Control and Tuning Methods in Switched Mode Power Converters
Prof. Santanu Kapat
Department of Electrical Engineering
Indian Institute of Technology, Kharagpur

Module - 02
Modulation Techniques in SMPCs
Lecture - 11
Synchronizing Simulation and Script Files in MATLAB

Welcome back. So, today is lecture number-11. And in this lecture, we are going to consider Synchronizing Simulation and script file in MATLAB. So, in you know earlier lecture, we have discussed basic MATLAB. You know how to generate how to build Simulink blocks, then how to run Simulink model, then how to take data into MATLAB files, so all these things we have developed. And in fact, at the end, we have also considered the parallel RLC circuit and which is used to simulate a buck converter.

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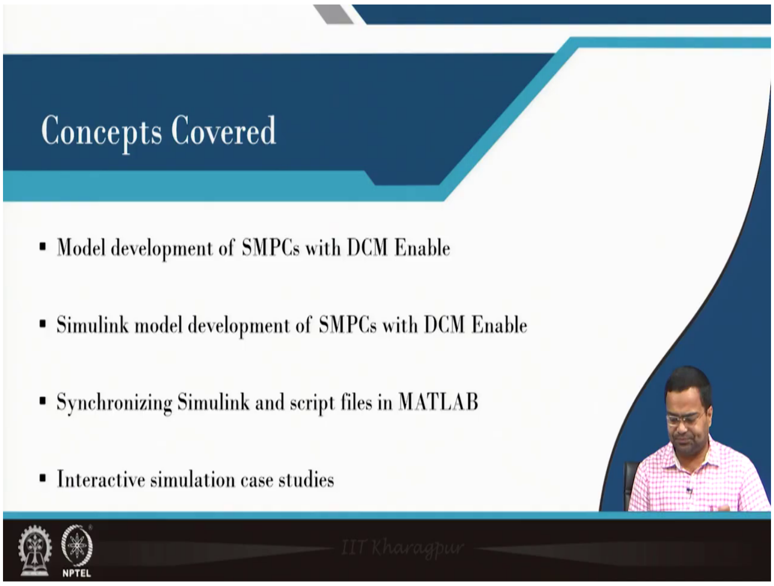

In this course, we want to go deeper into the Simulink model, and we want to build conventional buck and boost converter. I want to simulate and also want to show instead of running through simulation, we can run the Simulink model from dot m file. And we can create different test cases. We can create different design oriented test cases. And simulation can be made faster by running through the dot m file rather than going to the simulation file – Simulink file.

So, the concept cover the topic covers are like a model development of switch mode power converter. Here we are also going to consider discontinuous conduction mode. Then we want to discuss Simulink model development of switch mode power converter with DCM enable blocks. Then synchronizing Simulink and script file in MATLAB, and then interactive simulation case study.

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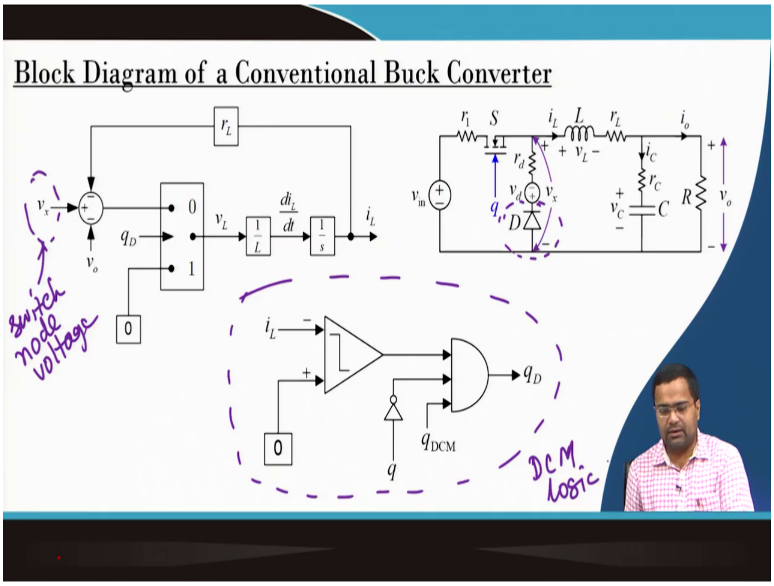

So, first we will take this block diagram, which we have discussed in lecture number-4. And we have already built this circuit using a block diagram and for a synchronous buck converter. So, here ok, so this is our synchronous buck converter. Sorry it is not the synchronous one, it is the conventional one. And we have discussed that we can this is a conventional buck converter because we have a diode here.

And we have discussed earlier that this model we want to make a generic model which can be used for both synchronous buck converter and the conventional diode you know diode base conventional buck converter. And we want to also show a comparative study when by considering a load step down transient that what happened if we use a synchronous buck converter throughout and if we enable a diode conventional buck converter ok. So, this model is well known.

And this block we know that this signal is our switch node point, switch node voltage. And this block is designed for DCM enable operation that means DCM logic.

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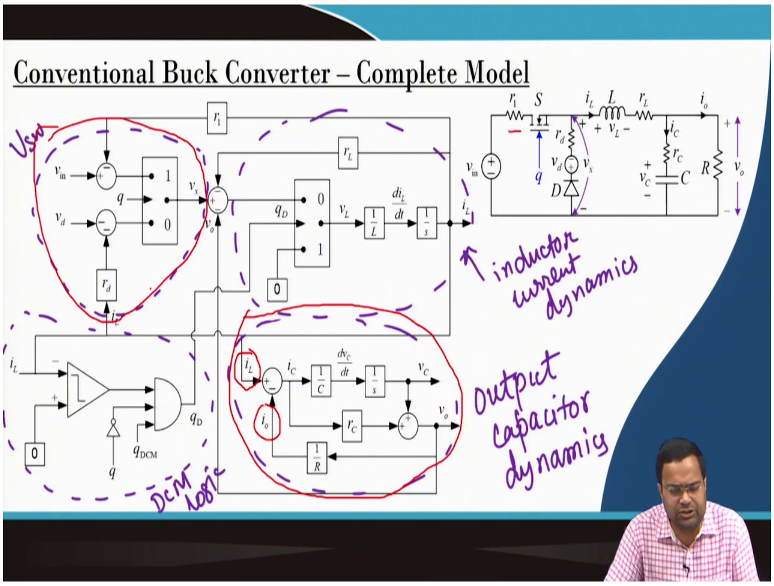

And if we take the complete circuit, then this block is responsible for you know switch node voltage that means, V sw or V x here, it is shown switch node voltage. This block is designed for DCM logic. This block is used for output capacitor dynamics, and this block is designed for inductor current dynamics, ok.

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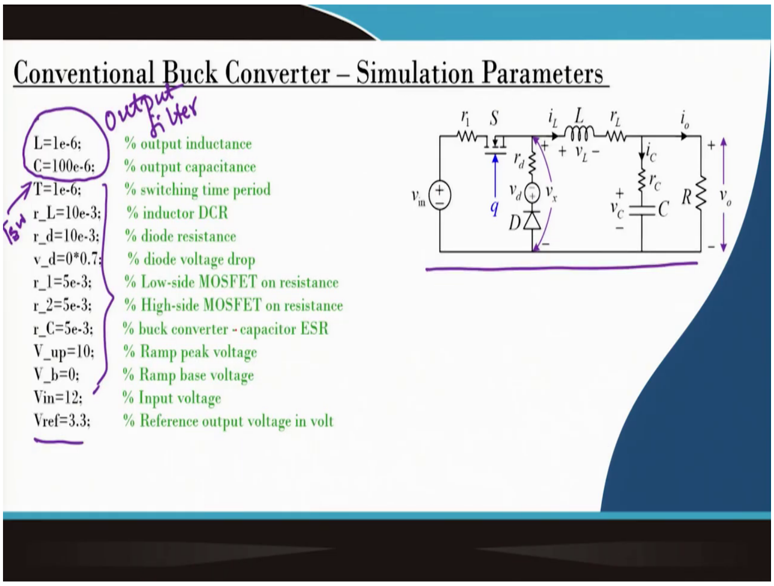

So, now what we start, what we need? If we want to implement this converter, we need to select some parameter values. That means what are the parameters that we are going to consider. So, here we are talking about output inductance like output capacitor. This is related to our output filter. This is related to our output, filter which consists of an output inductance and output capacitor.

And here we have taken inductance value to be 1 micro Henry because we are trying to operate at 1 mega Hertz switching frequency. And this is our switching period T sw, and which is nothing but 1 microsecond that means that corresponds to 1 mega Hertz switching frequency.

So, these parameters are you know we have to take this parameter from a datasheet because here we have taken some values, but you know you can always pick up those values from a datasheet specification that what are the r ds on. And if you go to the datasheet of the inductor, then what is the DCR of the inductor? All these parameters we may not get the perfect value, but you can get an estimate about the parameters from the datasheet.

Here we are using a set of data which you can change it, and these were actually creating a dot m file ok. Input voltage of 12 volt and output target voltage of 3.3 volt ok. So, now, we are going to implement this block using MATLAB Simulink.

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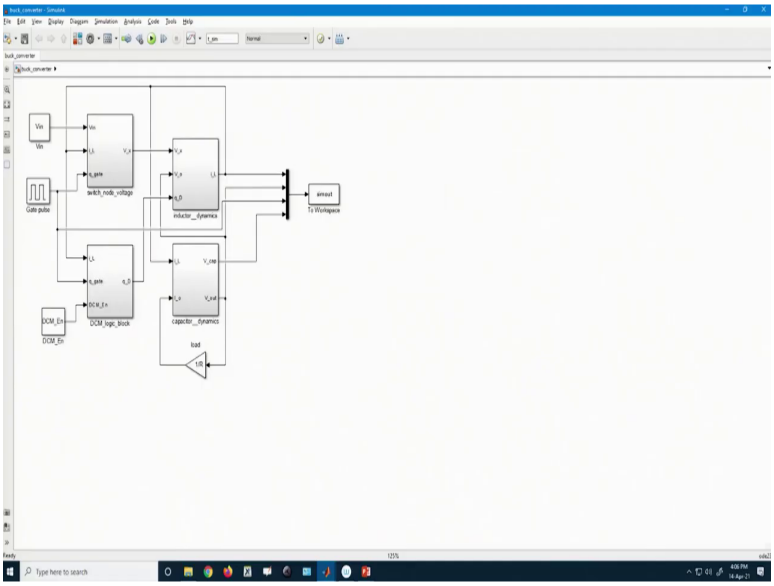

First let us go to MATLAB model, I mean this is we are now considering this MATLAB ok.

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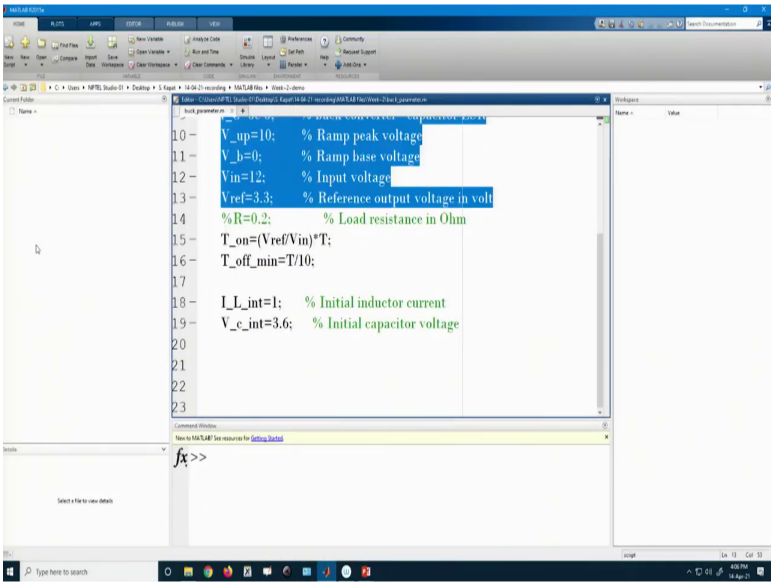

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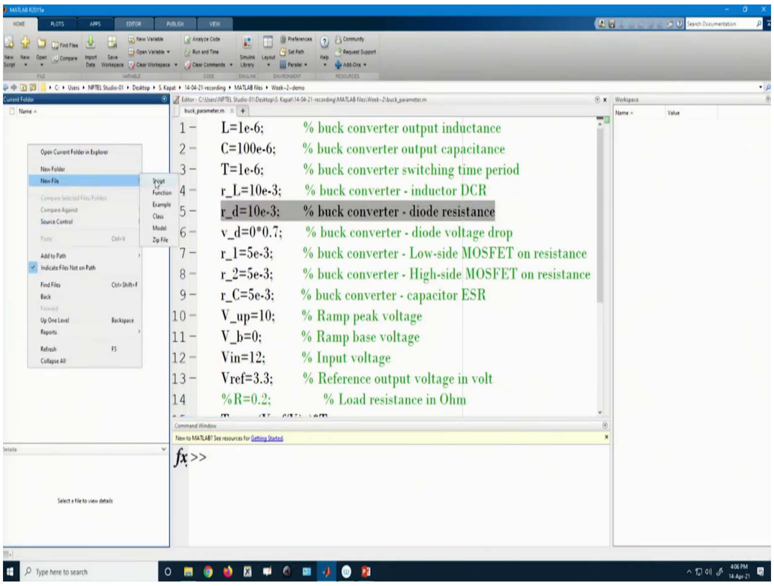

So, first we have to create we are trying to planning to create. This is a file. Let us open a file, new file script file.

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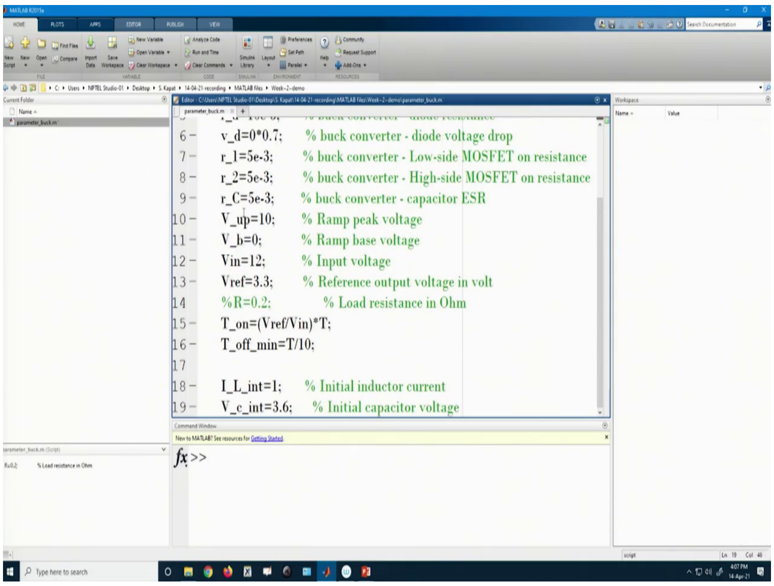

We can name it as a parameter buck converter. And this is a new file and I'm using the data existing data from some other file. So, you can simply put this file.

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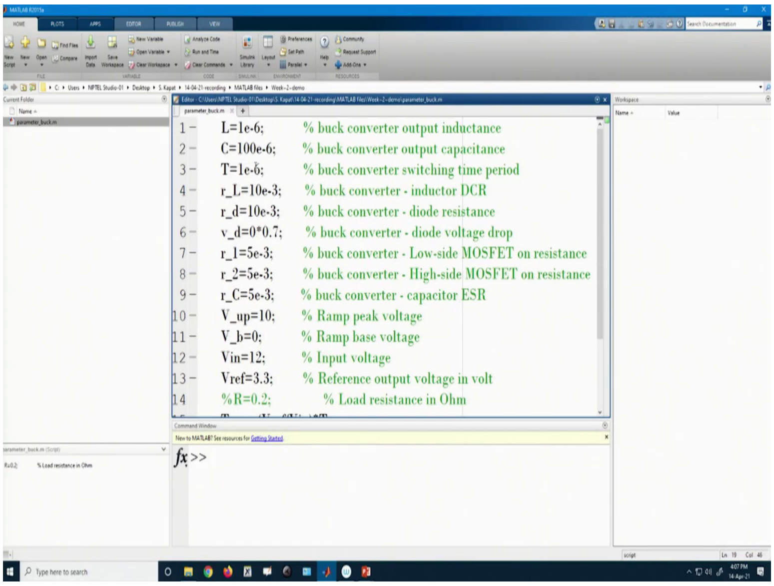

So, what I have kept here all these parameters like inductance, capacitor, then time period, then r L, the DCR, diode resistance. Here I have kept diode drop to be you know 0, because if we in fact we can make you can keep it. But you can create a situation if you use synchronous configuration, the diode drop can be ignored; if we use conventional configuration, then we can add diode drop. So, we can use either of these, but here I have taken diode drop to be 0, but you can incorporate it ok.

So, input voltage is 12 volt and output voltage reference voltage is 3.3. And this is taken as if you want to take a sawtooth voltage that we discussed. We took an upper value and lower value, the lower value is the best value which we kept as 0, and upper value is 10 volt. Although in this presentation I am not going to use this; I am going to use a fixed time period for simulation. Then what we will do? Ok, let us now we want to create a Simulink model, that means this is our parameter file.

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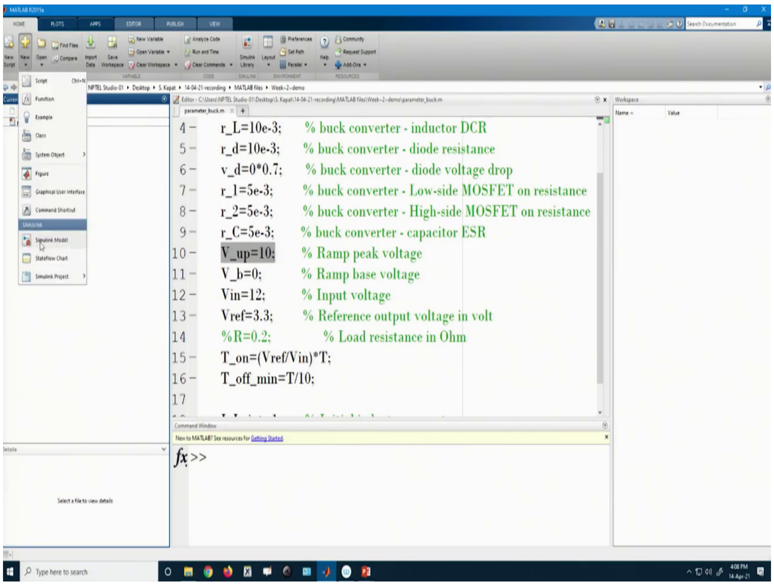

Then we need to I need to open a new file a Simulink model.

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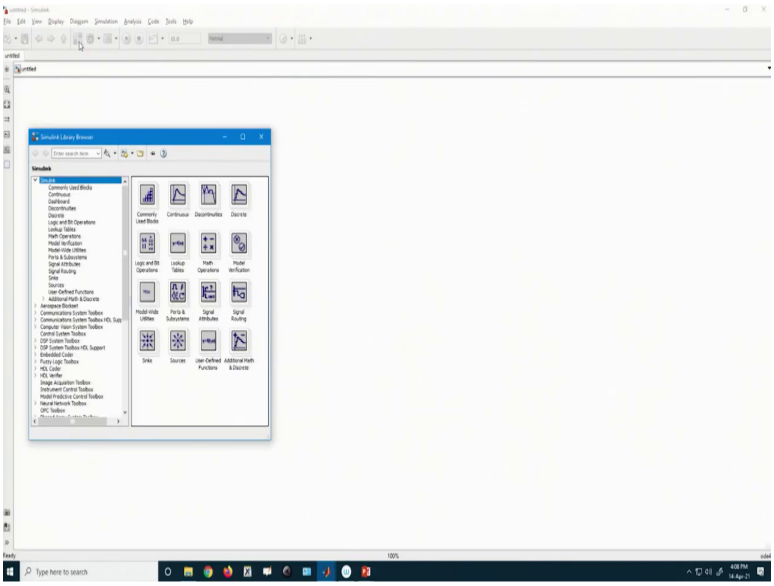

So, in this Simulink model we know how to develop these blocks, that means, let us start.

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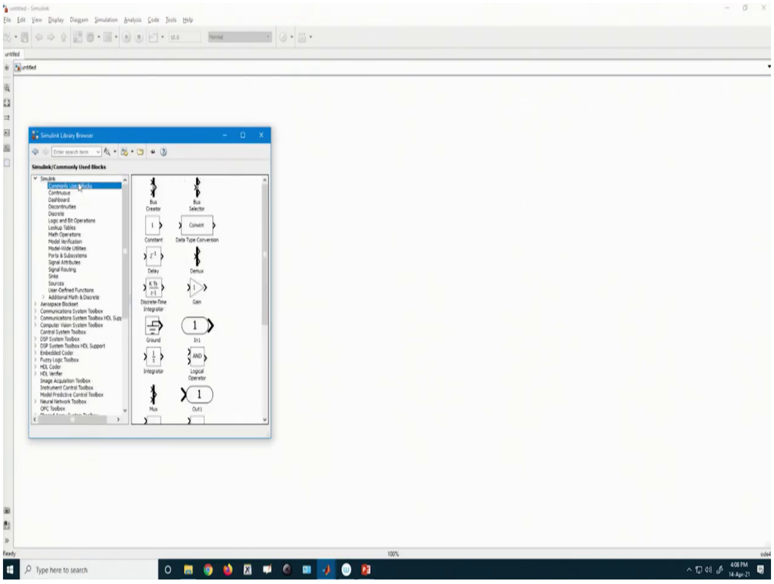

With a basic commonly used block, what basic blocks we need? We need some constant.

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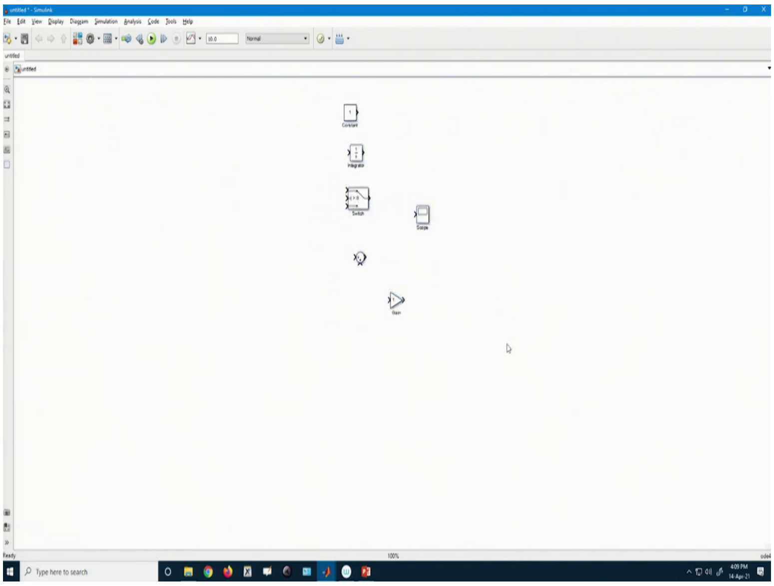

Then we need integrator. Then we need summation switch block. Then we need scope if you want to simulate, then we need relational operator if require; at this point, we may not require. Then we need summing block so on. And then we need also a constant because sorry again because these are there, these are the thing we need to we are going to consider in this building of Simulink block.

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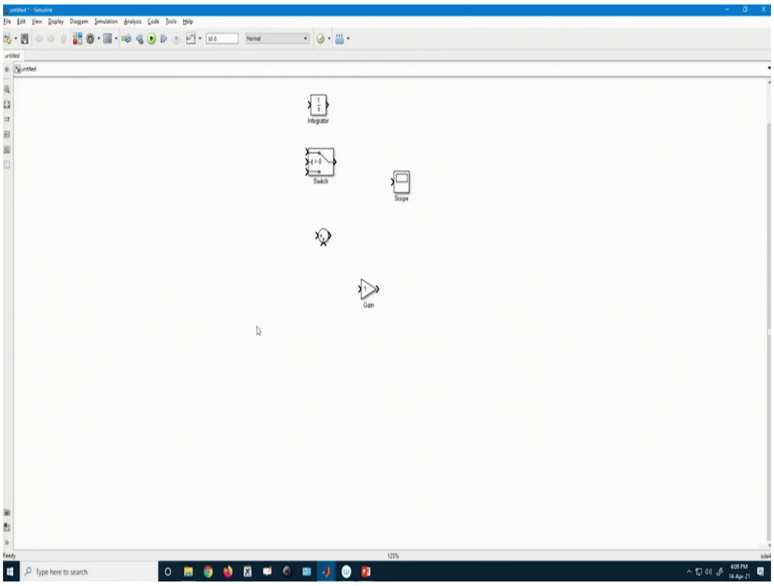

So, first we want to realize the current dynamics. What is there in the current dynamics? If you refer to our presentation, if we refer to this model, going back the current dynamics here, this particular block we are talking about, we are talking about this block. In this block, what is there in the current dynamics? That means, first inductor voltage, we have to generate inductor voltage.

Inductor voltage. If we do not consider the discontinuous conduction mode, then what is the inductor voltage here? The inductor voltage is nothing, but this side is a switch node voltage minus the drop across this resistance, that means, this is my switch node voltage, this is the drop across this DCR, and then this terminal is the output voltage. This terminal output voltage. So, that means, V L is equal to V x minus r L i L minus V 0 that is by L sorry that is my V L ok.

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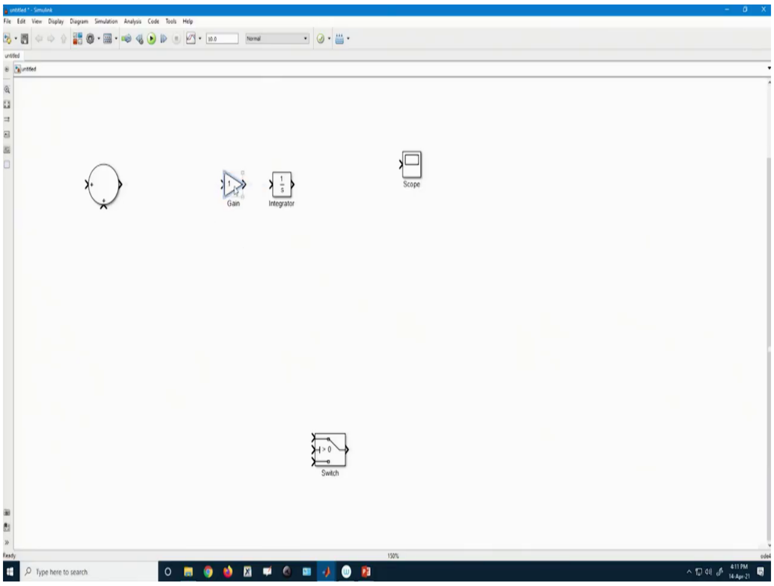

So, let us start our block diagram ok. So, we want to first create a V L block. What is V L? That means, after V L, what is there? We know that L di L dt L di dt is equal to V L. So, l di di L dt equal to V i L by L. So, here we should use 1 by L. This thing we already did it earlier.

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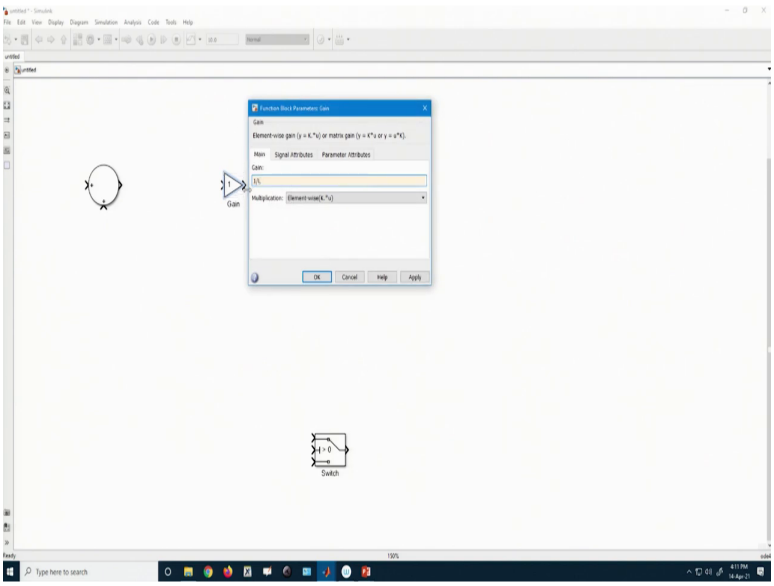

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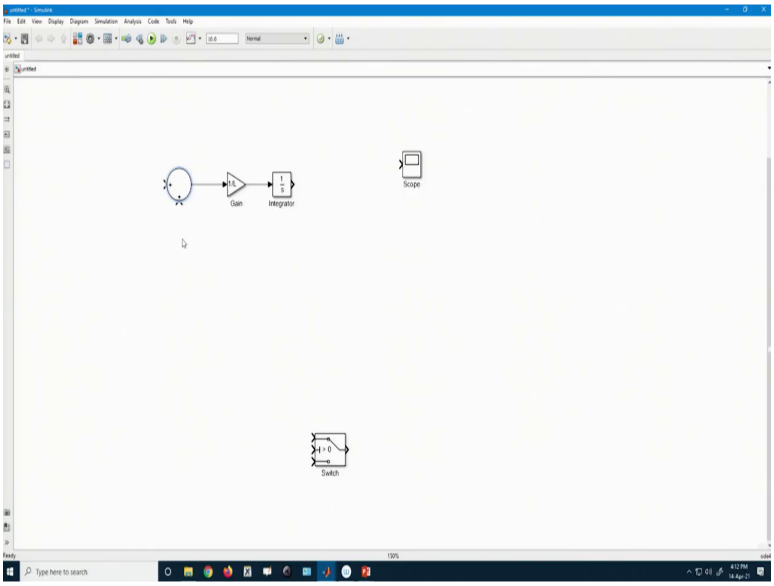

So, it is 1 by L. This is my inductor value. So, this part we can insert some text, so this part. Then this is our V L. What is there in the V L?

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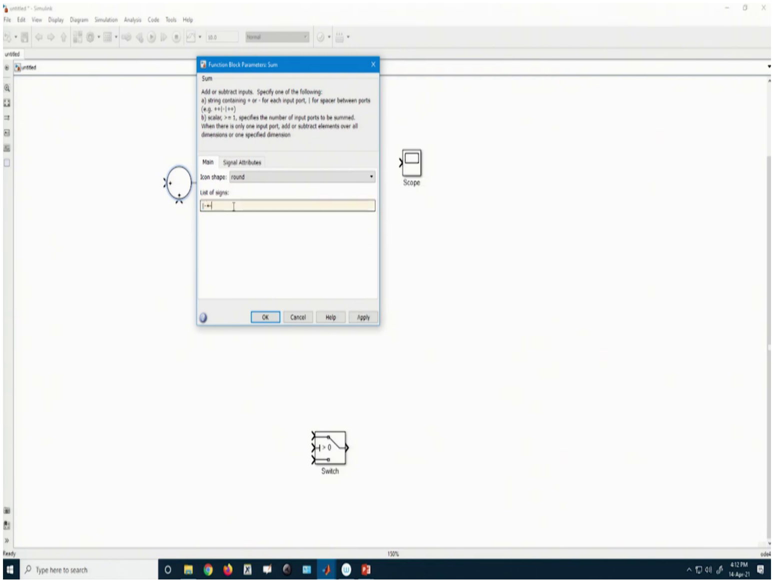

Let us consider the V L, it consists of V x minus that means, minus plus minus ok.

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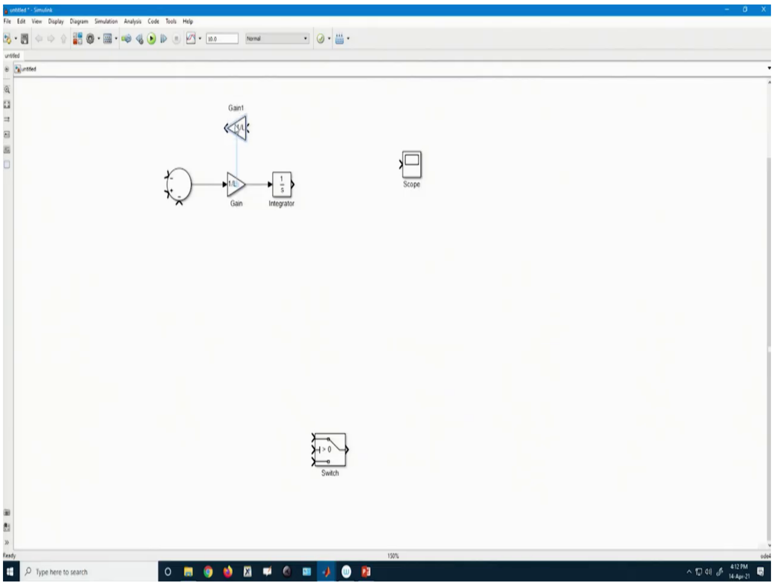

Again we need to have a gain.

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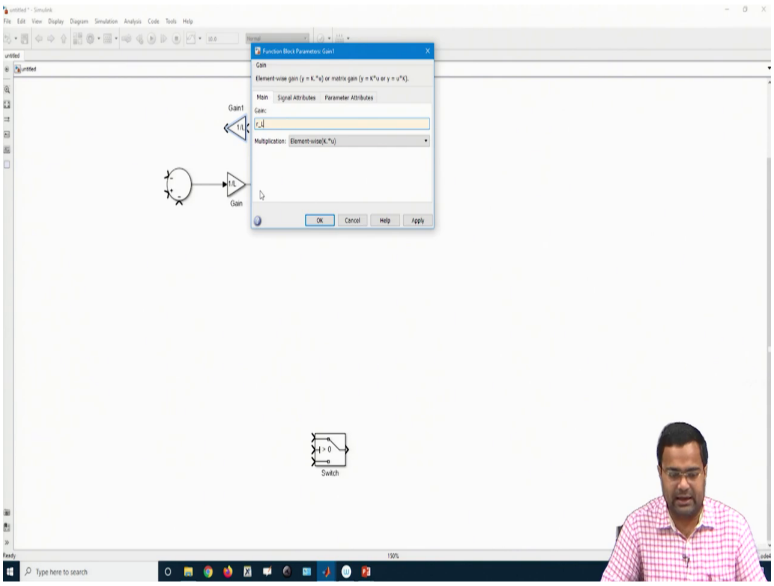

And this gain is r underscore L that is my DCR.

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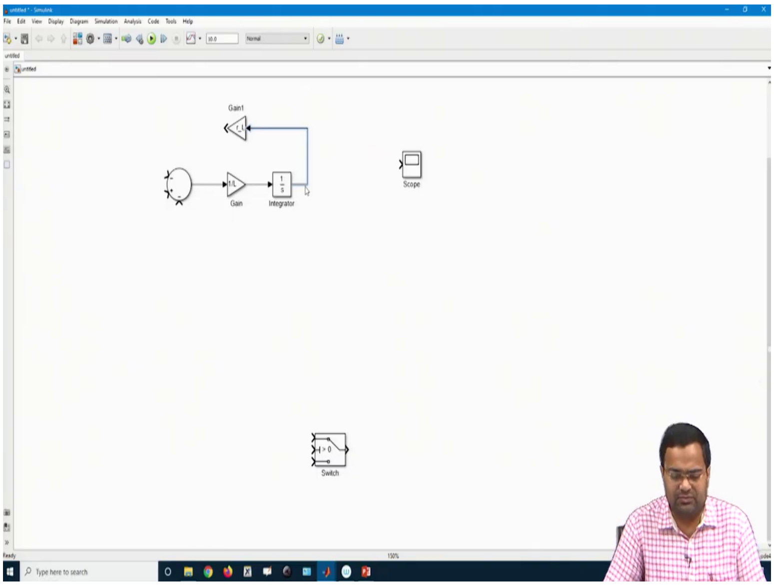

And this is connected here. It is because this integrator output is my inductor current initial value ok.

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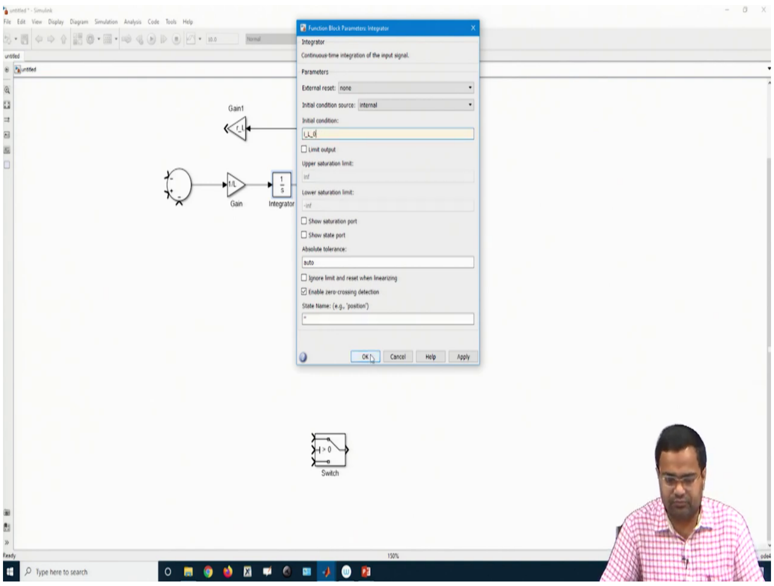

And we can set the initial value i, L, 0 that is my initial value.

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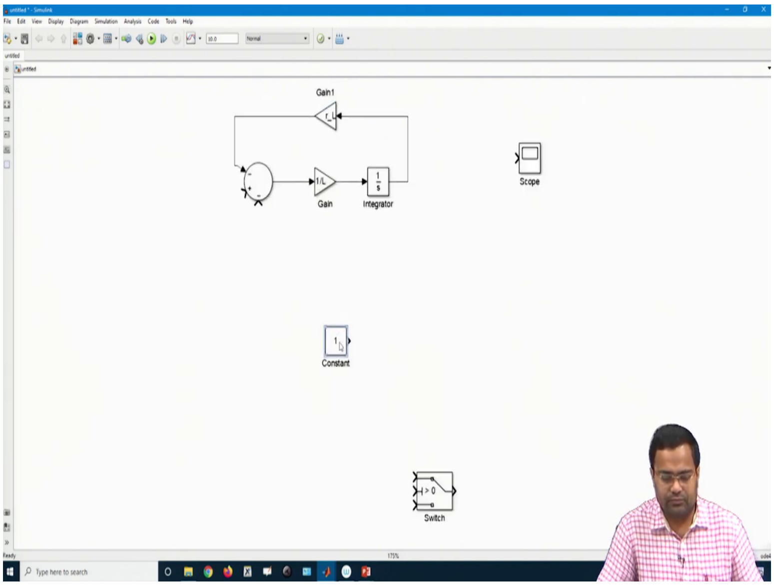

And we have to define this initial value in the script file; otherwise, the symbol will not be executed. We have to give some assign some value ok. So, we can connect to this block. Next we need V x. What is V x? So, I think what we need another block is that, yeah we have some constant here.

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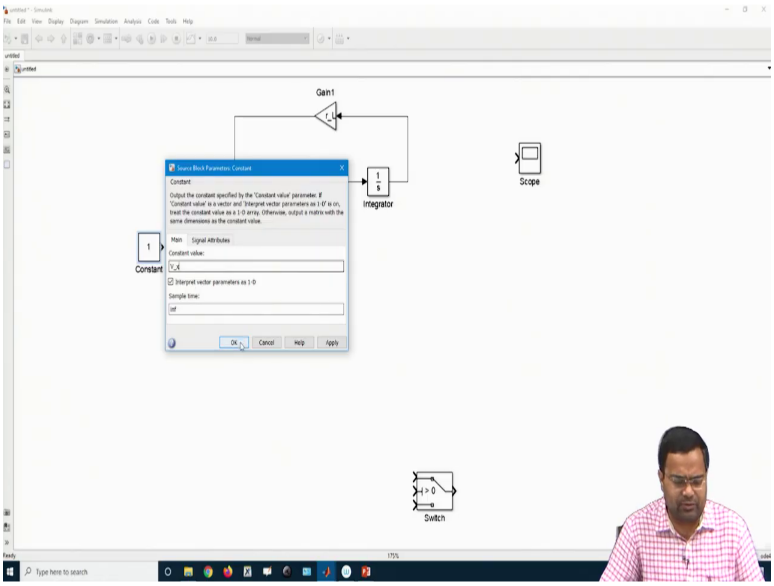

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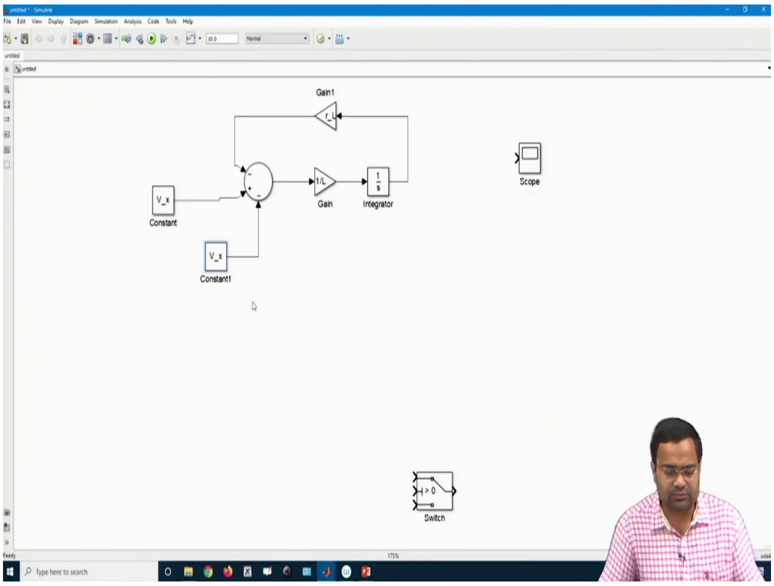

So, this constant let us say we define as a V x, let I will replace what is V x. So, this V x is added here. That is my switch node voltage. And then what else we need to consider is that output voltage, that means, I need another is the output voltage. This will create my the dynamics of the inductor current, that means, inductor current dynamics comprise these parts.

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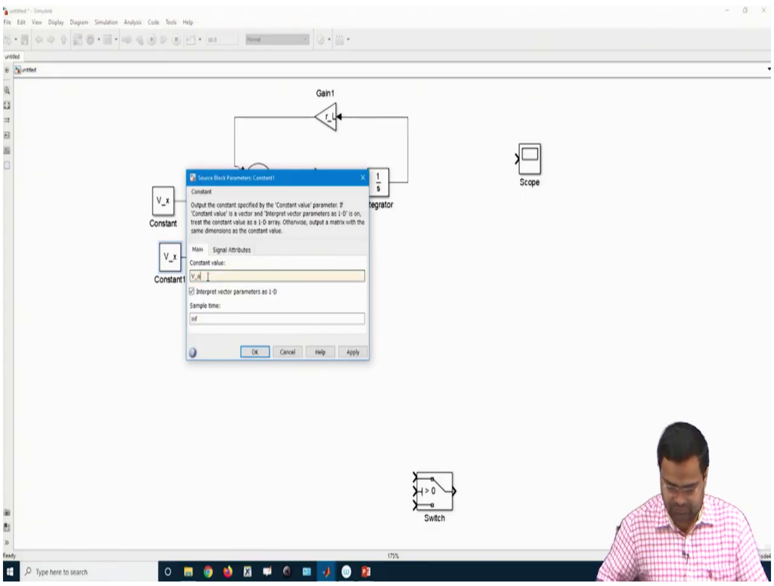

Now, this is my V 0 output voltage.

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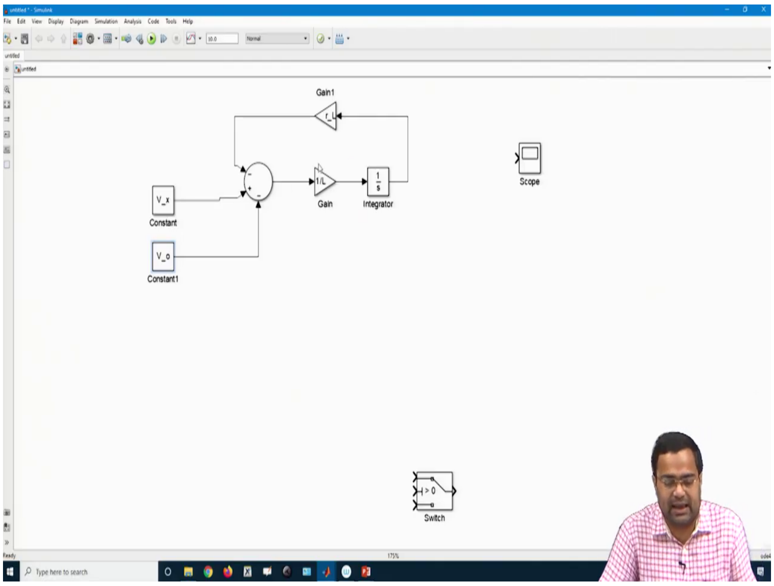

So, this will give me the inductor current dynamics, but as I said this is V L, but the V L in general, when there is no discontinuous conduction mode, this will be this one. But if we incorporate discontinuous conduction mode, the V L will be 0 when DCM point is detected. 0 current is detected and you have a diode. So, in that case, we need to incorporate a switch ok.

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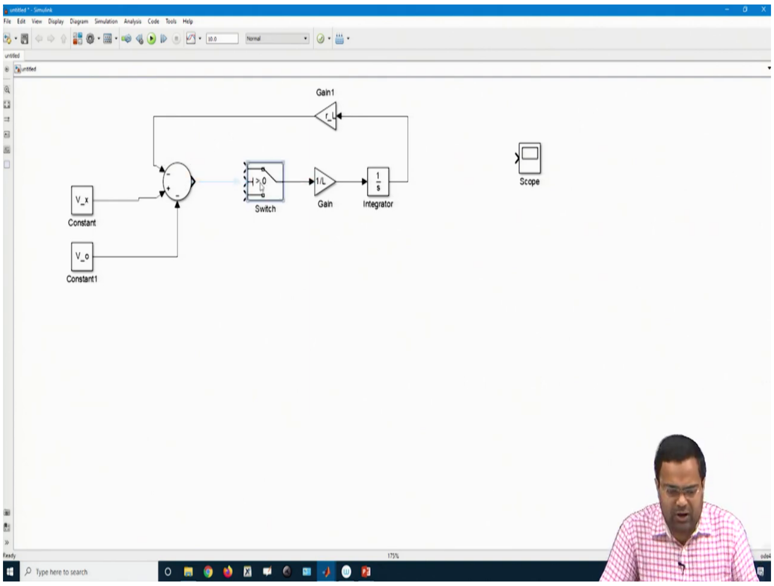

So, let us take it back; instead of directly connecting to this, we need to connect through a path. What is that? This is my path.

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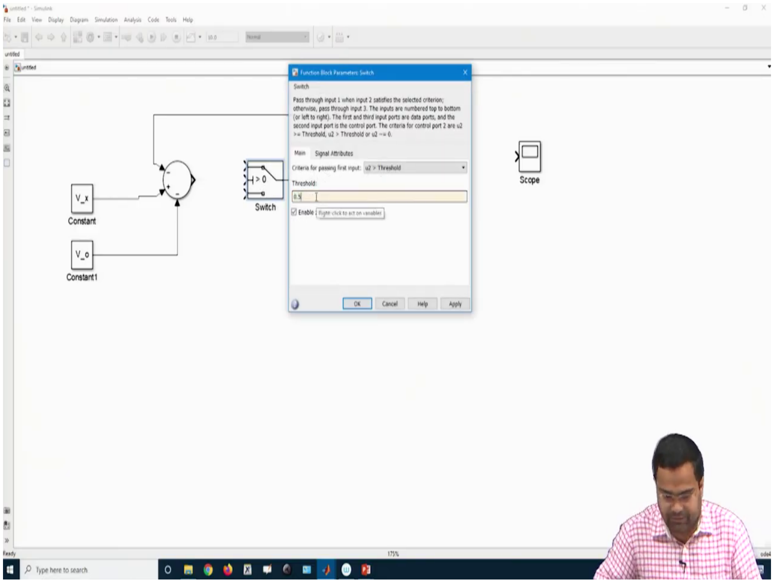

Now, this block switch if what is the logic of this switch, we will put a threshold of 0.5 ok.

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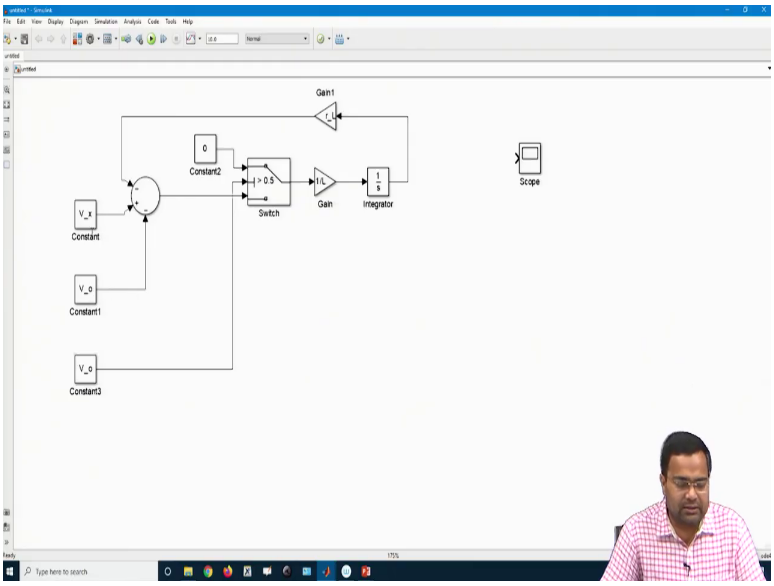

So, that means, if my the middle one that mean which is my control signal, if it is greater than 0.5, it will take first channel the first input, the output will connect to the first input. If it is less than 0.5, it will take the second. So, in our case, it is the second input because we are going to generate a control signal which will be 1 when the DCM is enabled and the DCM is detected ok. So, that means, this is my signal.

And for which we need to put 0 that means when the DCM is detected, then we will set to 0 inductor current dynamics. And then we need another signal here, which is my q D that means my 0 current detection logic. So, in this what do we need, this block this particular block, these are my different requirements of the input. This is just a constant.

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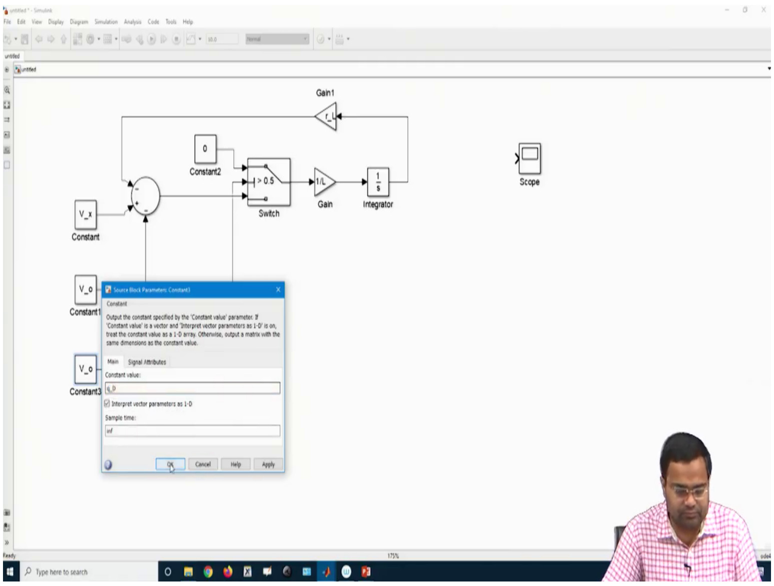

So, if you take it, for this inductor current dynamic realization, this q D.

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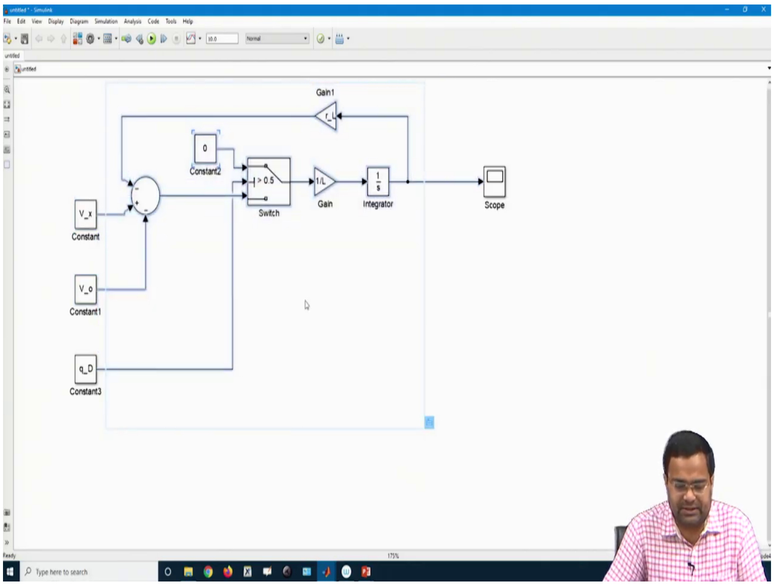

This logic is my discontinuous. This is a logic signal which will be either 1 or 0. If it is 1, it will take the V L will become 0. If it is 0, then V will take V L, that means, induction voltage will be equal to V x minus i L r L minus V 0 that we have already realized ok. So, now, we want to create subsystem ok. So, I want to create subsystems. So, this has scope and that we have already discussed.

So, in this subsystem, this is the block what everything will be inside the block. So, when to create a subsystem, click it a right click, create a subsystem.

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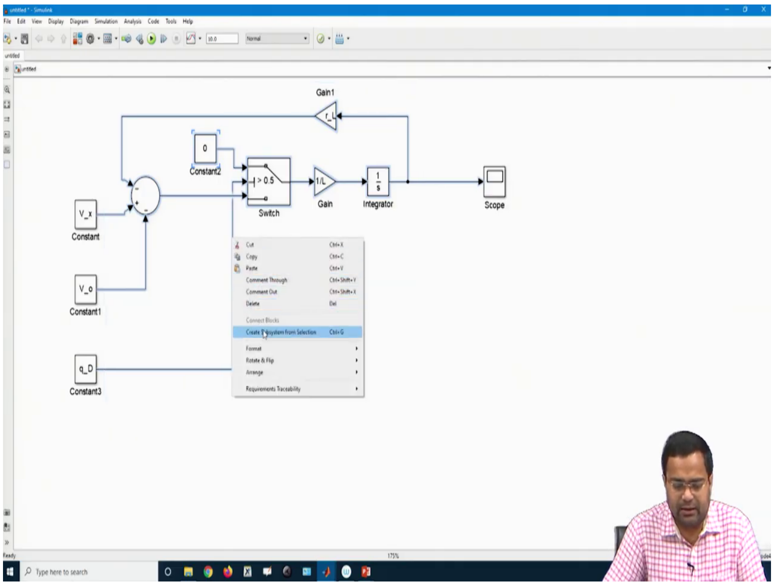

Now, it creates a subsystem.

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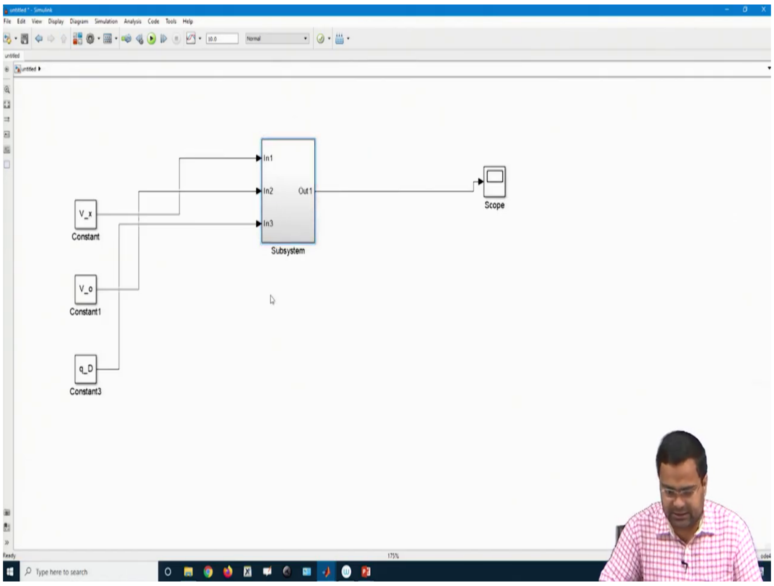

If I go inside, we will go inside the subsystem, so this subsystem is for current dynamics.

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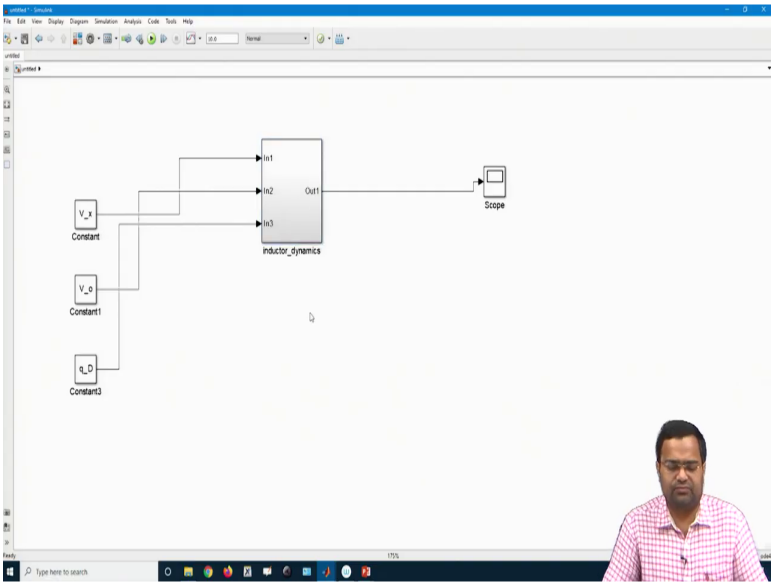

So, for you know it is like inductor dynamics ok. So, it is corresponds to inductor dynamics.

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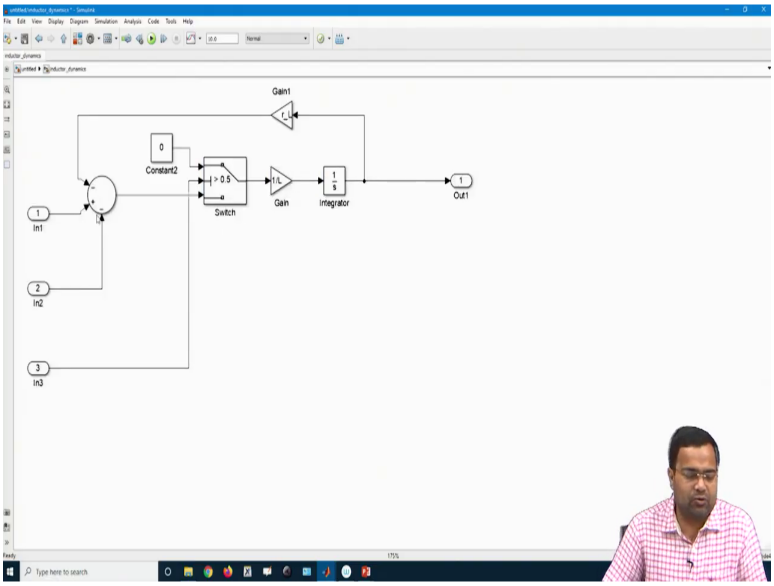

What is the input? The first input we need this is my switch node voltage V x.

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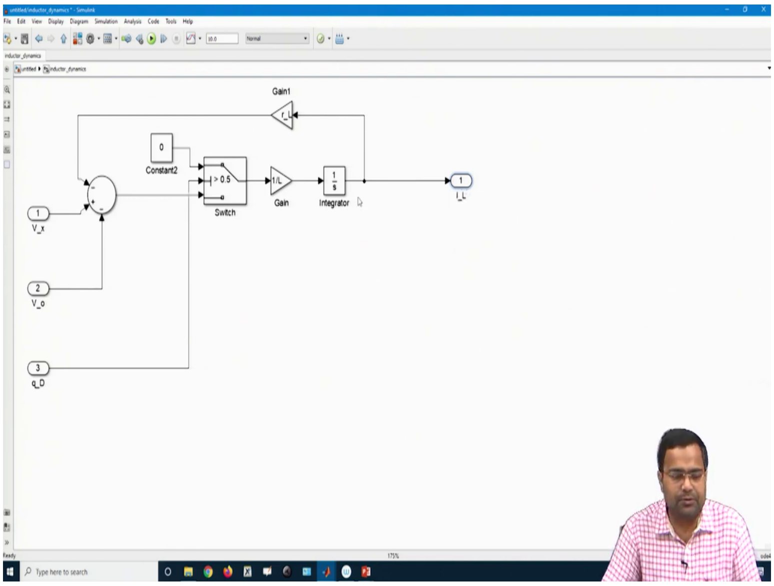

What is the second input? This is my output voltage. What is the third input? This is my q D, q D. And what is the output that I want here is my i L that is my inductor current.

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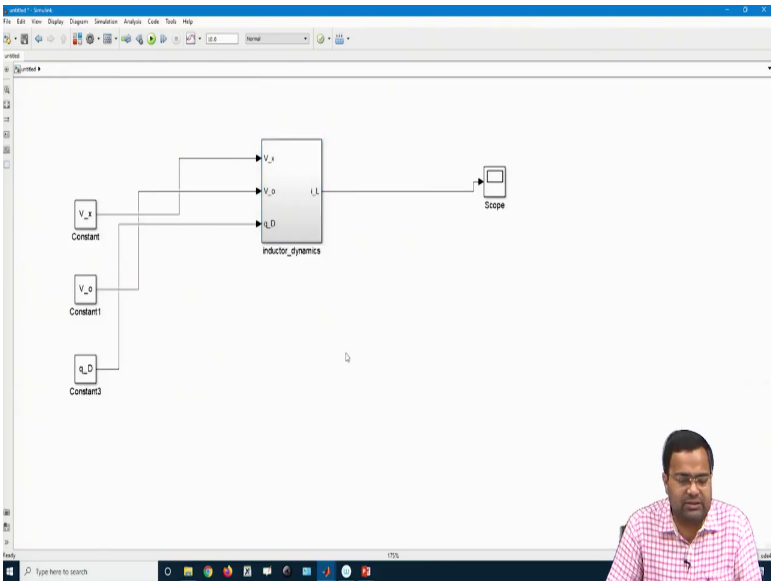

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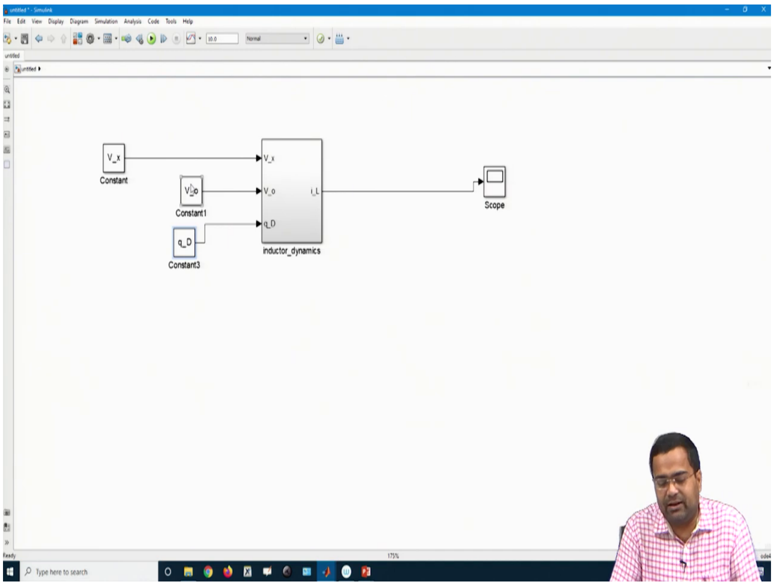

So, this is consistent that you know we have connected V x to V x, V 0 to V 0, q D to q D, but neither V 0 is available not q D is available nor V x is available. So, you cannot generate inductor.

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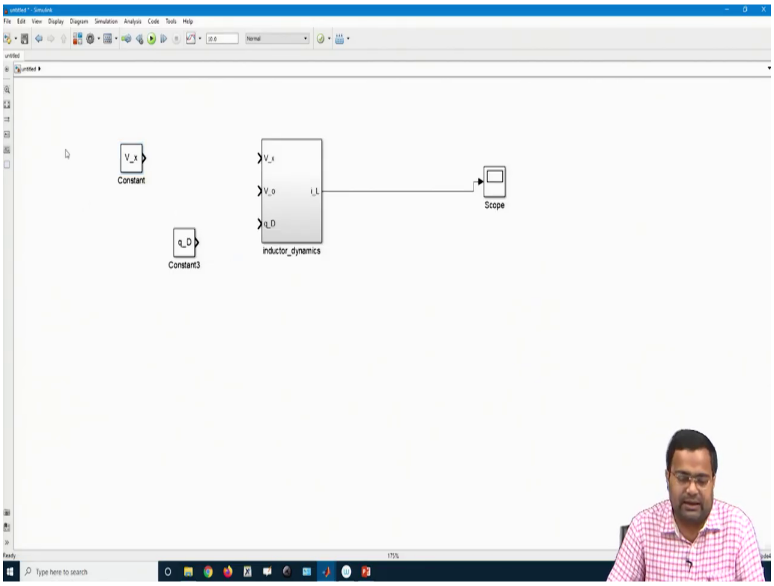

So, we will keep this block by inductor dynamic. So, you need to generate these blocks also.

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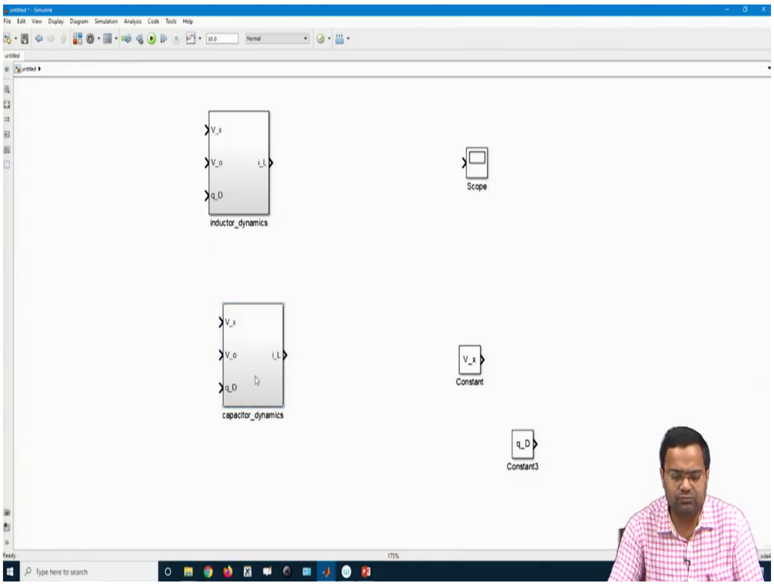

So, this is the first block we have to generate is the current dynamics. You really do not need to connect a scope at this point of time. Now, since we have already created a subsystem, we can create another subsystem for voltage dynamics. So, it is for capacitor dynamics, capacitor dynamics. That means, what is there for this? What is the input to the capacitor dynamics? If you go and see, this is my capacitor dynamics.

If you go to the previous slide ok, so previous slide ok, so this is my capacitor dynamics, that means, what is the input to the capacitor dynamics is the inductor current, and all other elements are and another input is the load current. This is my load current–one input; the other input is the inductor current. And output is capacitor voltage and output voltage. So, you can keep capacitor voltage and output voltage ok.

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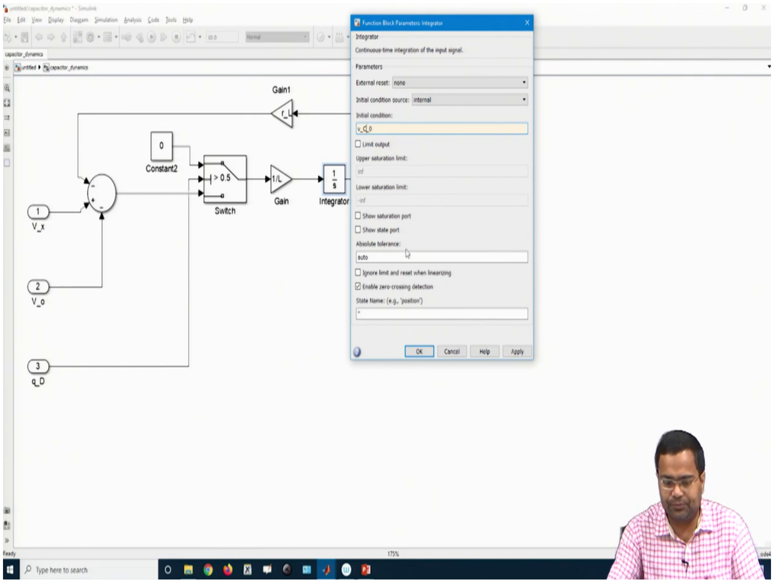

So, with this let us go to the Simulink block. Here we will write v C, it is a capacitor voltage.

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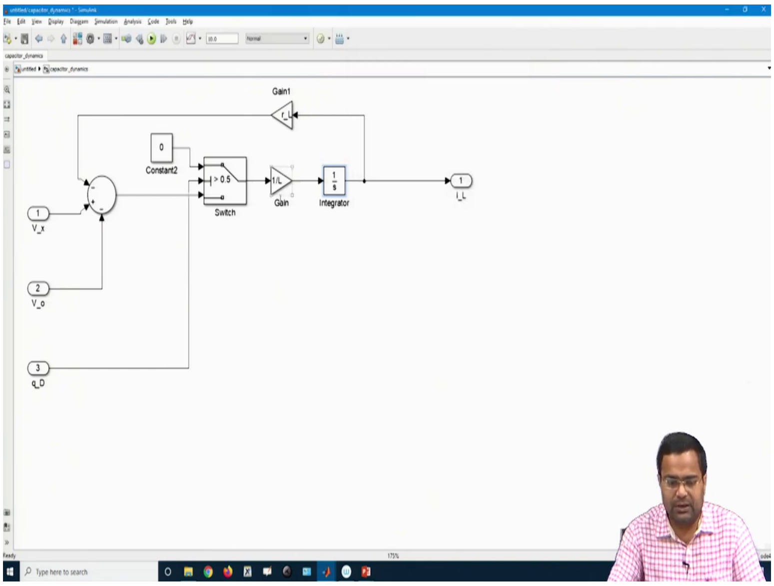

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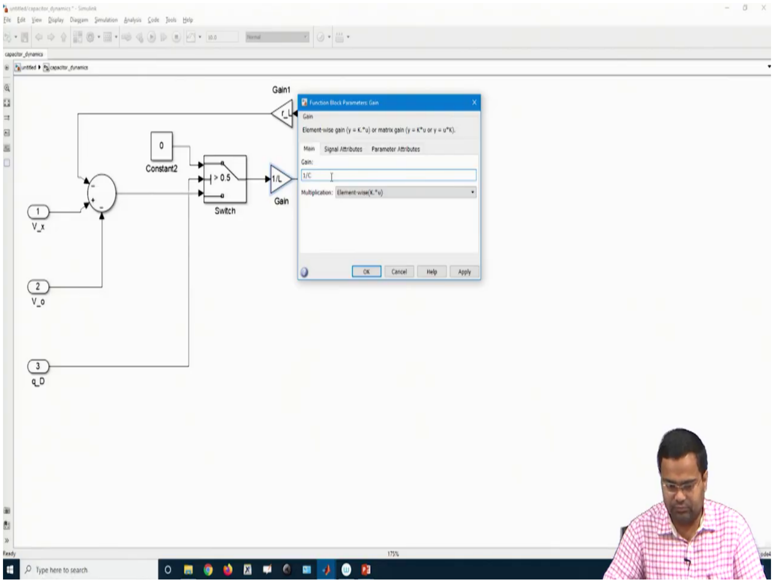

v C 0 and this should be 1 by c.

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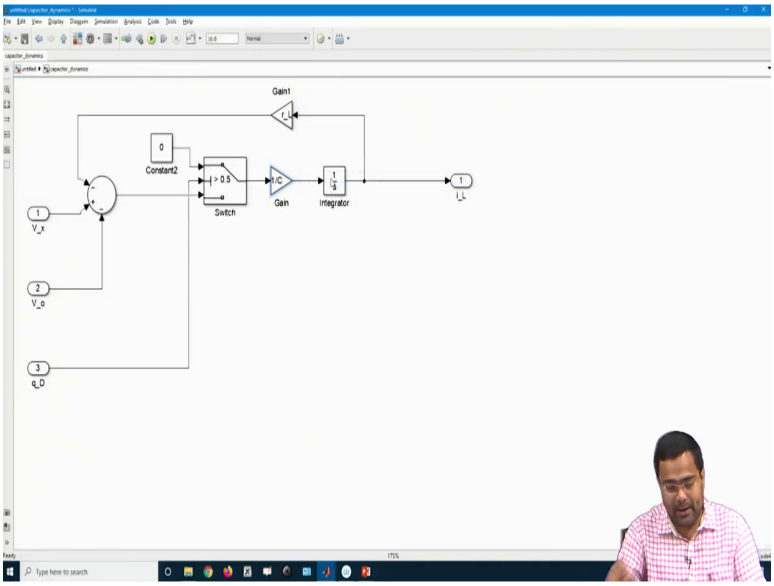

Here we do not need any switch.

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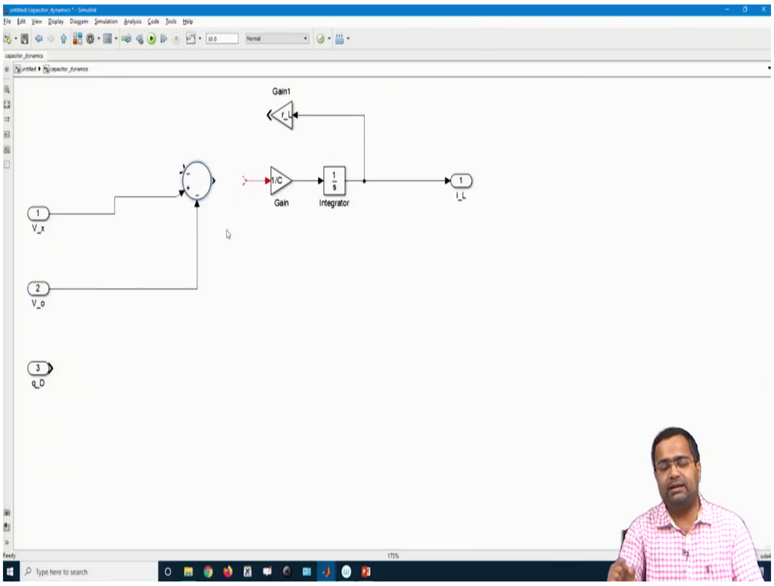

It is simply what we need? We need inductor current minus load current ok. So, we need inductor current minus load current that is my capacitor current.

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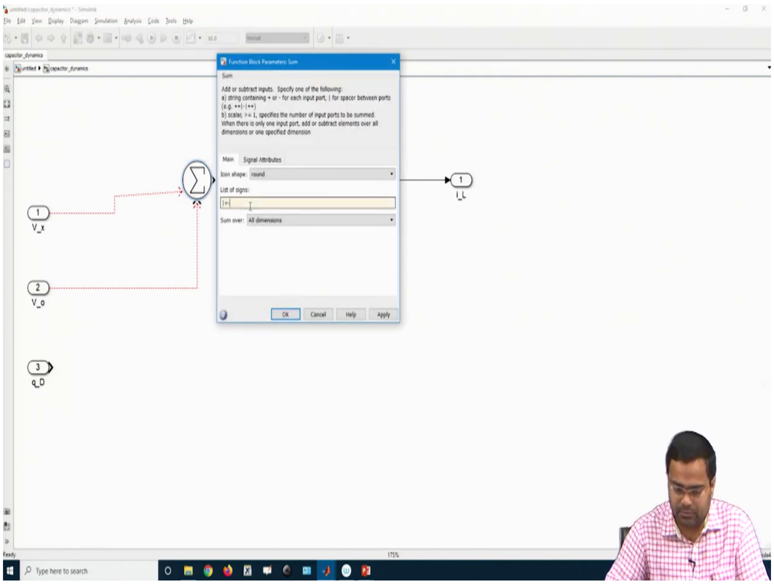

If I take this up to the summing block ok.

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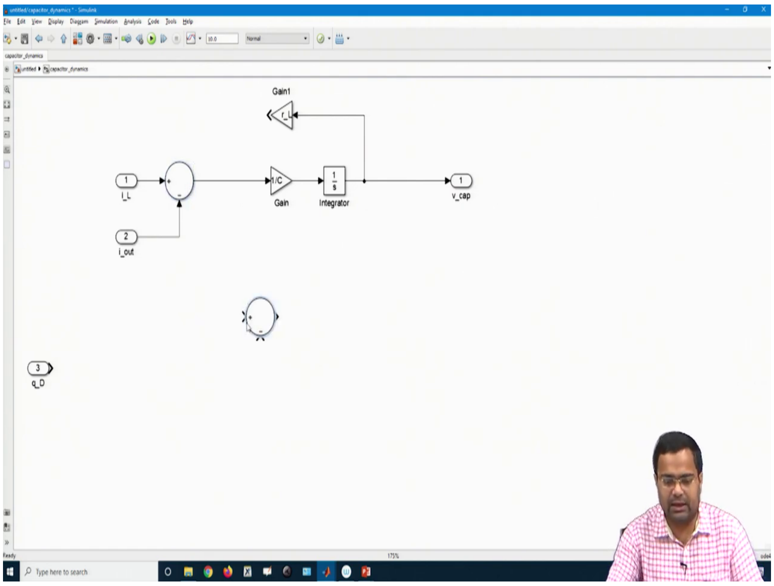

So, this will be what? This should be my inductor current. actually there it is repeating. So, here we are talking about V c, V cap capacitor voltage, and here we can take i L ok. So, this is my inductor current dynamics. Then I can use load current here. I can use I_out output current. If you subtract, this will become my capacitor current, and this is my capacitor voltage.

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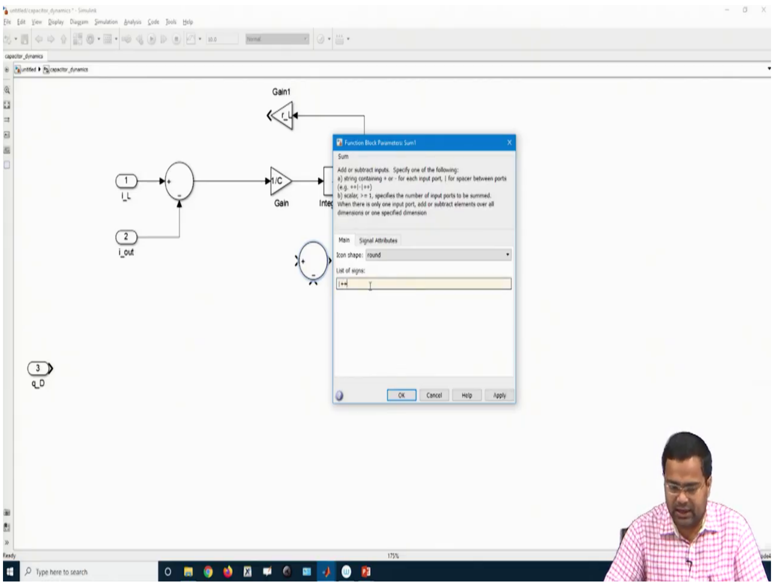

And then what is the output voltage? It is the capacitor voltage plus the drop across the esr.

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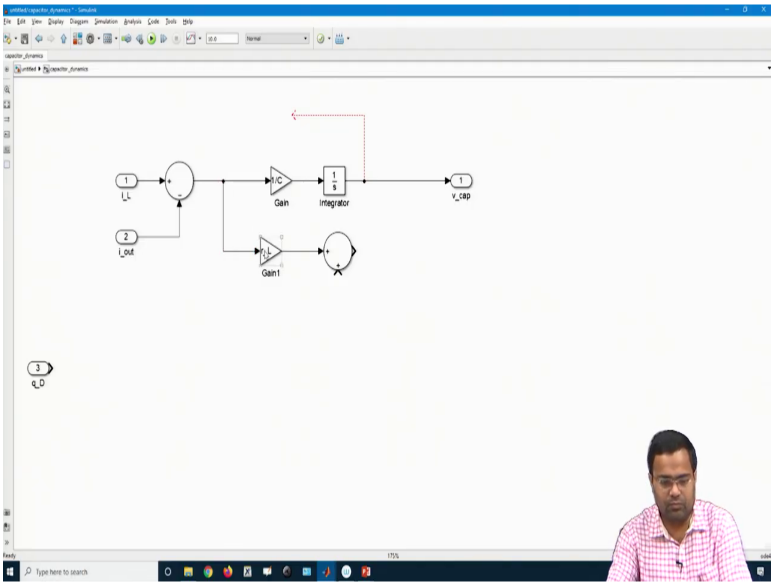

Which is r C into i C; that means, I need to use this block.

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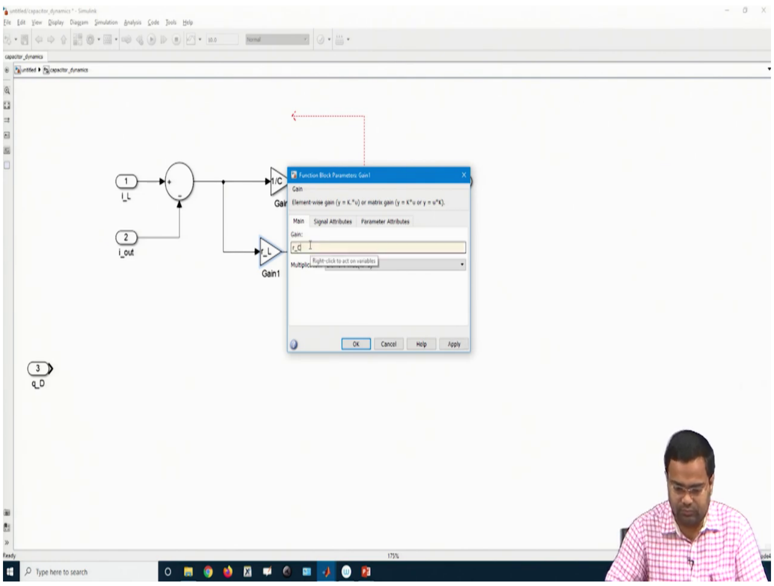

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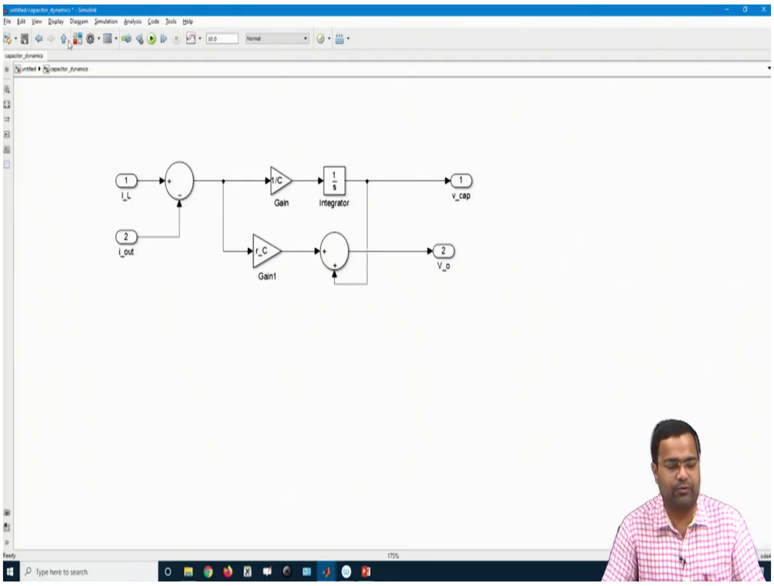

And this block is my r C, the symbol must be consistent; otherwise it will give error ok. So, now we are ready, this is my output voltage. And what else you have to add? You have to add the capacitor voltage and that will give rise to my output voltage. That is my V 0, yes. So, do not need. So, this is my output current output voltage dynamics.

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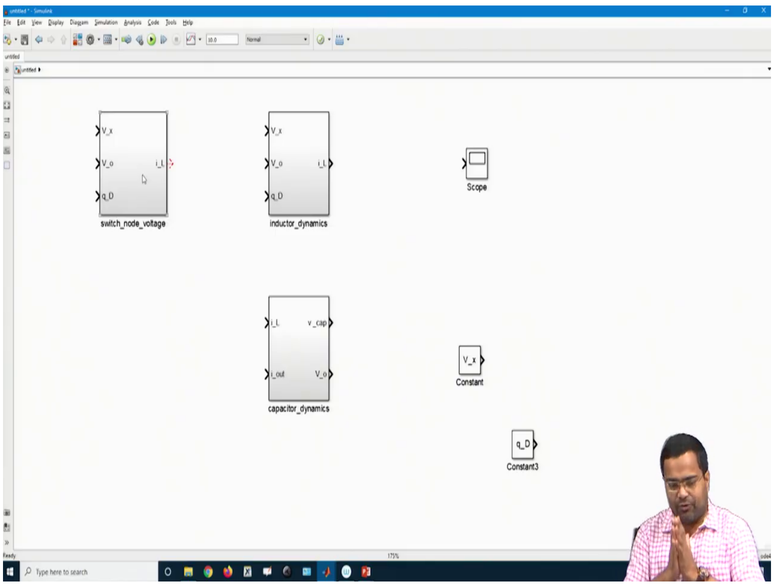

That means the capacitor dynamics I got it. It consists of it require input as an inductor current and output current, and then capacitor voltage and output voltage. And you will see for our resistive load, the output current is nothing but output voltage by resistance. So, you can add a scaling factor outside, so that I will discuss ok.

Now, what else we require? The next block is require the switch node voltage, that means V x is not known. So, we need the switch node voltage ok. What is the input to the switch node voltage? In switch node voltage, if you go to the circuit, what you will find? The switch node voltage is I am talking about this particular part.

So, it consists of input voltage minus when the switch is on this is input voltage minus the on resistance of the high side switch into i L the current when a switch is off it is minus of V d i d r d into i K; that means, a diode drop into r L let us see ok. Just switch node voltage, we can go for switch node voltage. So, what is the input? So, what output we are talking about?

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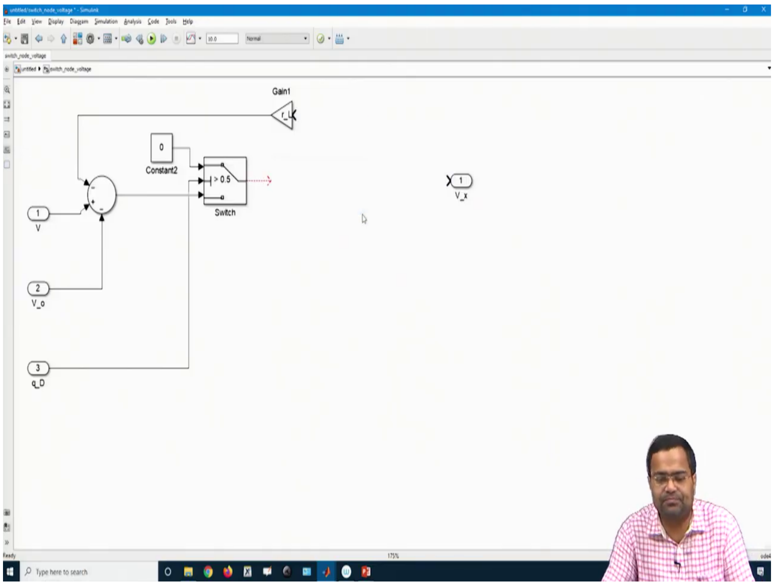

So, this is let us say. So, output is V x we are going to use the switch node voltage V x is my output I do not need any dynamics here.

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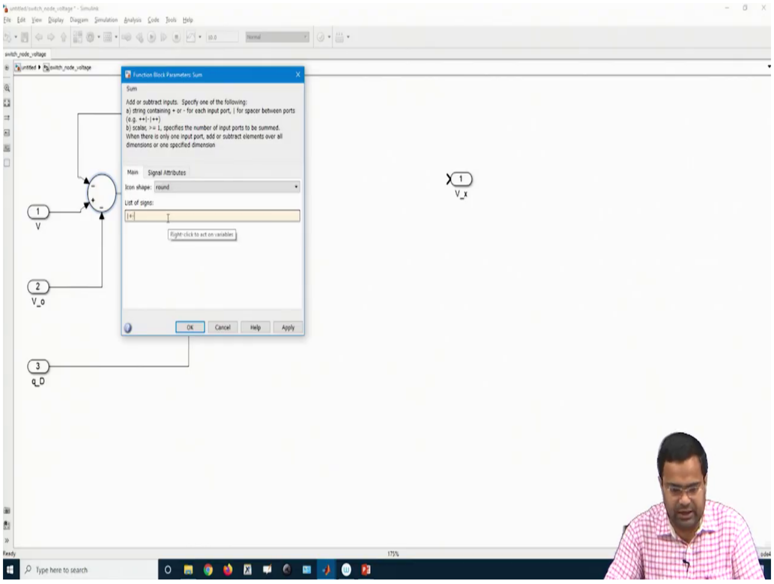

Switch node voltage.

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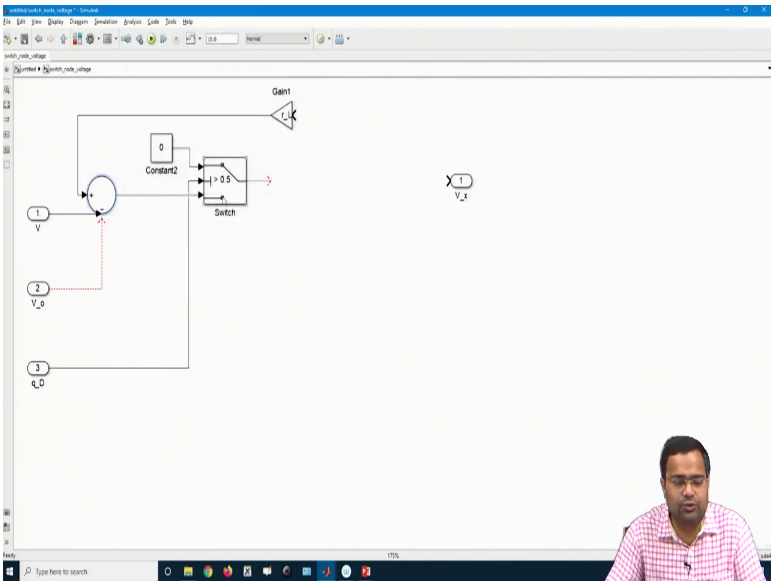

What is switch node voltage? That is equal to V in minus sorry, yeah fine.

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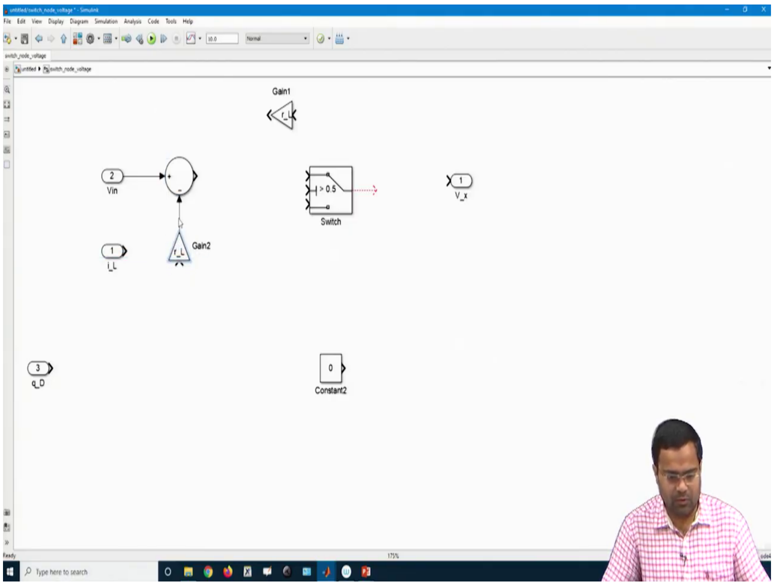

So, just a minute we disconnect all these path. So, first let us figure out what is the switch node voltage. So, here we are taking inductor current as a input sorry it is the input voltage inductor current, let us not connect ok. So, we need first is that input voltage V in – input voltage. So, we need input voltage? Yeah, we need input voltage V in. So, V in should be connected here. Then what is there? I want i L into r 1, i L into r 1 is my another one ok.

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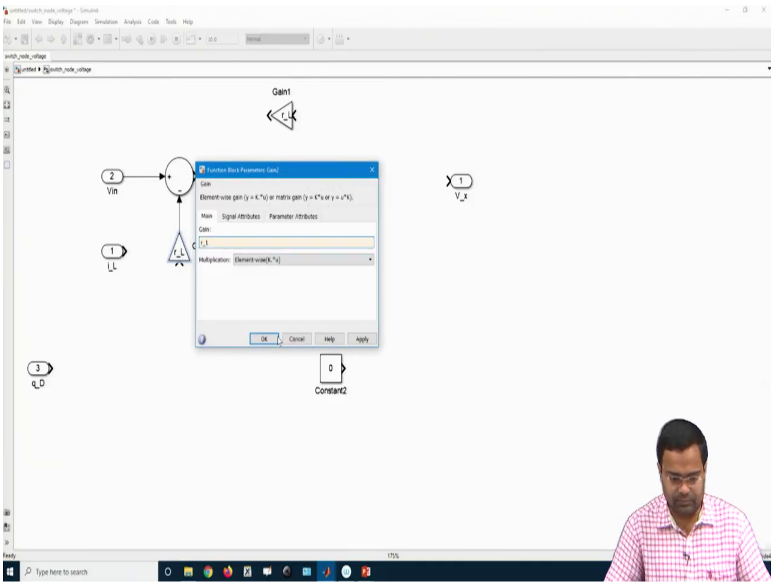

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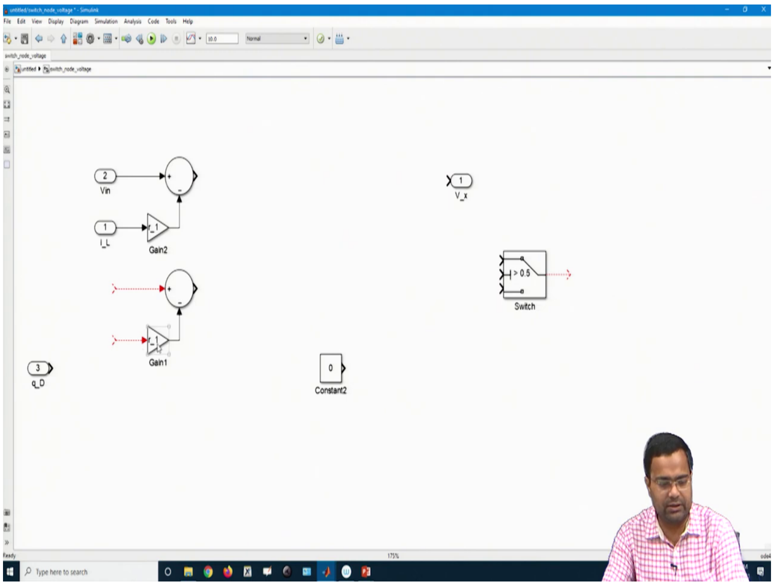

And next one this is my first one. In fact I can use like. This is the other one that I can take, yeah. So, here it is minus V d ok. So, I do not need.

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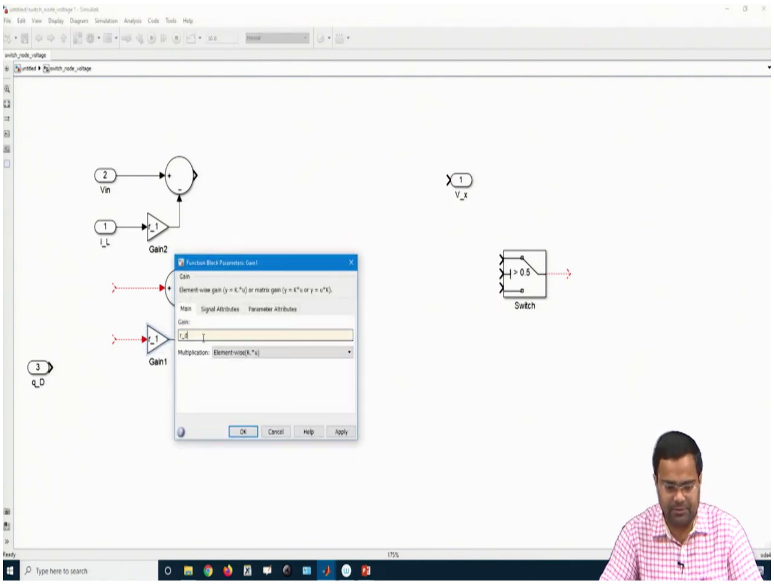

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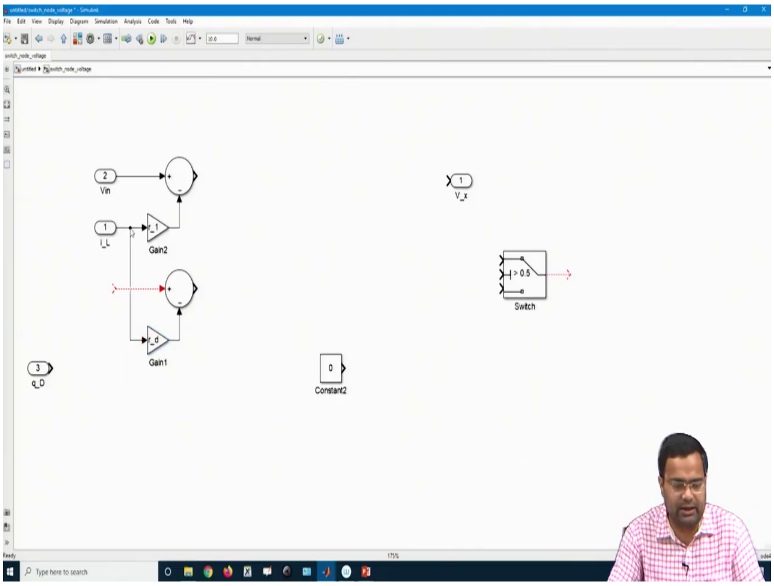

This is my r d the diode resistance multiplied by inductor current.

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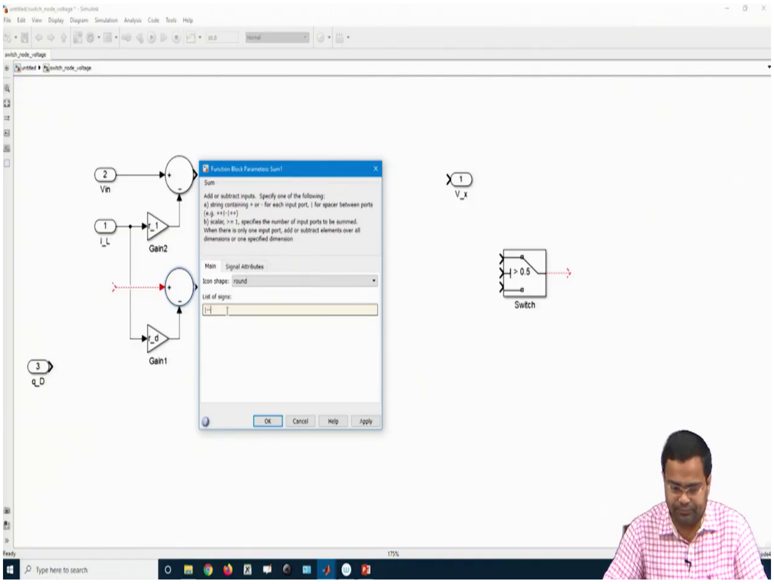

And these diode drop all are negative.

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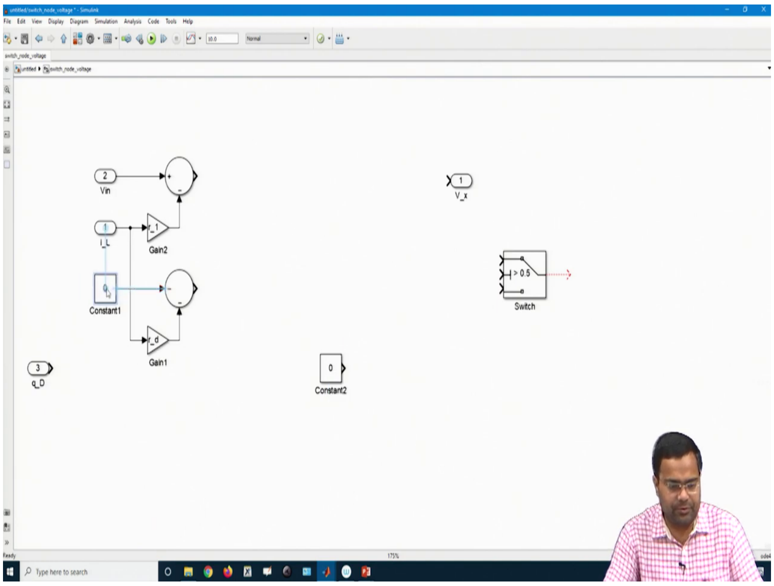

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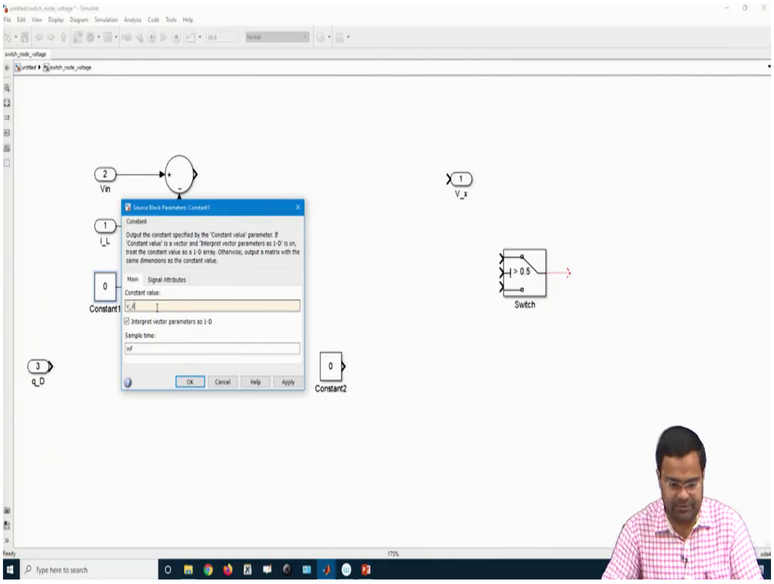

So, constant is my diode drop. So, this is simply v underscore d, v d.

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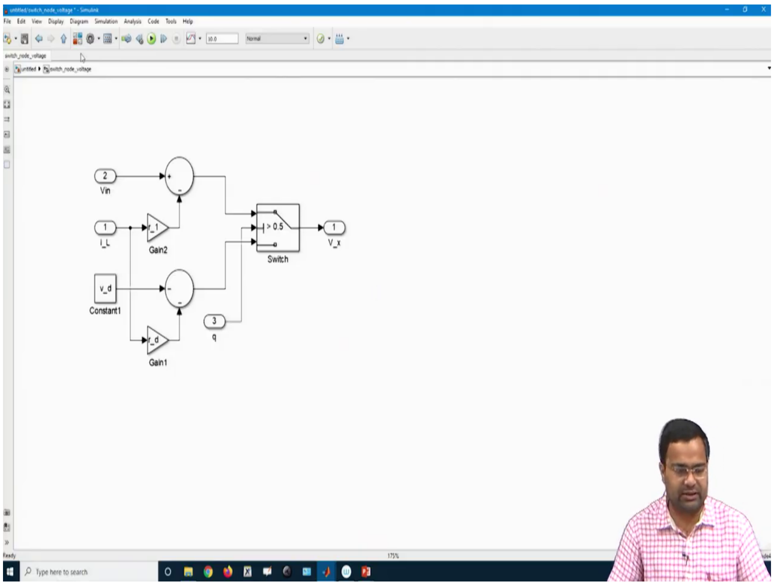

And then we have to connect a switch. So, it will take the first input when the switch is on; otherwise, it will take the second input when the switch is off. And this q is my q it is my gate signal, that is it and that is my V x. So, we have generated V x. When the q is 1, it will take the first input; when the q is 0, it will take the second input.

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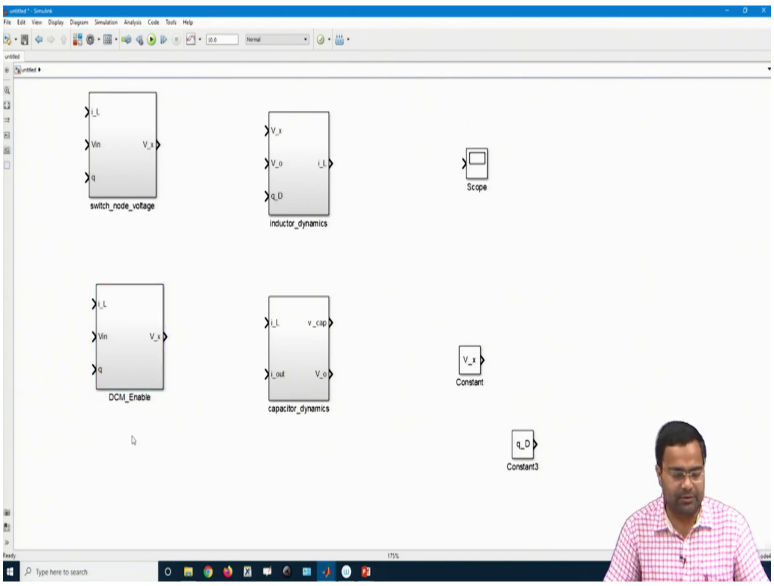

So, we have developed this V x. Next part what is left is that DCM enable block. The next part is require is that DCM enable block. What is a requirement here? We need to sense inductor current. And also as I discussed inductor current is there, we also need to I can remove all these stuff here.

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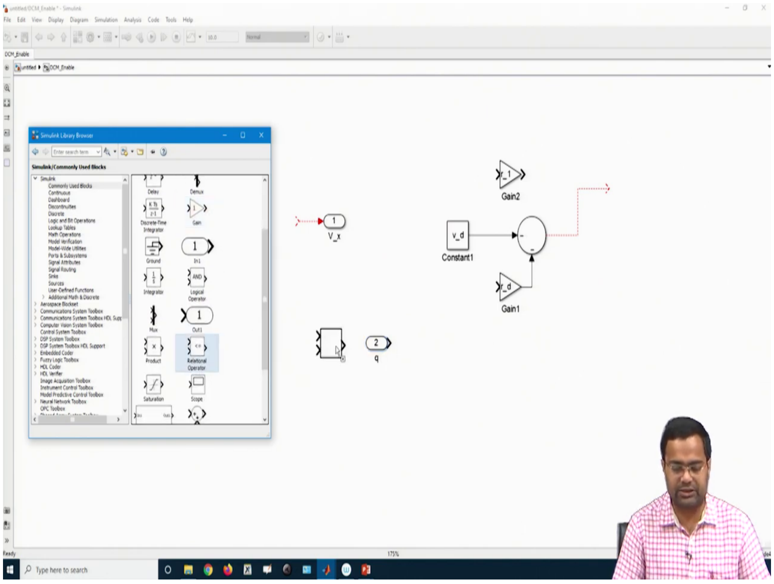

Because of this I just copied pasted from the previous block. So, we do not need input voltage here. We just need inductor current, all we can keep this side no require. What we need to do? First inductor current should be compared with zero current that means, we need logical block comparator ok relational operator.

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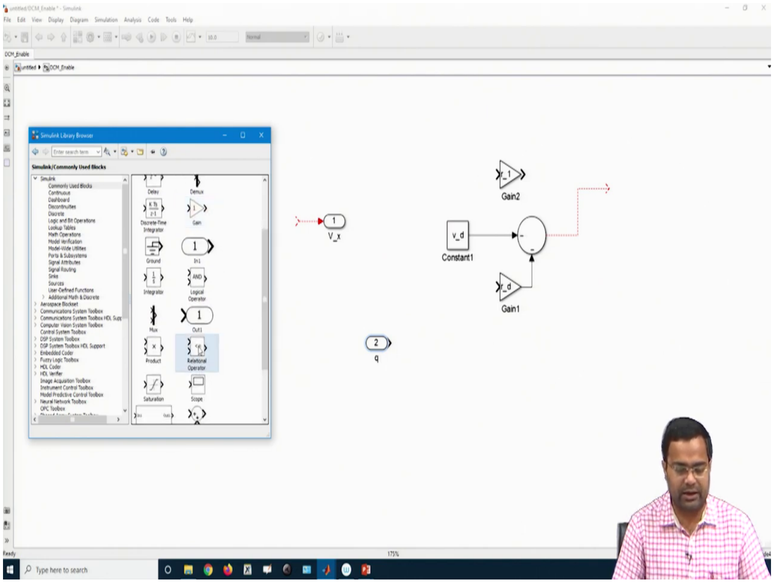

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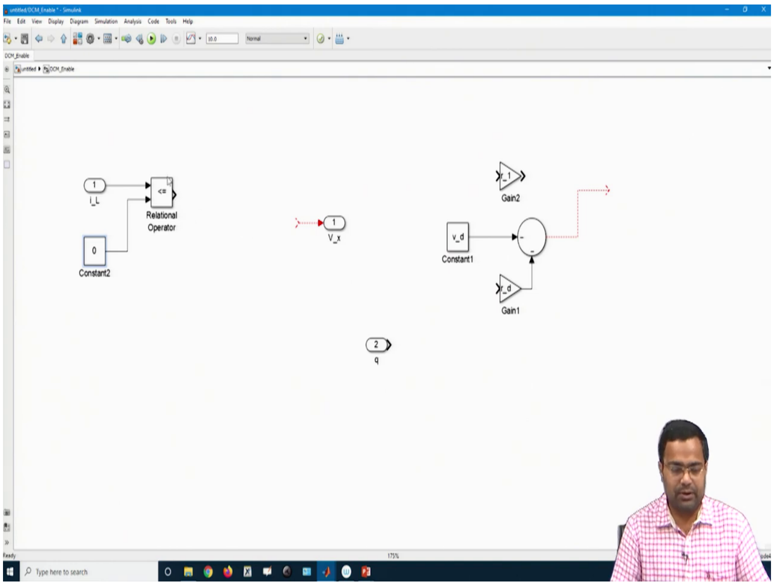

Now, we have to check whether inductor current is less than 0 or not. So, these are first input. And what do we need to compare with? With 0, this is only 0 ok. So, if the inductor current goes below 0, then this output will be high.

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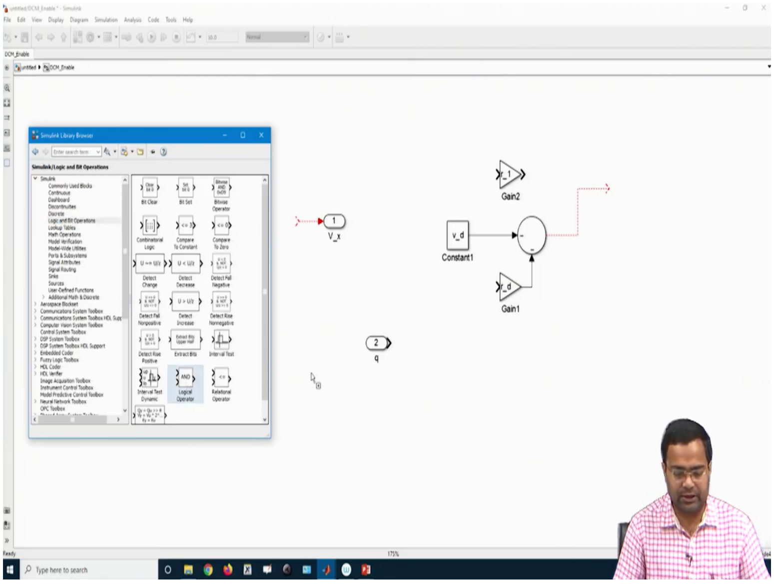

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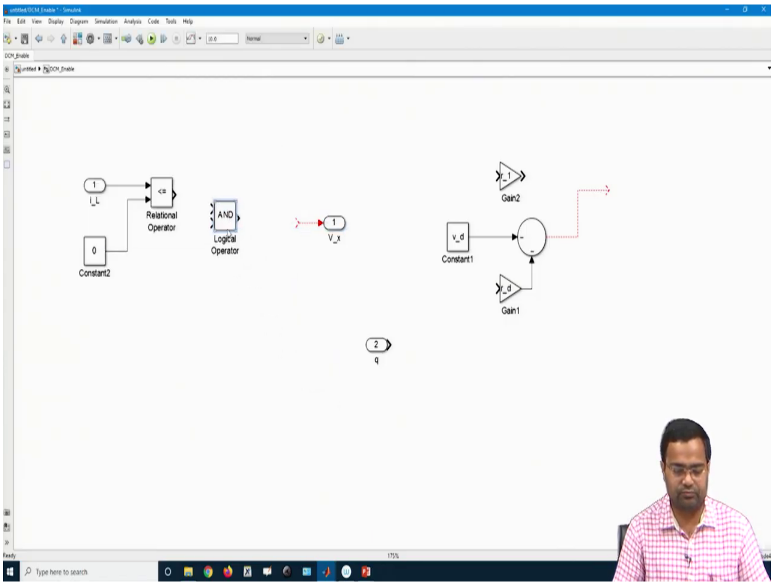

Now, we need you know logical logic block, that means, logic it and logic.

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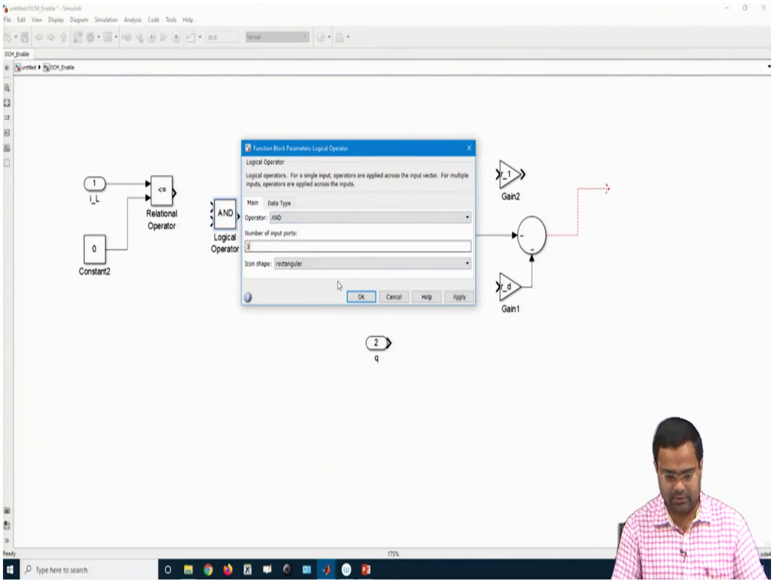

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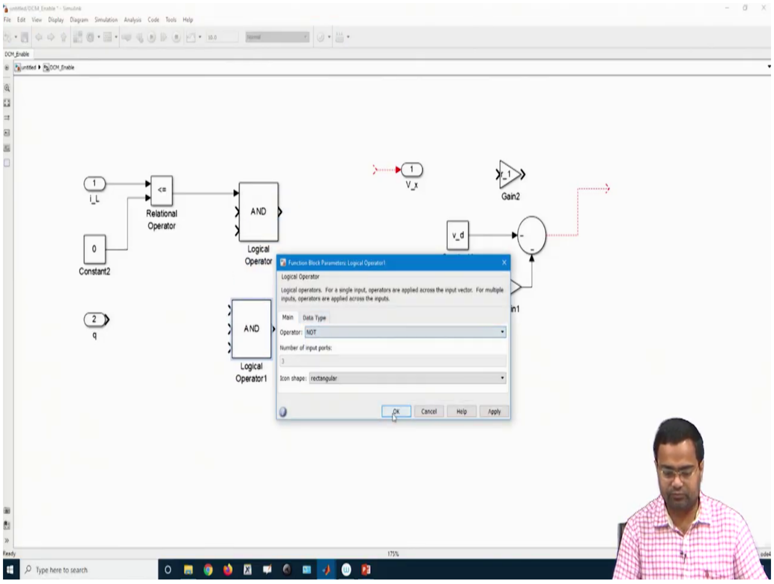

And we need 3 input AND, 3 input AND. What are these? What are the first input? We have discussed this 0 detection circuit output is one of the input to the AND gate.

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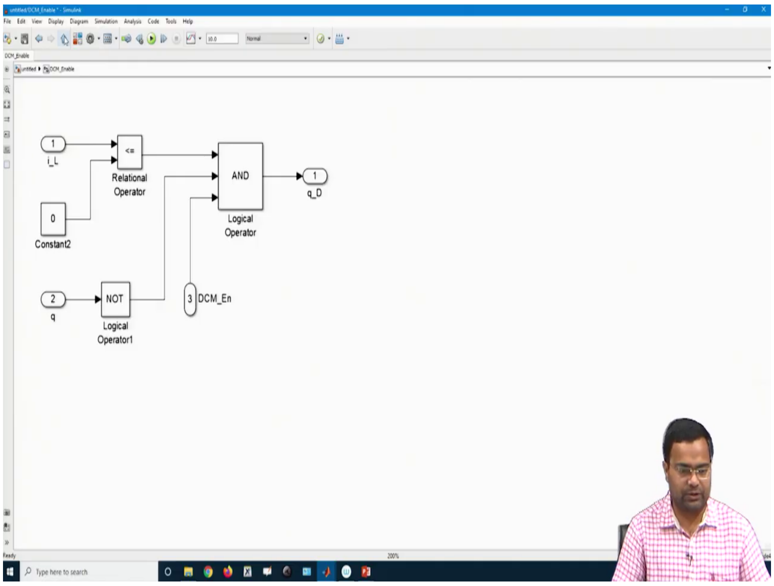

Then what is the other input? The inverted logic of the switching signal, that means, we can create another NOT gate, smaller size NOT gate; this block we have and we need to give a DCM enable logic, which is our when say DCM enable logic, which can be set to either 0 or 1 logic. And the output is my q D here. This is my q underscore D that is it where more or less than.

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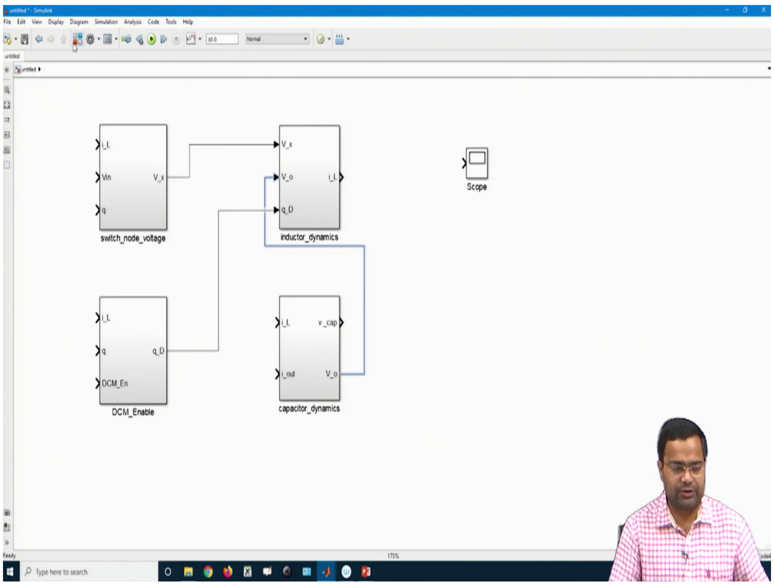

Now, we are ready to go for the next. So, now, we have DCM enable block; we have switch node block, inductor dynamics, all these blocks are there ok. Now, we want to slowly connect different, so that means, this V x should be connected here the switch node point. So, we need to bring a little bit down ok. Then output voltage should be connected here ok. Then q D should be connected here zero current detection.

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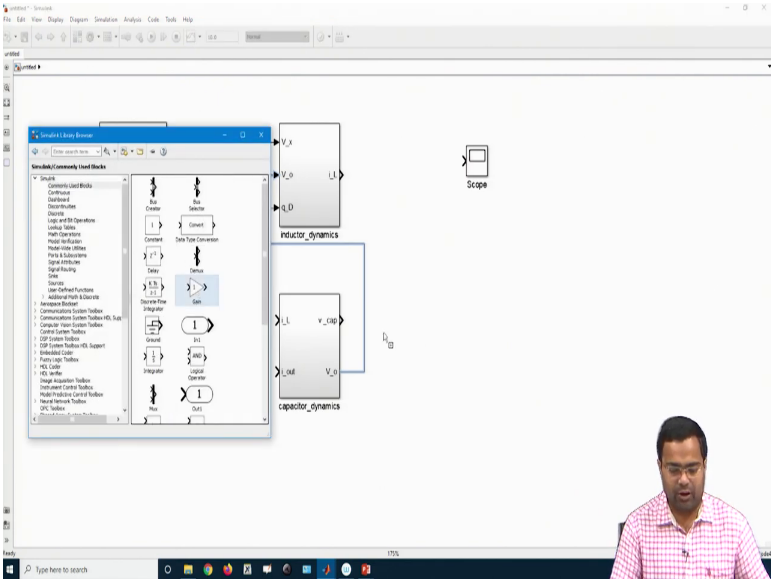

i out that means, we need to consider a gain block here which is 1 by R that is my load resistance.

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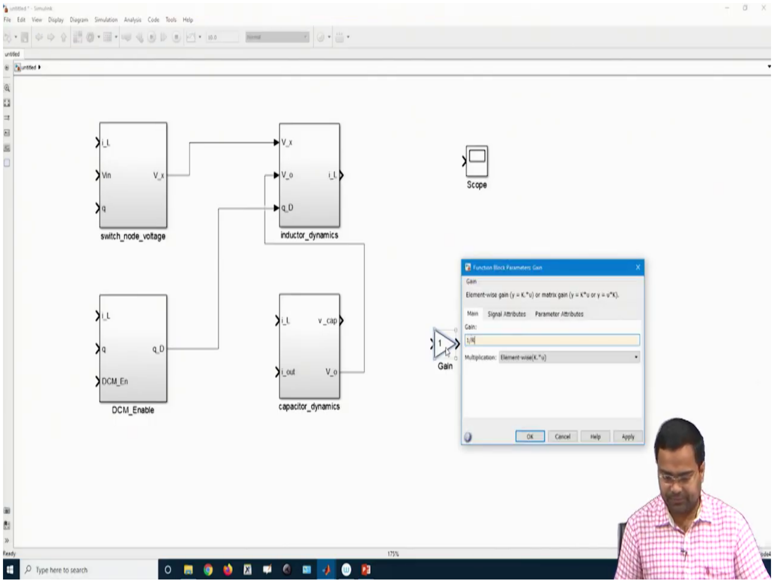

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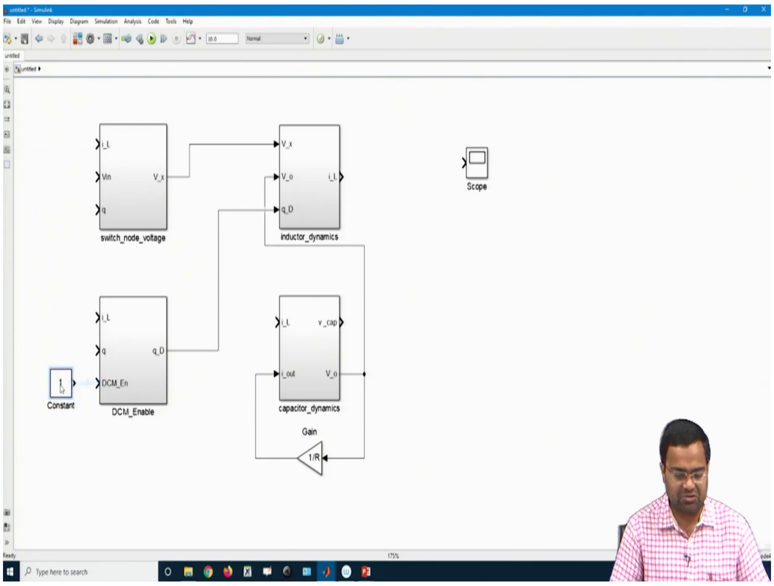

But I can use, I will show you I can use constant current load also combination there is no problem i out ok. Then for DCM enable, I need to consider a constant.

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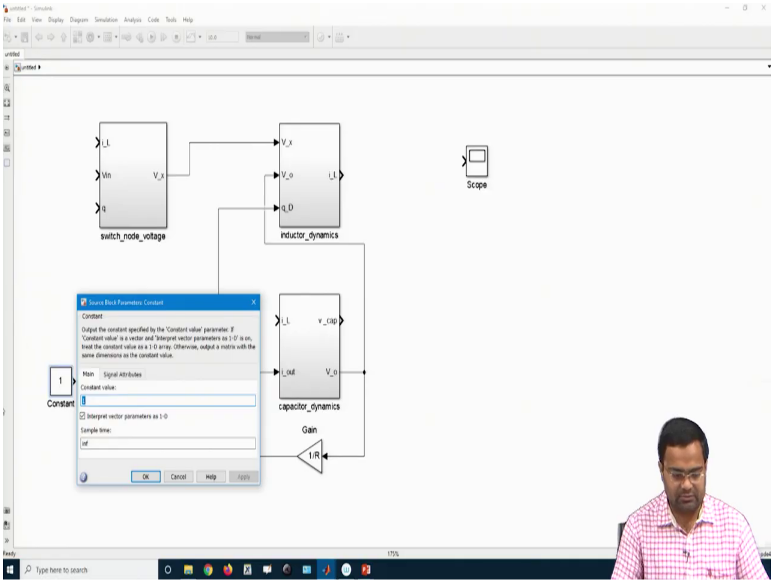

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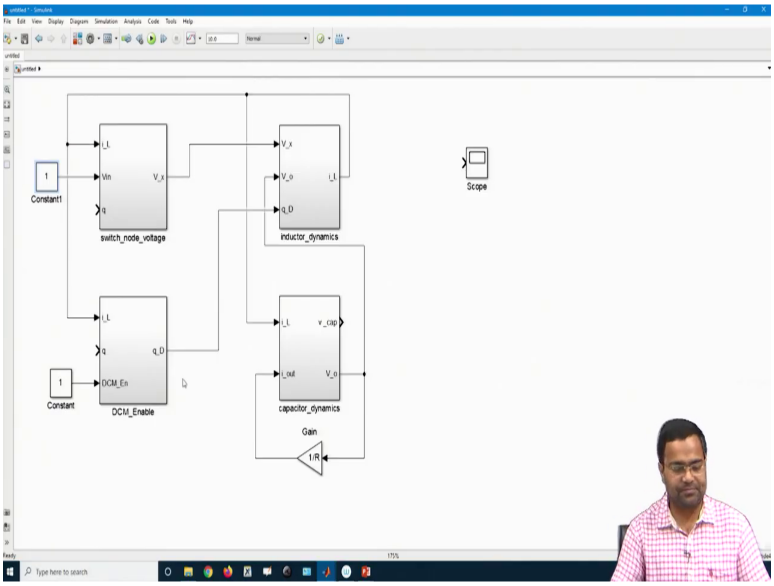

Constant which can be you can set to 1, then the DSM will be enable; if it is set to 0, it will be disabled. I need to use a proper gate signal you know so that is my input is required. And I need to connect through the inductor output. Then inductor current is also required here ok. Now, I need to consider input voltage, here also I need inductor.

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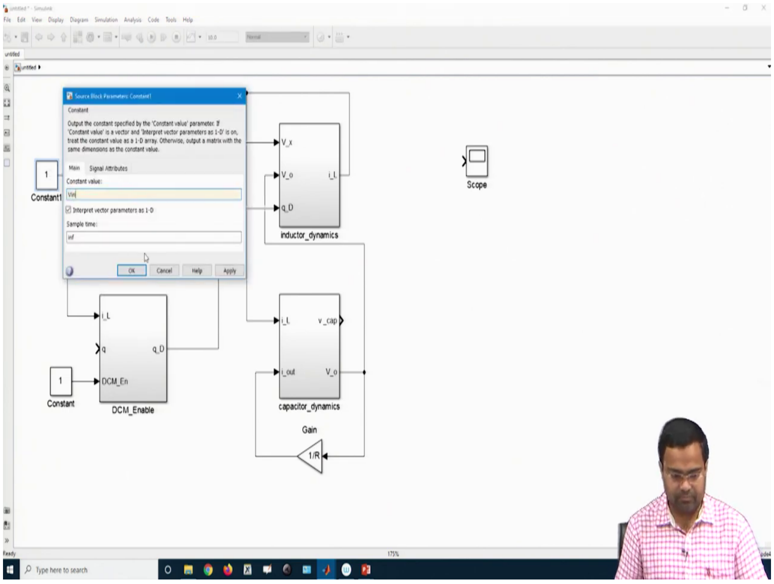

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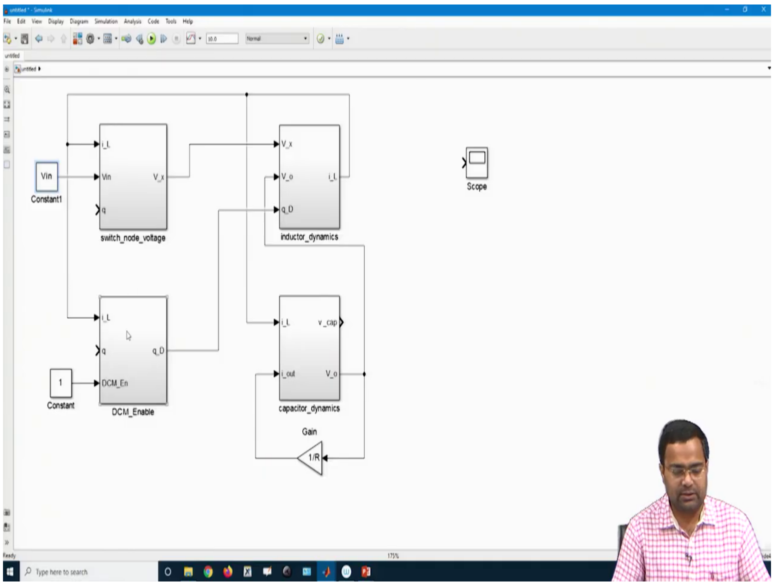

Then input voltage is my V in alright.

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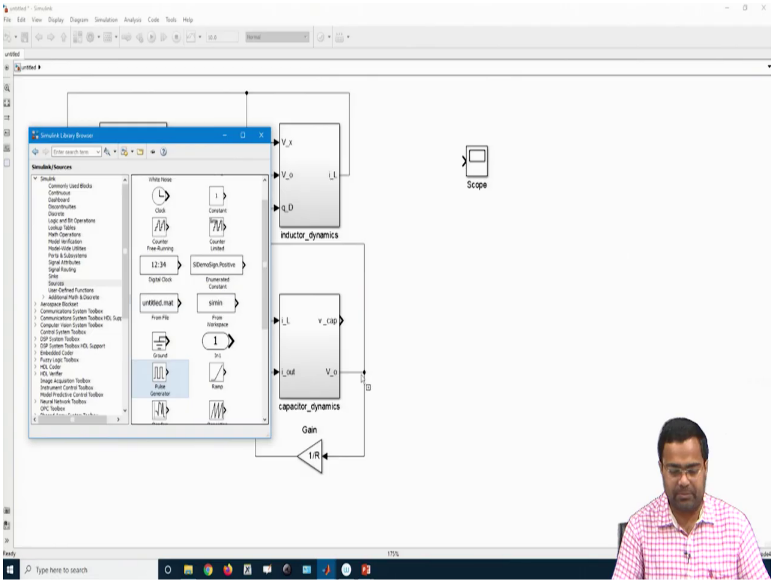

Then I need to consider a source.

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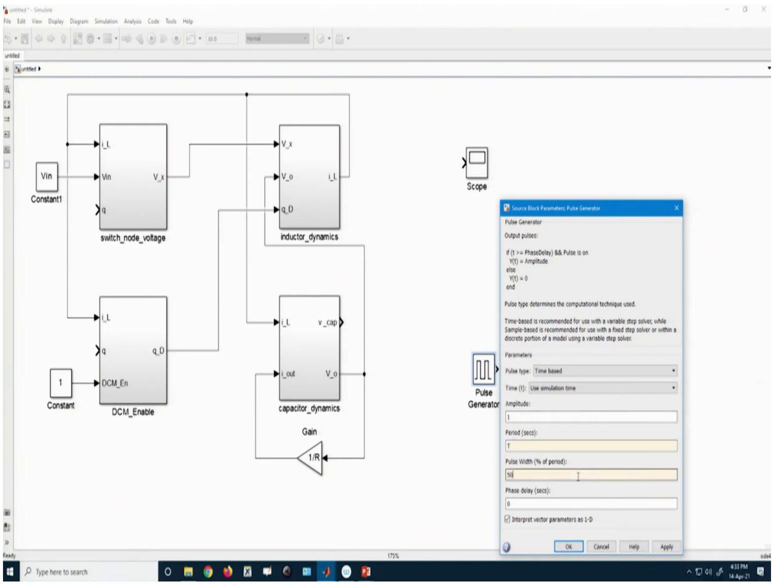

And here I am taking a pulse width source. The pulse width source amplitude is 1, time period is T. And let us use a 50 percent duty ratio.

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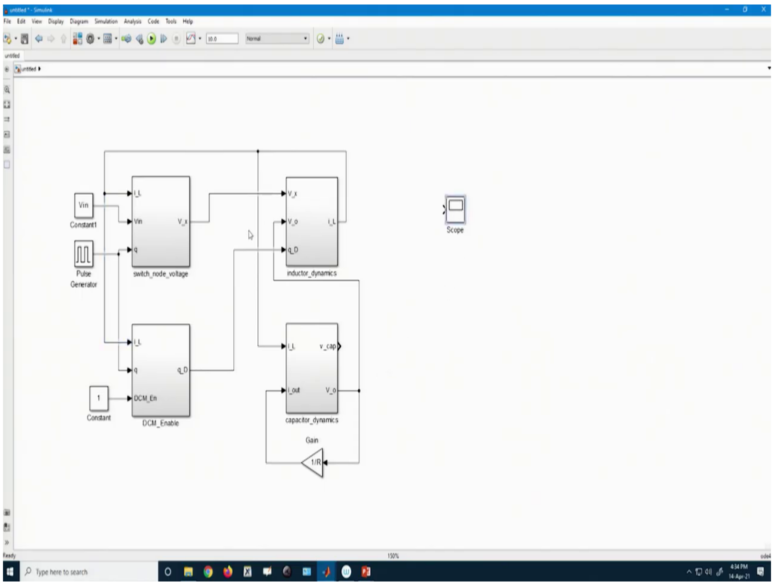

And that I am using for you know semi converter, yeah. So, I am using a pulse here for my switching. Right now, I am using a fixed frequency pulse now same is connected here 50 percent duty ratio.

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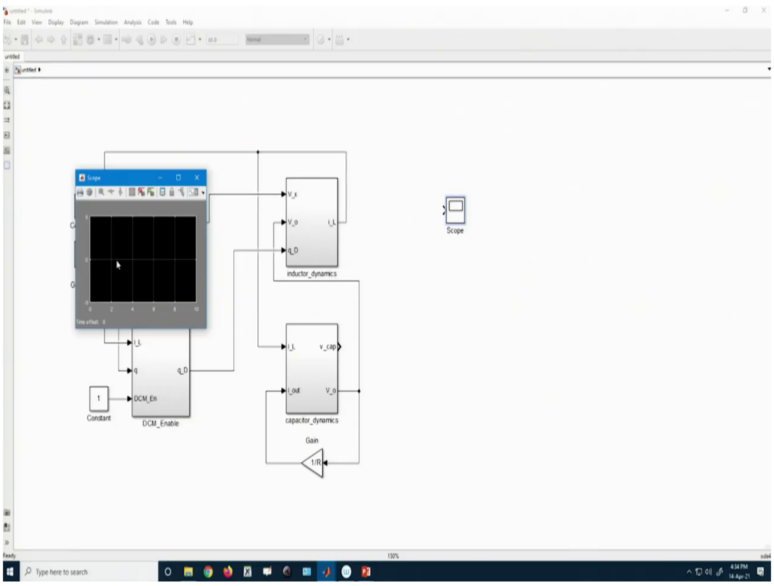

And I want to see various output like you know.

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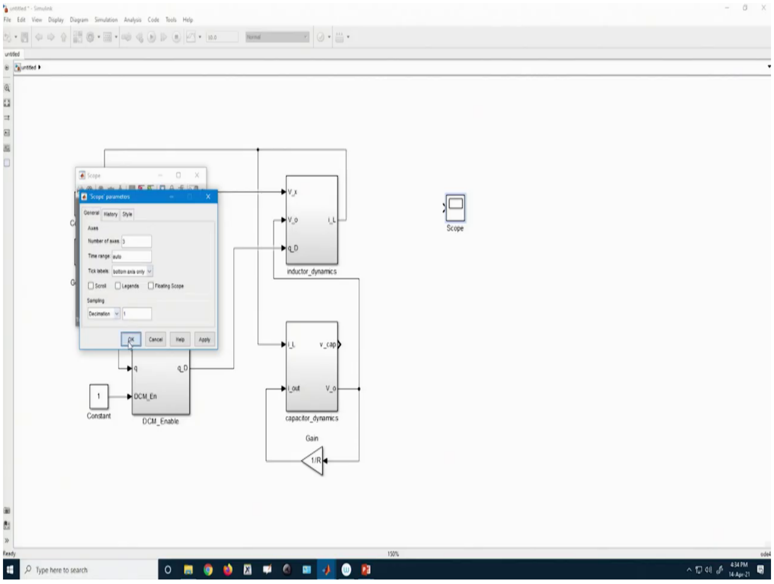

So, I need to check three axes.

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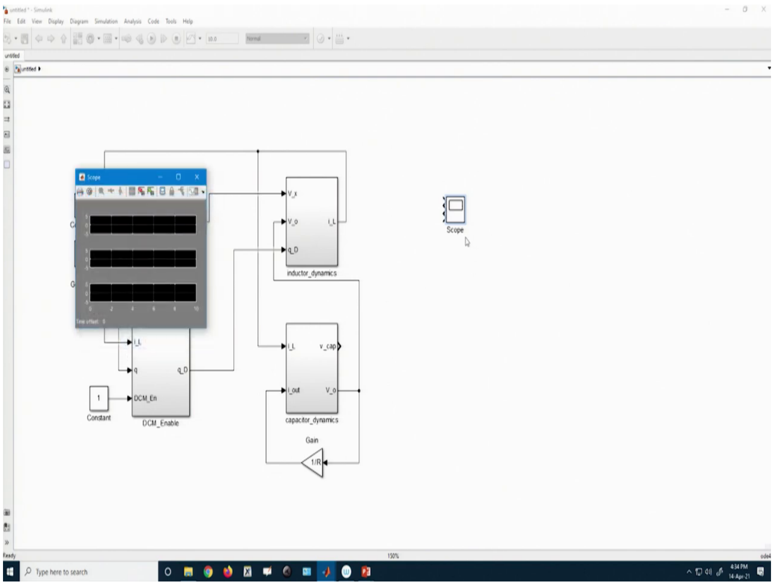

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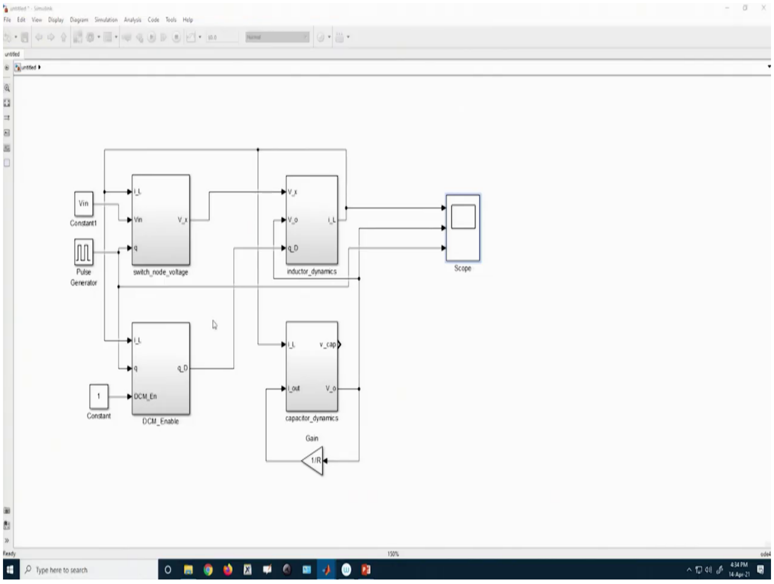

So, one will be my inductor current. The other will be my output voltage. And the third one is my gate signal which is connected here.

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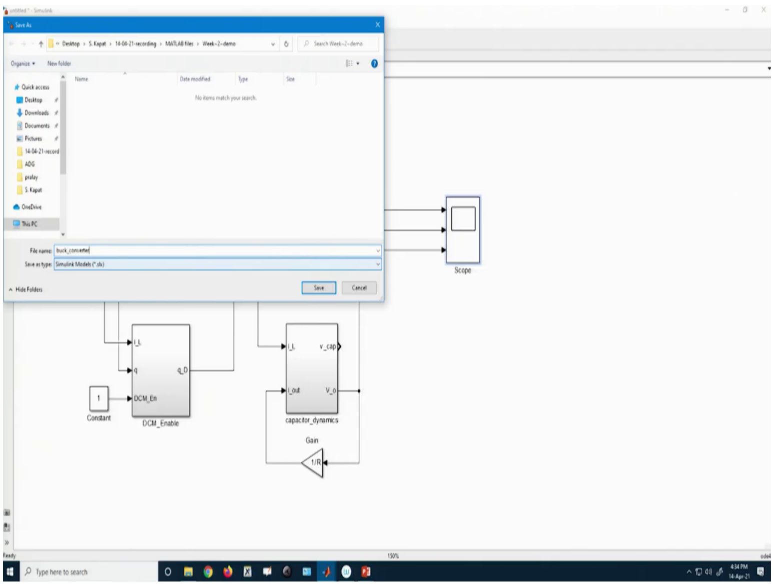

Now, we are ready and we need to give a name here. So, it is a buck converter that is it.

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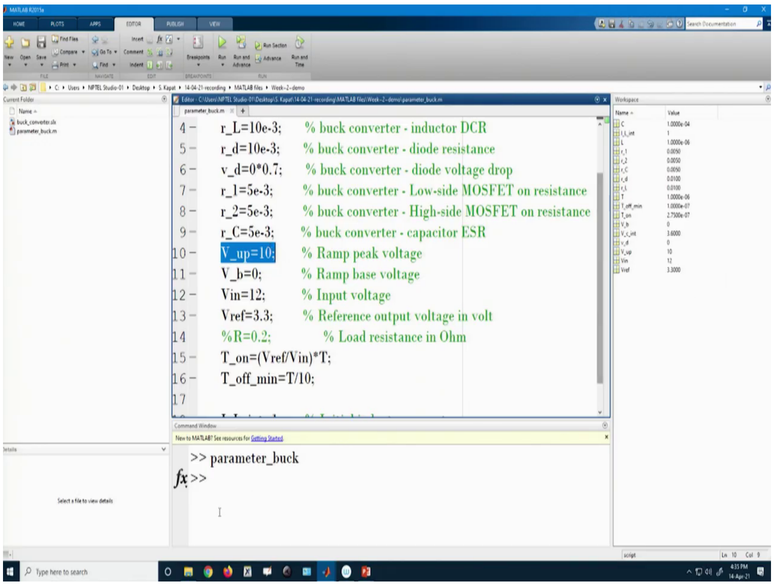

Then what else? Let us go to the simulation file. We have defined all these parameters. We have to run this parameter file first. Then the values are loaded here. Then let us try to run it.

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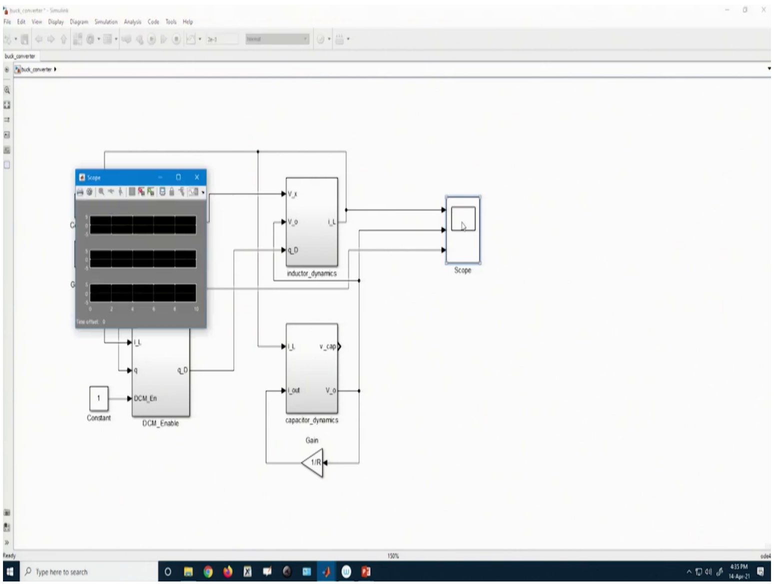

So, it will run for 2 milliseconds and see what happened.

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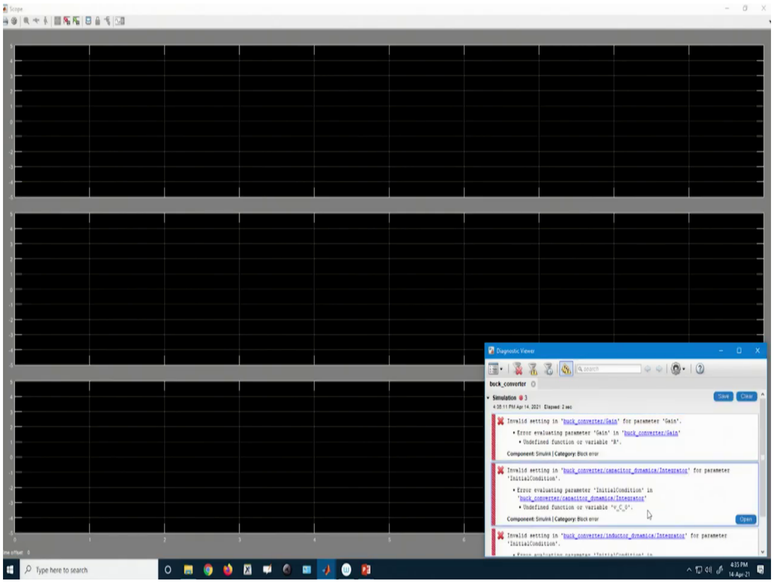

So, some of the gains are not defined like r, vco initial conditions are not defined. So, we need to define those parameters as well, that means, i L 0. What are the symbol that you have used here for current dynamics?

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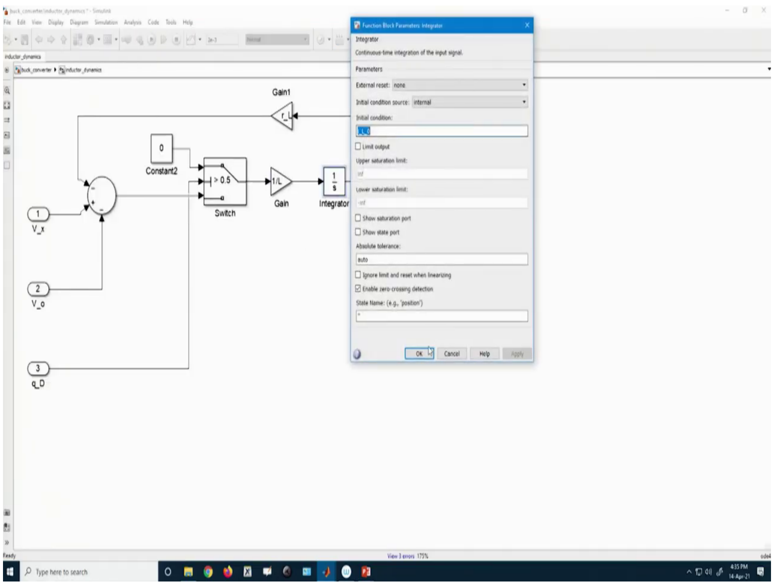

i L 0. So, that we need to set here i L 0.

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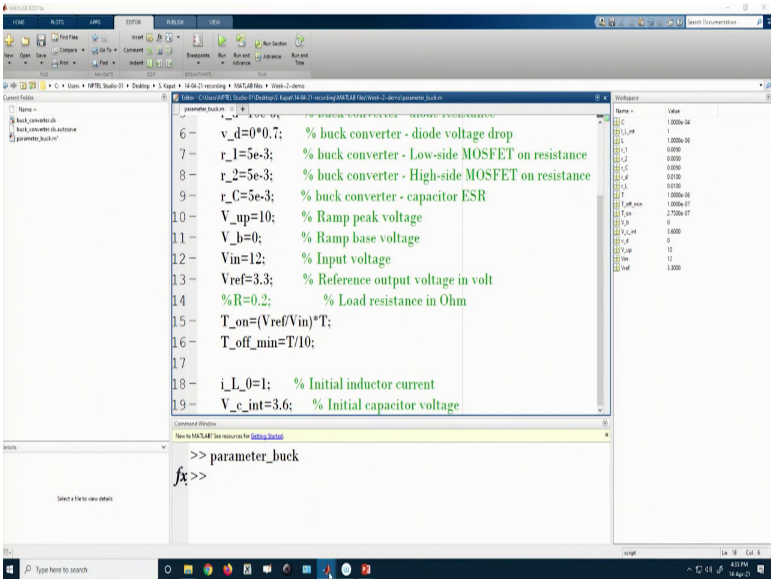

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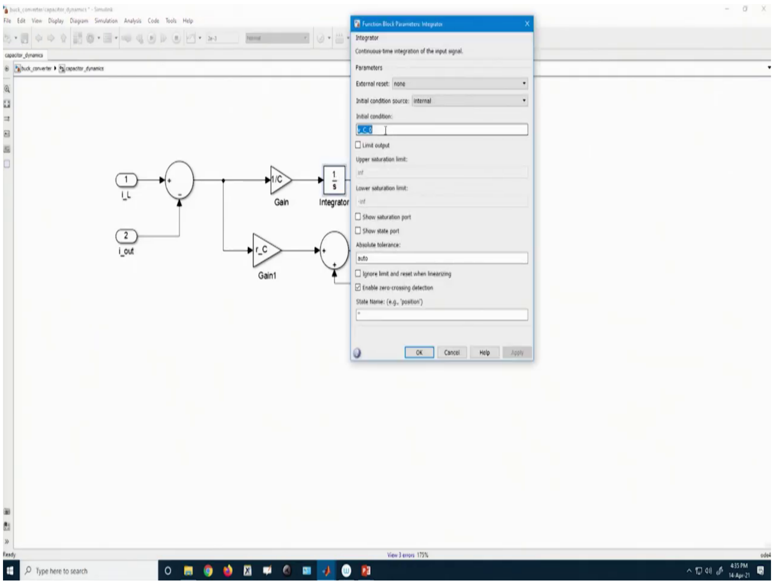

And then other parameters for the capacitor voltage is this.

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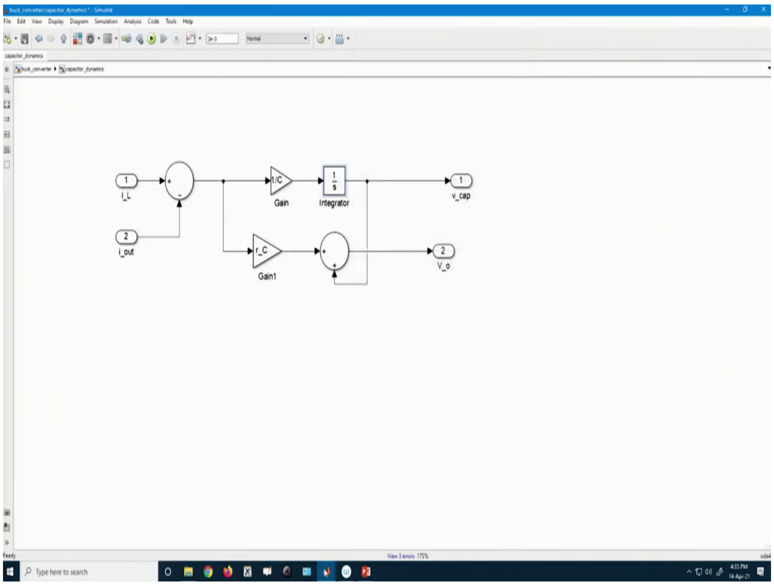

So, that also we need to define ok.

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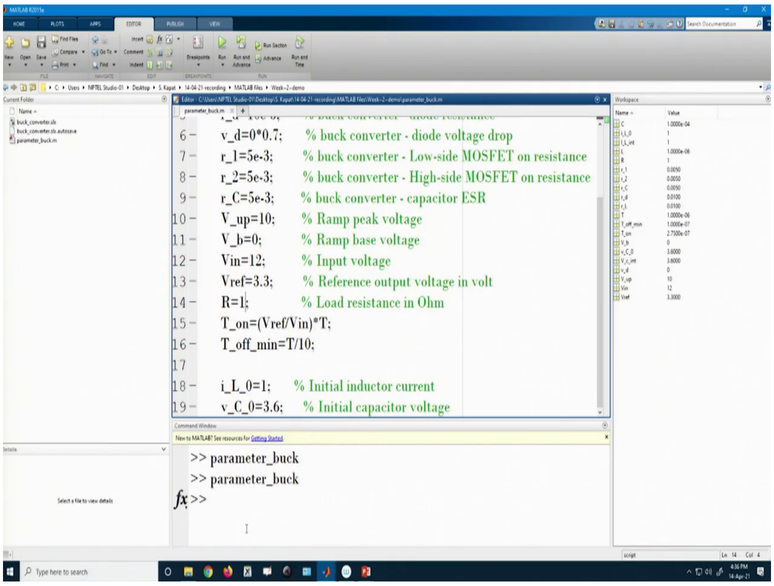

So, now R let us say some resistance load resistance of R is equal to 1 ohm. We run it again. And then we want to run the buck converter, and see what happened.

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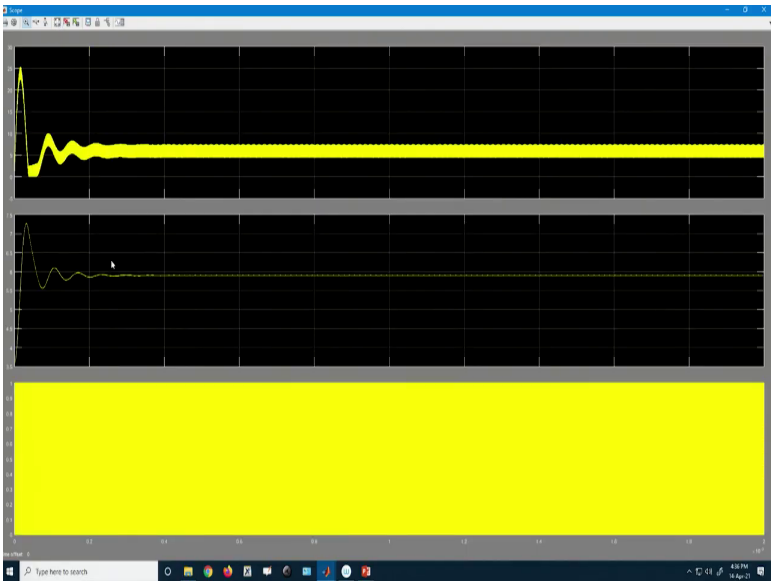

So, this is the simulation of the buck converter where 12 volt was my input, and 0.5 was the duty ratio ok.

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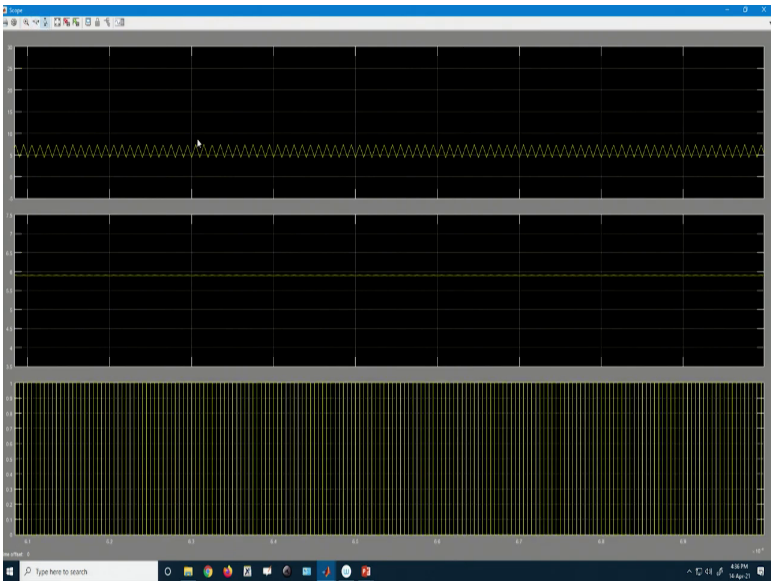

So, let us see what are the simulation results.

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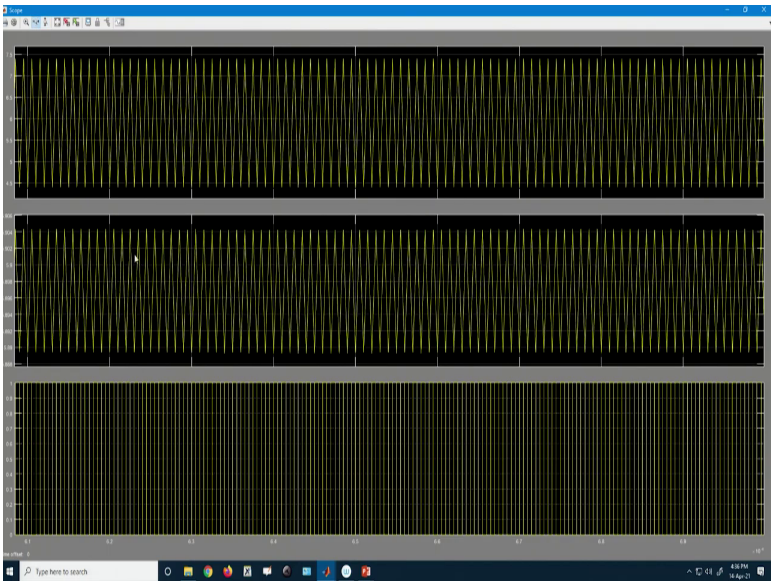

So, this is my inductor current; this is my output voltage.

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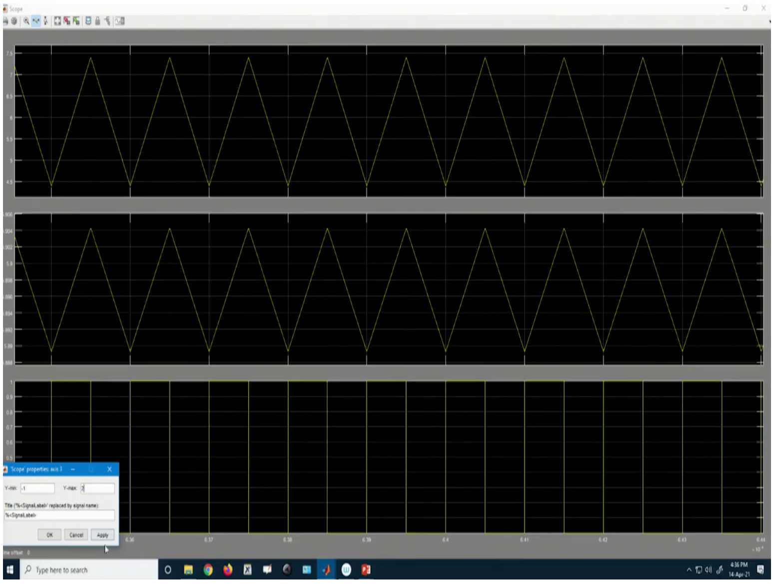

And this is my gate signal. So, if I want to keep some property of this one.

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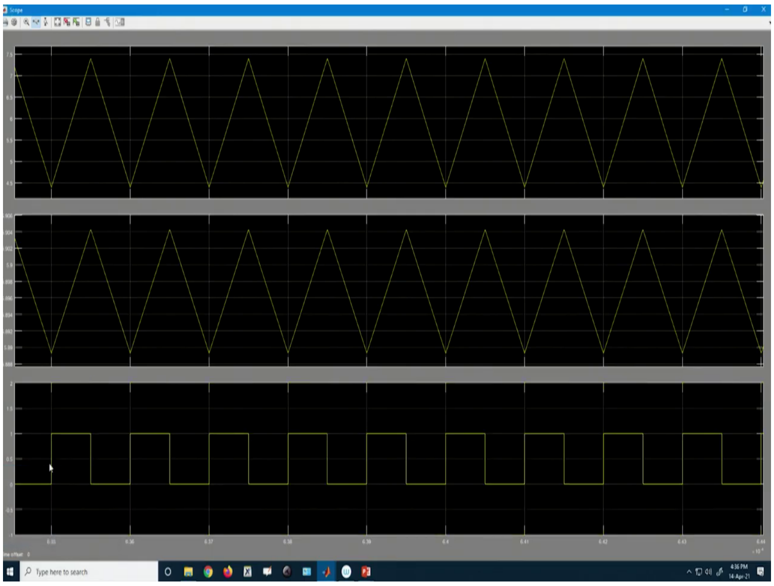

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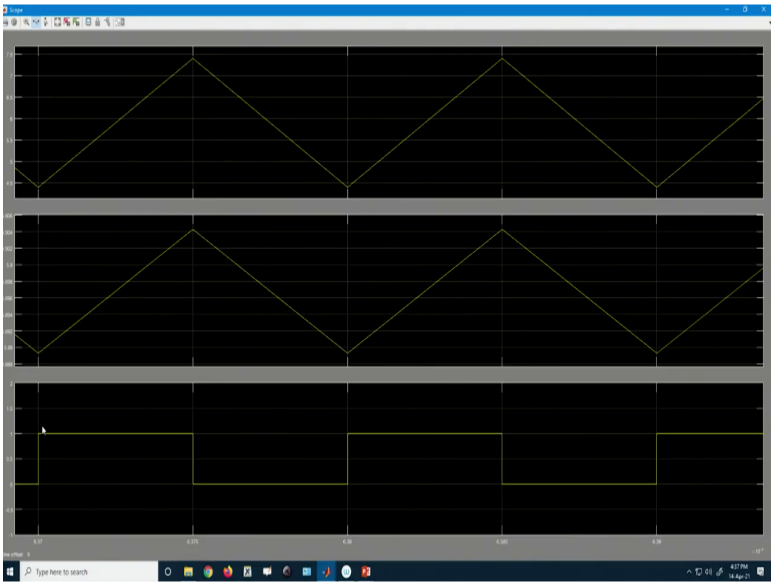

So, I have to show you that when the switch is on, you see when the switch is on; the switch is on, then the current is rising; and when the switch is off, current is falling. And the output voltage profile looks quite similar to the inductor current profile.

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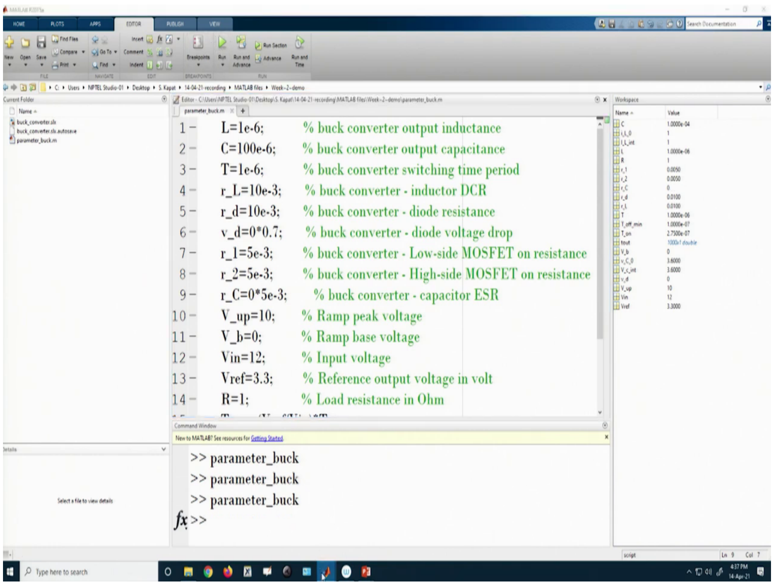

And we discuss if we set esr to be 0, for example, we set esr to be 0, then will get ideal capacitor.

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And then if we run the simulation we will see what is happening.

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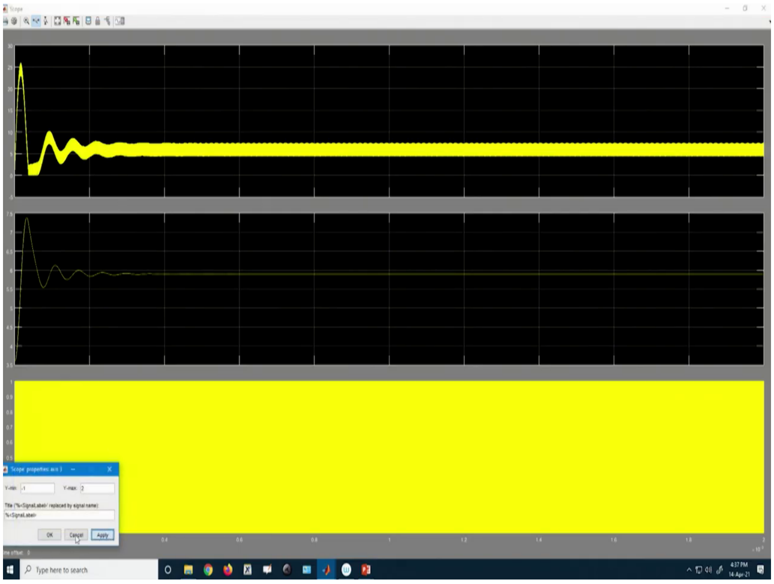

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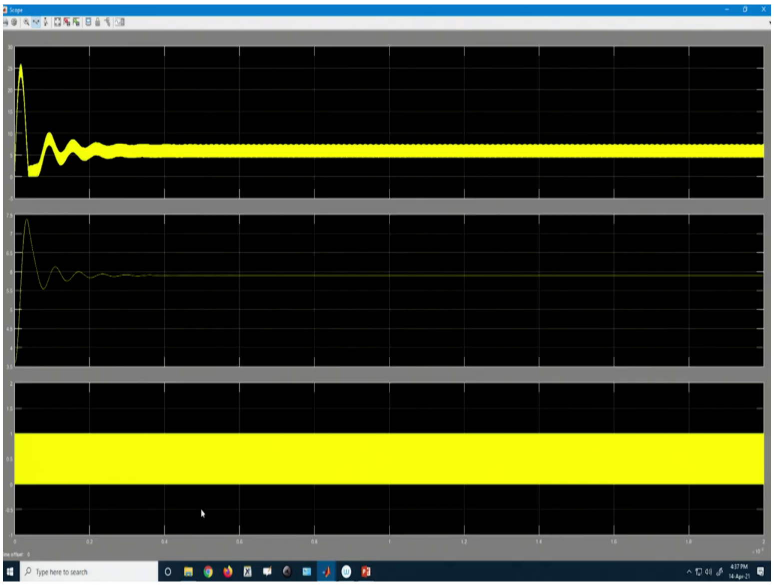

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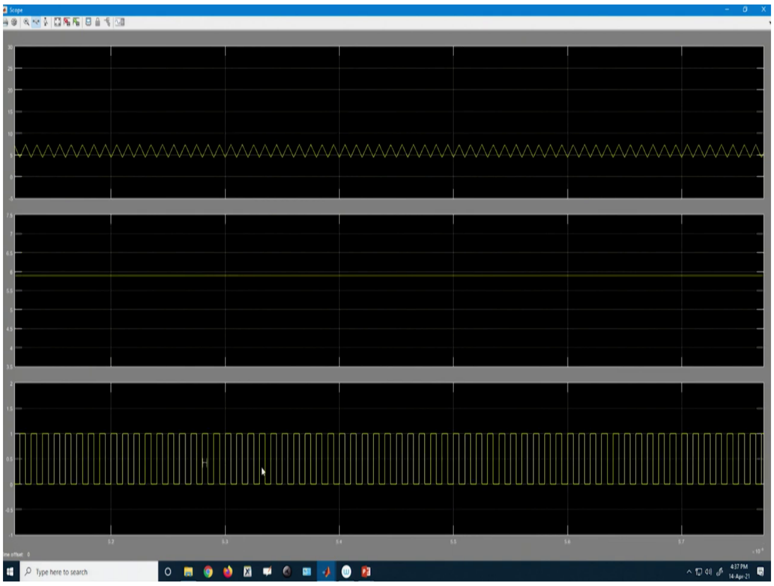

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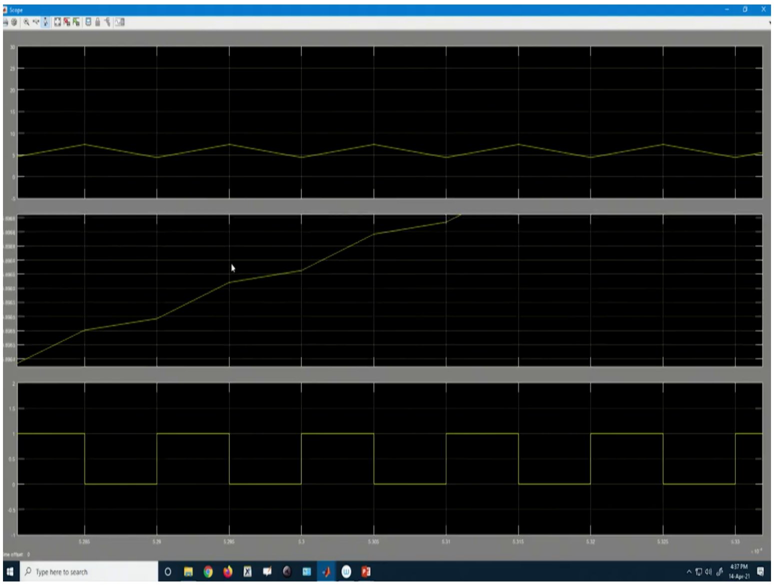

Now, if we want to see how does the voltage profile look like, they are not exactly same as yeah it is just rising. So, it has not raised steady state.

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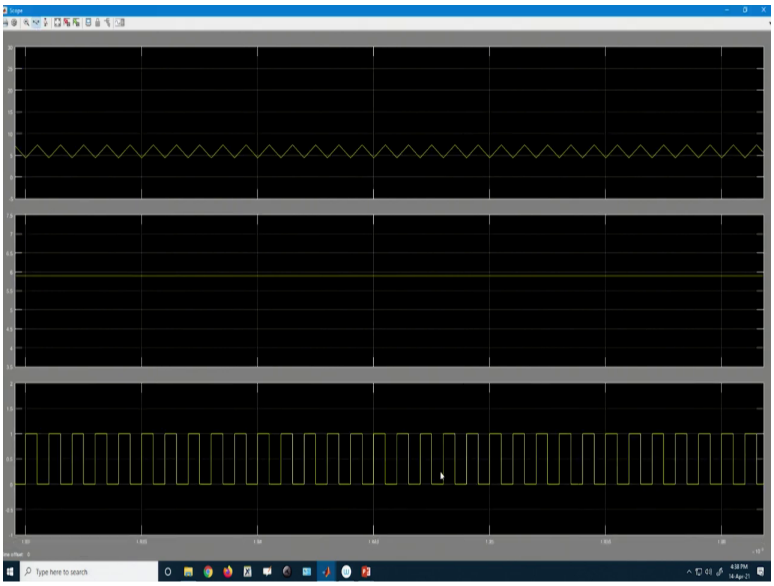

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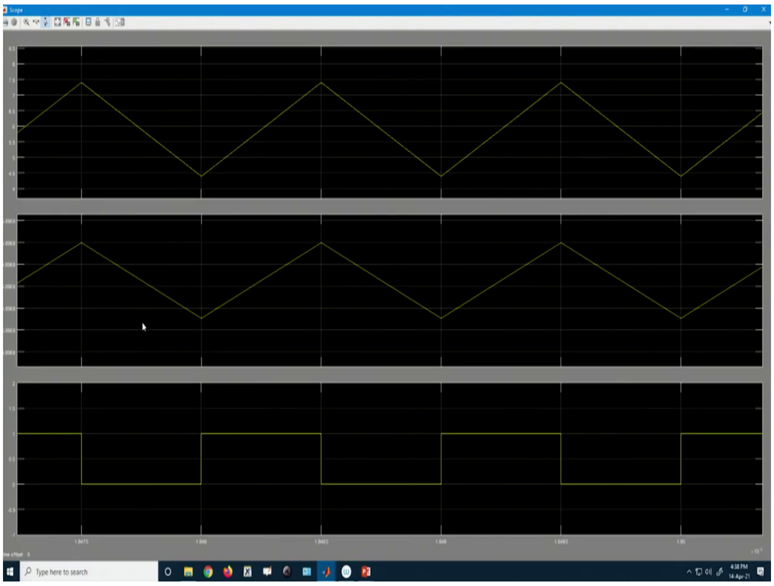

So, if we take a few cycles here, then if we try to see the voltage output, still there is there are some you know we have kept esr to be 0, but it is still showing the profile although very small, maybe it is a numerical error.

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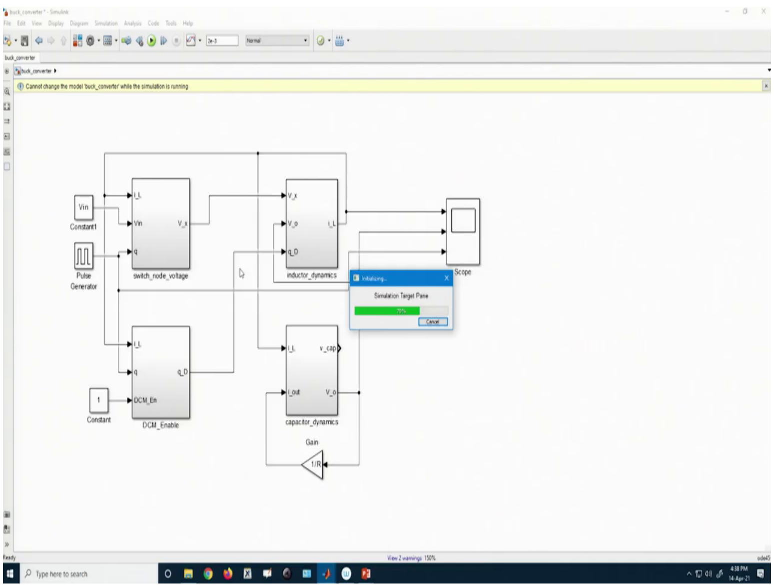

So, we need to set the simulation configuration parameter if we want to improve the accuracy of the simulation.

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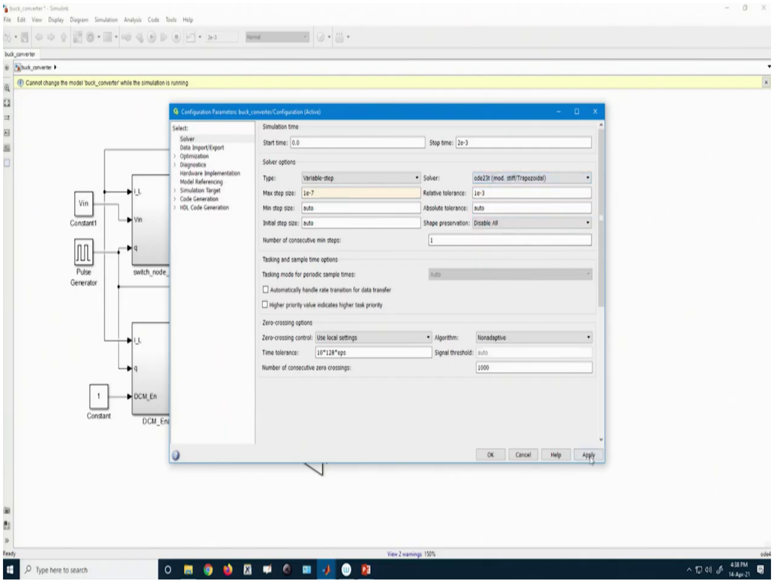

And let us see what is the simulation, yeah. So, maximum step size we should not take any arbitrarily. So, let us say we say at least a very low value.

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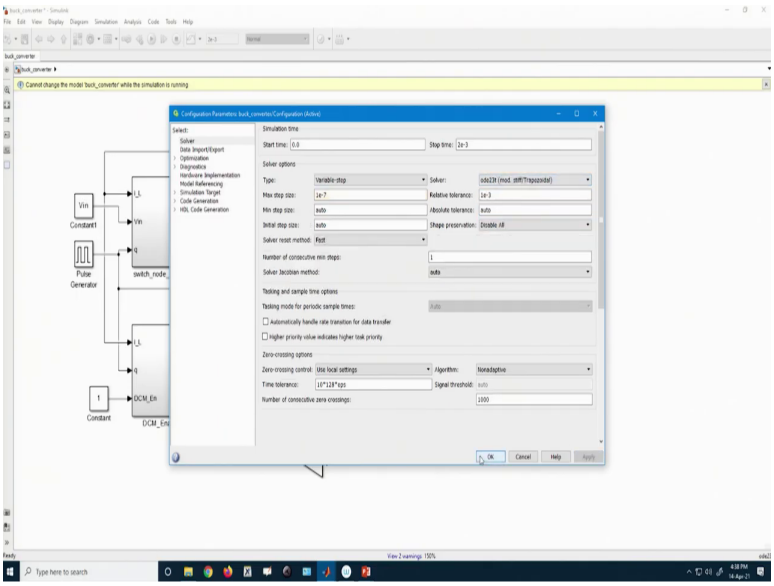

And here you can see trapezoidal method, relative tolerance also need to improve because that is quite large.

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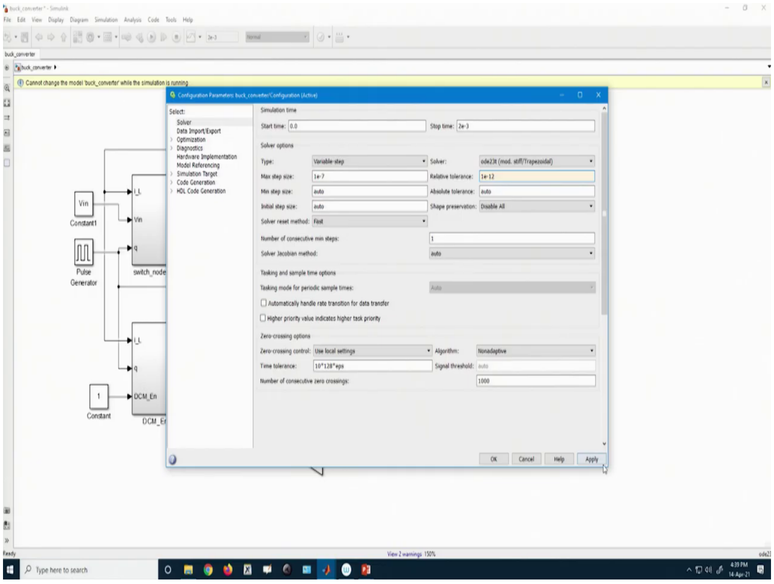

So, I generally prefer to use like a 12.

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Now, if you ran the simulation, maybe the simulation will be slightly slower.

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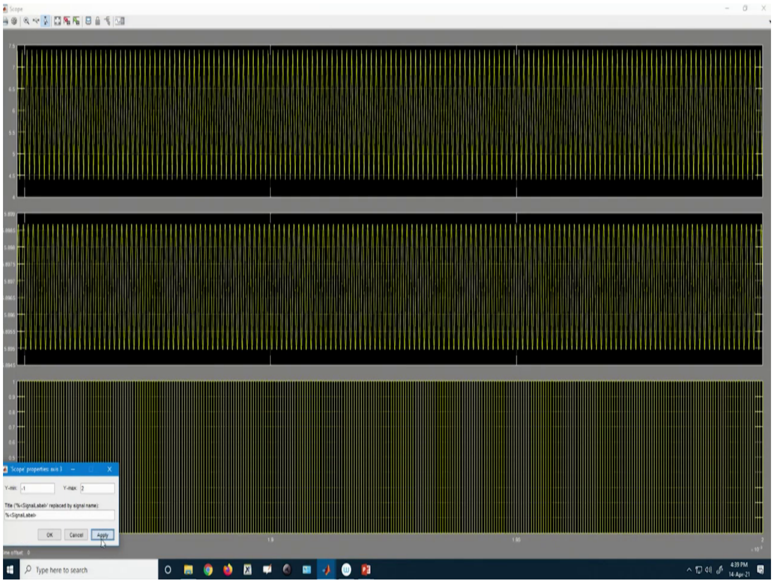

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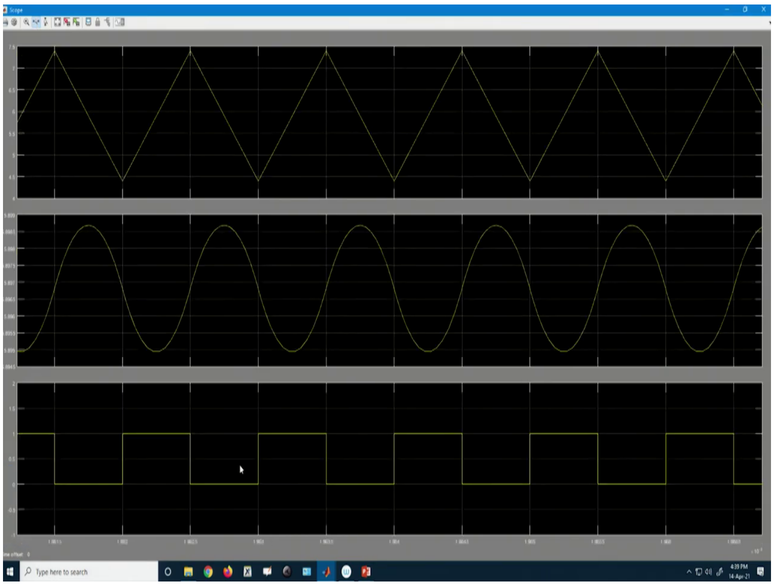

But that is ok.

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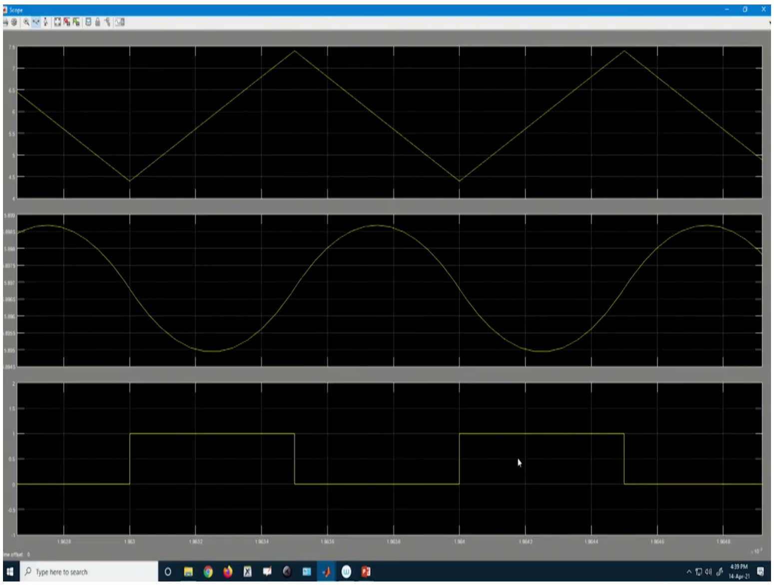

So, now if we want to see the voltage profile, it is look perfect capacitor voltage that we have discussed, that means, whenever the average inductor current reaches its average value from that point capacitor start charging, whenever it again falls below the average value when capacitor voltage starts falling. So, that is very consistent because the capacitor current is positive.

When inductor current is above the average value which is the load current for this case, and below it is still below the load current. So, this we you know we want to we can also implement. Now, we implemented buck converter.

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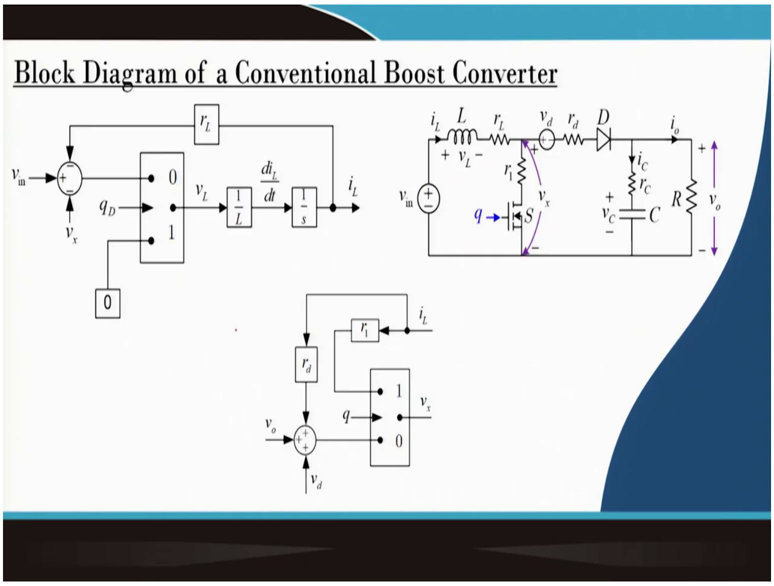

And next I want to you know we can take the boost converter example, we can buck converter, we can do simulation, we can also implement boost converters. So, I will, in the next lecture I will show different boost as well as buck convertor simulation example.

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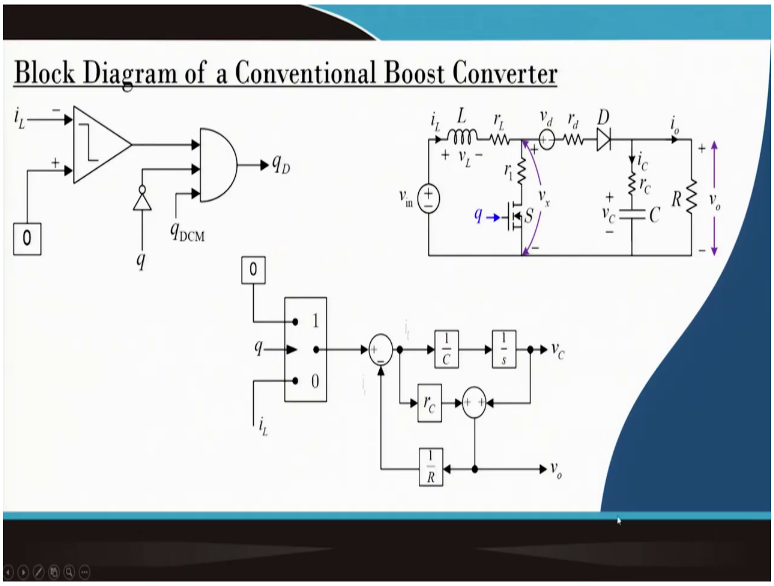

And just you know final touch like you know in this case I want to show that this Simulink model that we have developed.

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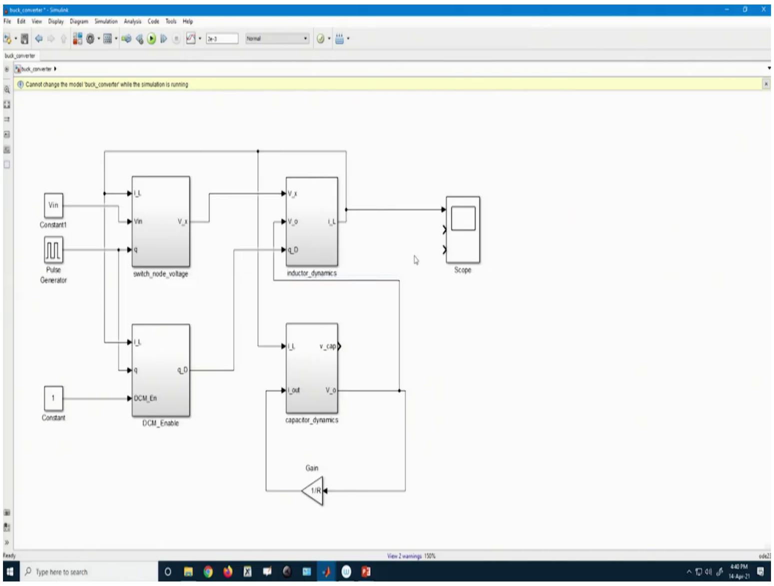

That means these are the input various inputs if we take them little bit away from them. And we want to further create a subsystem, that means, you know if we do not you know ok, so we want to create a subsystem of this block.

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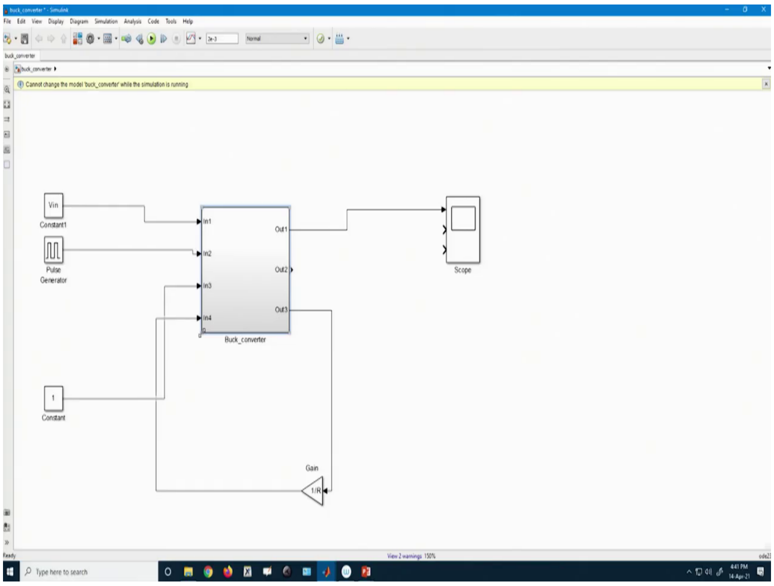

So, it is possible that you create a subsystem. So, in this subsystem, it is a buck converter, complete buck converter.

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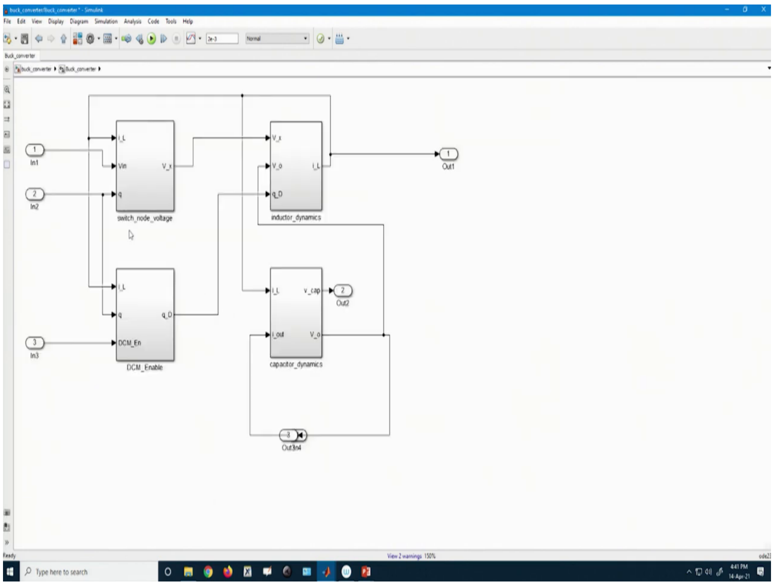

What are there in the sub system?

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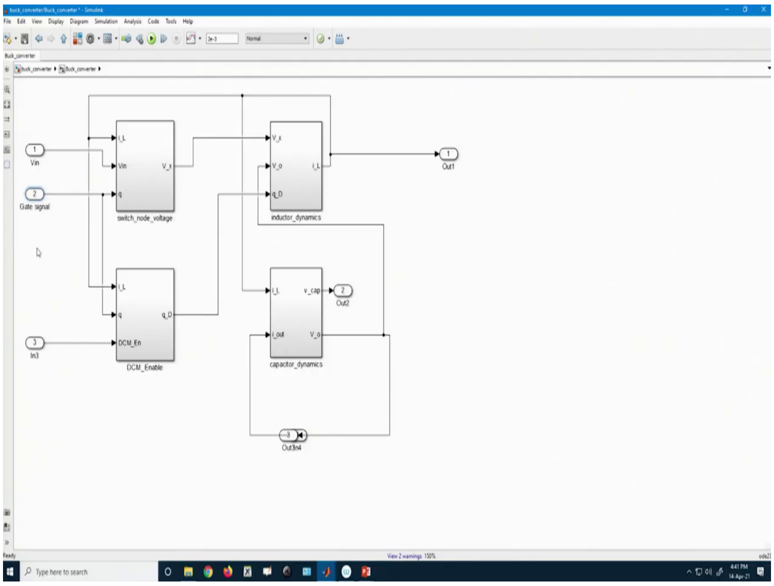

The first one is V in. The second one is gate signal, that means, I can say gate signal.

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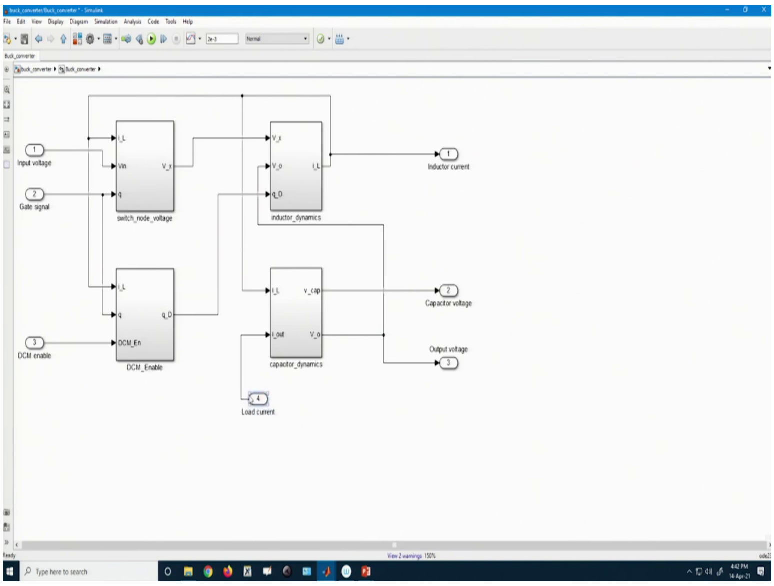

The first one is my input voltage. The third one is my DCM logic, DCM enable. This one is my output voltage. Now, this is my inductor current. And this is my capacitor voltage. And if I want to see output voltage, yeah, it is already there. So, this is my output voltage. And this is my load current ok, because load current is an input here.

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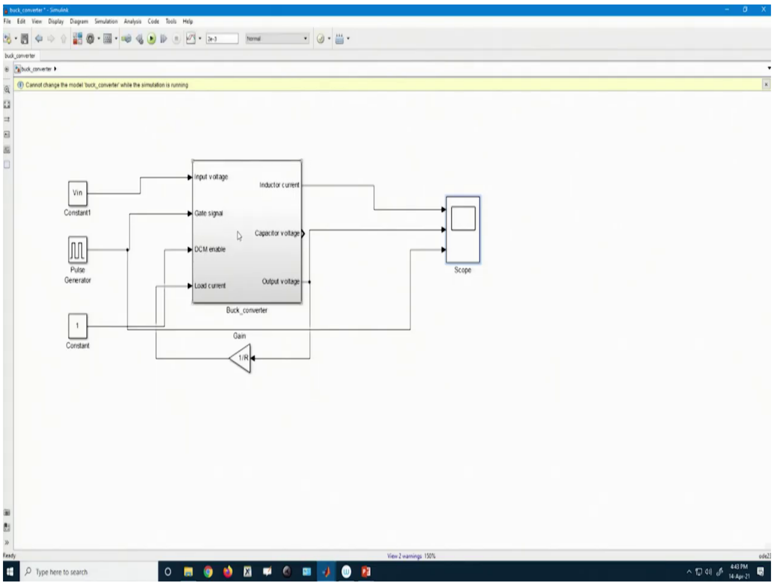

So, now I can make I can create I am going to use this model in the next lecture. So, we also have boost converter as well. So, you can connect between output voltage and input voltage this enable logic. And we can continue to simulate like you know whatever I did. This is the output voltage, and this is the now what do you say the gate pulse.

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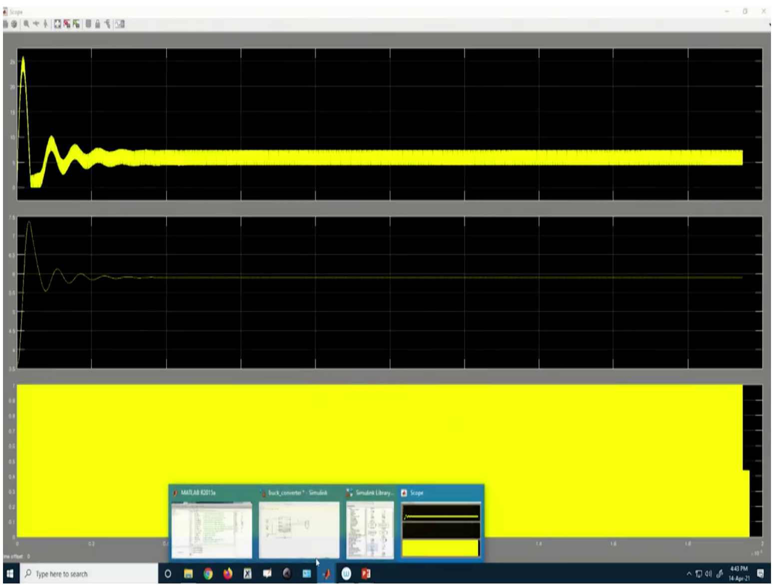

And again, run the simulation and the same thing. But this subsystem will make the whole converter is a single block. And we can if you want to connect multiple converter in cascade, so you will just drag and drop those blocks, and you can connect it. So, that means, we have discussed MATLAB Simulink model development. And I think this presentation we want to limit our discussion to this point.

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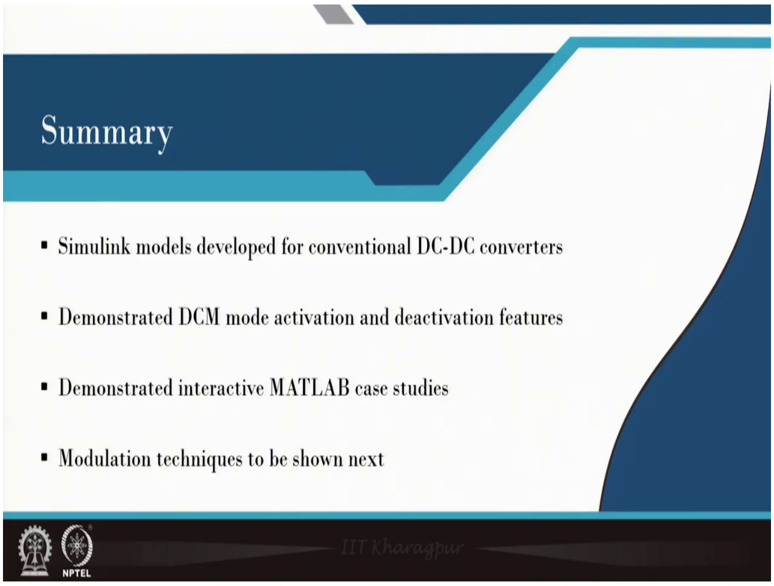

So, we have developed Simulink model with DCM activation logic deactivation feature. And interactive case study with MATLAB study, we have demonstrated simulation case study, but interactive case study using script file and the Simulink file that will be shown in the next lecture. And we have developed buck converter model. And now the similar approach can be used to generate boost converter model. So, that is the; that is the end of today's present lecture.

Thank you very much.