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 - 21
Recap of Voltage and Current Mode Control Implementation using MATLAB

Welcome back. So, in this lecture we want to recapitulate our, you know Voltage and Current Mode Control Implementation using MATLAB.

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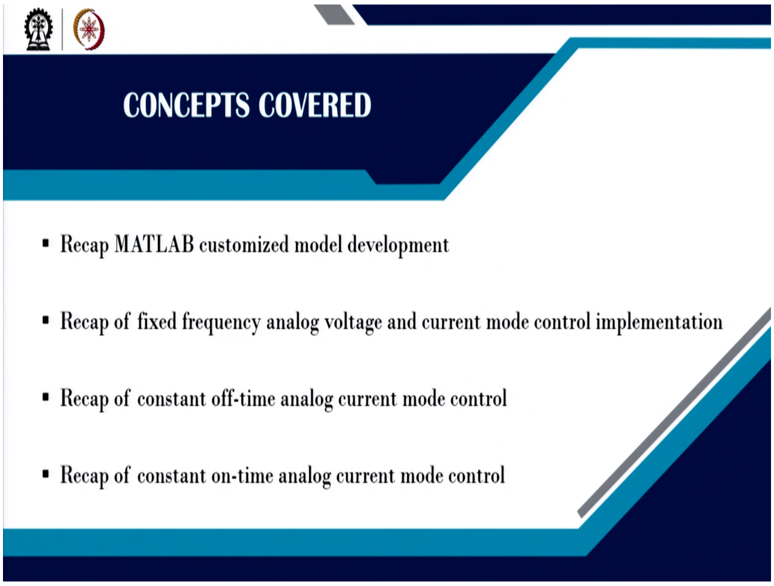

So, here I want to recapitulate our customized model development and I will be referring frequently to our previous NPTEL course, where you can get the detailed material. Then we will recapitulate fixed frequency analog voltage mode control as well and also current mode control implementation and then we recap we will recap the constant off-time analog current mode control and constant on-time analog current mode control.

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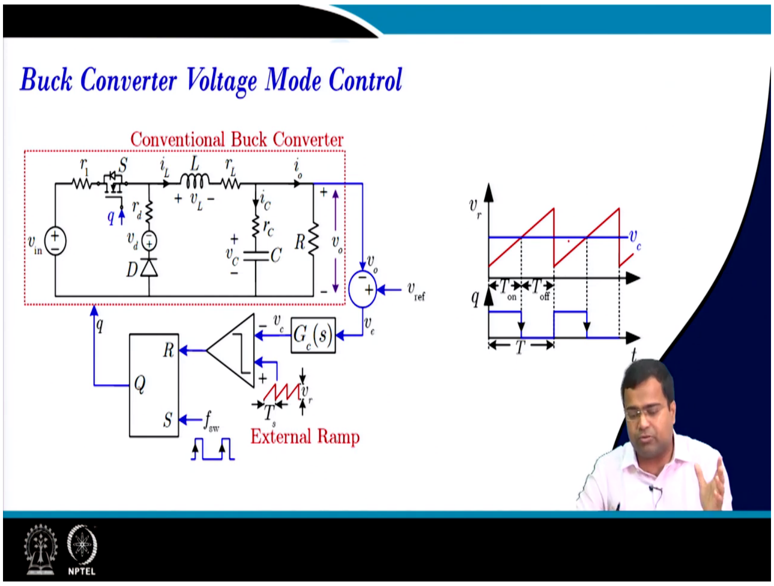

So, first, we will take the buck converter voltage mode control. So, here this is a conventional buck converter. It can be a synchronous buck converter also and we are talking about a voltage mode controller we know about the sawtooth waveform and the control voltage is compared to the sawtooth waveform to generate the acceleration.

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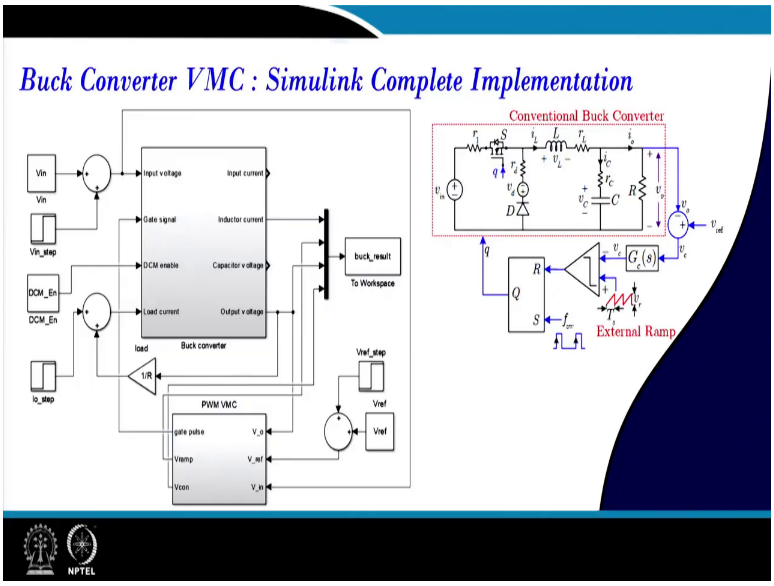

What does the MATLAB file look like? So, this is the overall structure of the system, and if I go to MATLAB.

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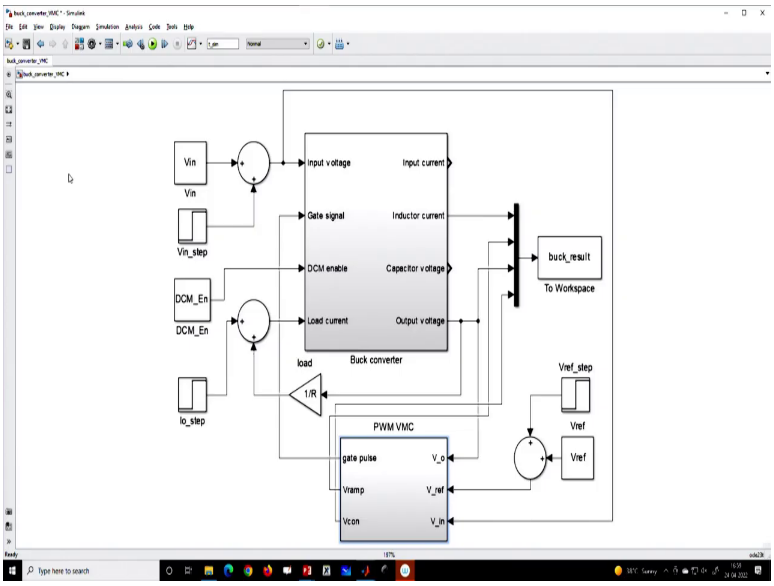

So, let me go to MATLAB. Now, this is the MATLAB block diagram of this voltage mode feedback control of a buck converter. Here this is the power stage; which means, the power converter.

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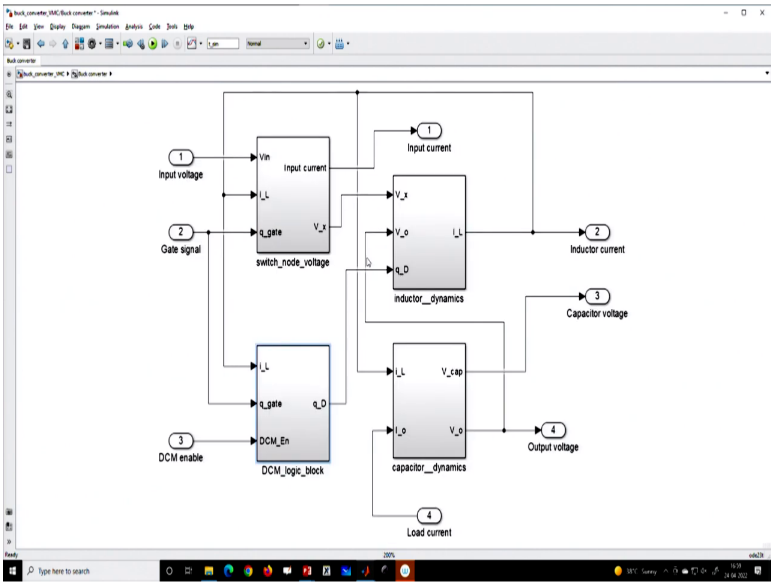

And you know if you go inside, then the switch mode voltage inductor current dynamics the DCM enables logic then the capacitor dynamics. And this accepts the input voltage where we can also apply a step input voltage here is the DCM enable logic if it is set to 1 it will become a conventional buck converter. If it is 0, it will become a synchronous buck converter. Then there is the load current. So, here we are talking about two types of load. One is the resistive load which is why it is 1 by R, which is connected to the output voltage of this load.

Another is the step current load. So, we can create a customized load profile. So, we can get a low transient response and this is a reference voltage then you can reference voltage and nominal reference voltage then we can apply reference step transient here we are logging all the data into the workspace we are saving, and then this is a feedback controller. So, let us go to our presentation. So, this is the overall diagram that is showing.

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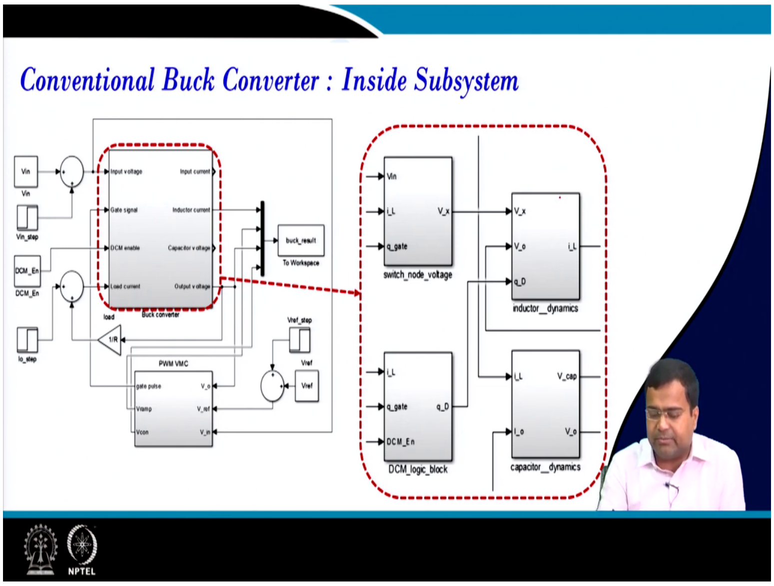

Next, if you go inside this converter. In the power stage, I have shown you the switch node configuration then inductor dynamics DCM logic, and capacitor dynamics.

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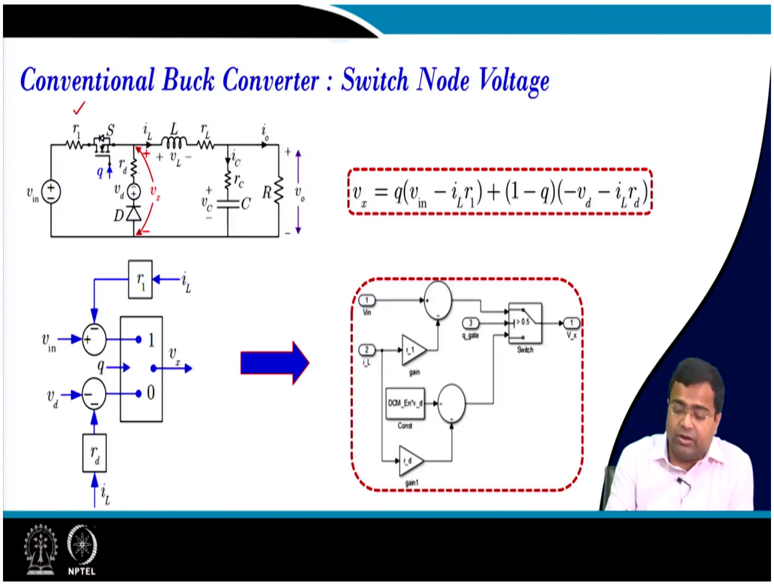

How does it realize? That means, if you take the switch mode voltage it is q v in minus I L r 1 r 1 is this one, then 1 minus q minus v d I L r d. So, v d is the direct voltage drop r d is the direct resistance drop. And this can be implemented using this logic and we can create a DCM that enables logic like this.

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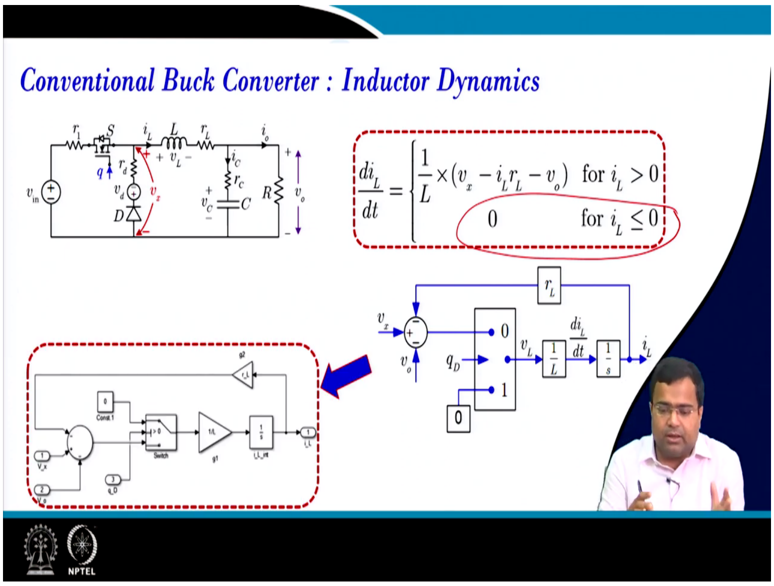

Similarly, if you go to inductor current dynamics, we can write di L at 1 by L, and this particular term is incorporated to enable the DCM operation it can be realized by this and you can get the complete block diagram using this architecture.

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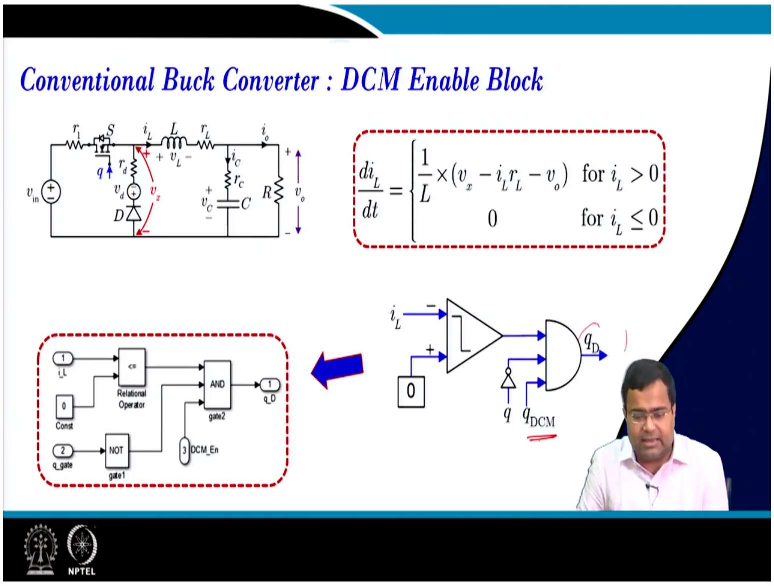

So, this DCM enables block; which means, we have a DCM enable if we set it to 1, then it will enable this DCM block depending upon whether the inductor current is touching 0 or not. But, if you set it to 0, then it will not the inductor current can go to in the negative direction. Because this always will be 0; that means, the DCM enable logic is a DCM enable logic is disabled and this is the overall block diagram for the DCM enable logic.

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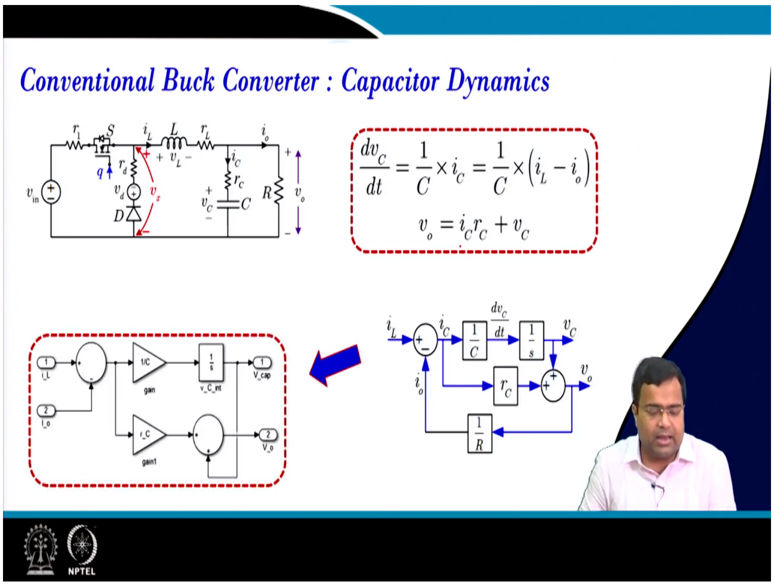

And the conventional buck converter. If you take the capacitor dynamics then the capacitor voltage capacitor dynamic output capacitor dynamics d v c it can be written like this and this is the output voltage in terms of capacitor current and the capacitor voltage and you can get a complete realization.

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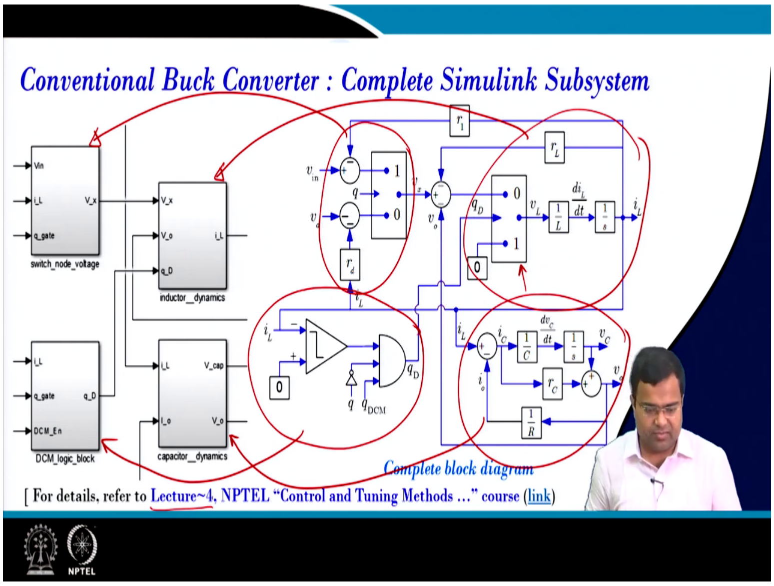

So, the complete conventional buck converter, you can get this detail in this NPTEL online from our previous lecture in lecture number 4. So, here we are not again wasting time to again you know explain the all details of the power stage architecture, but this represents the complete block diagram of this converter.

Here are the inductor dynamics and that includes the DCM. This is a DCM enable logic, this is the capacitor and the output voltage dynamics and this is the switch node voltage. So, this corresponds to this block, then this corresponds to this block. Then this DCM enables corresponds to this block and this corresponds to this block. So, all detail can be obtained in this lecture number 4 of this NPTEL course.

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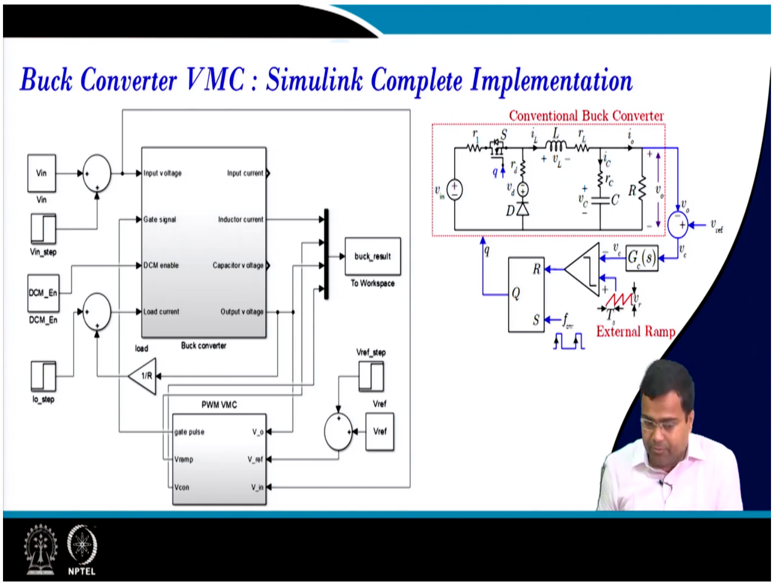

Now, if we talk about the voltage mode control Simulink diagram. So, this is what we are going to consider.

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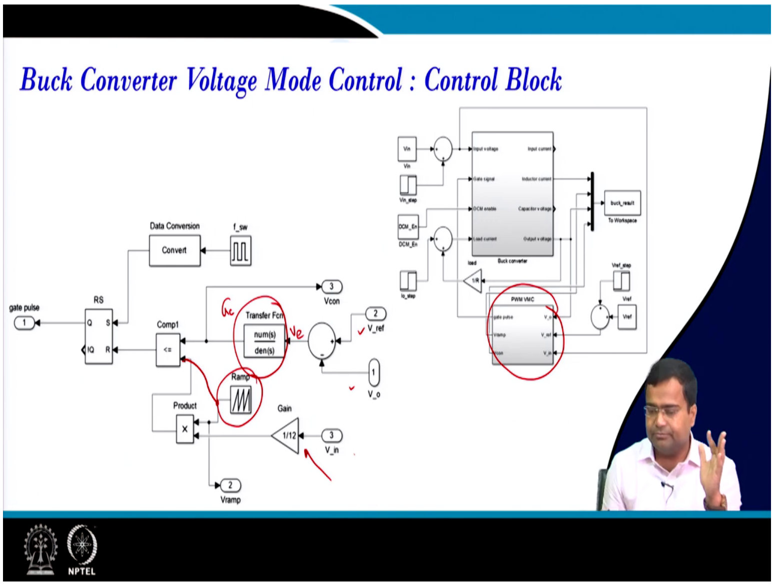

In this diagram what is inside? Inside this controller; that means, you are taking the reference voltage and the output voltage and this is the error voltage this is the controller which is GC and we will program this GC from outside; that means, the transfer function will be the poles and zero that will program from the outside right or you can realize inside also there is no problem. Then here it is a ramp voltage and along with the ramp we are considering input voltage feed-forward.

So, if you remove the input voltage feed-forward, then this terminal can be simply connected with this RAM. If you bypass the input voltage feed-forward. And why it is used? As we have discussed in our earlier course that input voltage feedforward will help to overcome the supply you know the audio susceptibility problem or the line regulation problem in voltage mode control.

Because that is one of the problems, because we know in voltage mode control the loop gain is input voltage dependent and that is why it will suffer from poor line regulation that can be overcome by input voltage feedforward and you can make the loop gain independent of input voltage by this arrangement.

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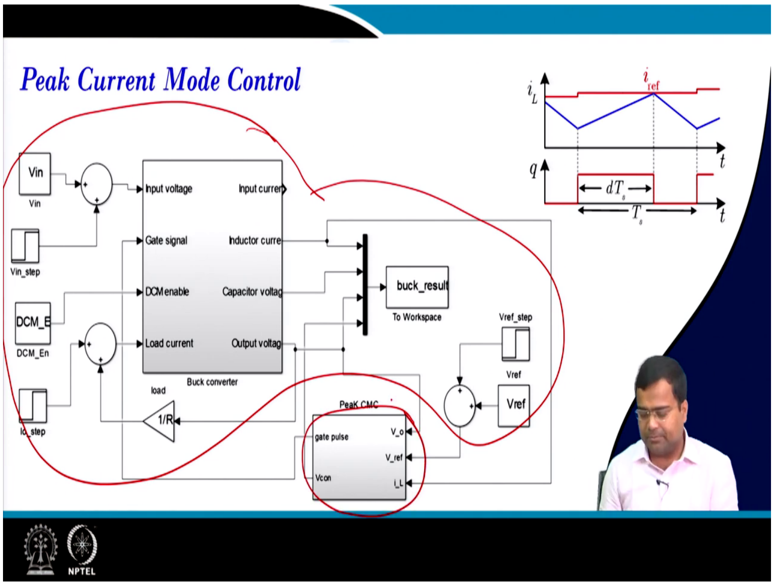

Then in this course in this class, I will also show the MATLAB simulation of peak current mode control. What does it look like? So, peak current mode control means your reference current inductor current is compared with the reference current. This is a complete block diagram you see this block remains the same. So, overall this block remains the same we are not touching this block, but only this is going to change ok.

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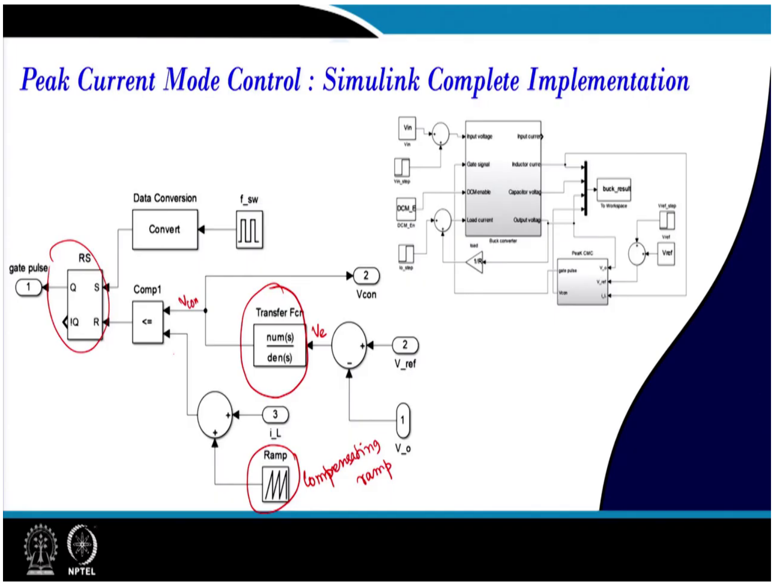

What does it look like? Here again, this error voltage is the same compensate structure is the same, but we may consider a pi controller. Earlier we may consider typing 3 or PID here you can use type 2 or pi, then this is the inductor current and we can add an external ramp compensating ramp. So, this is our compensating ramp, but this is optional. We may or may not use it. The compensating ramp then the overall block is compared with the output of the controller. So, this is a v con and then it goes to the latch circuit ok.

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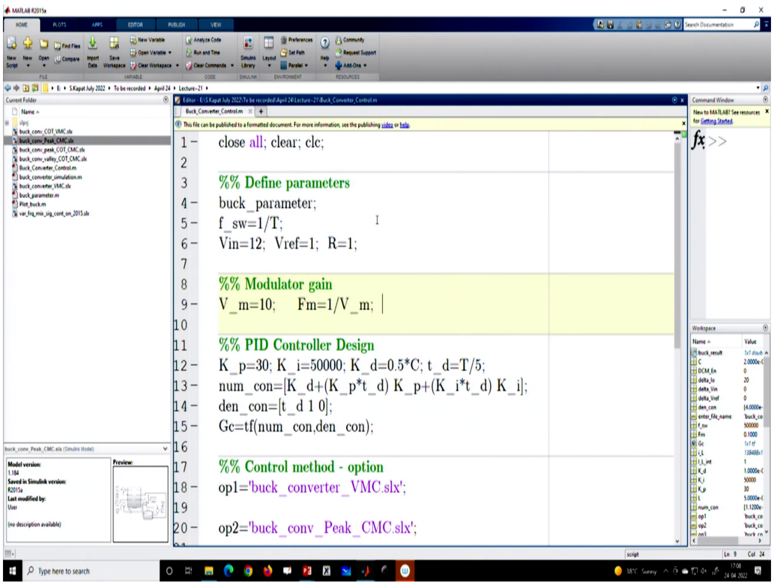

So, let us go to the MATLAB block for this current mode. So, I will show you this is the peak current mode control that I was showing. So, this block we are going to consider this.

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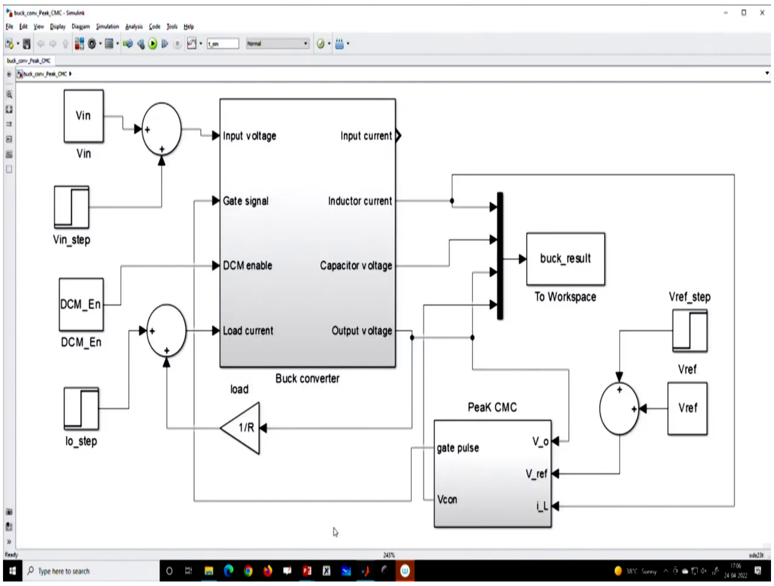

This is the peak current mode control block, I was showing.

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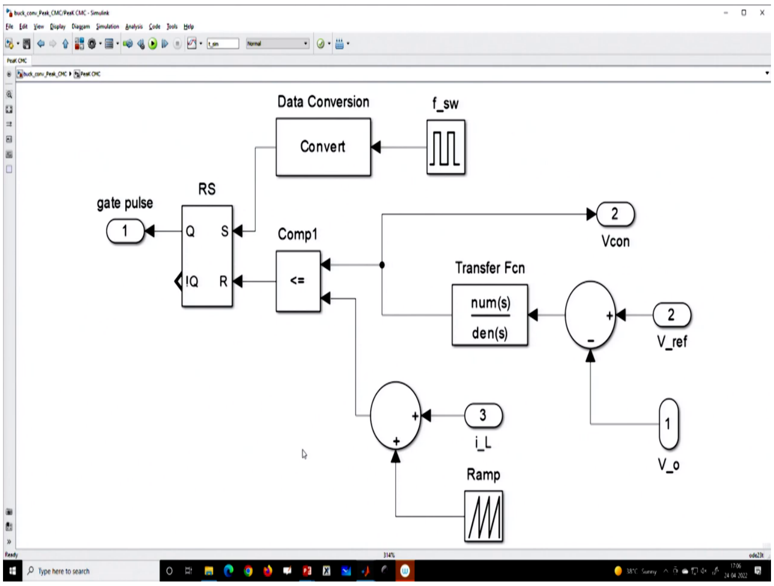

And if you go inside you know this is exactly the block I was demonstrating. So, you can get all this architecture.

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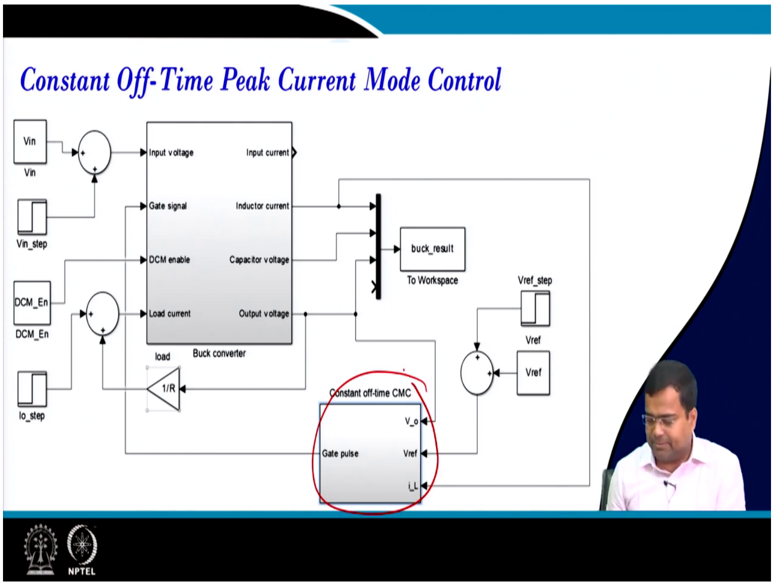

Next in this lecture, I will also show MATLAB simulation of constant off-time peak current mode control. Again this block only is the difference ok everything else is the same.

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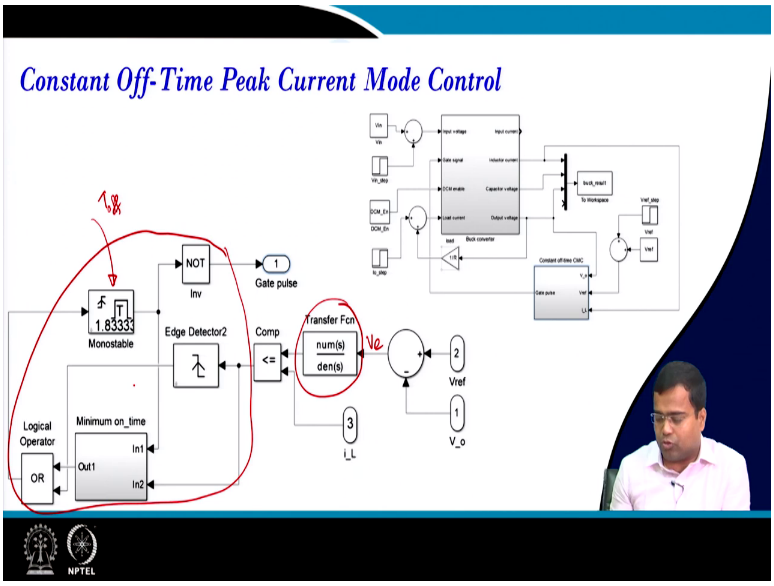

How does it operate? Here again, it is the error voltage, it is the compressor. So, this part is common, and here is the inductor current. But, after this comparator this whole logic is different. In fixed frequency, we had a latch circuit, but now instead of a latch we have a mono short timer and this is loaded with the constant of time ok.

Because this is an inverted logic and then it needs to we need to consider minimum on time because in all commercial products constant off-time control products you need to consider minimum on the type and then you can realize the whole block ok. So, by this, we can realize the constant of time which is analogous to peak current mode control.

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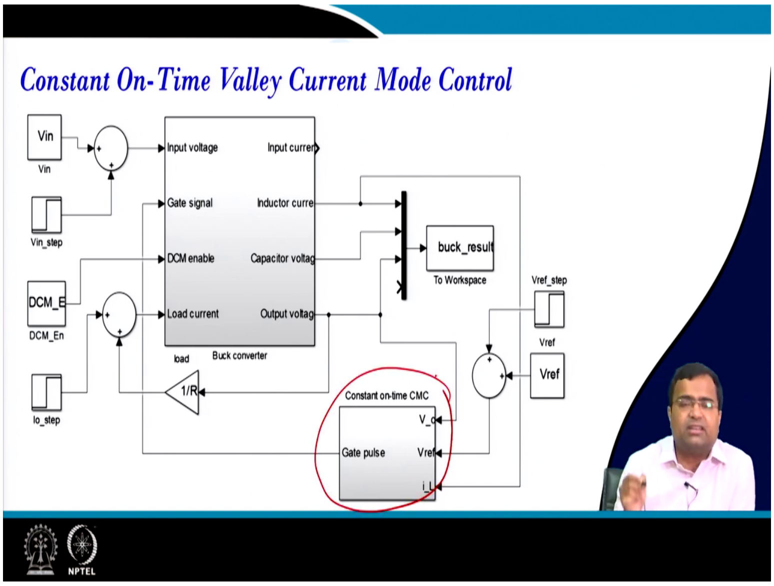

Let us say the constant off-time peak current mode control. The constant on-time valley current mode control, again only this block is different everything else remains the same.

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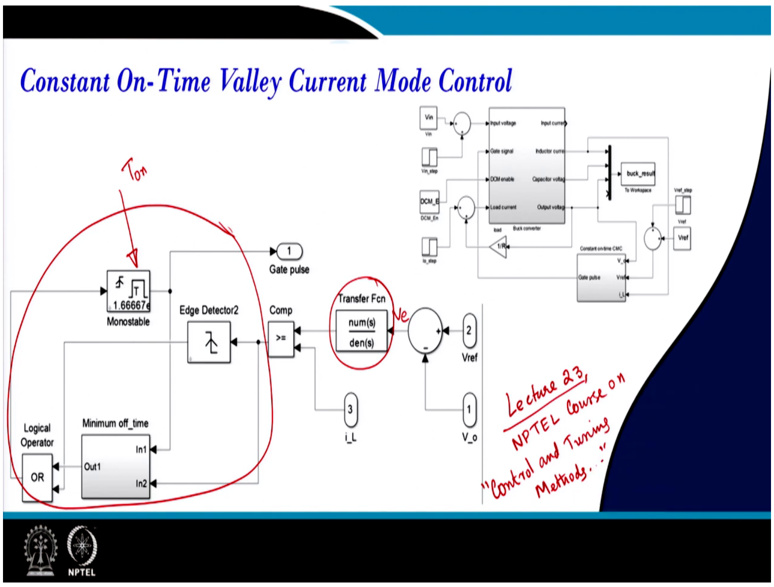

How is it realized? Again this error voltage part is commonly compensated is common and this is compared. So, this is different. Here again, we are considering a monostable timer that will be loaded with constant on-time ok. And all these are discussed in lecture number 23 of our earlier course; that means, in our NPTEL course on control and tuning methods.

So, in this course, you will get details of this implementation. So, you can just search here. So, in lecture number 23 you will get the detailed implementation of this. Let us go to MATLAB. So, in MATLAB again this is what we have discussed earlier in our earlier course.

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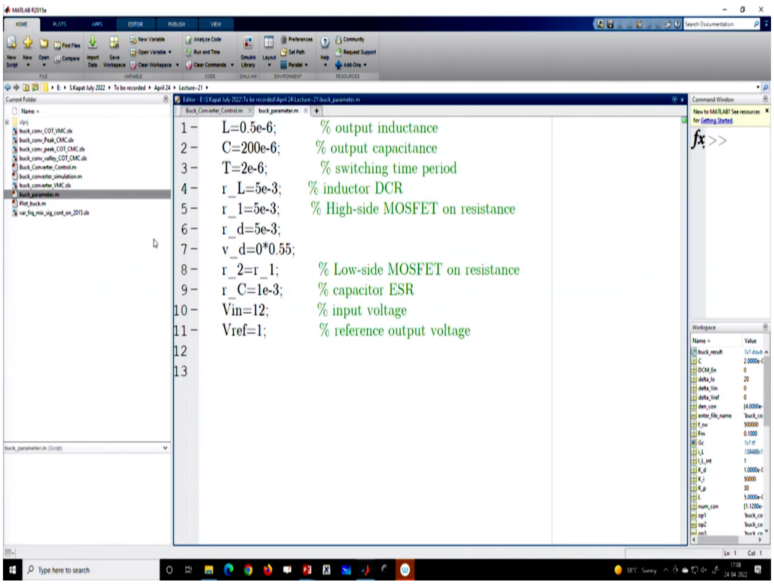

So, I am just summarizing that here we are considering a buck parameter stage. So, these are the parameter values. Then we have a buck converter control block; that means, where it will call the parameter file, it will load the parameter file. You can customize the input voltage that you want.

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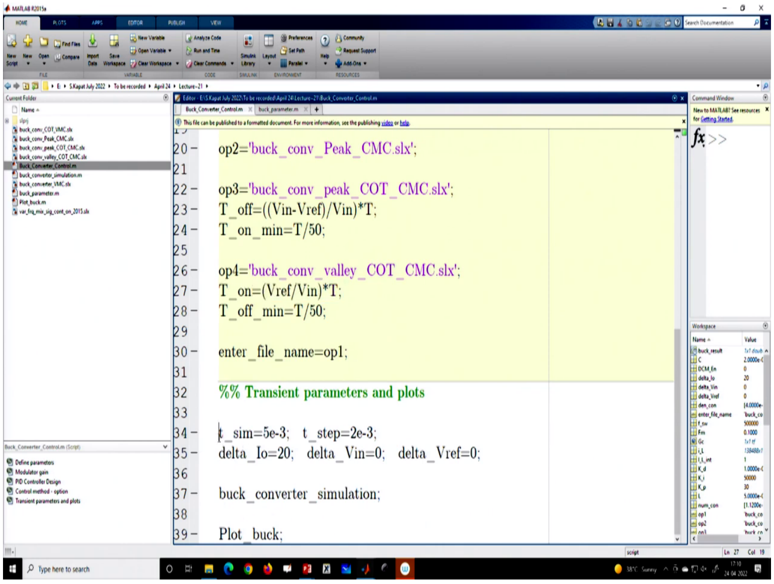

You can customize what is my initial load resistance value, and refine the voltage. Modulator gain; that means if you want to set the ram the maximum voltage is 10 volts. If it is Fm 1 by modulator gain, then PID controller in this particular class I am not going to design controller.

I am just taking some arbitrary value of PID and we know that PID controller practical PID controller has a time that tau d ok and that we discussed in our earlier lecture. So, I have just taken some values and then you can compute the numerator and the denominator as well as the controller transfer function, then there are many options the same controller can be used for many options.

One I can simply use a voltage mode control. The one I can use is peak current mode control. I can use peak current mode control on time control. I can use valley current mode constant on-time valley current mode control. So, all these possibilities are there. Only for constant off-time control do you need to specify what is my nominal off time and I have set it as 1 minus d into T. Then what is my minimum one time? For constant on time what is my nominal on time?

Then what is off time minimum off time? Then you can accordingly select. Here we are going to simulate for a total of 5 milliseconds and I am applying a step after 2 milliseconds then I am taking a load transient of 20 ampere. You can also consider the input voltage transient or the reference voltage transient, then I am calling this a bulk converter simulation file.

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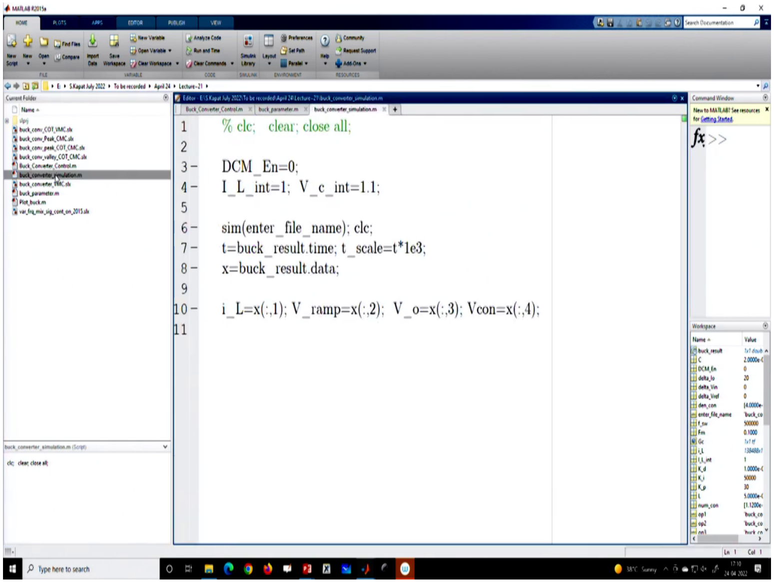

What is the bulk converter simulation file? If you open this file you will find I have said this same enable to 0; that means, it will operate in a synchronous mode. I have considered the initial currents of the inductor value inductor current and initial capacitor voltage, then it will ask for the file name I will simulate the Simulink file from the MATLAB dot m file, but the name of this Simulink file depends on what preference you are giving at the outside; that means if you say the simulation enter file name is here.

Which option are you selecting? Are you talking about voltage mode? Are you taking the current mode? Are you taking or talking about constant off time or on time? So, you can simply configure and this will come here. Then after the simulation is over all the data's are stored in the workspace and we are calling back all this data inductor, current ramp voltage, output voltage, and control voltage and we can plot it according to our requirements.

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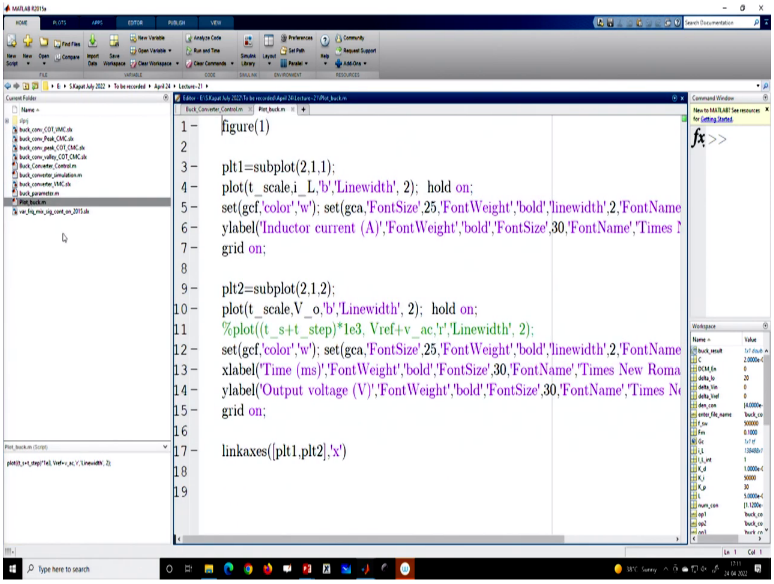

Now, you will find here also there is only a plot buck. So, if you go to the plot comment we are using subplot 2 plot 1, and plot 2, 2 subplots under one figure and we are plotting inductor current and these are the setting. So, you know we will provide this you know maybe in another presentation a tutorial presentation.

How do plot all the step-by-step guidelines that will be given? But in the current lecture, I want to make sure that you know this thing whatever I am showing if you want you can plot it or you can plot it separately. It is just the plotting of the inductor current data. So, one subplot will be inductor current, the other subplot will be output voltage ok and then I am linking in the link axes.

So, that the two subplots can be linked and so that if you zoom both of them can be equally zoomed ok. So, let us run the first option which is a voltage mode control. So, if we run this voltage mode control. So, let us see we are trying to see that load transient performance using voltage mode control in a synchronous buck converter.

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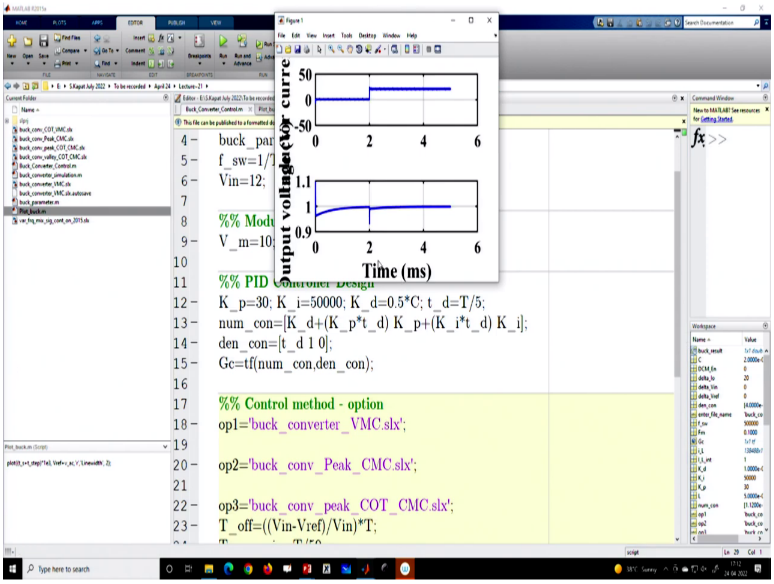

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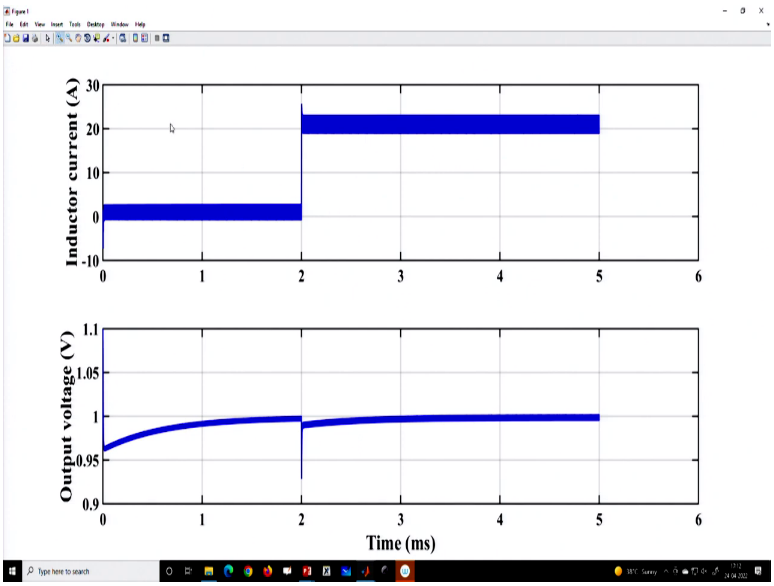

And this is the load transient performance. You can see this is the inductor current and this one is the output voltage.

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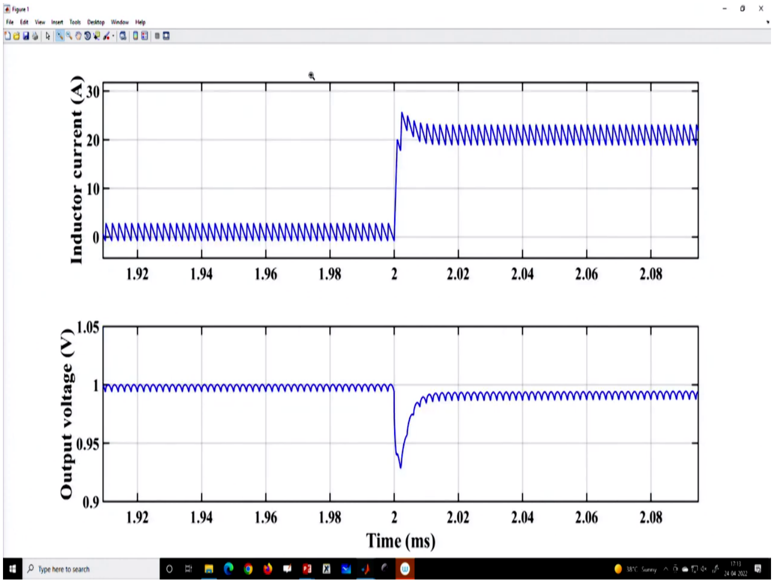

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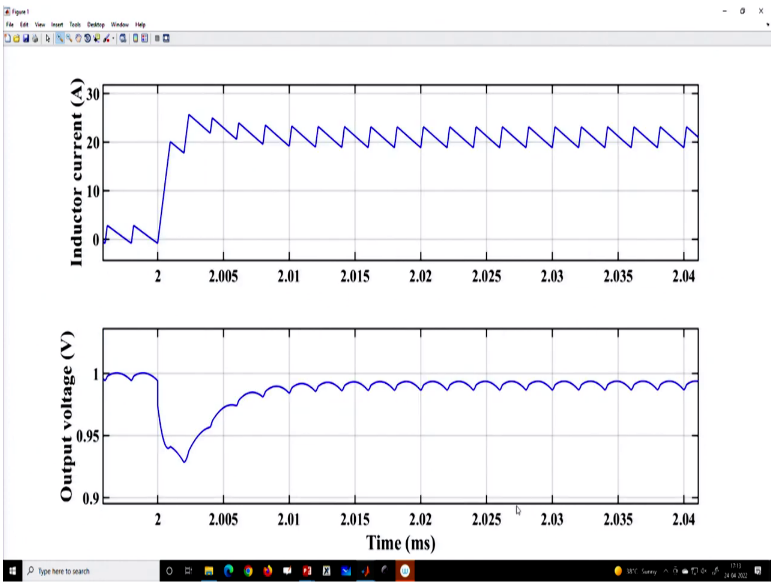

And here I am showing it is using a PID controller and this is a transient performance. So, how I am designing? I have here I have taken some adult value, but as we move forward when you go to week 5 we will talk about the design methodology. How to design voltage mode control? For analog voltage mode control design, we have already discussed you know it is already taught in our previous course. But, we will summarize, but how to design digital control that we will discuss.

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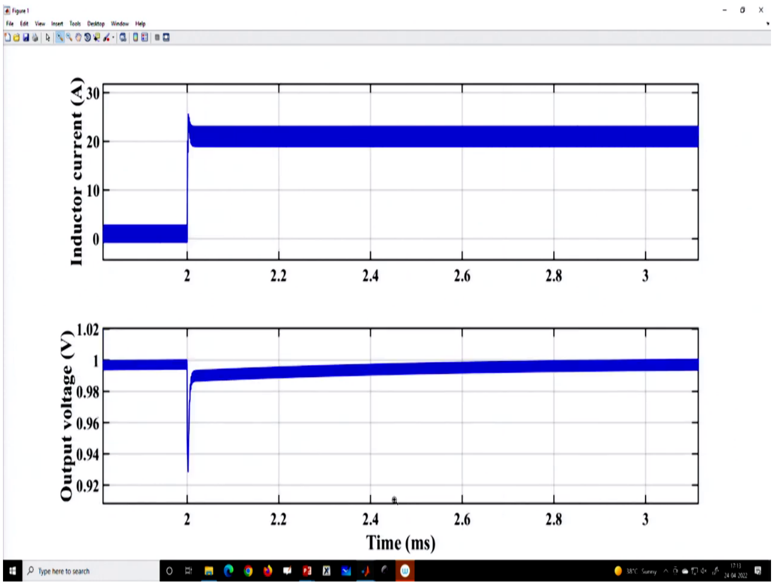

But here for a given parameter value, this is the load transient performance.

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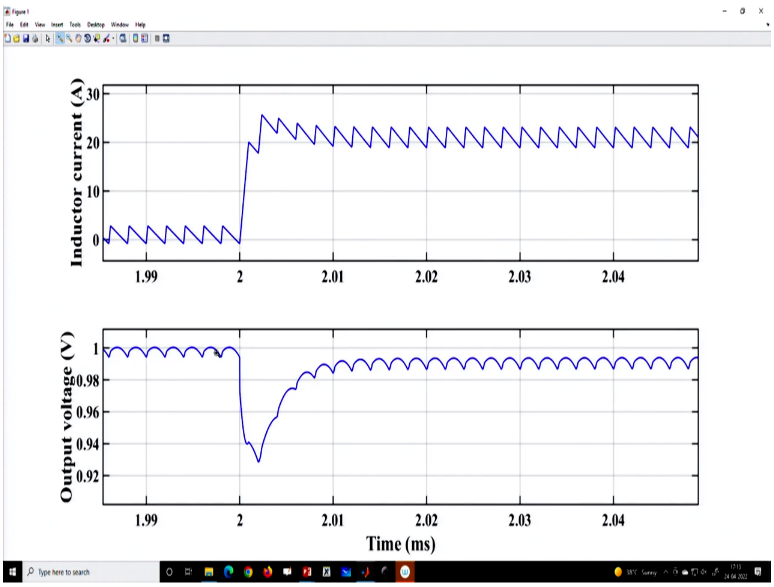

So, you can see if you zoom here, then it will also be equally zoomed here ok. The next part is that now we want to compare this with the current mode controller so; that means, we will hold this we will hold this.

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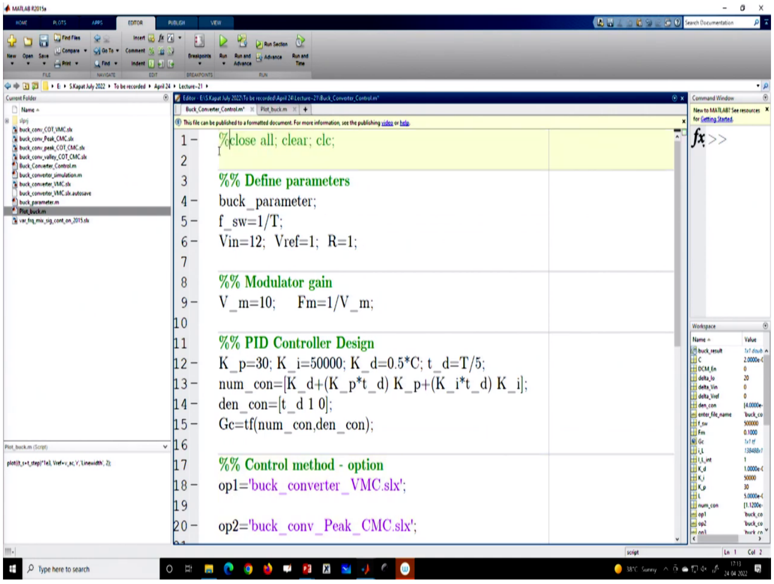

The next part since it is a current mode control does not require any derivative.

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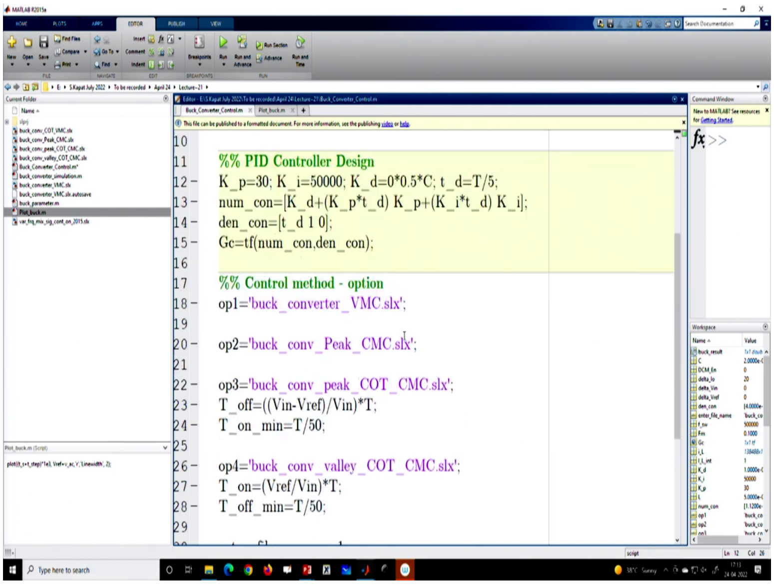

So, we can simply replace and now we will select option 2.

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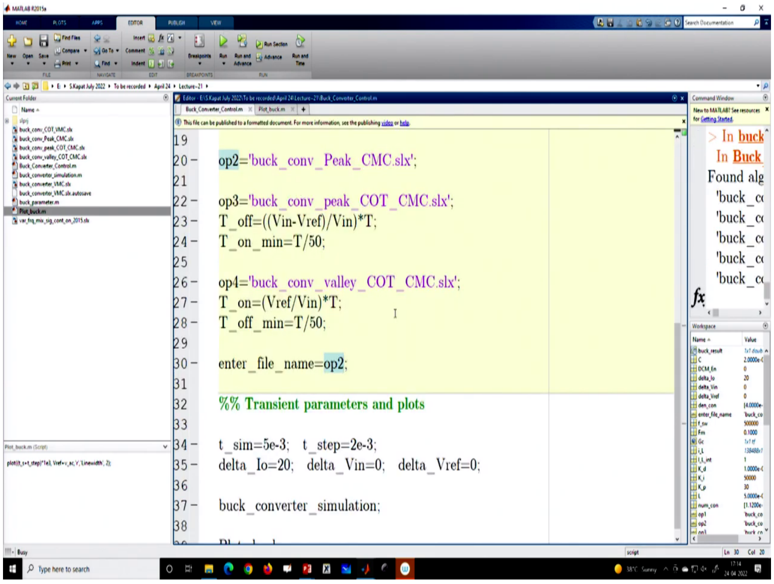

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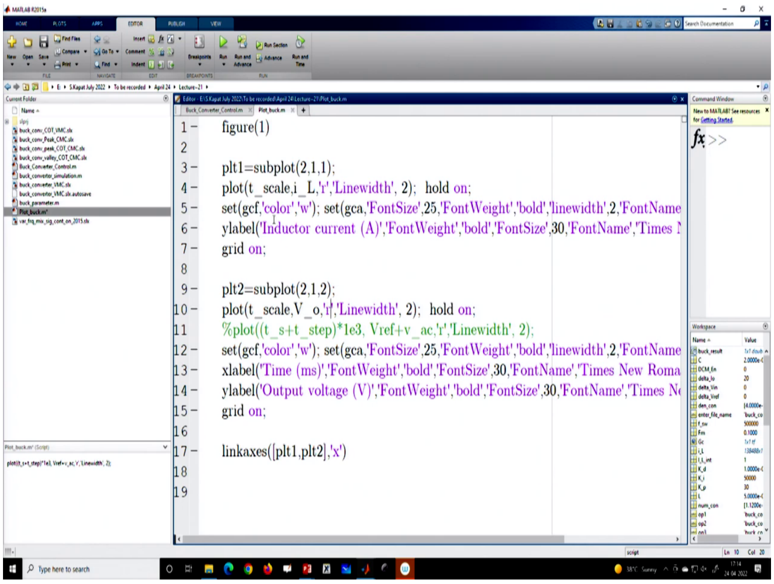

And we will change the color here, we will change the color to red otherwise we cannot distinguish.

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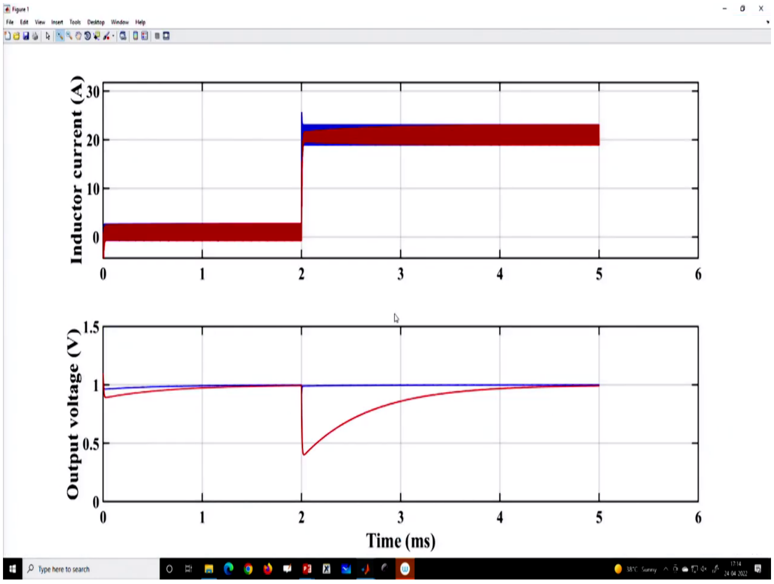

So, let us run now we are running using the current mode control and it is compared

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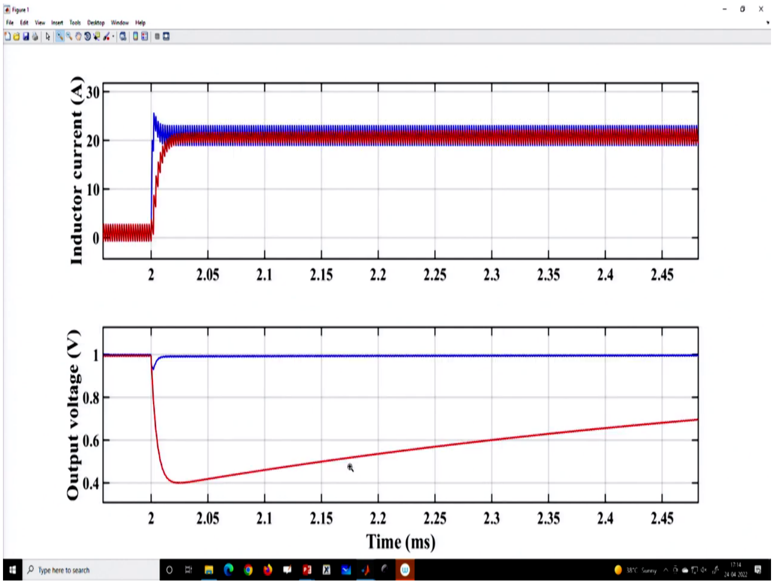

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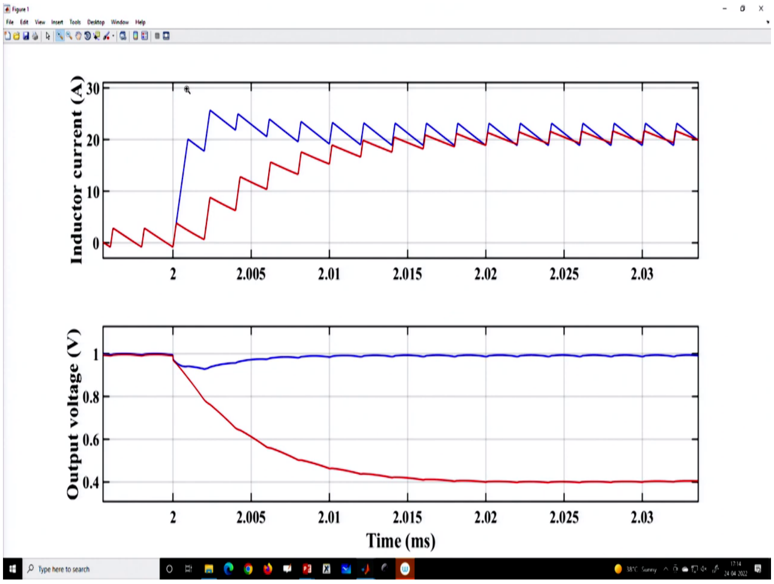

So, you can see the current mode control we have not tuned properly, but it is only a pi controller not sufficiently high gain. So, that is why the response is much more sluggish ok.

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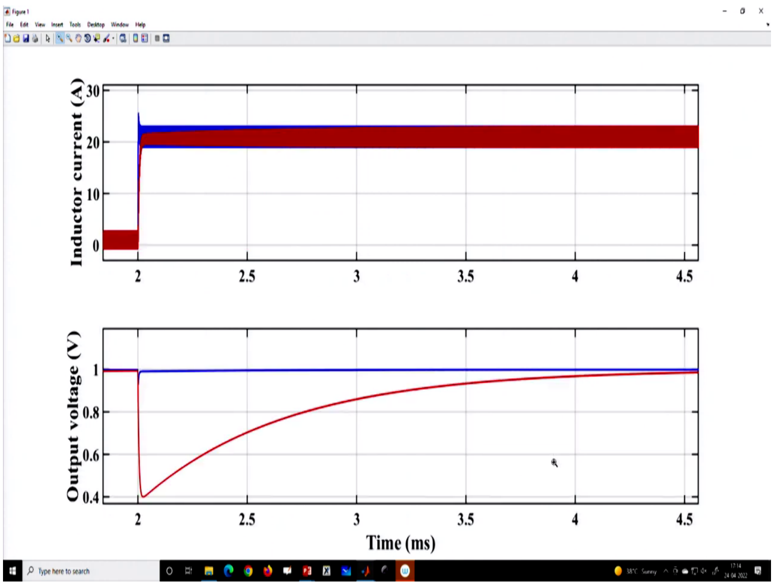

But we will discuss how to make the current mode control faster ok.

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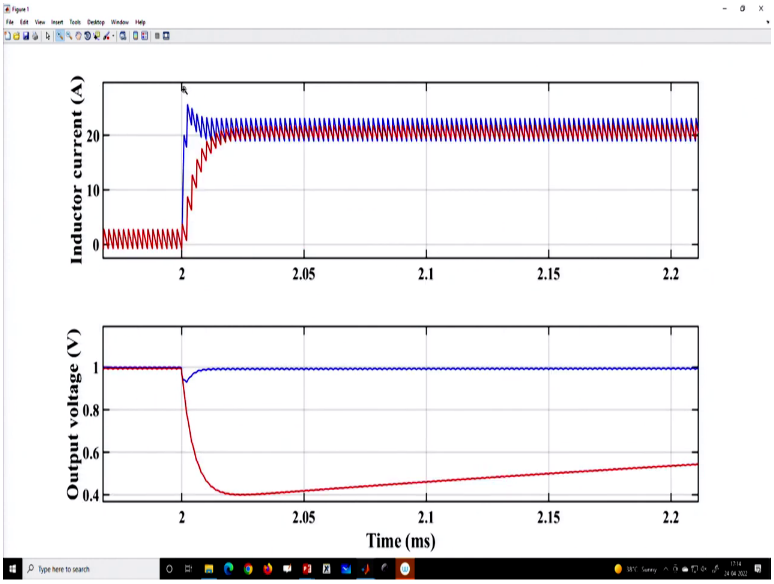

So, because we are using an adapted value of pi value. So, if we increase the proportional gain we can speed up the transient performance, but generally current mode control we saw in our earlier course that the current mode control behaves like a first-order system. So, that is why it is kind of an overdamped response. So, unless you do load current feedforward it will be somewhat difficult to speed up very fast within the small signal control bandwidth.

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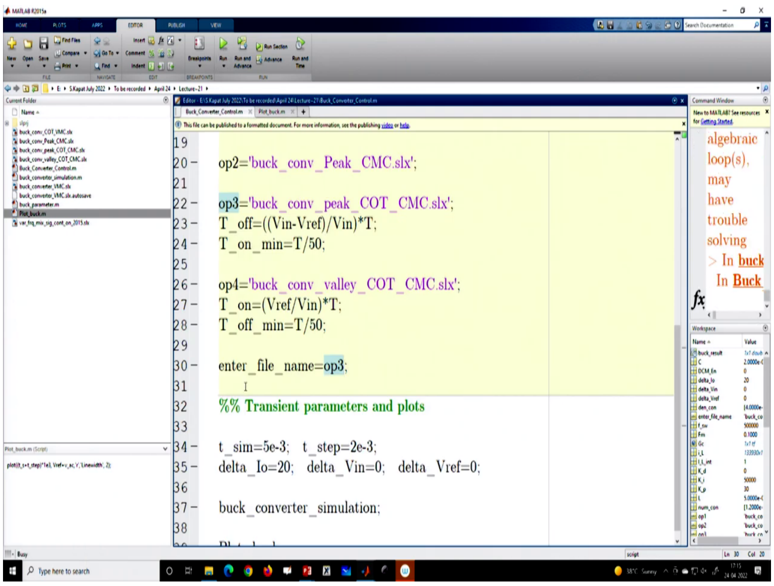

So, then we can also plot option 3. So, with the same controller setting, we can go for constant on time and we can change the color to let us say magenta.

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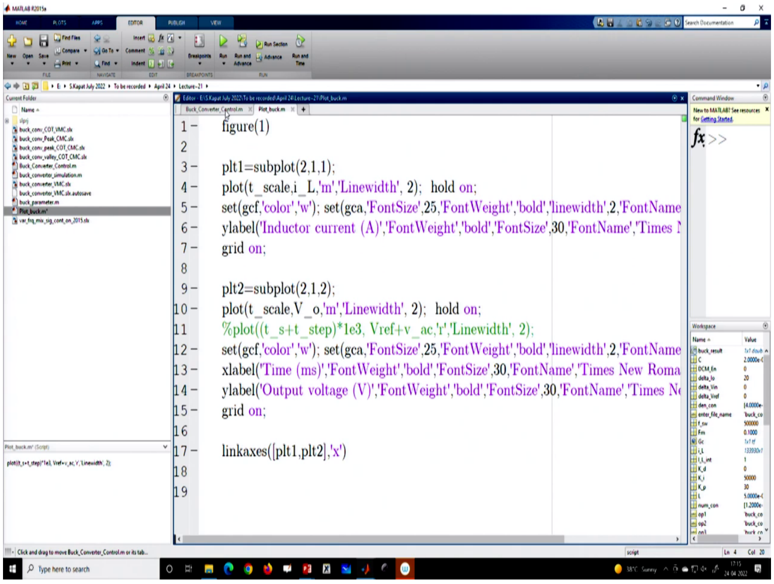

So, now we are changing the color to magenta, and let us plot. So, we option three means we are going by peak current mode constant off-time control. So, earlier it was a fixed frequency control on time control sorry fixed frequency peak current mode control.

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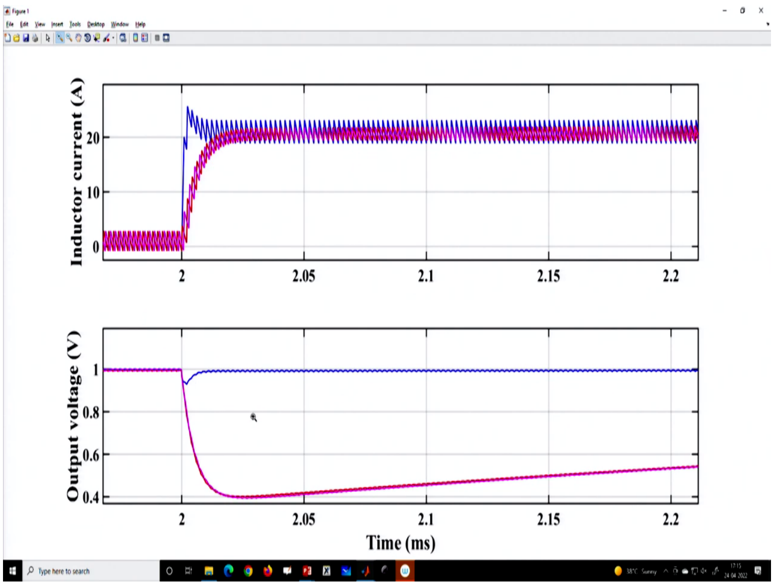

Now, we are talking about constant off-time peak current mode control.

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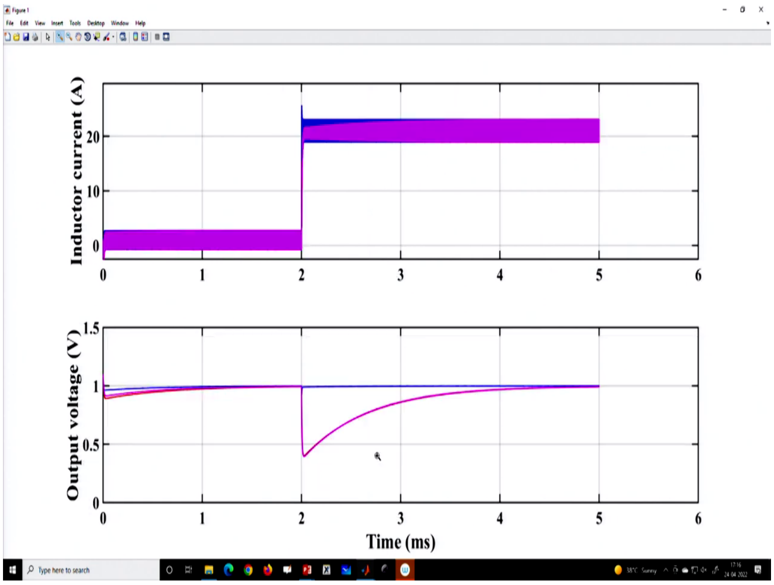

You see the response are more or less identical.

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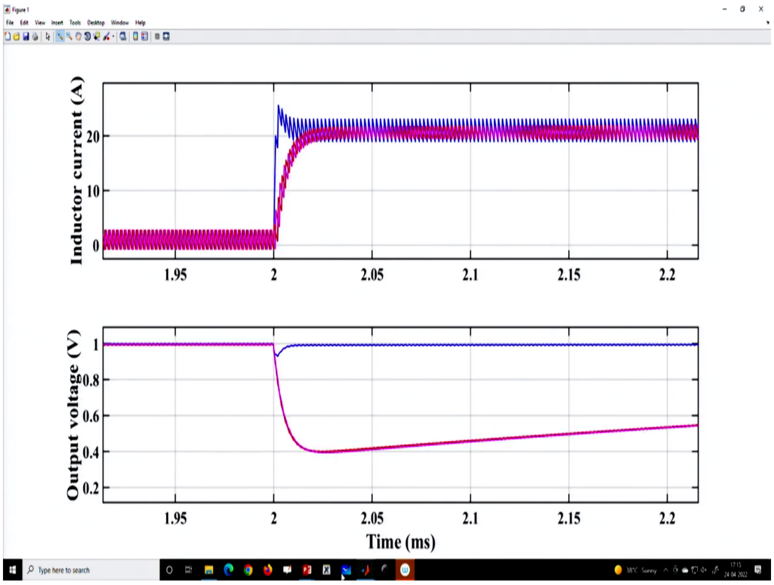

There is no significant change concerning the current mode.

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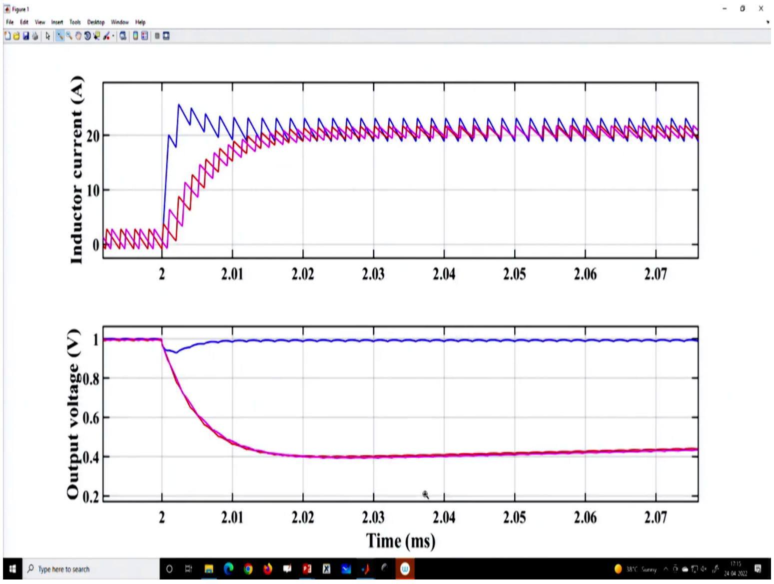

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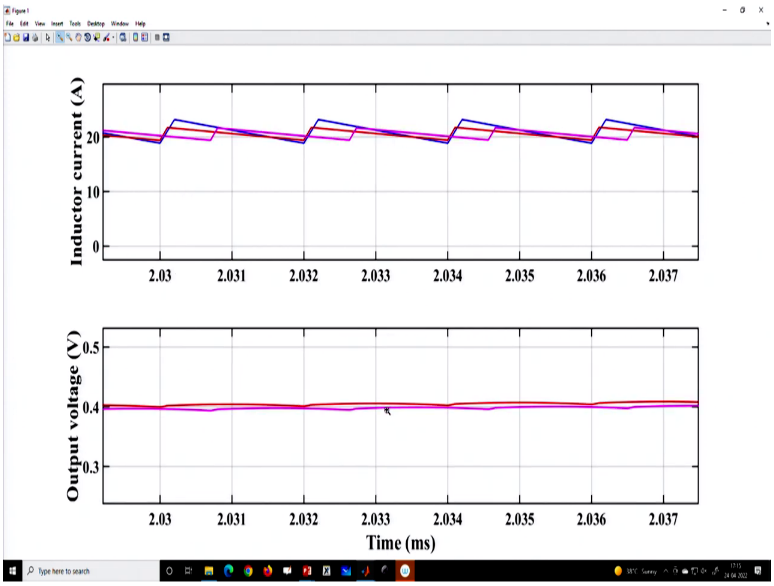

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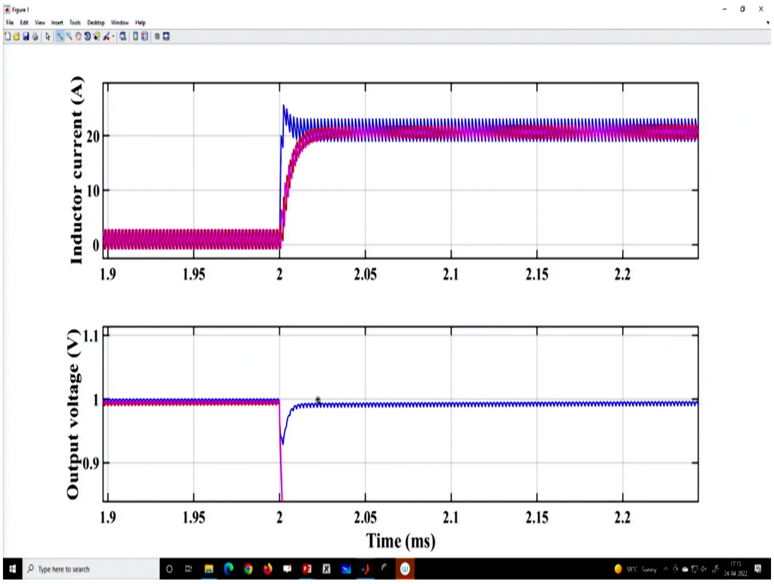

I am talking about red and magenta. They are more or less the same, but the voltage mode control is different because we are using a PID controller and we have discussed earlier that this derivative action is set in such a way it will look like you are providing sufficient damping.

So, it will act like it is retaining some information of current and load information in voltage mode control, but we are not discussing the design procedure here. But for the time being, let us say this is how the two-three methods are compared.

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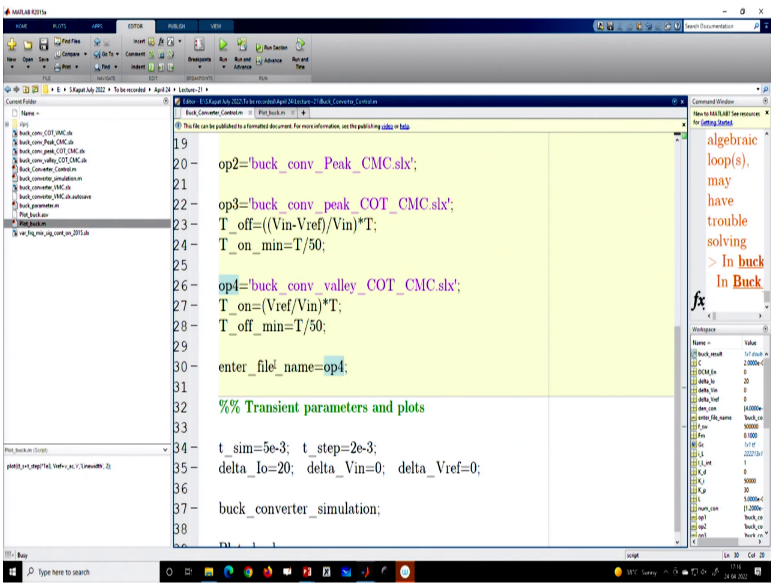

And the final method we want to compare option 4 which is the constant on time. That is a valley current mode control constant on-time valley current mode control.

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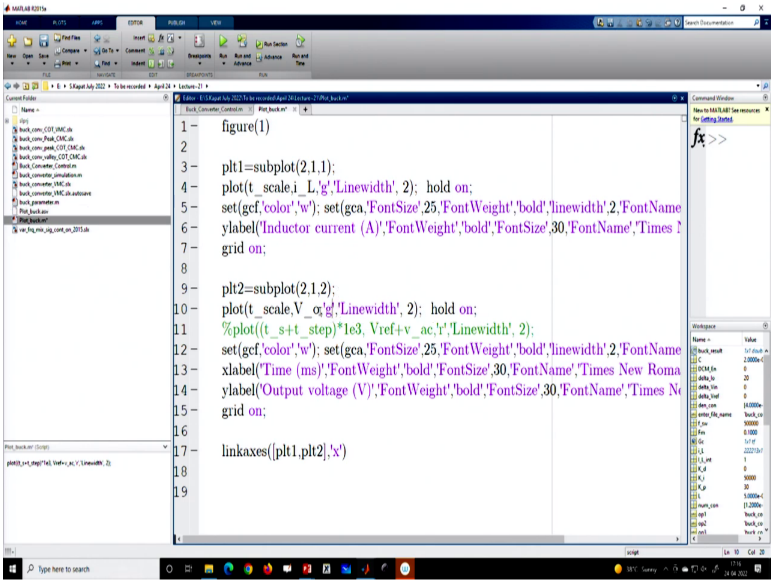

And let us use a green use green color and it may be expected that again the response will be more or less the same as the current mode control. For all three current mode control, we are using the same controller. They should be more or less the same in terms of their transient performance, but different.

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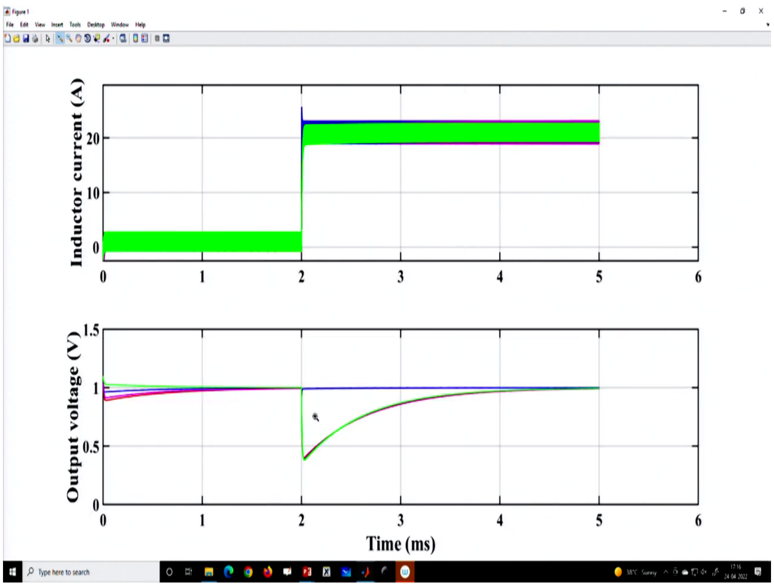

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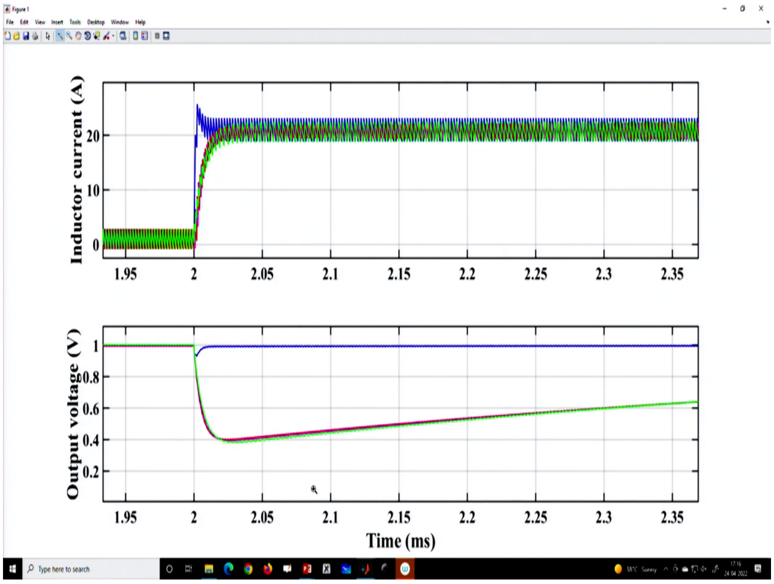

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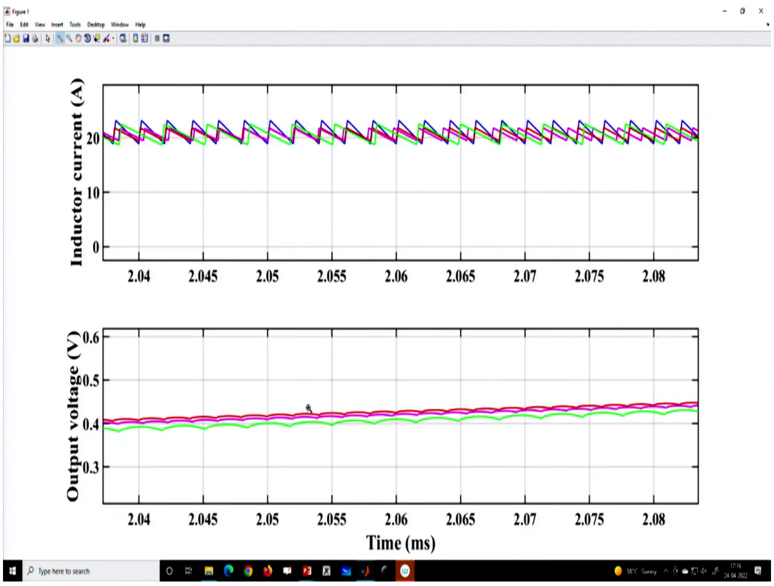

So, you can see the transient response of all these three control techniques are more or less the same not fundamentally very different unless you tune it properly ok.

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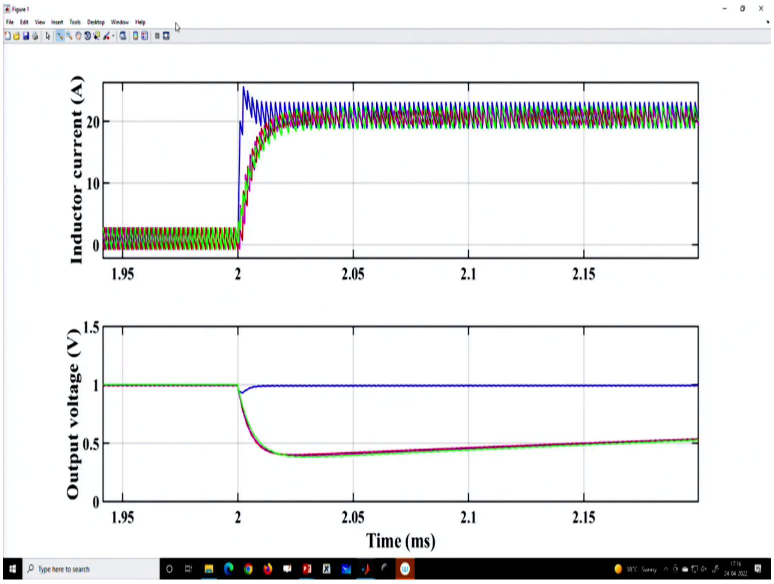

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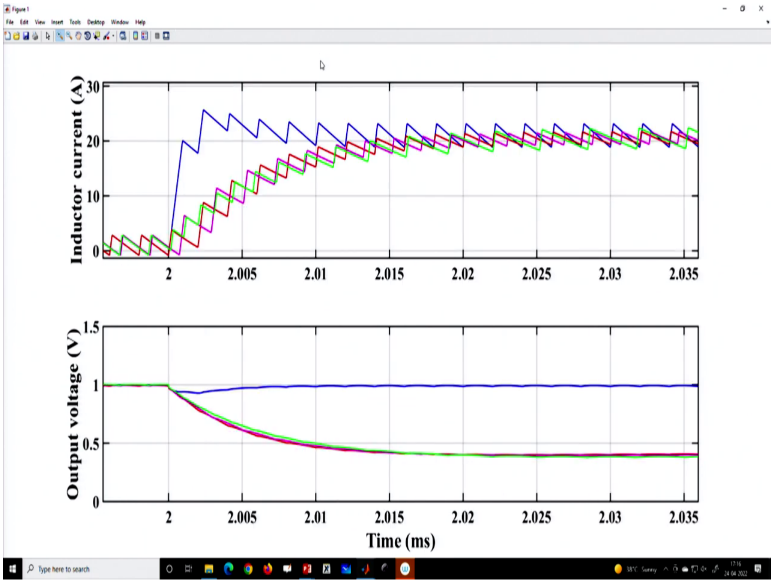

So, you can see, that their modulation techniques are different; that means, we have discussed various control technique and their MATLAB simulation.

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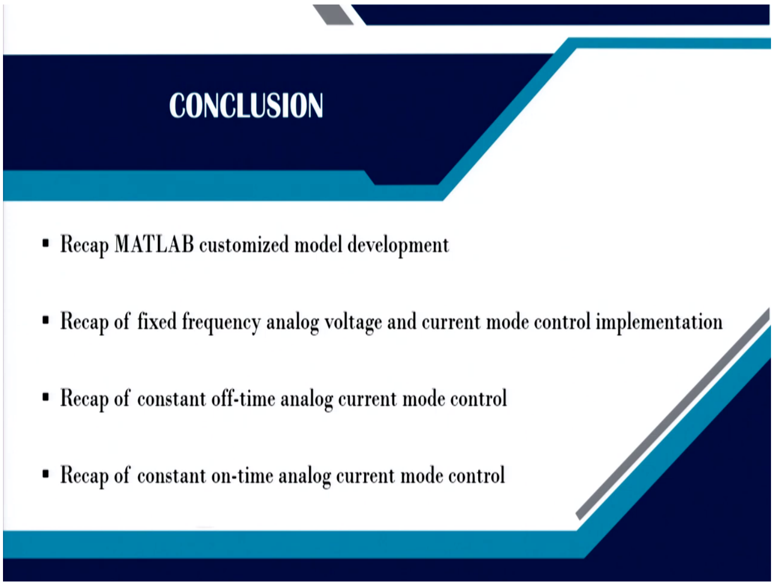

So, in summary, we have recapitulated MATLAB customized model development. We have to recapitulate fixed frequency analog voltage current mode control implementation then we have also presented constant off-time analog current mode control and we also discussed constantly on-time analog current mode control technique. So, that is it for this lecture.

Thank you very much.