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

Module - 04
Modeling Techniques and Mode Validation using MATLAB
Lecture - 36
Validation of Discrete-Time Large-Signal Models using MATLAB-II

Welcome back. So, this is the second part of you know a lecture, you know we are continuing from the previous lecture, where we are going to validate Discrete Time Large Signal Model and here we are considering a boost converter case study.

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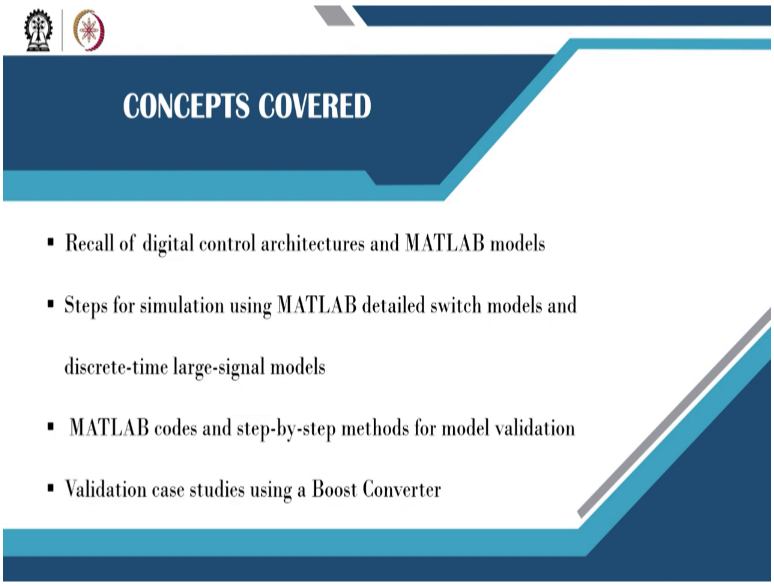

So, here we are again talking about digital control architecture, particularly the voltage mode control and its MATLAB model, we will show steps for simulation using MATLAB detailed switch model and discrete time large signal model.

Then we will talk about the MATLAB course and step-by-step method for model validation, and we will take a few case studies of a boost converter digital voltage mode control.

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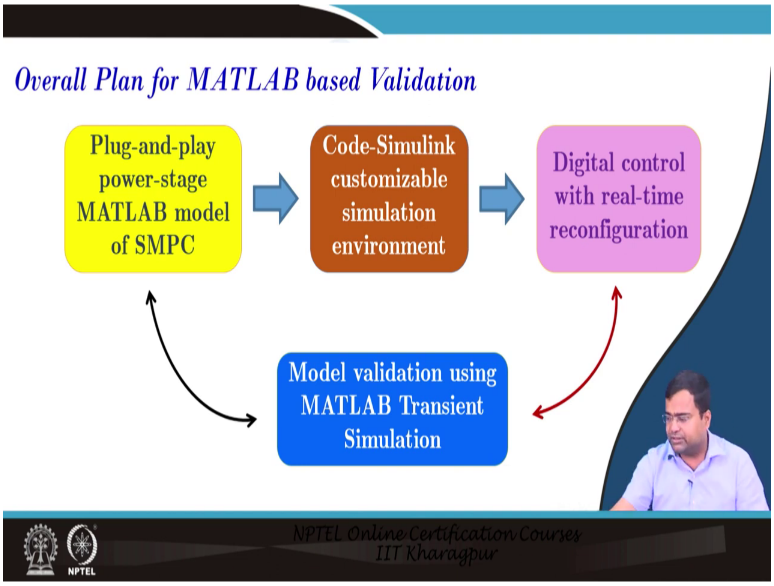

So, here is the overall plan again the plug-and-play power stage model MATLAB model of the boost converter, then we will have a code Simulink customizable model and then we can also have a Simulink model for the digital controller, and finally, we want to validate our discrete-time large signal model with the actual switch simulation.

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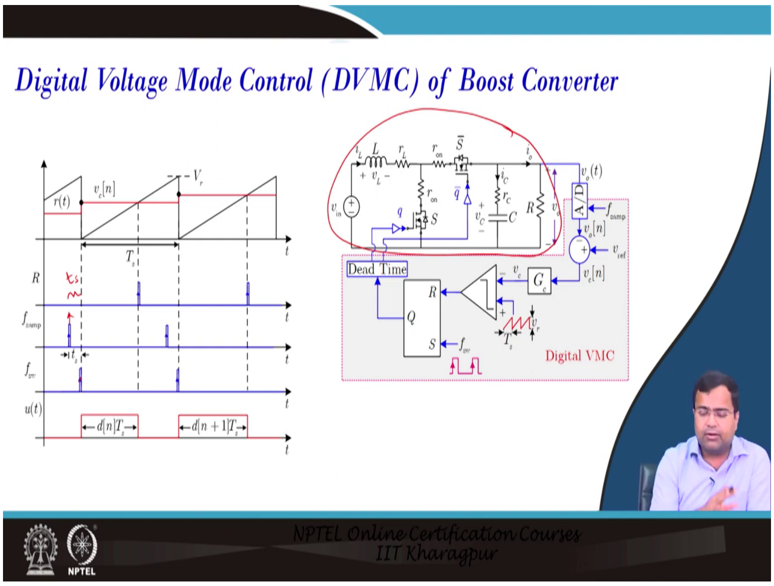

So, here we are talking about it is the same as the previous lecture, here we had only we have changed the boost converter power stage ok. And everything else is the same as the previous one. So, here we are first taking the sample, and in this sample, we are providing some delay here t s, after which we are turning on the PWM switch because it is running under trailing edge modulation. So, this delay is to account for the ADC conversion and the computational time; and that we have discussed.

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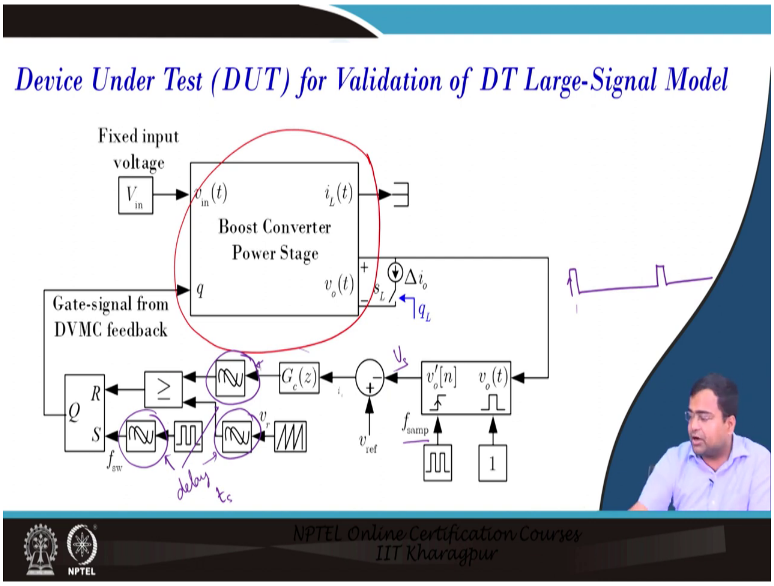

And we have also discussed, the power stage. So, this is the boost converter power stage, we have captured it as if like we are going to implement it in Simulink, and then here we have considered the delay. So, these are the ok let us use a different color. So, we are talking about a delay. So, this is one block, this is another block and this is another block. So, these are our delays.

So, the delay is t s. So, this block and this block are the delays. And here we are using a sampling clock, which is a fixed frequency clock like this, and every rising edge of this clock with sample and the output voltage sample.

Then it is computed through this you know the PID controller, then it is delayed by this signal. So, all clocks are delayed. So, that they are synchronized. So, there the PWM action starts.

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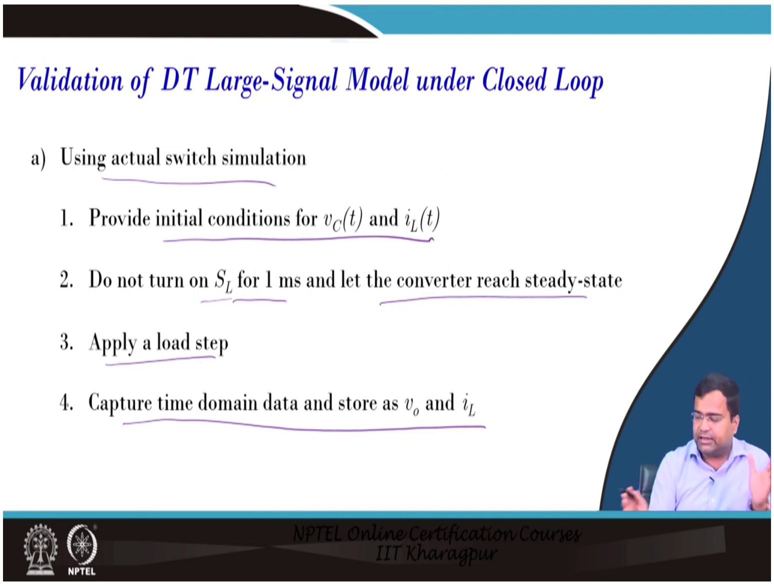

Now we have discussed the validation state. So, we have to first run the actual switch simulation, where we have to set the initial condition of the capacitor voltage and the inductor current. Then we will run for one load resistance for some instant of time, here we are talking about 1 millisecond, but again it is flexible, then the converter will reach a steady state, then we will apply a load step; that means, we are changing the load resistance from r 1 to r 2.

And then, it will create a virtual load step and we will capture the all-time domain data output voltage inductor current and other data in the workspace.

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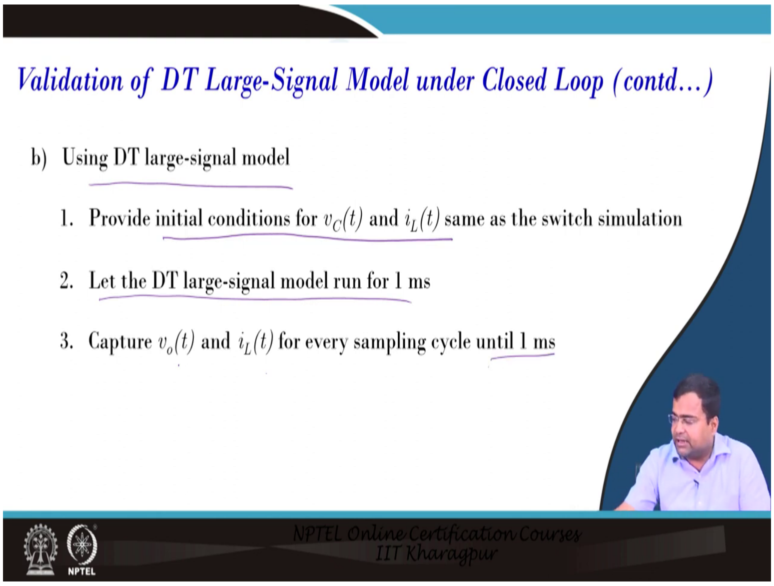

Then we will run a discrete time large signal model, and I will go to the MATLAB case study, we will keep the same initial condition of the capacitor voltage and the inductor current, the same as the switch simulation. Then we will run the discrete-time large signal model and we will run for 1 millisecond, then we will capture all the v 0 inductor current for every sampling cycle until 1 millisecond.

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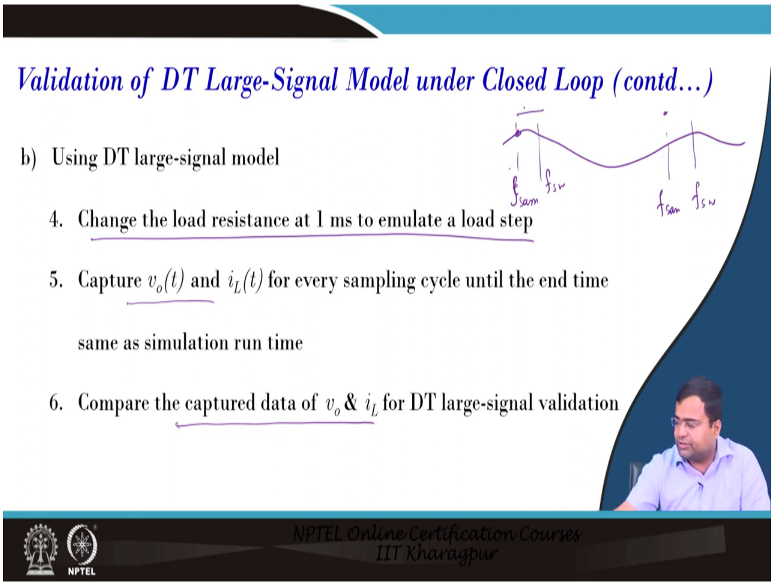

Then again we will change the load resistance from r 1 to r 2, I will come to that. Then again we will run our discrete-time larger signal model, and capture the v 0 and i L data for every cycle.

Because we are talking about the discrete-time large signal model; that means if you let us say we are talking about output voltage waveform like this if you are talking like this if this is your you know. So, this is your sampling instant; that means, your sampling clock, and this is your switching clock right? So, we are talking about the model, which means, there will be another. So, this will be the f switching f sampling.

So; that means, these two are the point, we are talking about the discrete-time models. So that means, we are capturing the sample at every data we are capturing the value of the like a voltage and current waveform, at the sampling instant. Then we will compare the captured data of the output voltage and inductor current of the discrete-time model, which will be compared with the actual switch simulation.

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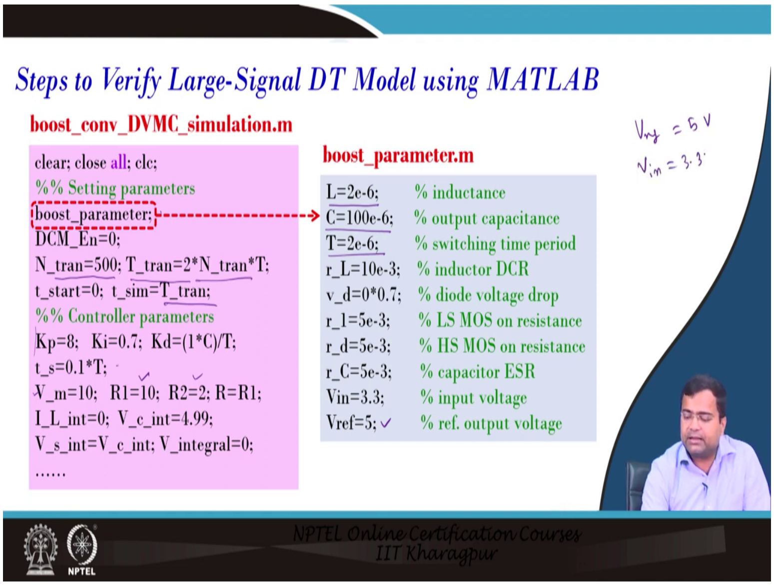

And again the seminar code, where we have discussed for the buck, only here it is a boost converter, for boost converter we have taken L equal to 2 micro henry, capacitor to be a 100 micro farad, 2 microsecond time period then all the parasitic.

Then again we are running for the first 500 cycles for 1 load resistance r 1, then another 500 cycles for another load resistance r 2, that is why I have taken the total transient time total is two times the 500 cycle; that means, N tran into t that is the time period.

And total simulation time is a T tran and we are setting some arbitrary Kp Ki Kd value in the discrete domain, and we are setting a delay of T by 10 ok. And the ramp voltage of 10 volt initial load resistance of 10 ohm, the final load resistance of 2 ohm, and the output voltage whereas, were desired output voltage V ref we have taken to be 5 volt, is written and the input voltage we have taken V in to be 3.3 volt, but again, it is flexible we can change it.

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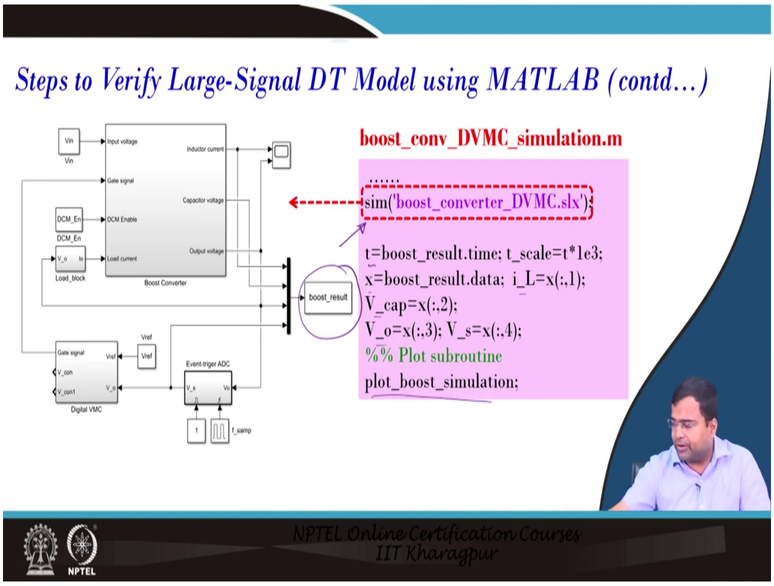

Next, this is the overall model, and I will go to the model very soon, we are running the Simulink model from the dot m file, using this command, then this is storing all the data in the workspace; then we are calling time vector and the data vector, data it is a structure, then we will take individual vector like a current, capacitor voltage, output voltage, sample voltage and so on. And then we will use the plot command.

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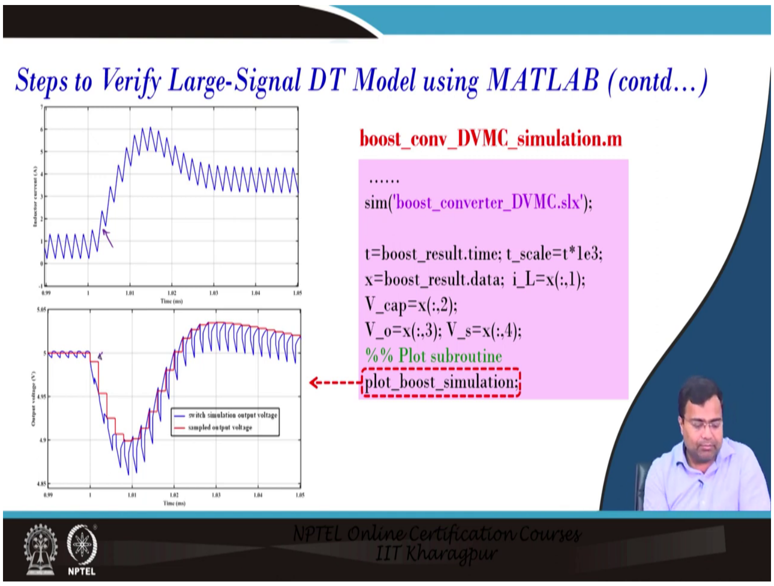

Then if we plot it, it will look like this. So, this is the actual switch simulation and here the red one is tracking the sample voltage.

But your actual switching instant is different and we will go to the case study soon.

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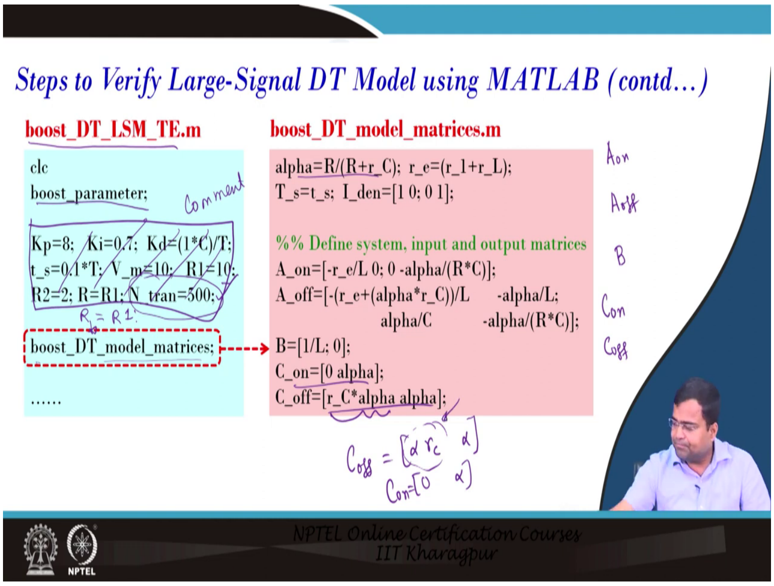

Then we have to run, for the discrete-time large signal model. So, the discrete-time large signal model is the file name. So, we will first clear, then we will have the boost parameter. Again this parameter we can comment, we can comment; because the only thing we have to define is the N tran because that is not there in your switch simulation. I think it is there; in the switch simulation. So, N tran is already defined. So, these are all you can comment on, you can comment on this signal.

Then, once initially it is running r 1, r 1 load resistance. So, r 1 is what? 10 milli ohm. So, the boost parameter has to model matrix has to be set accordingly. So, here initially it will take r equal to r 1, the first 500 cycles, then it will enter into this matrix, where the matrix will be set alpha this thing and we know for a boost converter, what are the on-state matrix, what are the off state A matrix; they are different.

And we know the B matrix is the same for the boost converter, because the input voltage is connected all the time, and then it has an output matrix that is different for on-state and off-state. So, the on-state output and off-state output matrix are shown here.

And because they are different, you can see this is the additional term, which will be extra in the off state; that means, our off state matrix is alpha you know r c, alpha r c ok. So, it is the alpha r c and it is alpha and on stage, the matrix is simply 0 alpha. So, this term is extra every switching transition will change and that will make the boost converter has a discontinuous output voltage ripple, at every switching transition because of this discontinuity.

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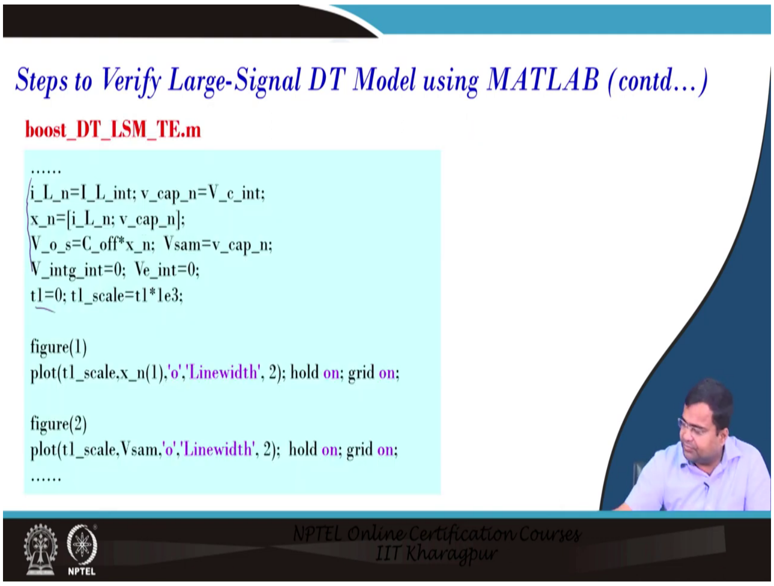

So, now we have the initialization value it will take from the Simulink, the switch simulation, and it will run for you know whatever times were are set already in the switch simulation. Then it will plot the discrete time value, and then we are going to match.

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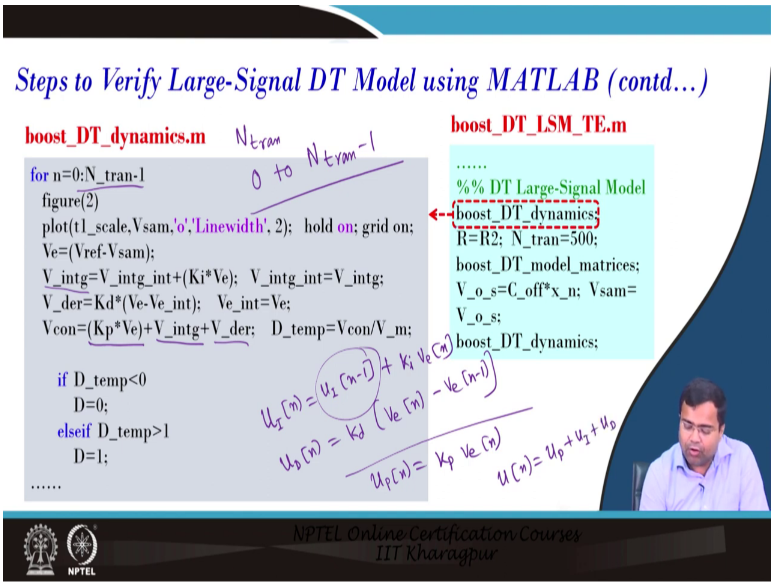

Now once we call; that means, it is continuing the large signal model, then next what is inside the boost dynamics? So it is running from totally for N tran time; that means, it will call from 0 to N tran minus 1 and that is exactly what is here. So, what it will do will first compute the PID controller. This is the proportional control, this is integral and this is the derivative.

And the integral control is nothing but the previous; that means, we know that u I of n is integral, will be u I of n minus 1 plus K i into V e of n ok and this is the previous value. Similarly, the u I D derivative part of n will be equal to K d into V e n minus V e n minus 1 ok.

And the proportional part is very common, it is simply K p into V e n and the total sum will be added u P plus u I plus u D all are n ok.

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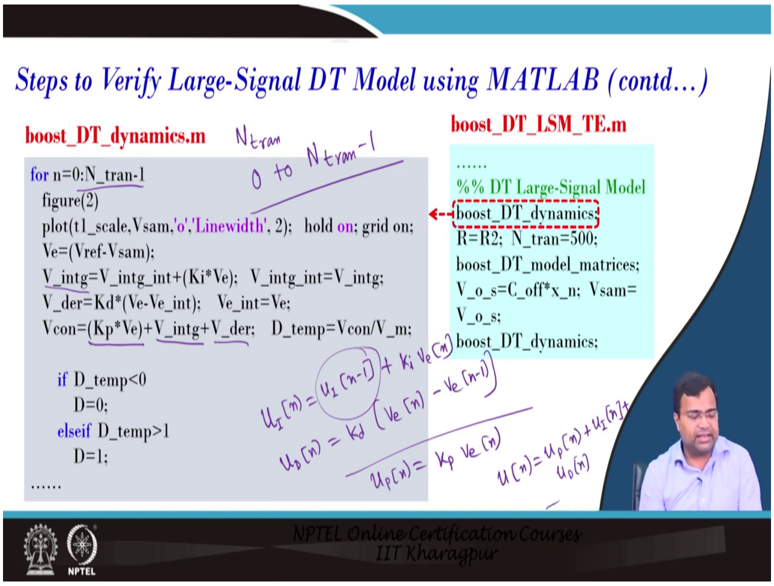

So, let me write like this. So, you are saying u P n plus u I n plus u D n will be there.

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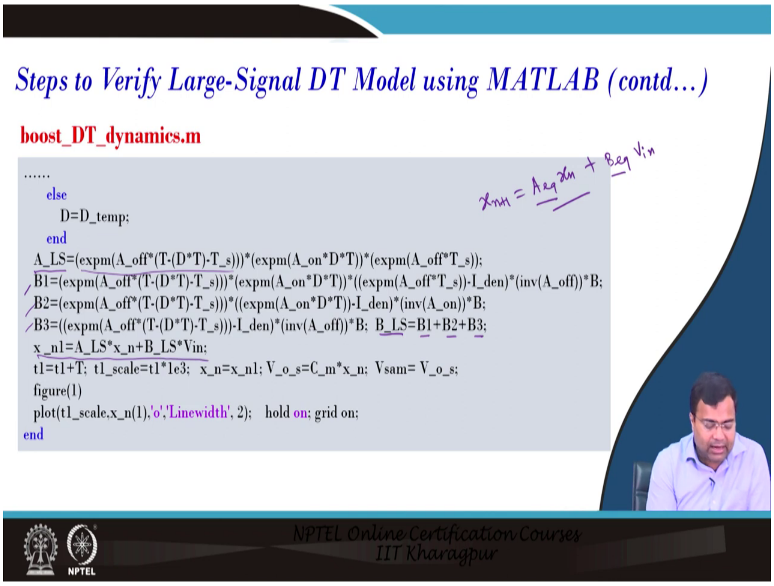

Next, this is continuing, now the large signal model will come and we know that X n plus 1 A equivalent to X n. So, this large signal model is discussed I think in lecture number 34. So, you can check it we are not going to repeat it, and then the B equivalent into V in. So, you have to and the expression of A equivalent is here. So, this is the whole expression, an expression of B equivalent is here which consists of B 1 plus B 2 plus B 3, where B 1 is written here, B 2 is here, and B 3 is here. So, it is somewhat you know large expression.

Then you will plug in this discrete-time model, and then once you obtain you run the simulation.

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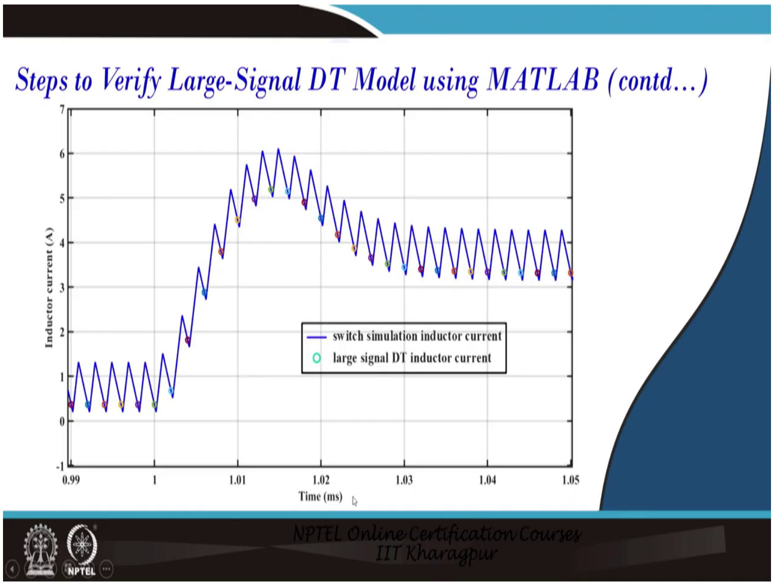

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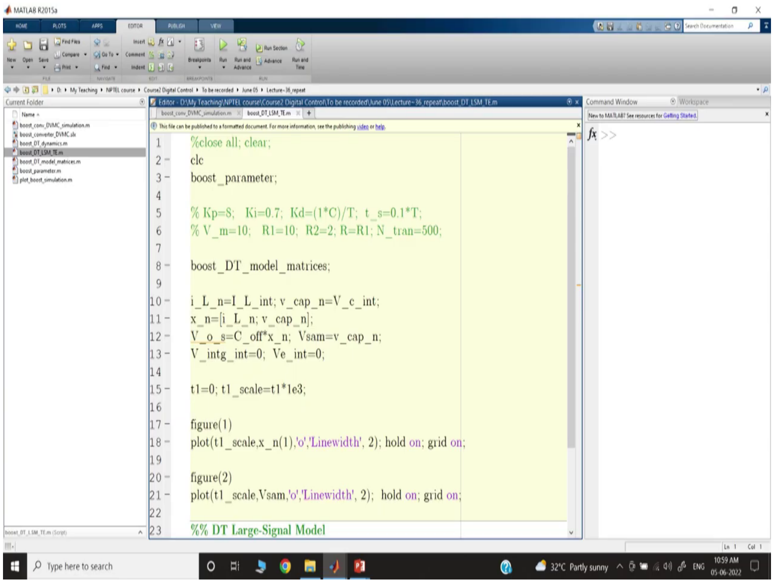

And this is the validation. So, let us go to the case study in MATLAB. So, you want to take the MATLAB case study. So, this is the boost converter large signal model, that we have discussed.

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So, this is the switch simulation; we are initializing this.

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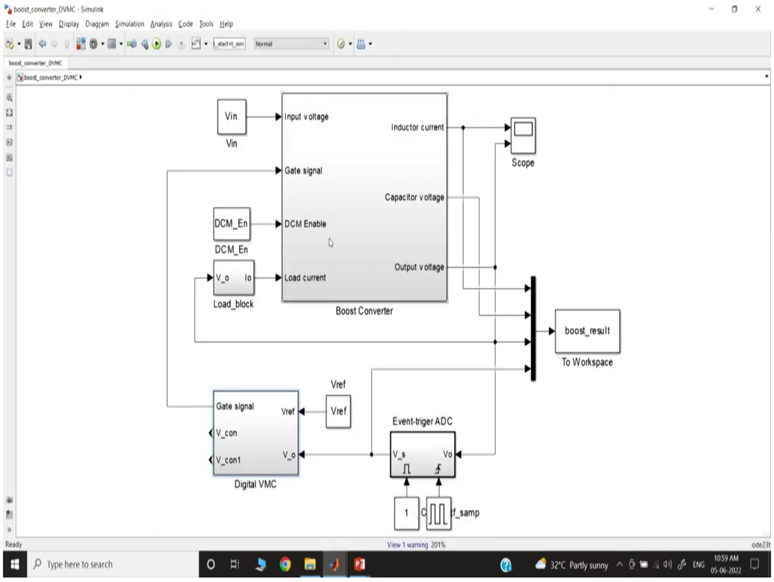

And if you go to the Simulink block of the boost converter. So, this is the boost converter.

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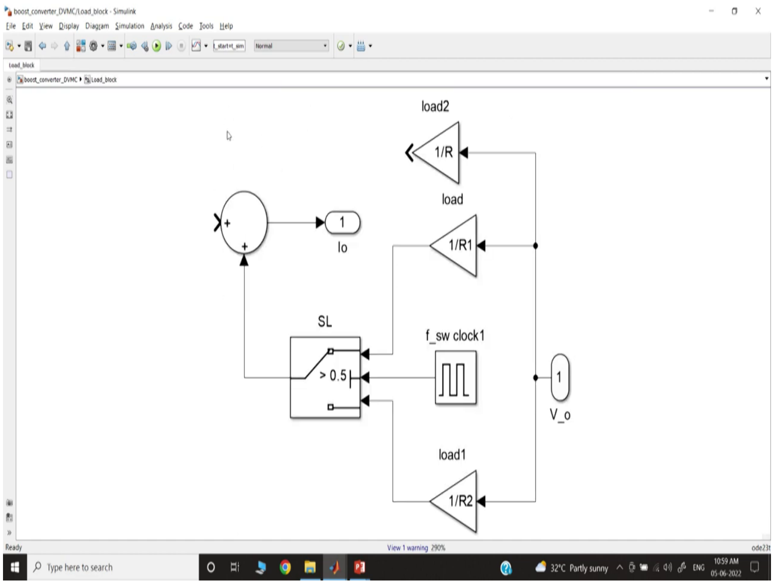

Again this is the load initially it is taking r 1 resistance and then it is taking r 2 resistance. So, r 1, r 2.

Then it is changing, then what it is taking, if you go up this is the controller.

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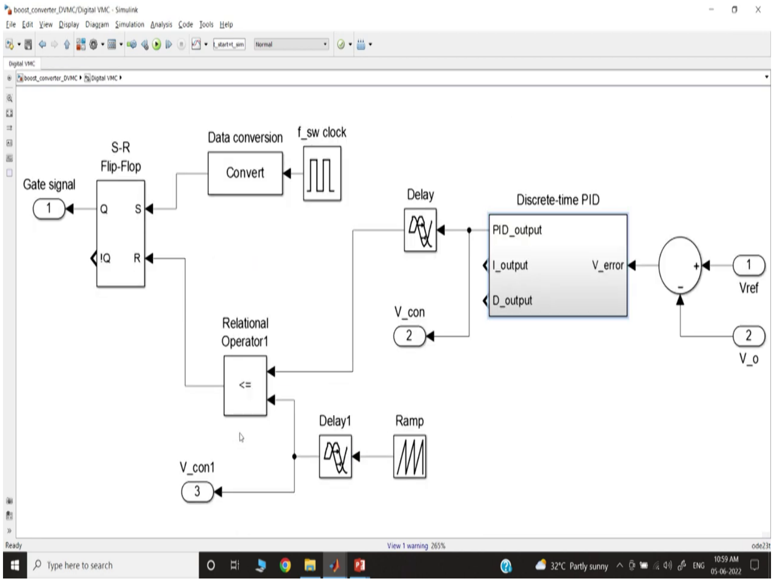

So, if you go inside the controller.

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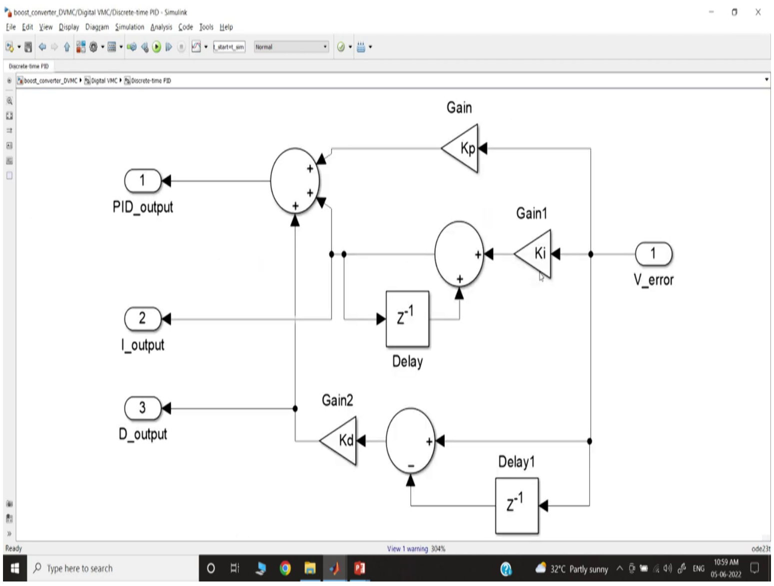

This is the digital PID controller. So, this is the integral discrete time integral control, the discrete-time derivative control, and the proportional control. Next, all controller is added to get the PID control.

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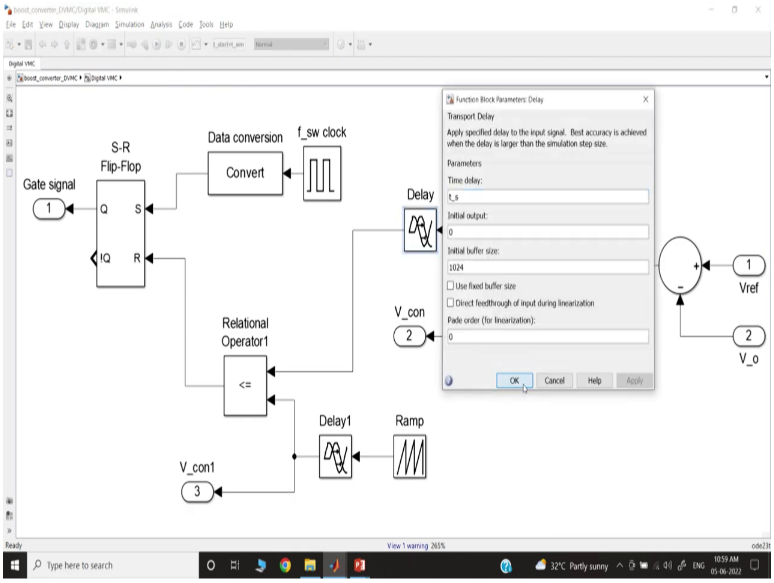

And finally, we will put a delay here t s and that is the same as the buck converter that we discussed the ramp is also delayed.

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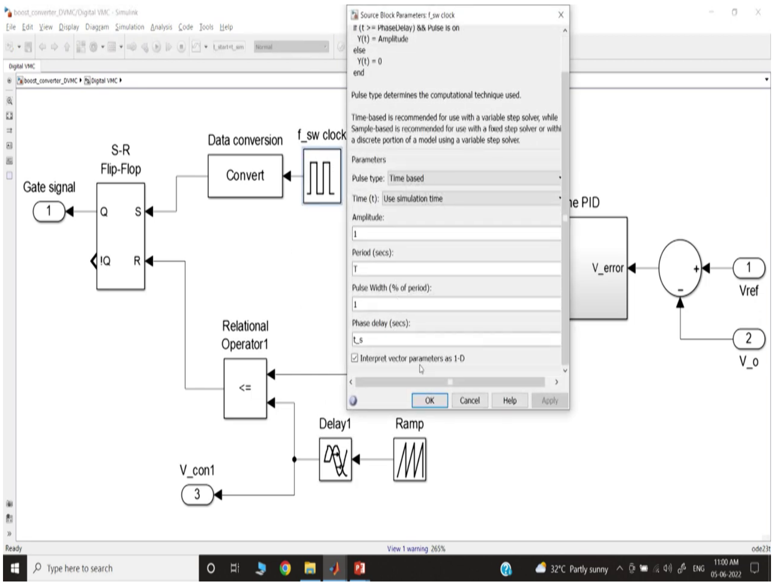

And the clock is delayed here ok.

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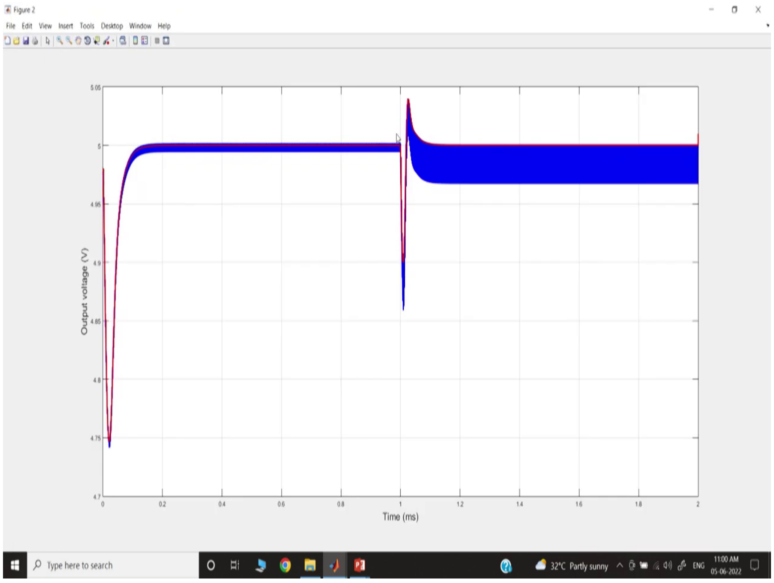

So, now let us go to a case study first. So, we are talking about the load transient case study of a boost converter, and you can see the boost converter you know.

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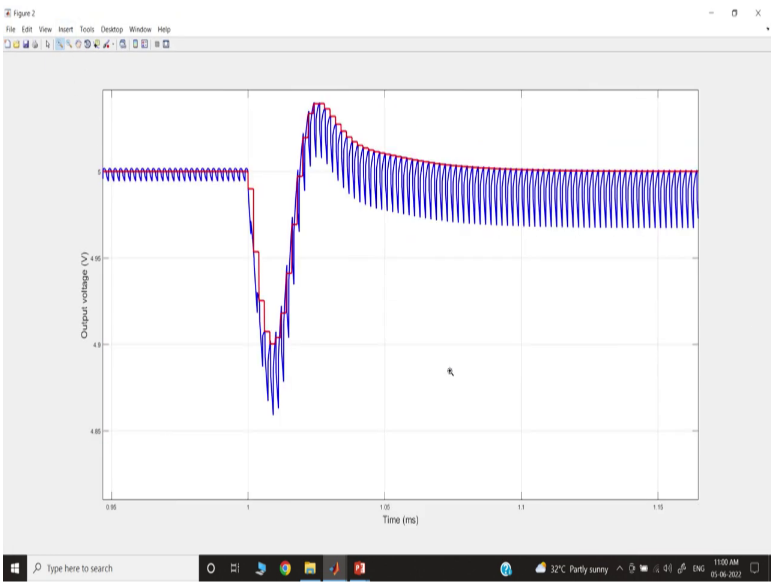

This is the boost converter case study, and this is showing that, if you go to the boost converter, here it is showing from the very initial part.

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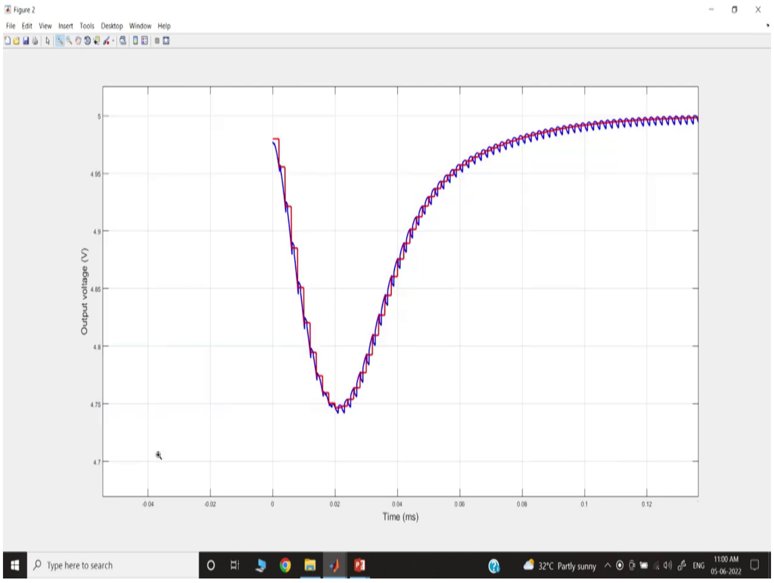

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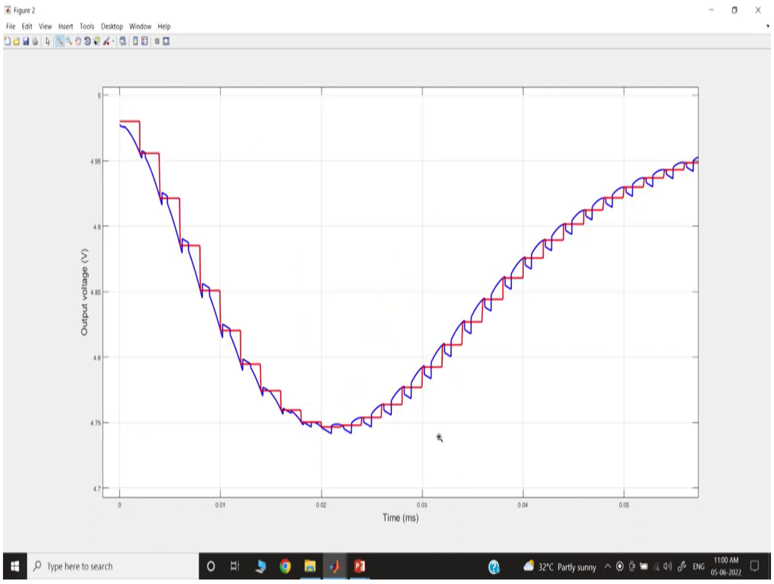

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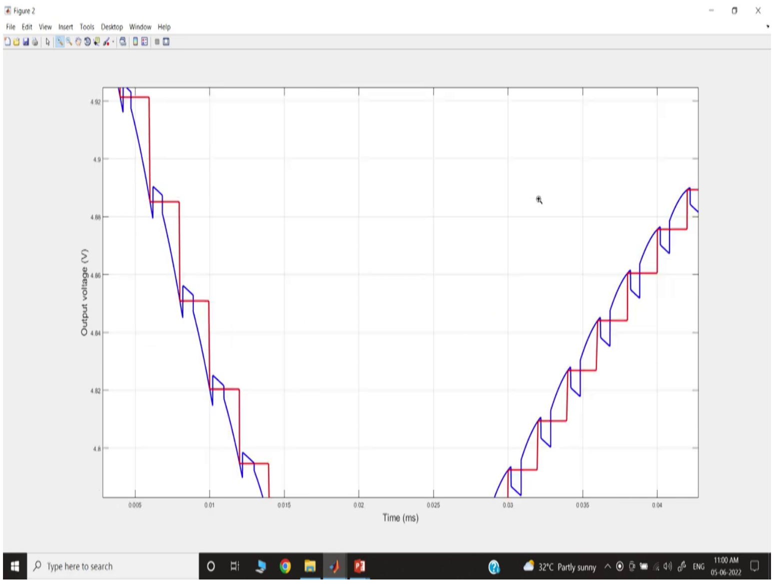

You can show that they are matching quite accurately.

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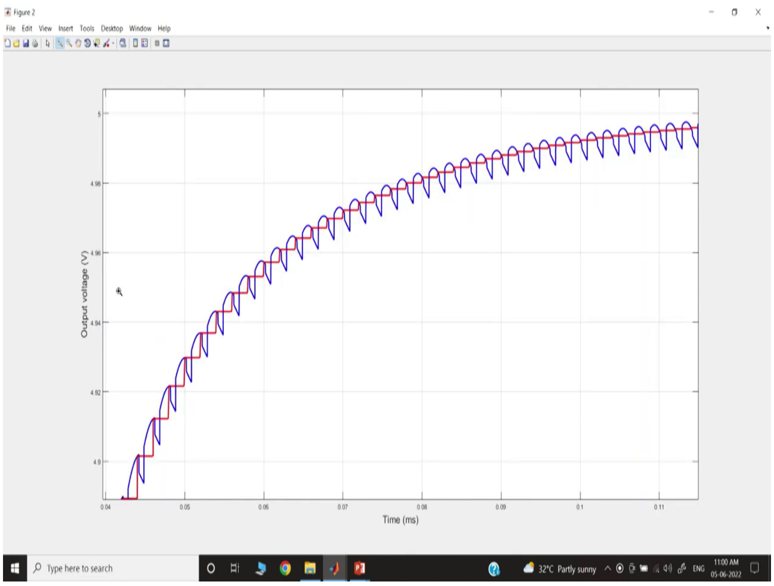

You know if you go like this.

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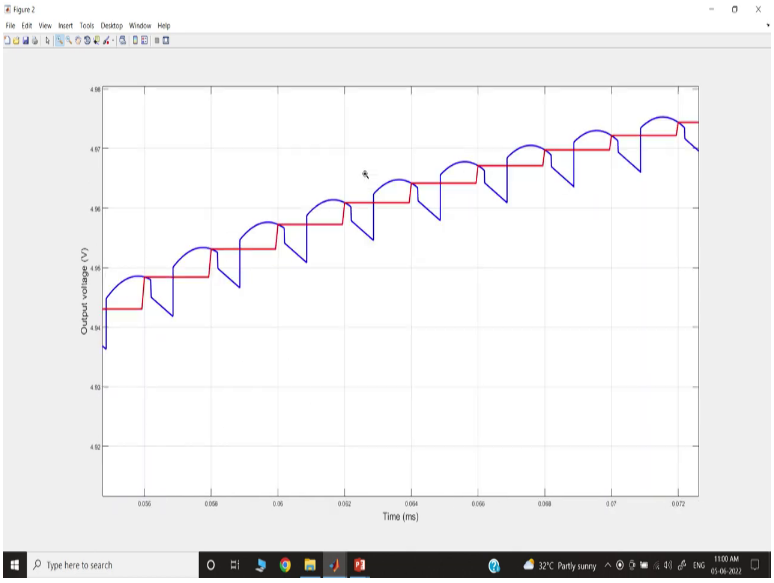

That means, first it is sampling and then it is switching ok.

Now, we want to run for the large signal model. So, let us go to discrete-time large say we are commenting on this gain, but it will take the same controller gain and there is a delay of T s 10 t by 10, now you are running the matching condition.

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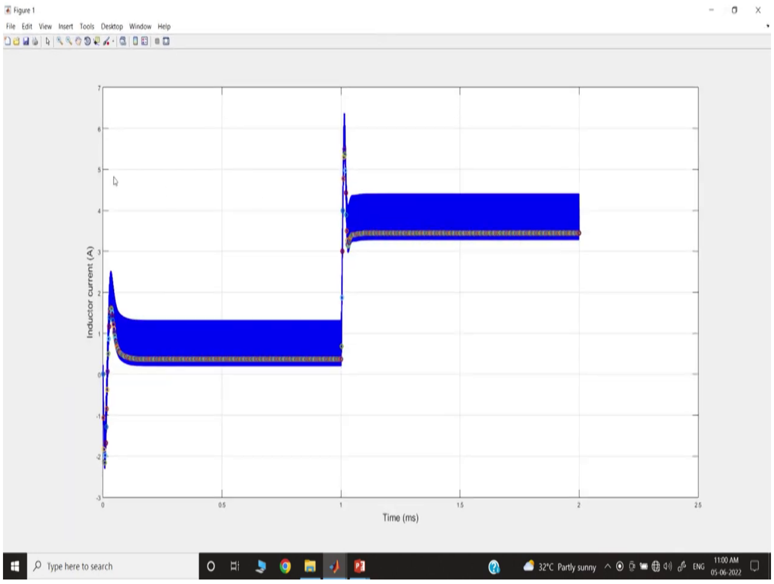

So, first, we will see, that if you take the inductor current waveform ok.

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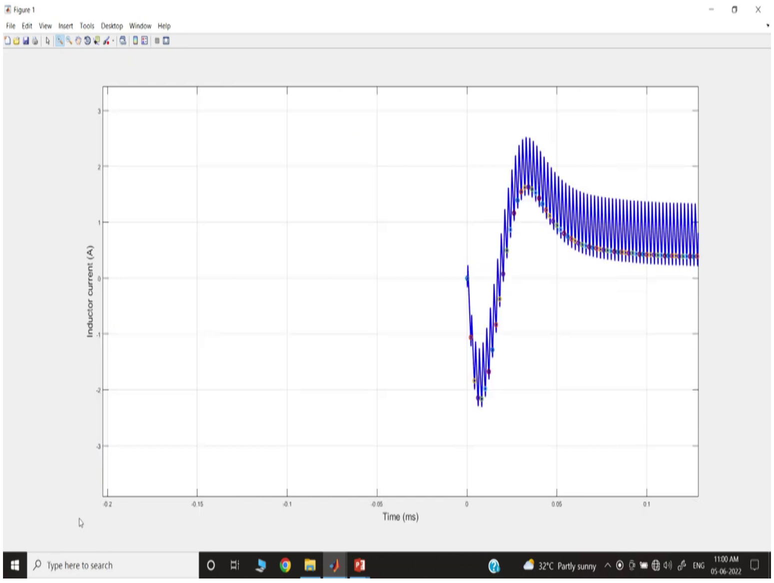

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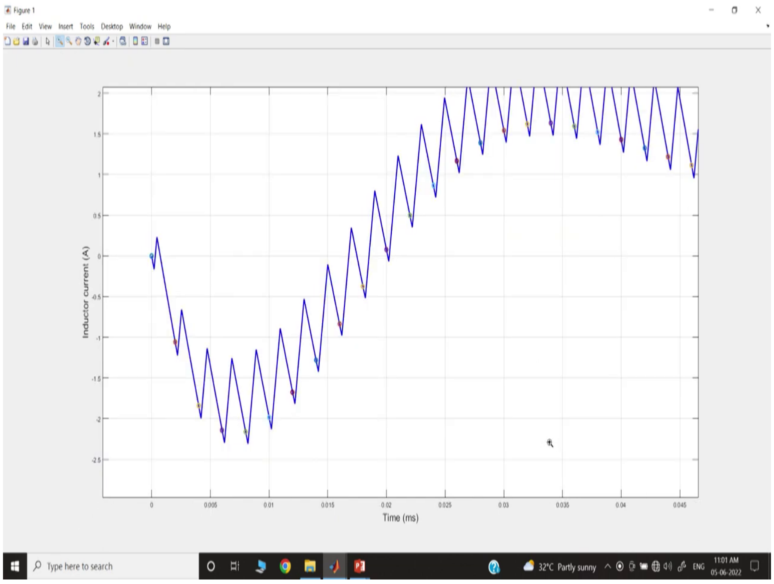

So, inductor current waveform you see they are exactly matching.

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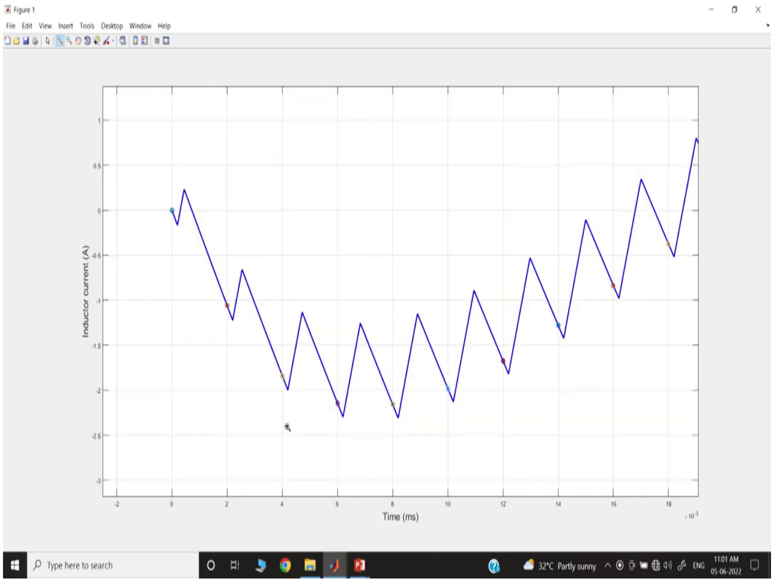

So, first, we are sampling, then after sampling, this switch is turned on.

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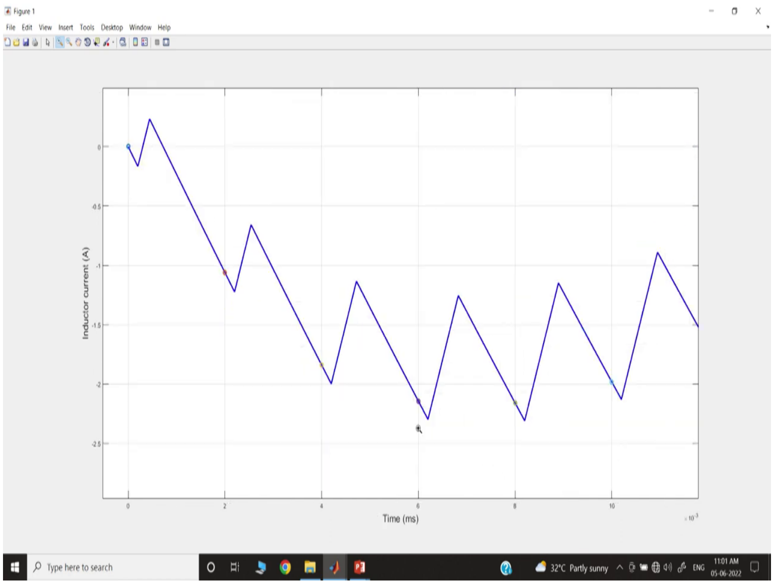

So, they are matching. So, these circles indicate it is coming from a discrete-time model.

And we are sampling at 0, 2 microseconds, and 4 micro. So, every cycle we are sampling, and after ts delay, it is switching ok. And then we can also show the output voltage sample.

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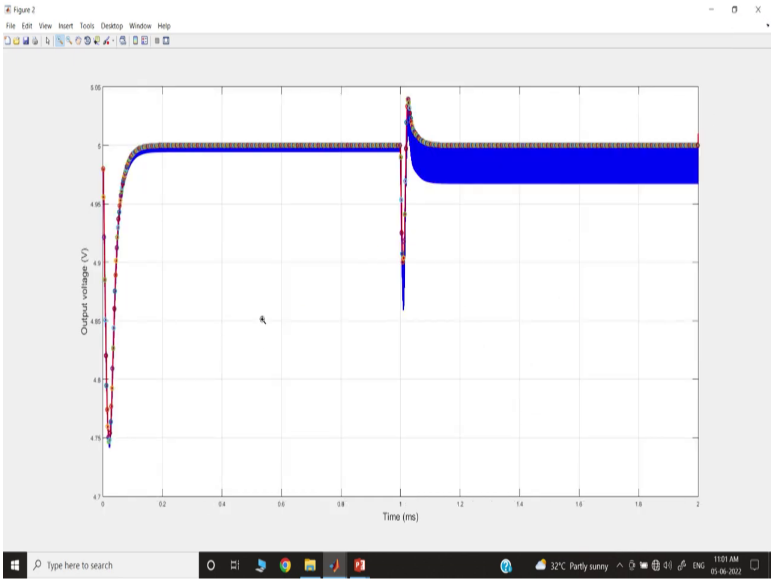

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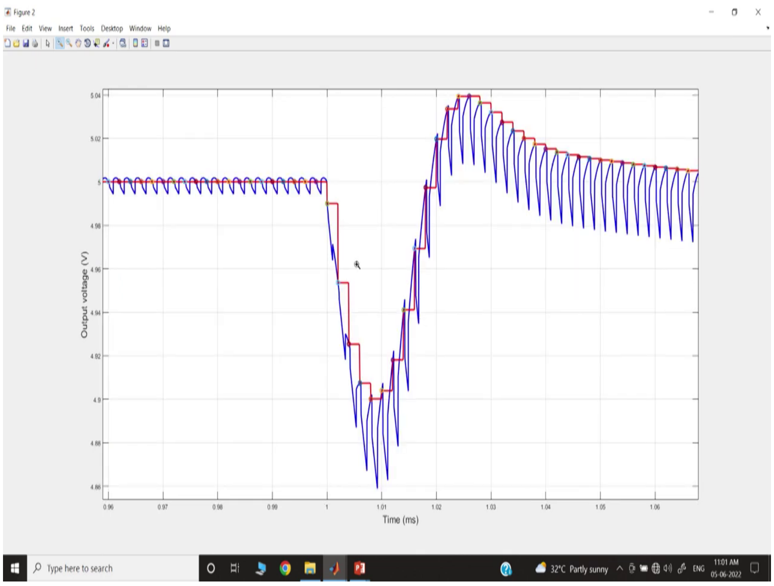

So, if you take the transient portion.

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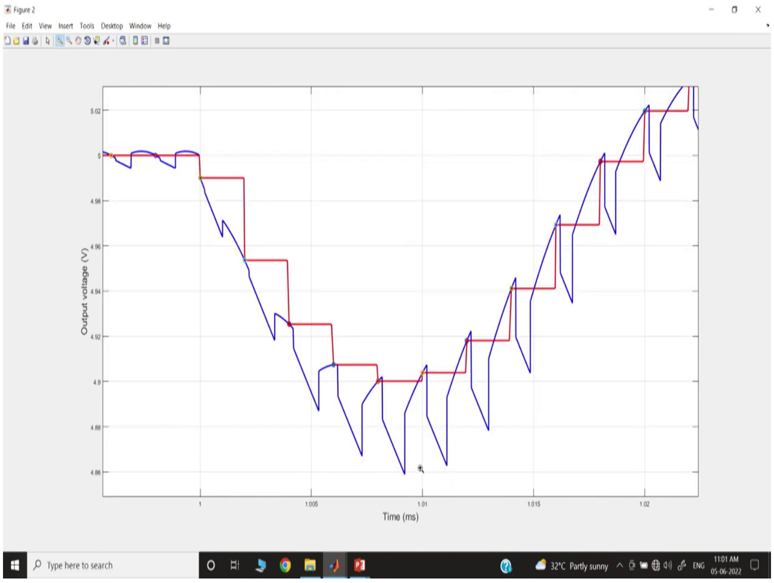

You can see after the transient.

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The model indicates in this particular circle, it is matching with the actual sample obtained from the switch simulation.

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So, it is coming from the switch simulation data sample; that means, we can show the case study of the validation case study.

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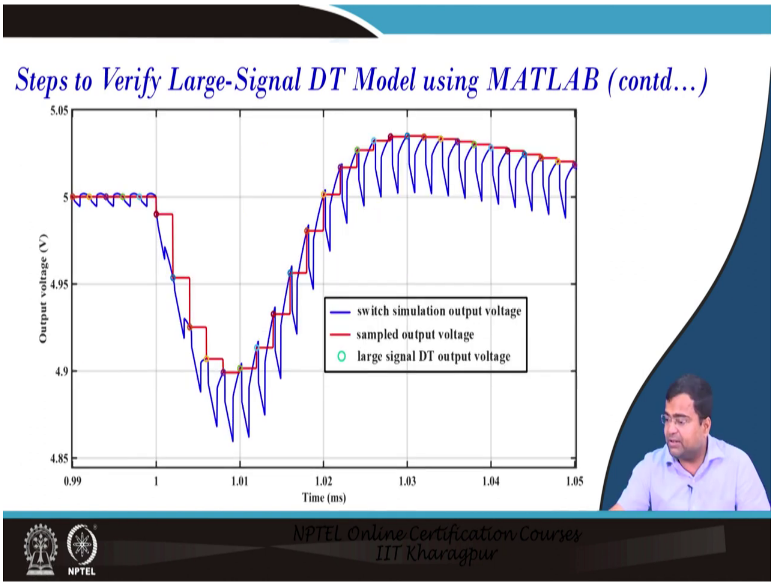

So, we have discussed this validation; that means, these circles are like a large signal model coming between the two subsequent sample points, then the red one is the actual sample coming from the switch simulation and the blue one is the switch simulation the time domain waveform.

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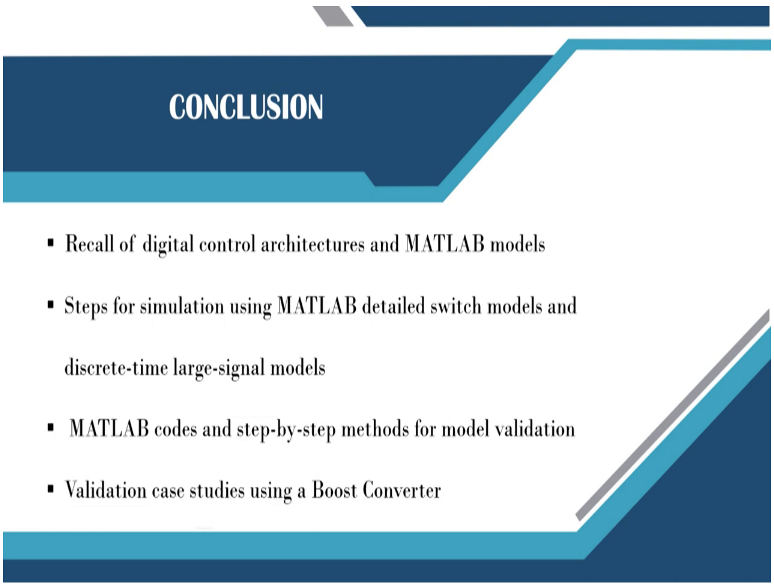

So, in summary, we have discussed digital control architecture and MATLAB model, we have shown the step for simulation using MATLAB detailed switch models and discrete time large signal model, then we have also discussed discrete time MATLAB course and step by step method for model validation and finally, we have considered from a validation case study using a boost converter.

So, I think these two lectures should be sufficient to understand how to do a validation case study, one can do this for current mode control also, but again this validation will not come in the exam or the assignment, but one should know how to validate the model, but it is important to know, how to model in MATLAB those things will be there, but the validation itself will not be asked in the assignment or the exam case study, that is it for today.

Thank you very much.