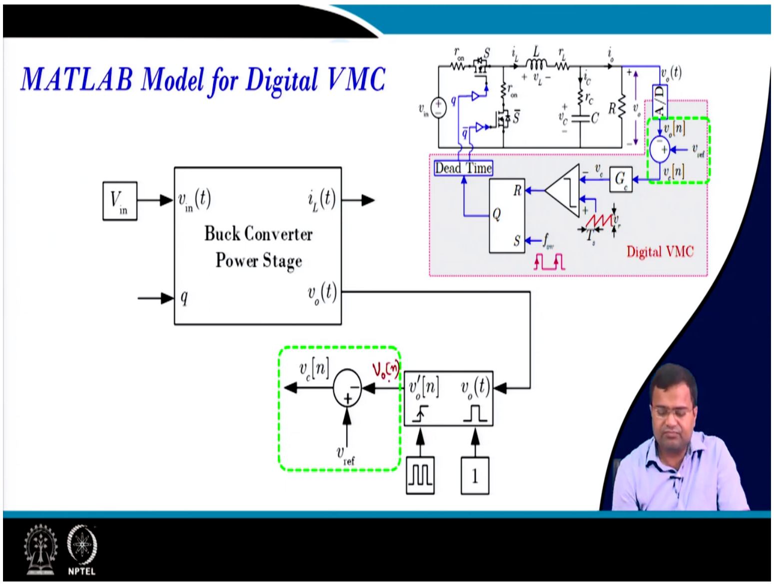
So now, in the MATLAB model, we have this buck converter power stage and this will go to. So, we have to close the loop.

(Refer Slide Time: 06:53)



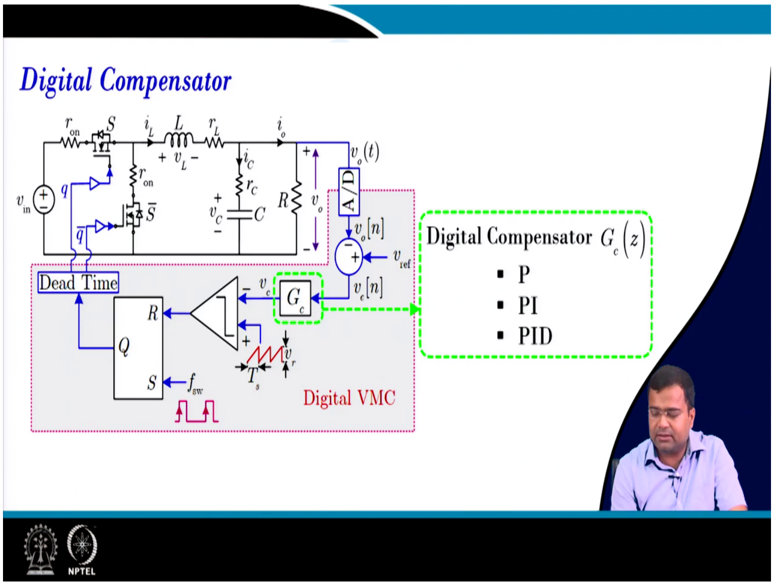
And this is our ADC block, the next part we need is an adder circuit.

(Refer Slide Time: 06:56)



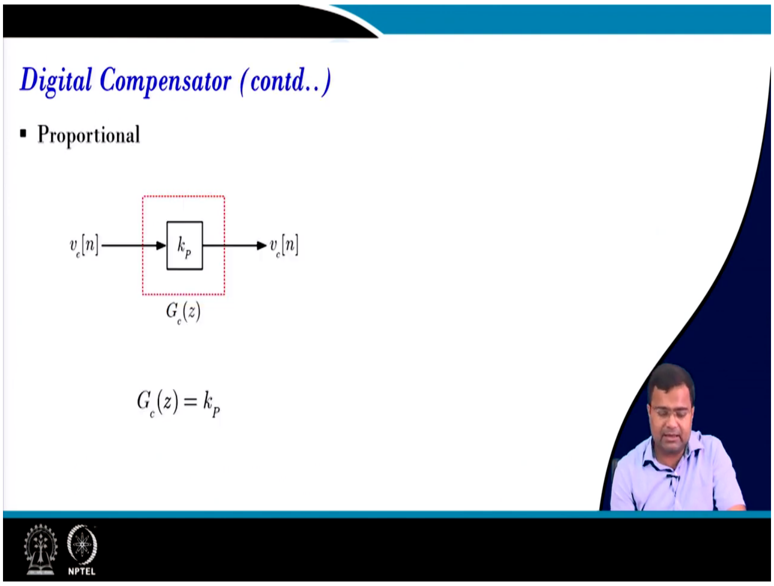
So, this is just a simple adder ok, this is our sample voltage.

(Refer Slide Time: 07:04)

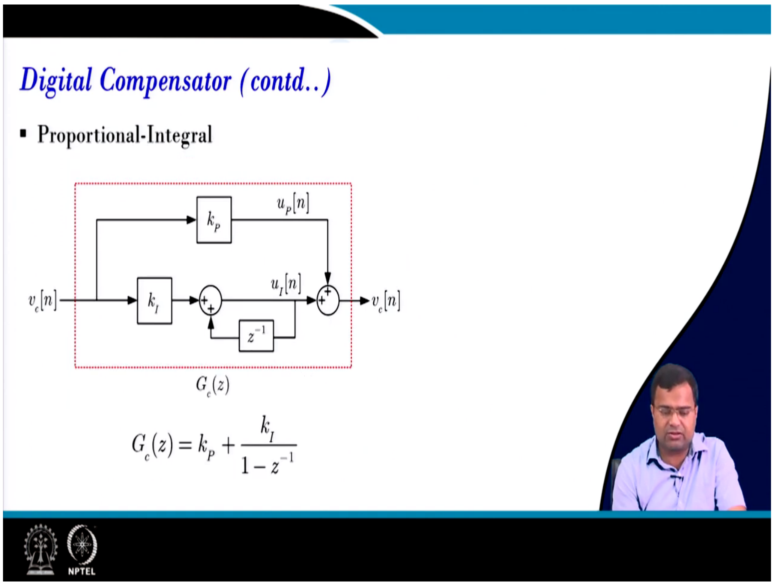


Then it is a subtractor, then we need compensators P, PI, and PID.

(Refer Slide Time: 07:11)

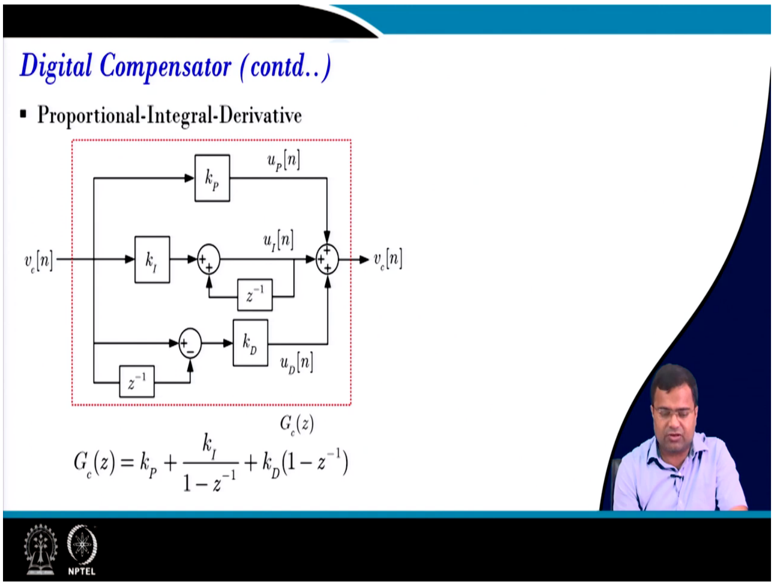


(Refer Slide Time: 07:12)



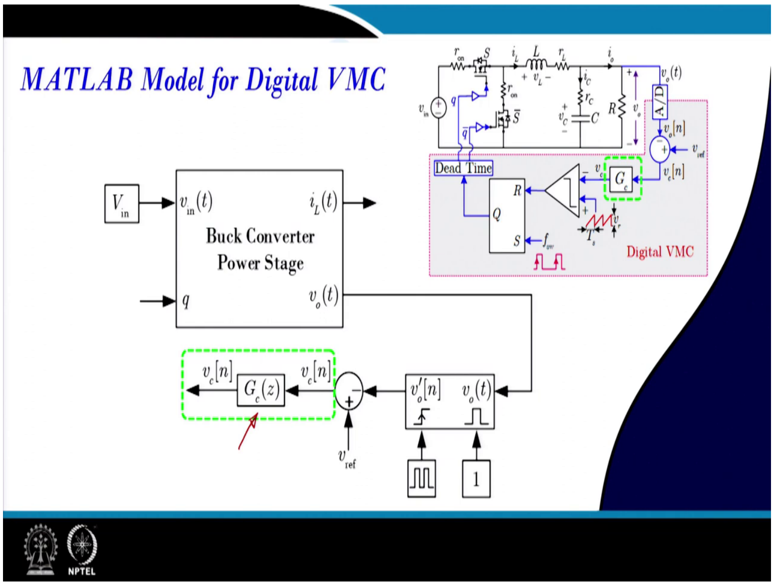
And we have discussed this compensator can be realized using clock driven, which we have discussed in the previous class.

(Refer Slide Time: 07:18)



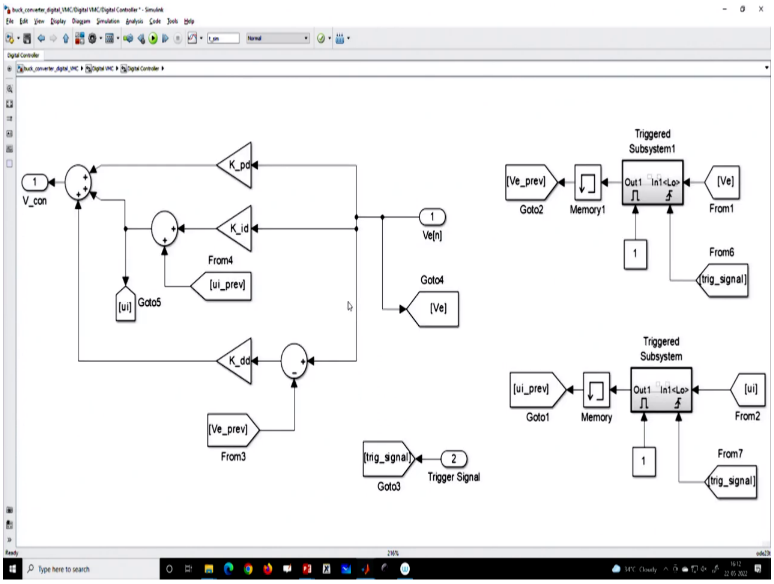
And so, this is for the PID controller.

(Refer Slide Time: 07:22)



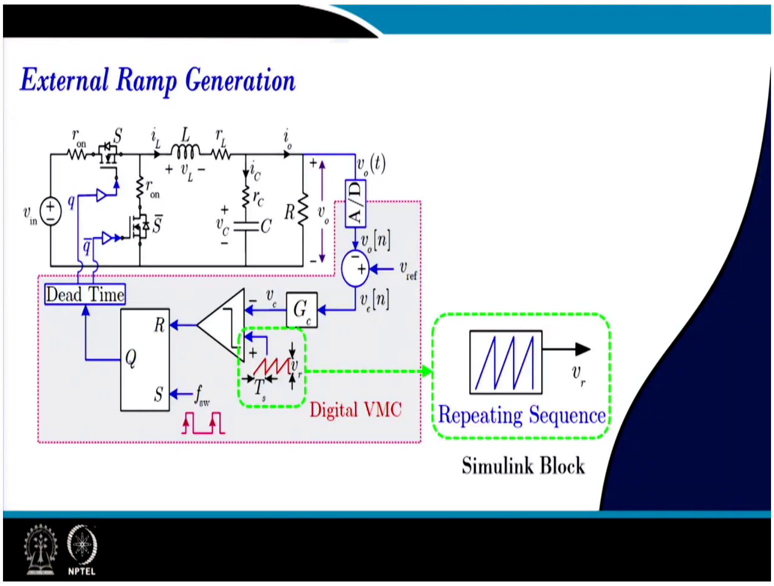
So, the earlier one is the PI controller. So, any controller that you can implement. So, this block although looks like a block, in MATLAB it is not a block.

(Refer Slide Time: 07:29)



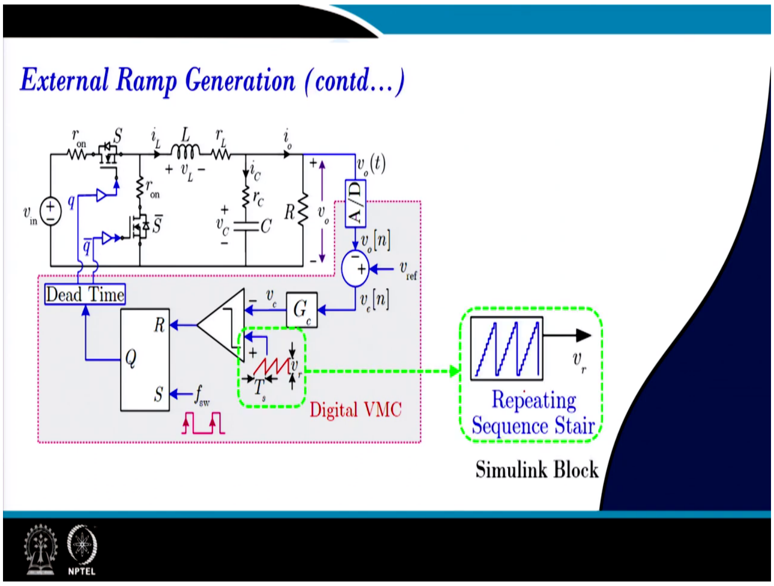
It is a difference equation if you go inside. So, this is the whole realization of this. So, in this part, you can consider your transfer function as equivalent to the transfer function. And that is realized using a difference equation using a clock-driven operation.

(Refer Slide Time: 07:47)



Next, once it is done then we can use a repeating sequence for the sawtooth waveform.

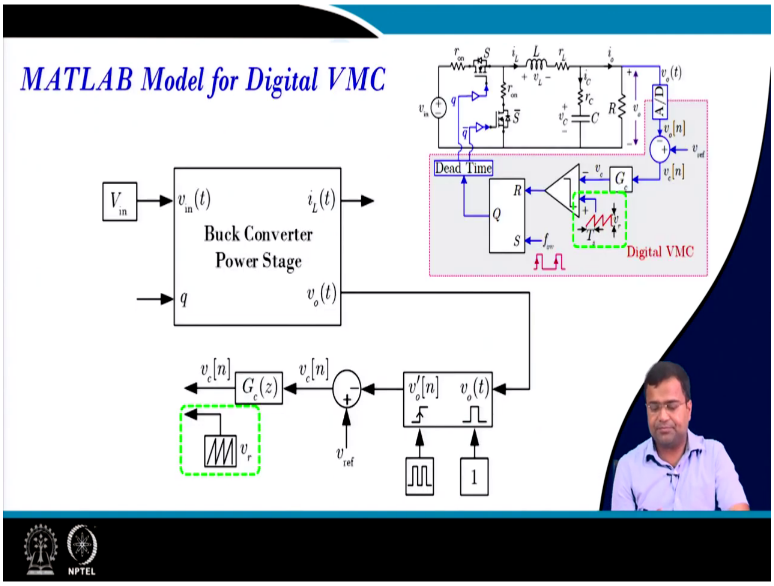
(Refer Slide Time: 07:53)



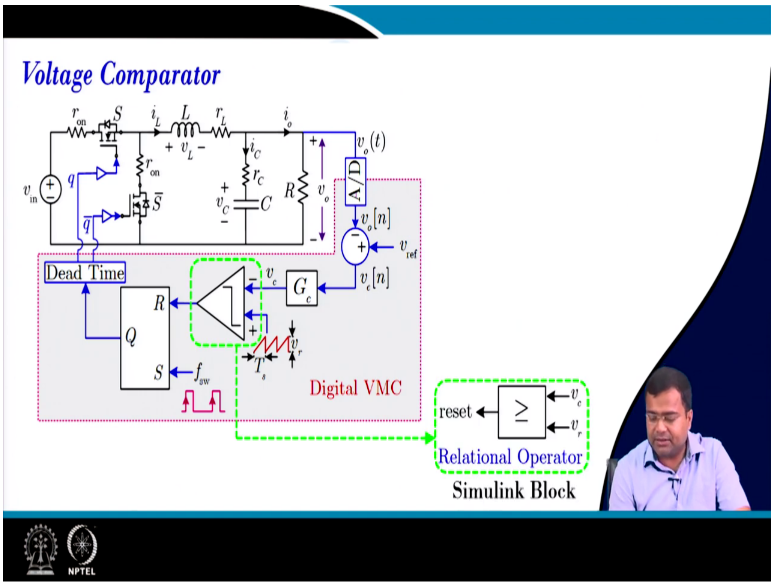
But you can also use a staircase-type repeating sequence, which will give you know the feeling of the quantized staircase because if you go to a digital platform this staircase will be generated inside a digital controller, and will be we have discussed this for different digital like a DPWM architecture.

So, you can use a simple counter-based DPWM to implement this or there is another accuracy like delay line DPWM or hybrid problems, but you can get this kind of sequence with the staircase effect.

(Refer Slide Time: 08:24)

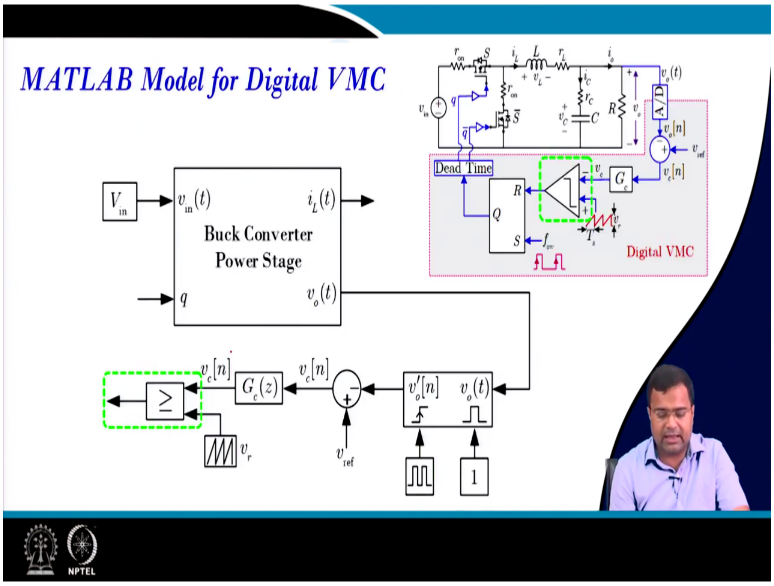


(Refer Slide Time: 08:26)

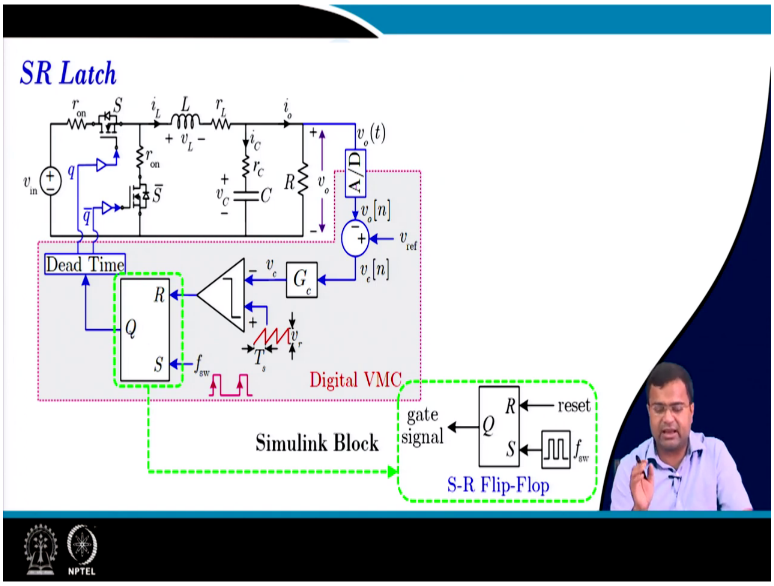


Then after this block you have to use a comparator, this is a comparator.

(Refer Slide Time: 08:30)

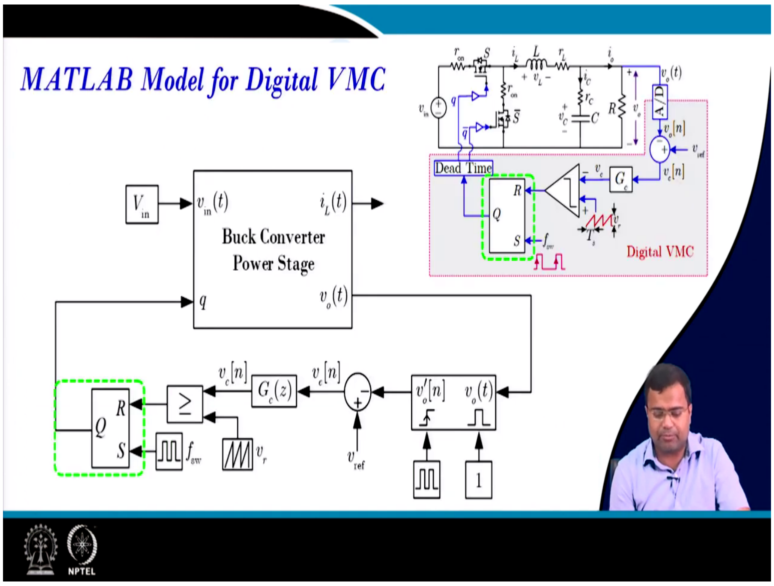


(Refer Slide Time: 08:32)

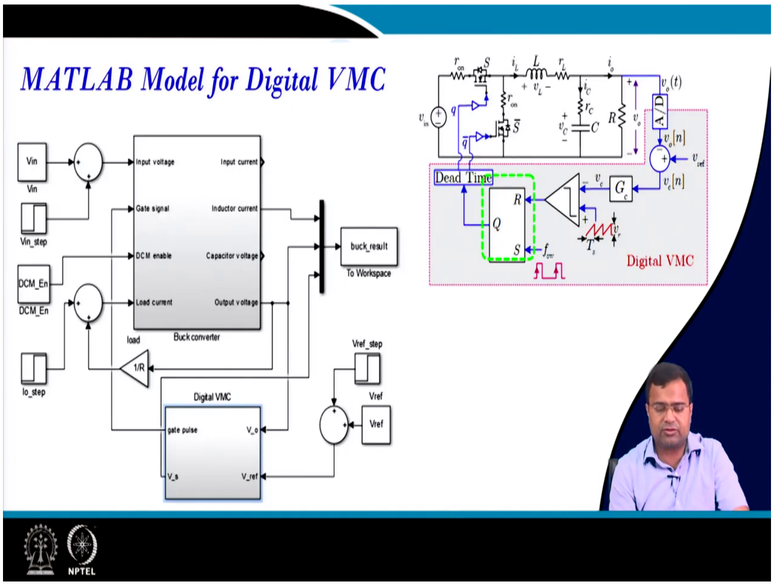


And then we can use a saw tooth; that means, the latch circuit. So, this is you know is the main pulse width modulation, trailing edge modulation block and then you can use the overall buck converter model.

(Refer Slide Time: 08:39)

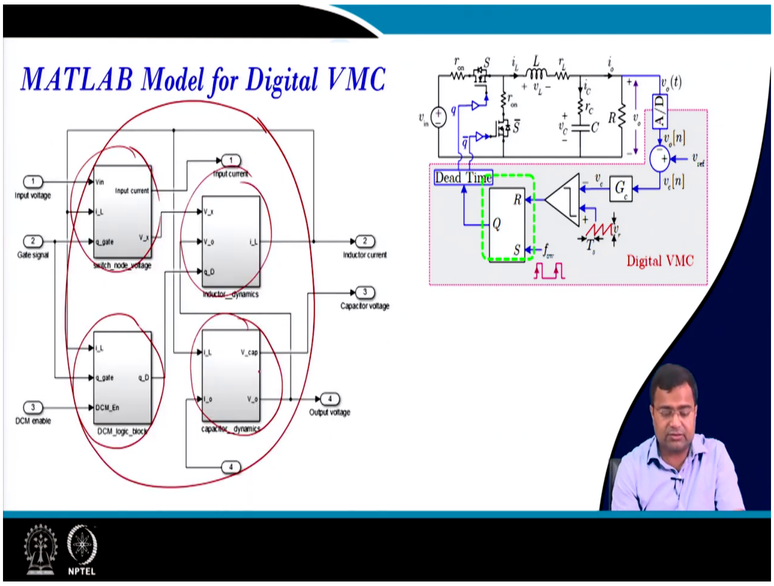


(Refer Slide Time: 08:41)

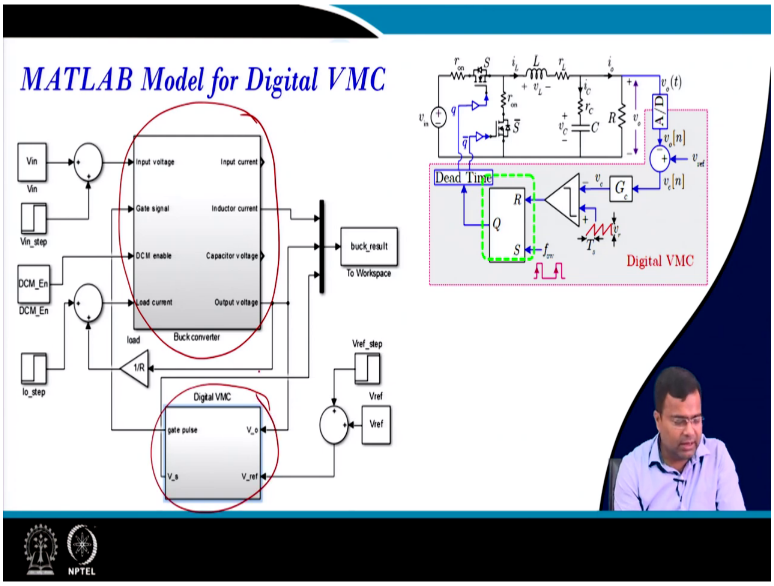


So, this is the overall digital voltage mode controller model, that we have discussed.

(Refer Slide Time: 08:47)

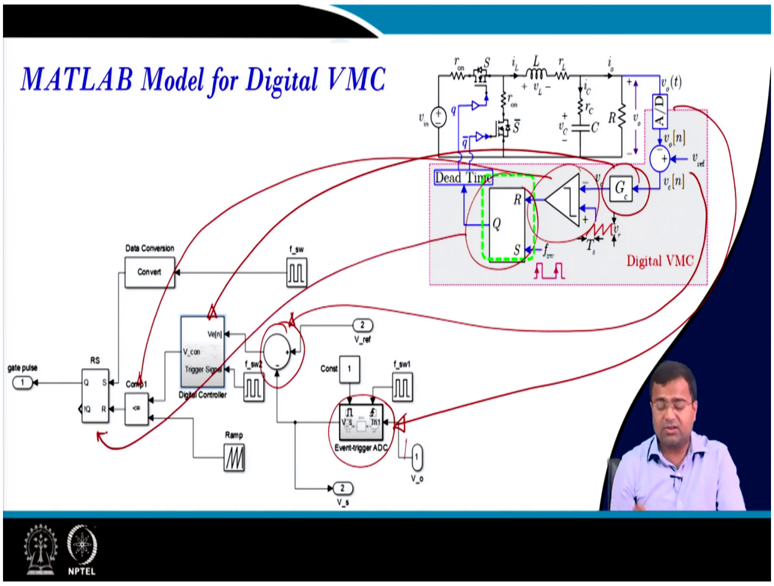


(Refer Slide Time: 08:51)



And if you zoom this portion; that means, if you zoom this portion we have discussed this is a power stage ok, where we have switch node voltage, inductor dynamics, then capacitor dynamics, and then DCM enable logic.

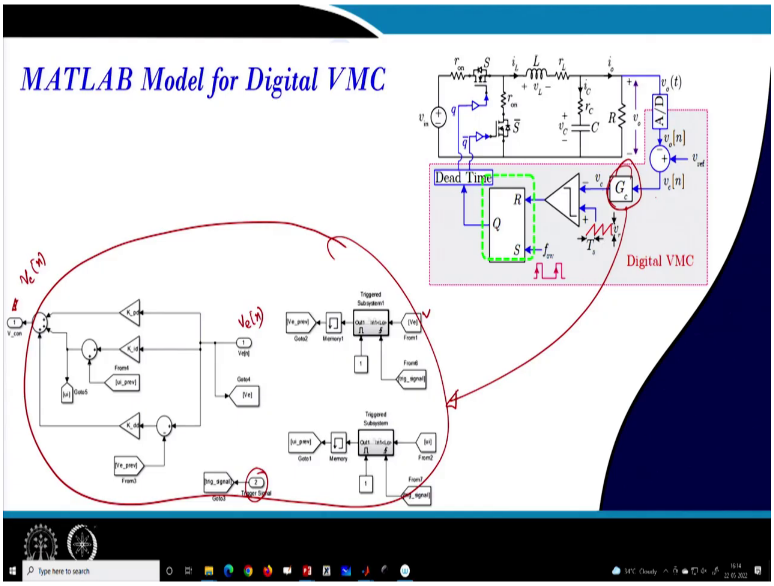
(Refer Slide Time: 09:04)



Now, if you go inside the controller; that means, you know if you take this controller this controller inside this controller is this block, where this is your output voltage this is your (Refer Time: 09:18) converter so; that means, this process is here.

Then we have this subtractor which is nothing but here, then we have this controller which is here, then this is our comparator which is here, and followed by this is our latch circuit which is nothing but our here. So, then it will generate the gate signal.

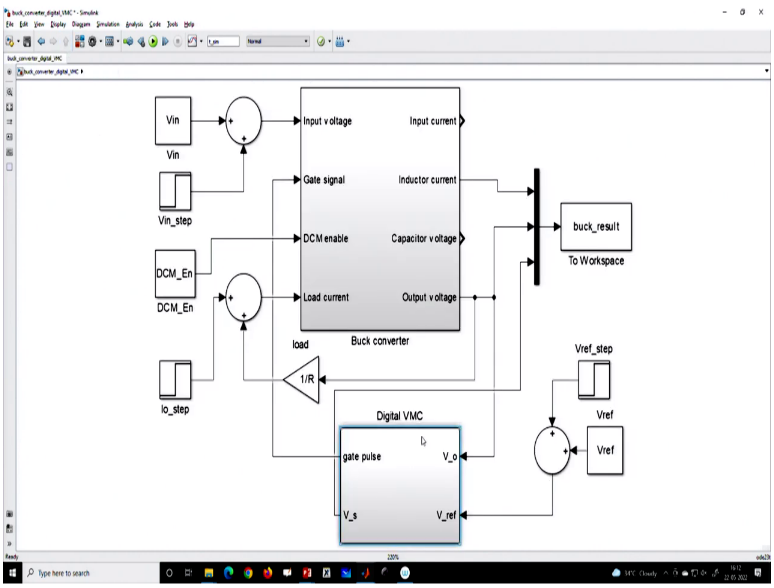
(Refer Slide Time: 09:47)



And this is a complete g this diagram. This is a diagram that is realized here the whole diagram represents what will implement; that means, the input to this block is error voltage which is the error voltage, which is your input and it is coming from v n. There is one more input which is a clock; that means, your trigger signal. So, we need to sample with respect to a clock and the output of this block is a control voltage which is here.

So, this is our control voltage ok so; that means, now if you go to the actual MATLAB block. So, this is what we have discussed in detail.

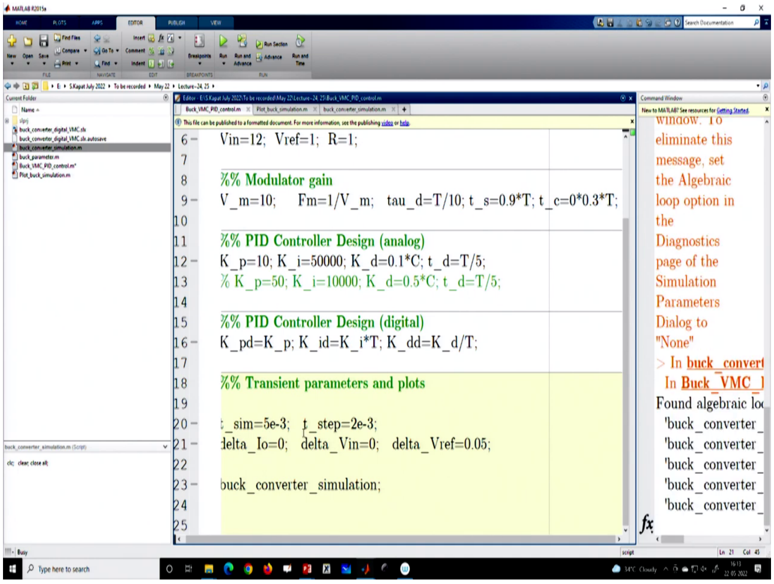
(Refer Slide Time: 10:32)



So, we can you know, for the digital controller we can customize the controller parameter from outside. You can use any tuning algorithm inside your Simulink block to update the parameter. So, whatever else you want you can discuss. And we will discuss that by using a trigger clock you can make the sampling process customizable and you can adaptively vary during the runtime ok.

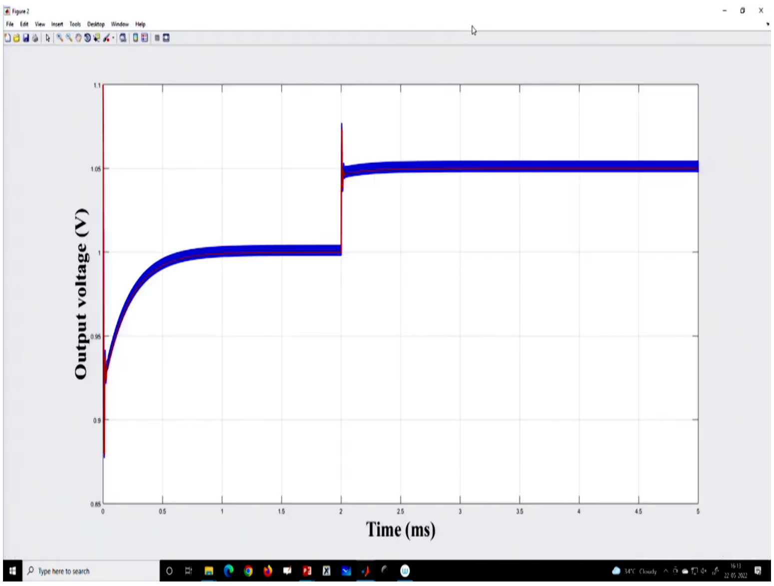
And we have made some simulation case studies. So now, you if you want to do a load transient case study with a 20-ampere load step, I am just showing the scenario. So, this is the simulation result of a 20-ampere load step. Now, you can reduce this as a proportional gain if you know all these blocks we have discussed.

(Refer Slide Time: 11:24)



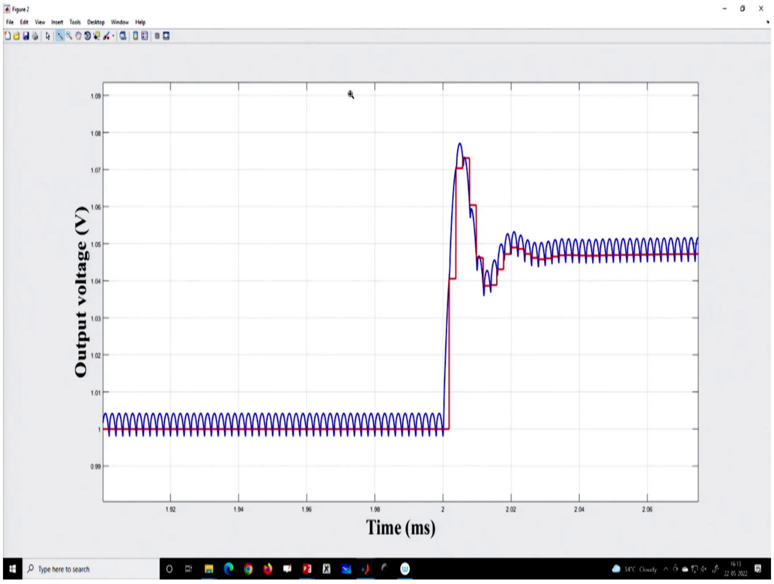
Now, if you want to make an instable load transient, I want to make a reference tangent. So, 0.05, just a 0.5-volt reference tangent, then you will see that now there will be a change in the reference voltage ok.

(Refer Slide Time: 11:35)

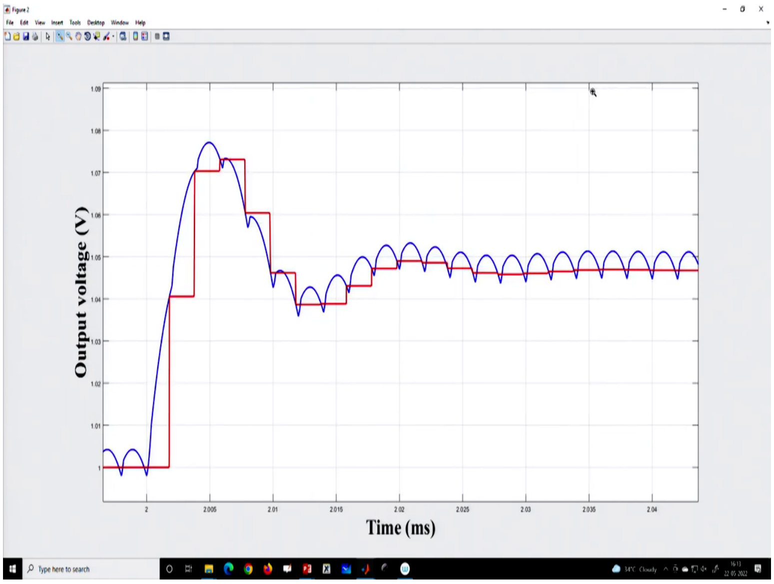


So, this is the reference tangent, I have not yet discussed the digital control design.

(Refer Slide Time: 11:41)

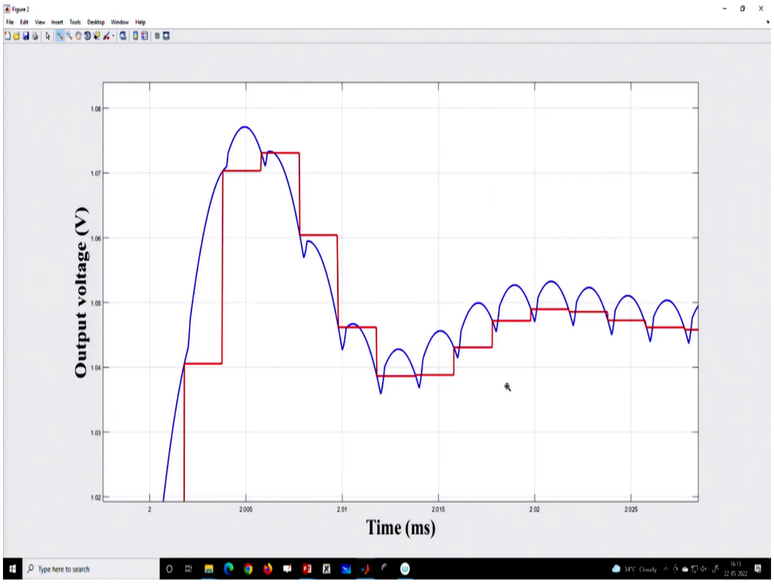


(Refer Slide Time: 11:43)

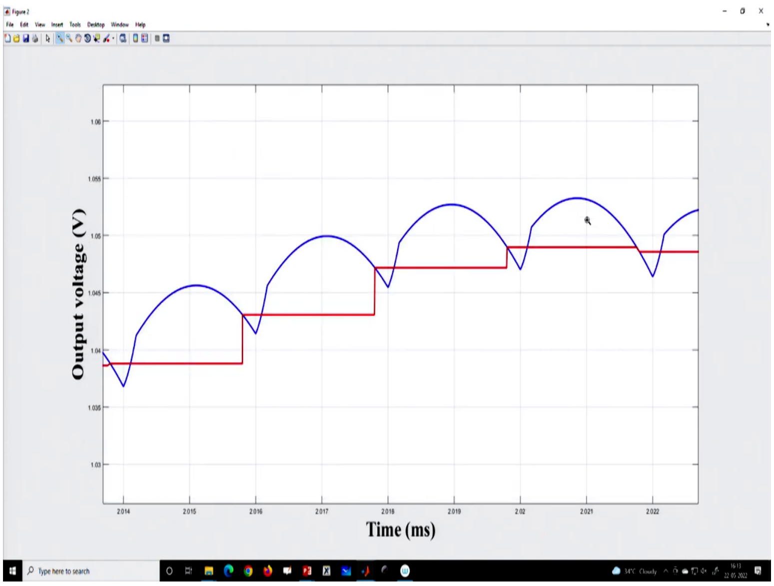


That is why I am just showing some I have chosen some arbitrary value of the controller gain, but it is just to show that you can realize this controller by using MATLAB. And here we are incorporating delay.

(Refer Slide Time: 11:53)

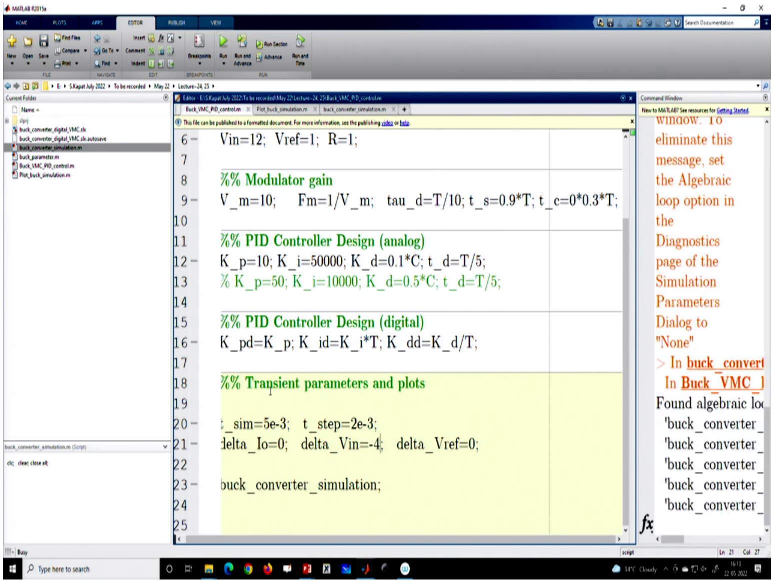


(Refer Slide Time: 11:54)



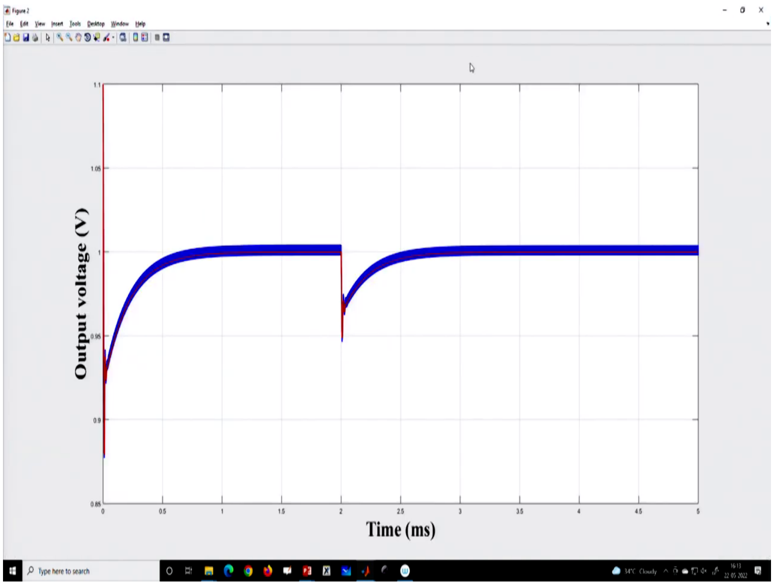
You can see the sampling time and the switching times are different. So, sampling is happening fast, and then switching is happening. So, you can customize this delay ok.

(Refer Slide Time: 12:06)



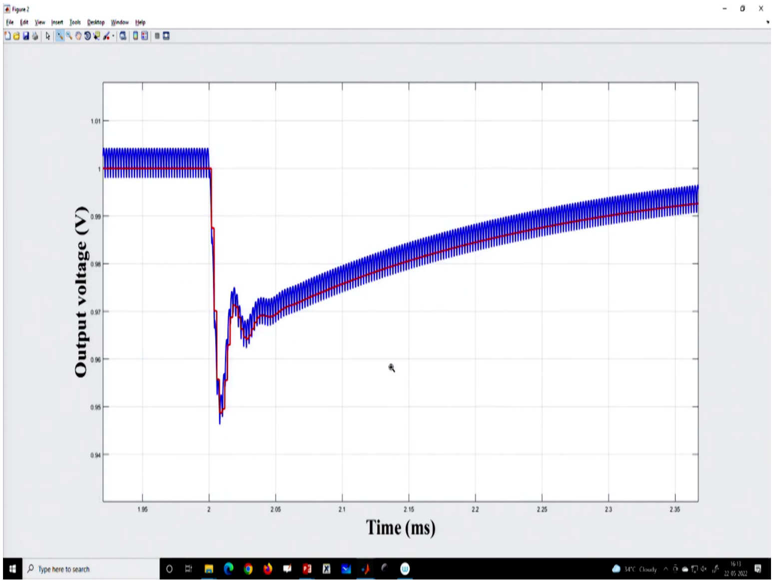
The next part is that if we want to do a supply transit; that means, we can do a supply transient minus 4 volts, let us say we can do a supply transient in voltage mode control.

(Refer Slide Time: 12:16)



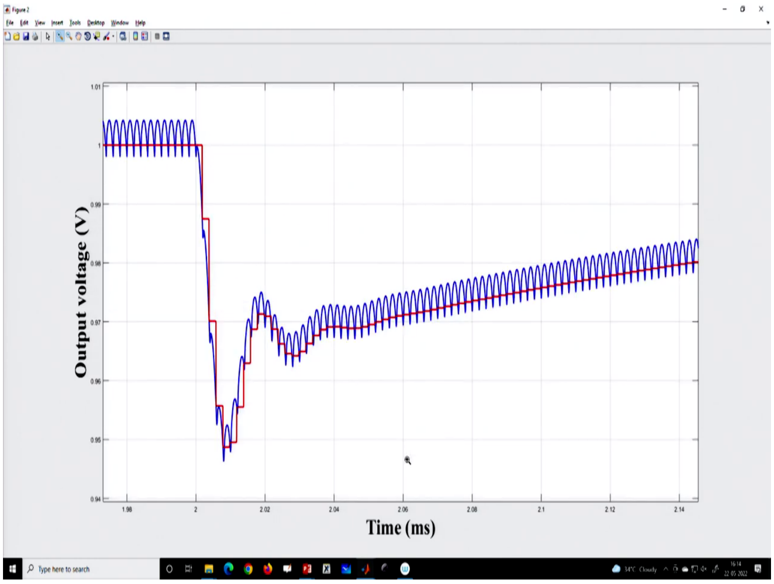
We have not considered any input voltage feed-forward.

(Refer Slide Time: 12:22)



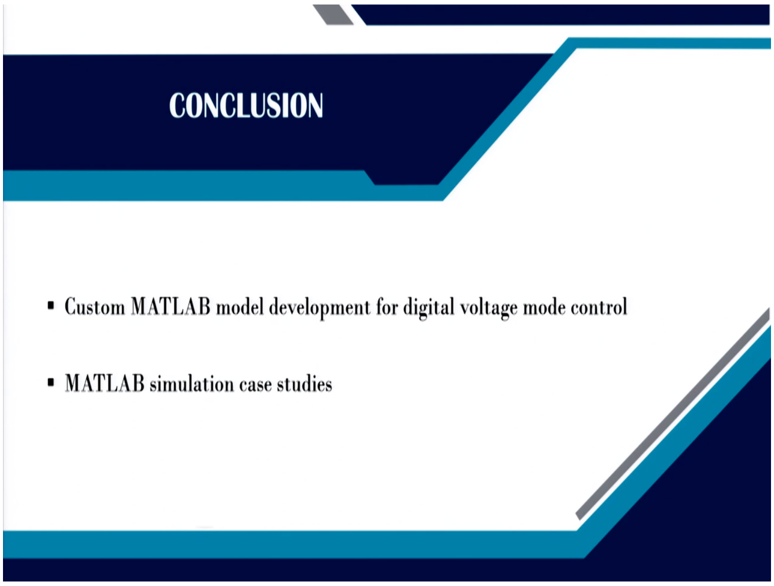
So, we can do input voltage feed-forward because the effect is quite significant, this is due to the nature of voltage mode control.

(Refer Slide Time: 12:31)



And if we do an input voltage feed-forward, then you can very easily nullify or reduce this effect due to the supply disturbance ok. So; that means, we have discussed you know various case studies and now with the model is ready so we can go for the design in the subsequent week. In the next week, we will go for the design I mean modeling and design will come in a subsequent week.

(Refer Slide Time: 12:53)



So, in summary, we have discussed custom MATLAB model development for overall digital voltage mode control implementation, then we have also discussed MATLAB simulation case studies. Then we will go for digital current mode control in the next lecture, MATLAB model development. So, I want to finish it here.

Thank you very much.