Control and Tuning Methods in Switched Mode Power Converters
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Module - 01
Switched Mode Power Converters and Simulation
Lecture - 06
Demonstration of MATLAB Simulation (continued)

Welcome back and this is lecture number 6, which is a continuation of lecture 5 regarding MATLAB Demonstration.

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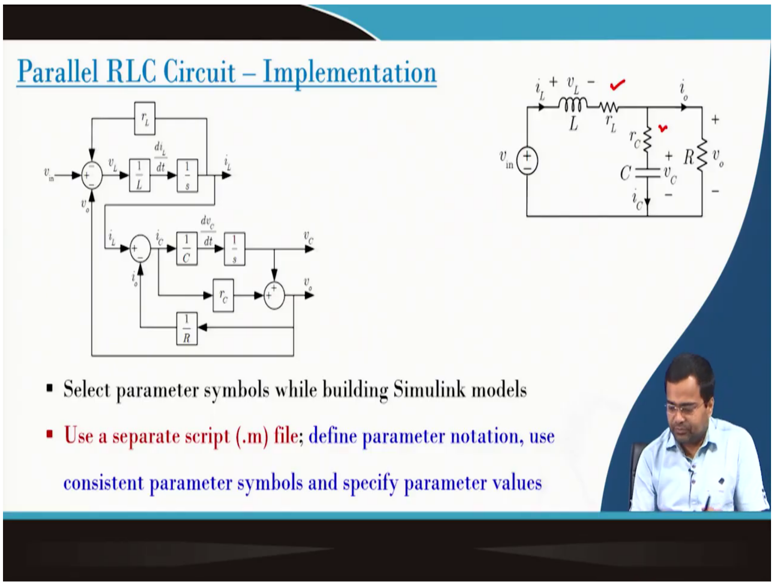

So, in this lecture, since we have already implemented a series RLC circuit, now here we want to implement a parallel RLC circuit with parasitic; that means, we are considering the inductor d c r as well as the ESR of the capacitor.

And, we already know from our lecture number 4, that this building block, block diagram was actually realized for this parallel RLC circuit. And, now the steps are common in order to build the block; that means you have to select the parameter symbol and we have to put those symbols into that dot m file script file. We have to also you know assign some values to these parameters and the same parameter should be used in the Simulink block ok.

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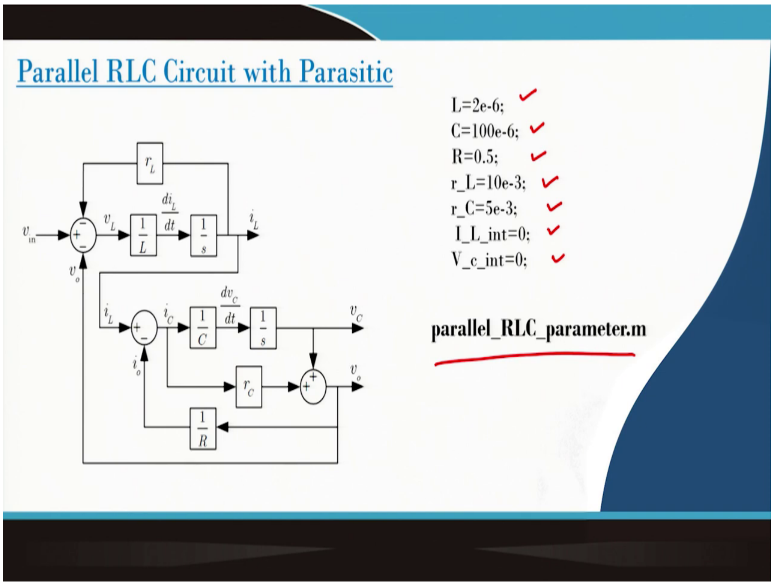

So, this file for this particular case study, we have consider inductor to be 2 microhenry capacitor to be 100 microfarad resistance as 0.5 ohm then r L the d c r is 10 milli ohm, then r C 5 milli ohm, then inductor initial value is 0 ampere and in capacitor initial value is 0 volt.

And, all this will be saved in a separate file dot m file, which is now named as parallel RLC parameter dot m. So, let us go back to the MATLAB simulation block. In this MATLAB simulation, ok, what we want is that our this file; that means, parallel parameter parallel blocks. These are already I have explained.

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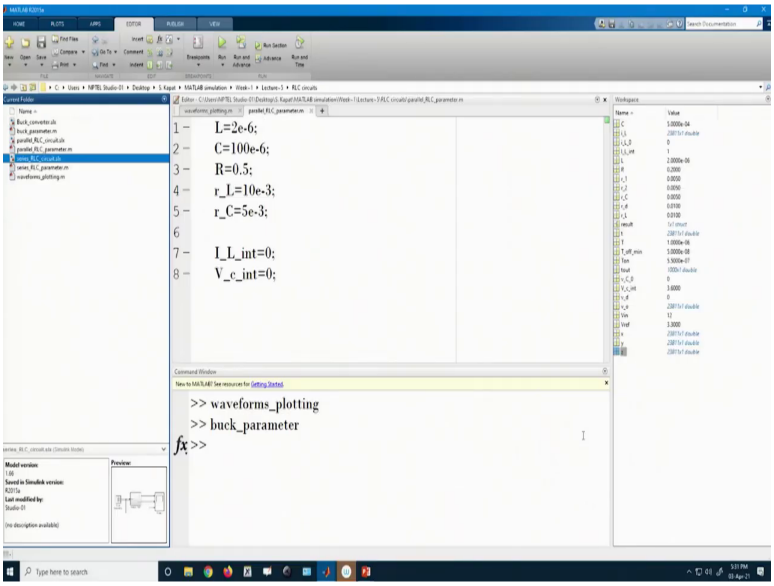

Now, we want to build this parallel RLC circuit. And, we already have the equations which equations are there, these equations are our this particular blocks, this block we need to plug in. Now, what is our next task? So, we need to go for simulink block.

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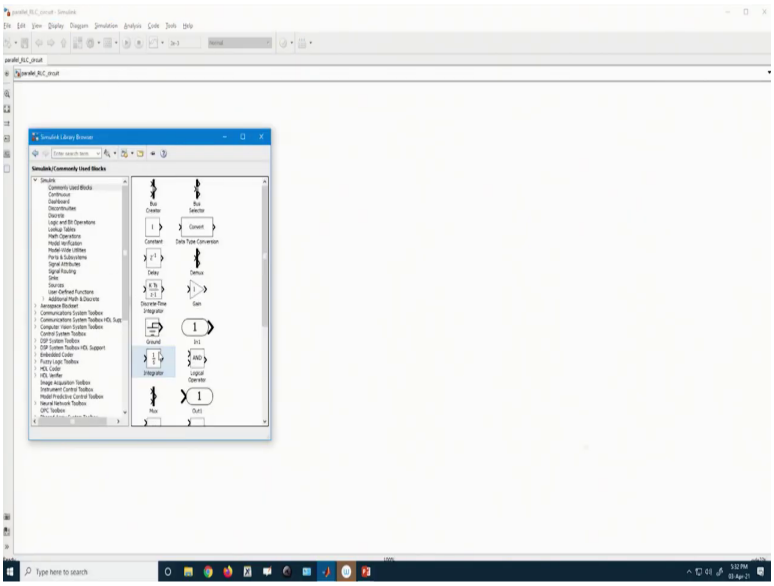

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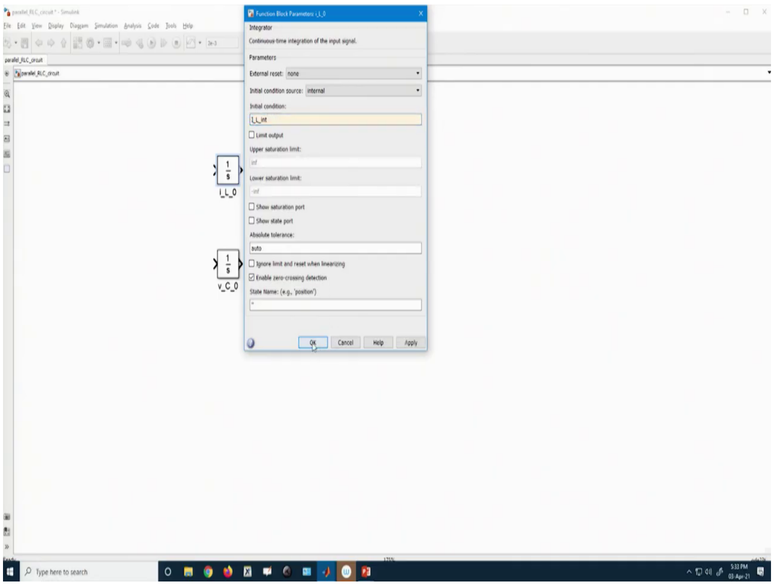

And, we already know the different blocks needed from the library, which are needed to realize this particular parallel RLC circuit.

So, this integrator corresponds to I L initial value I L, initial value we will call it as I_L_0 and we also want to use another for the capacitor, which is v_C_0 block. And, now we have this initial values which are here, here, this initial value we will store it here, sorry initial value and the other 1 we have this block, that we want to store as an initial value for the capacitor ok.

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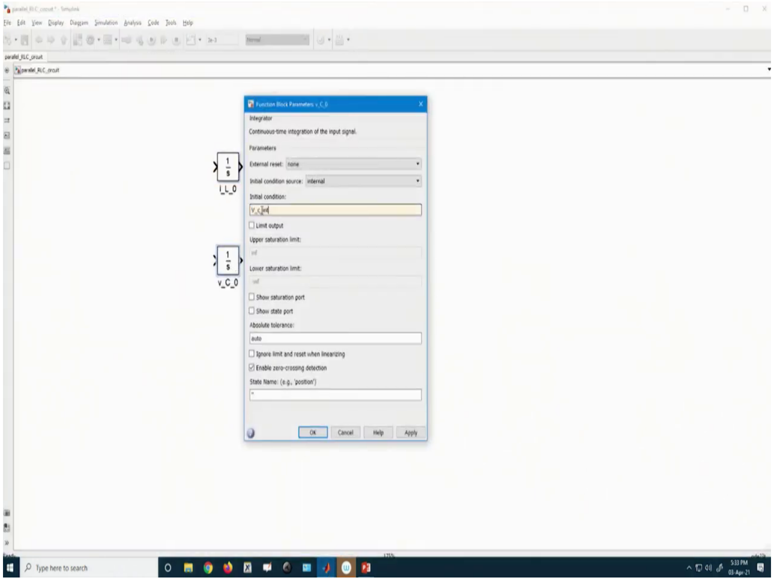

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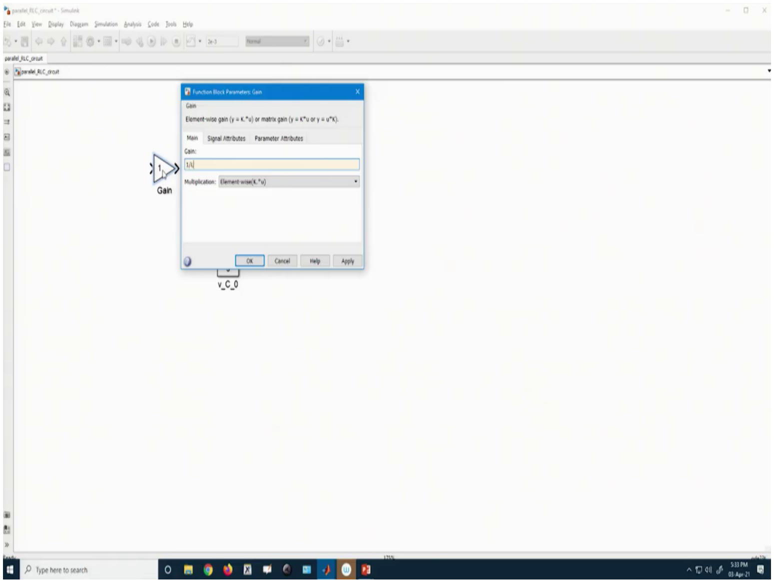

Next, we know the right side of this block will be an inductor and left side is a derivative. Now, we want to use another gain block, which will be used as a 1 by L in block 1 by L block. And, for the other one we need to put 1 by C block 1 by C.

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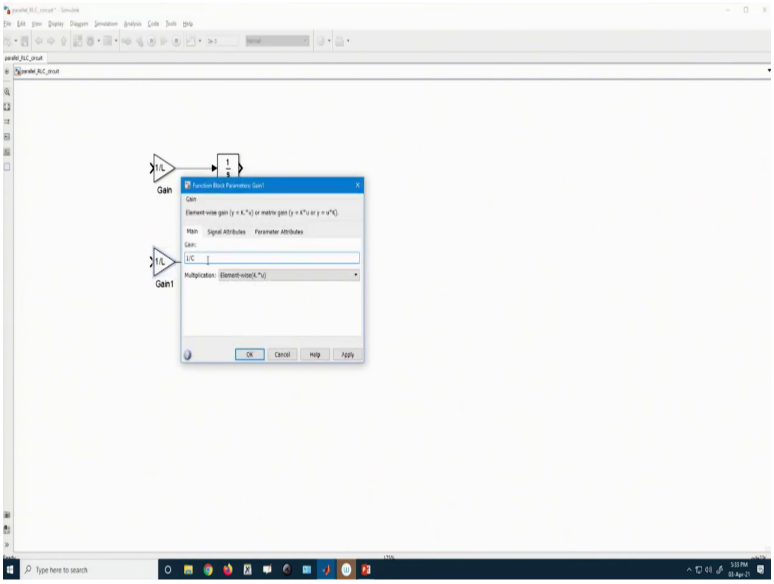

So, now we have one side we have ok, let me yeah one side we have the left side we have capacitor current and the right side we have so, this side is capacitor current, this side is inductor voltage. And, this side is inductor current, and this side is capacitor voltage ok.

Now, what is the next step, what is the inductor voltage v L. So, v L if you look at v L for this particular example, v L is V in minus i L r L minus v 0 ok, let me that means.

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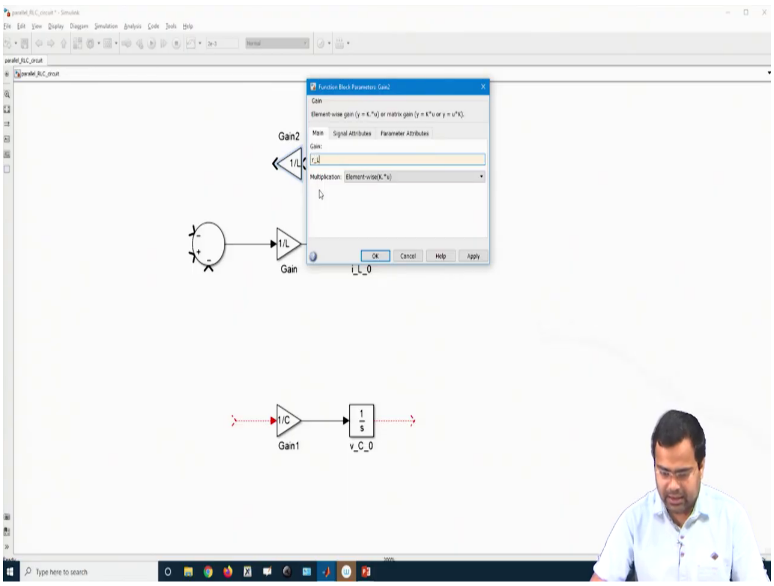

Now, we need to connect to this summing block and this summing block. So, the summing blocks and here we need 2 subtraction; 1 addition. So, the first subtraction will be the i L r L drop ok.

So; that means we need another block, another block here just a minute. Yeah we need another block. So, this block is r L it must be consistent with our this r L and r C ok. So, this is this must be consistent r L block and this is subtracted and this will be the first term ok. What is the second term? The second term is V in which will also set like an another constant.

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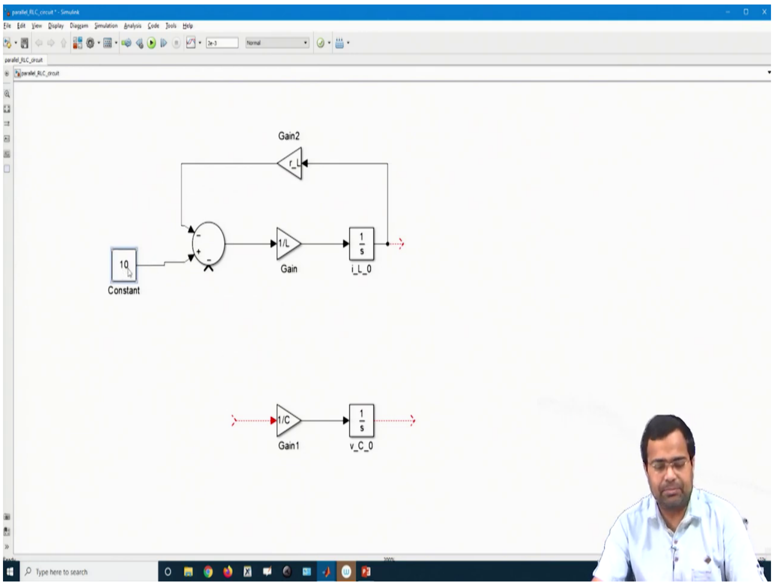

So, we can call it as a constant, we can set whatever V in 1. So, this is our V in maybe we can just give a constant value ok. If we want to choose a separate V in it is fine earlier example we took a whatever what we took? We took a source from the source and we take a pulse generator, ok.

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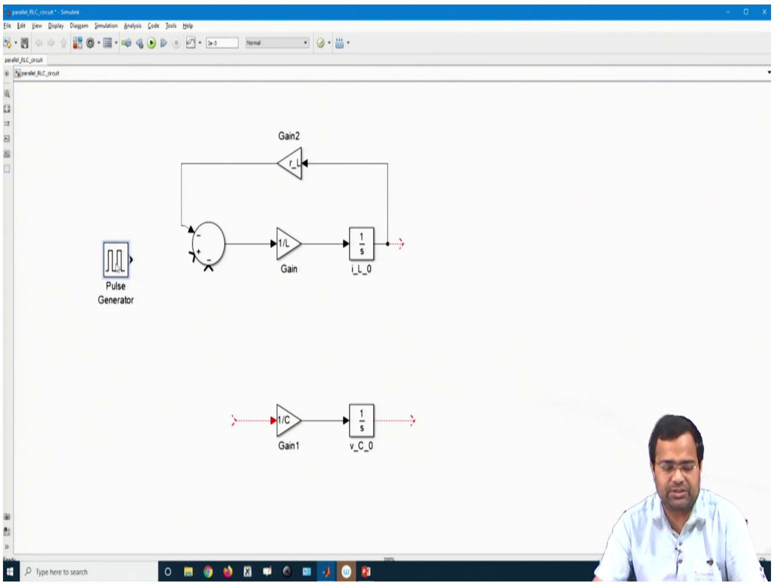

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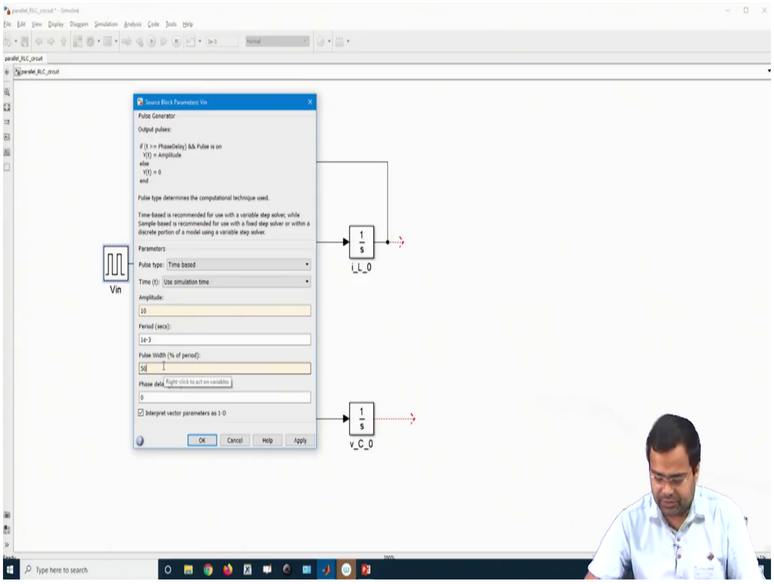

So, we will continue with this pulse generator and we call it as a V in. And, we use the same pulse generator where the time period was 1 millisecond and the value changes from 10 V to 0 volt with 50 percent width ratio that is it. Now the other subtracted block from the parallel RLC circuit if we refer to this circuit block you know, if we go back. So, this is v 0 this subtraction block is v 0 so, but we need to generate this block, this signal and this is generated from here.

So, the capacitor voltage, the capacitor current, is inductor current minus load current. And, load current is derived from output voltage by R and output voltage is derived as the capacitor voltage plus the capacitor current into r C ok. So, with this let us move to this MATLAB simulink block ok.

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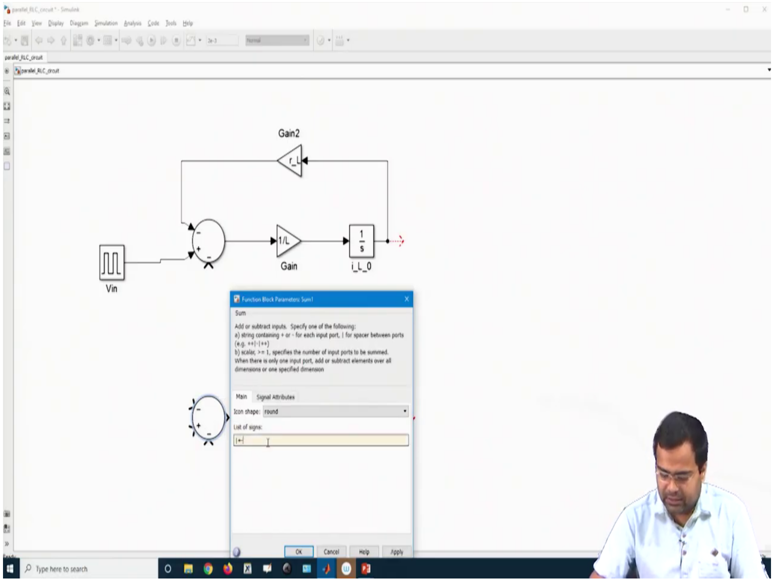

Now, we can consider a block here. In this block, we need capacitor current load inductor current minus load current. And, inductor current here we can simply connect here, we can simply connect here and this block I can raise a little we can simply connect here ok, we need to connect. So, this current is a capacitor current.

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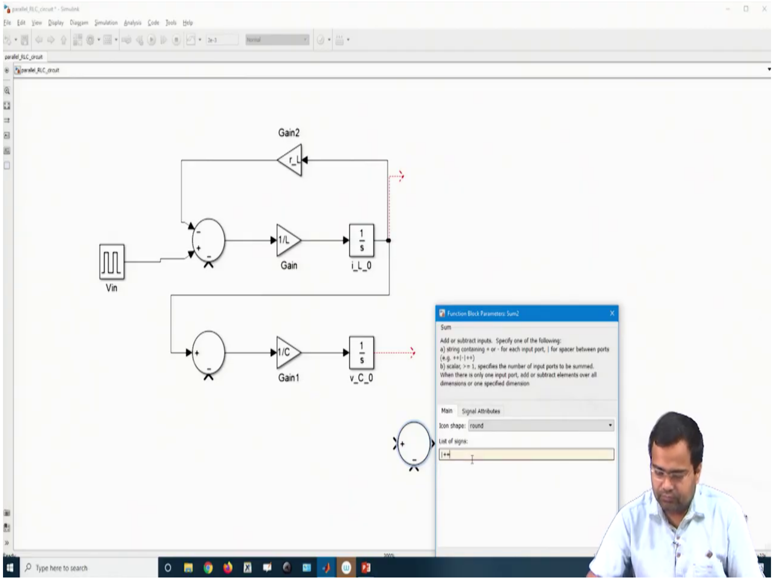

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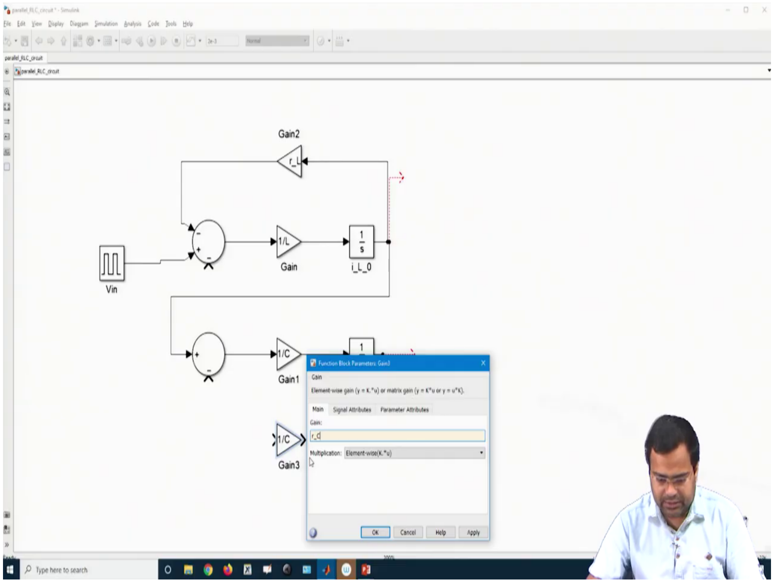

Now, if we want to generate the output voltage, what is the output voltage? It is a combination of ok; it is a combination of capacitor voltage, which is here straight away connected. And, the other combination we need to put r C, which is r C capacitor ok, r C and this is my capacitor current and this I will simply connect here, and this is my output voltage. Now, so, what is my load current? So, my load current is here.

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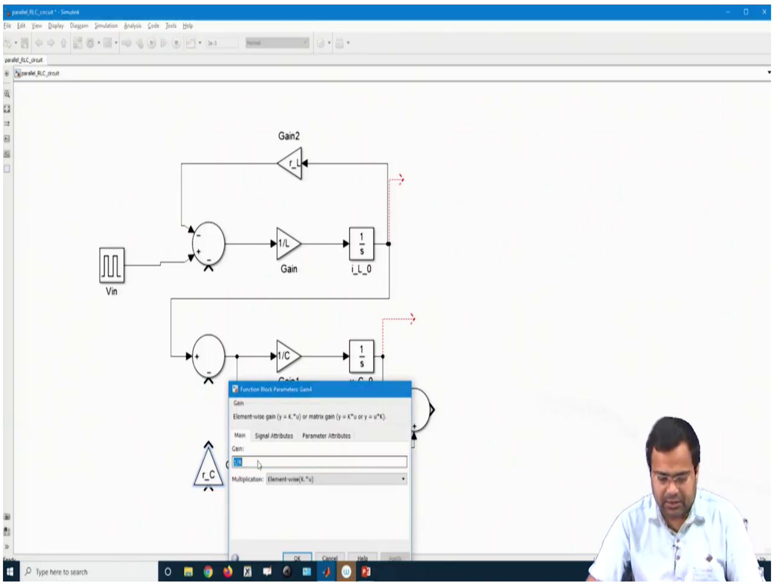

So, it is 1 by R; that means voltage by resistance. So, this is output voltage divided by resistance. So, that is my load current got it. And, now we have the output voltage. So, I can simply connect to it from this block. And, now this all about our now our model steady parallel RLC circuit, then everything I have included.

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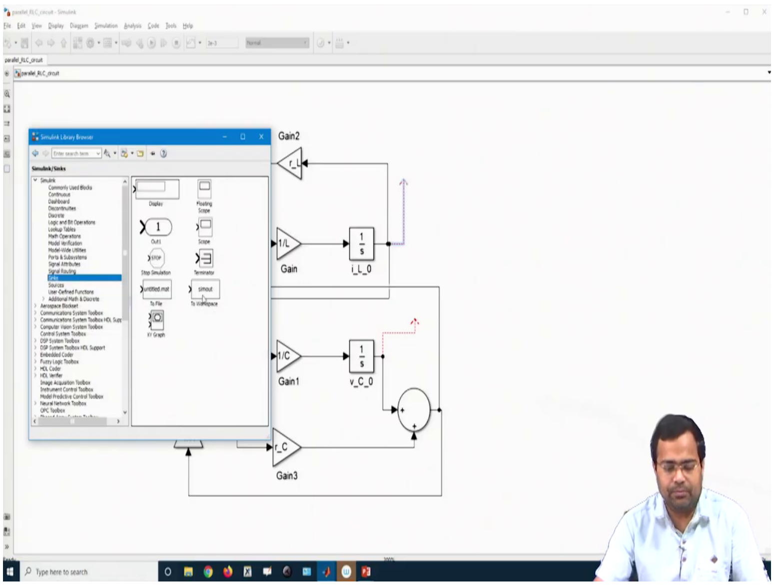

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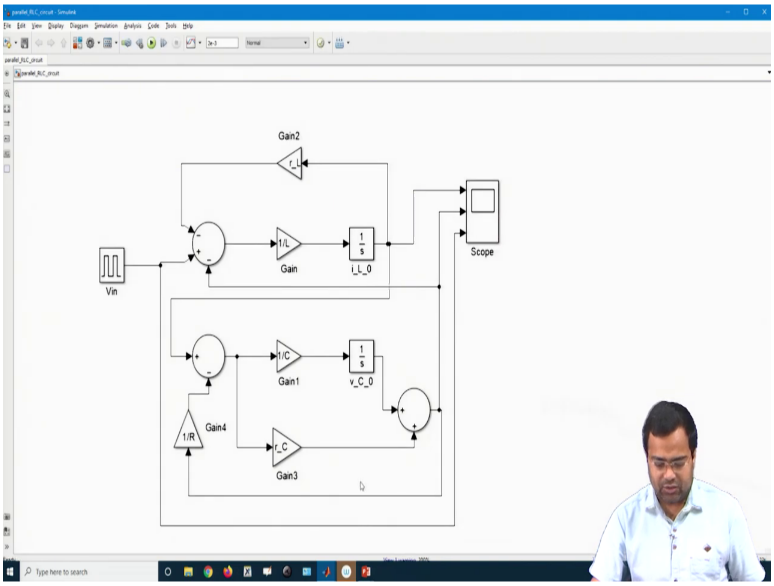

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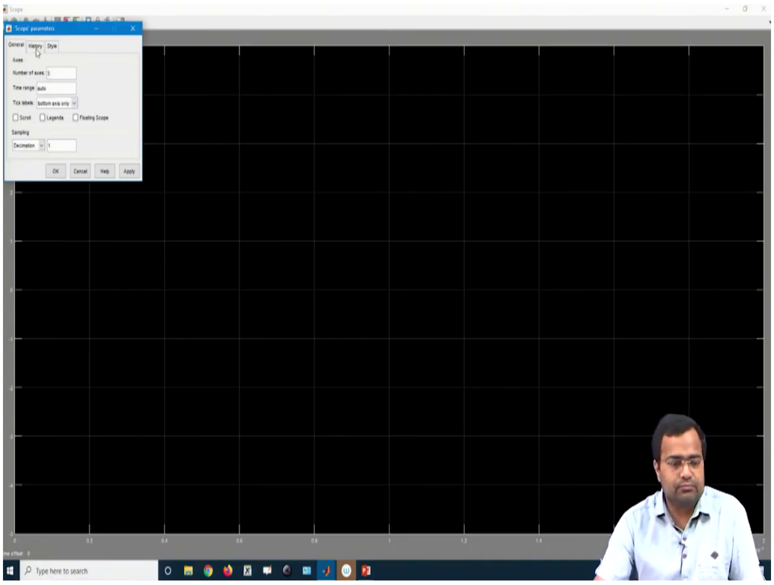

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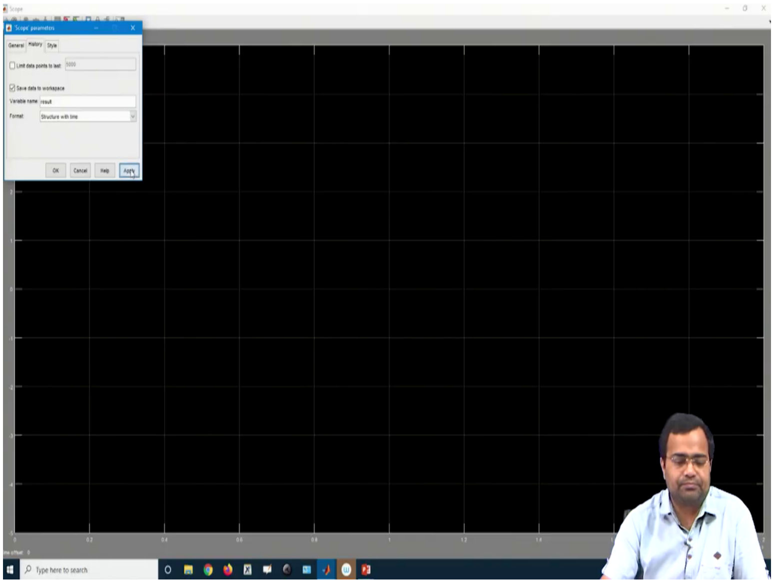

Now, we need to check the signal; that means, sync we need an oscilloscope; here it is a scope. I told the scope, we can set it like a 3 channel, and we can history term we do not want to we need to make like a result ok. And, it should be structured with time ok.

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Now, we have generate a 3 scope. So, this scope is actually the first channel indicate the inductor current. The second channel we want to show the output voltage, which is this voltage even we can see the capacitor voltage. So, whatever we want. And, the third one we want to see the capacitor voltage, let us say, for the time being. Let us see what happens when you stimulate it.

So, you can see that for this time instant, for this parameter value. So, the top waveform is showing the inductor current, output voltage and the capacitor voltage. Is there any difference between output voltage and capacitor voltage? Because there is a capacitor current multiplied by resistance so, some slight difference will be there ok, but I want to see the input voltage profile. How does it respond to the input voltage? So, I will connect to the input voltage.

And, like the previous case study, once you simulate it is not necessary. We need to see the result from directly the Simulink scope; we want to see the result using the MATLAB figure file.

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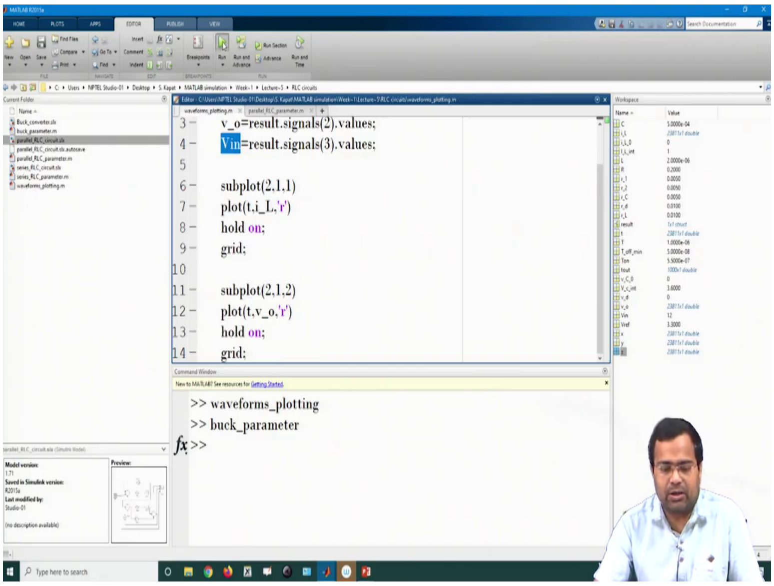

So, again we can use the same you know V in v 0 i L, we have connected consistently and we can use this plot command and plot it.

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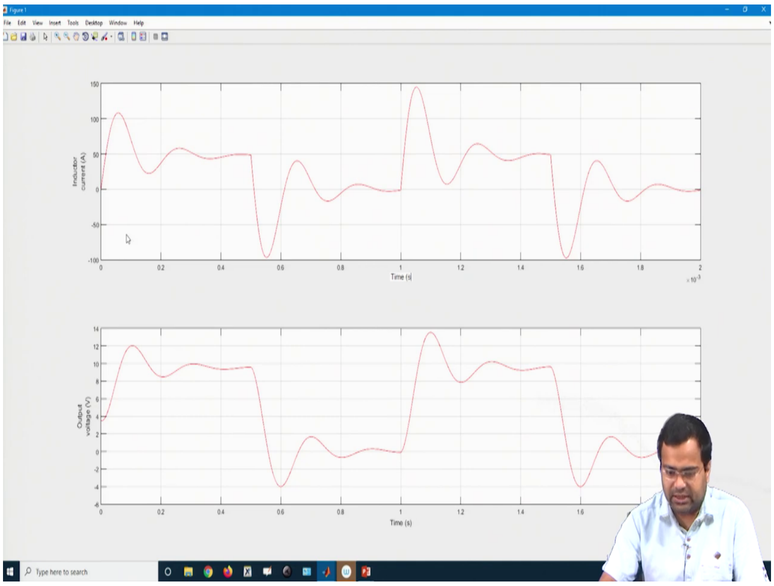

So, this is what it is shown and again we can put you know connect all the axis like you know if you select this channel, we can insert x level as a time, in second then we can y level, so, which is my output voltage in volt. And, this channel if you select then you can add inductor current, inductor current; and since the they have the same time axis.

So, it is not necessary that you need to put, but if you want, you can also set the x level for this also time in second.

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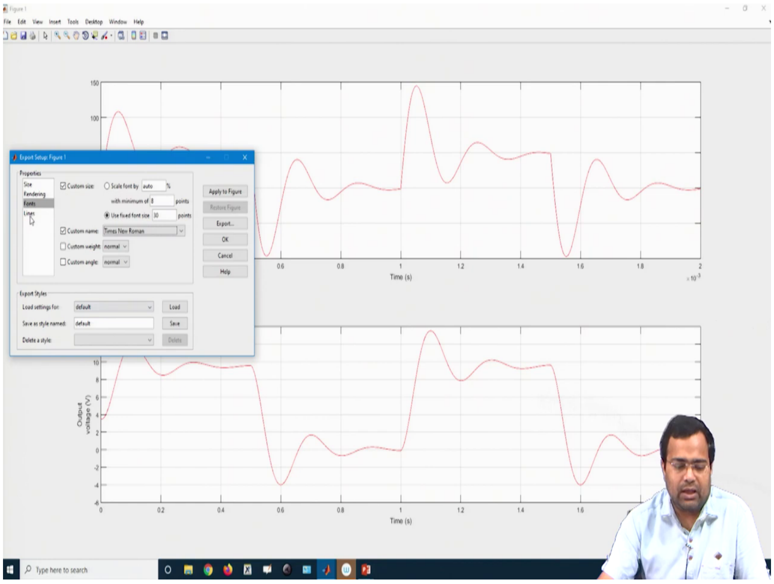

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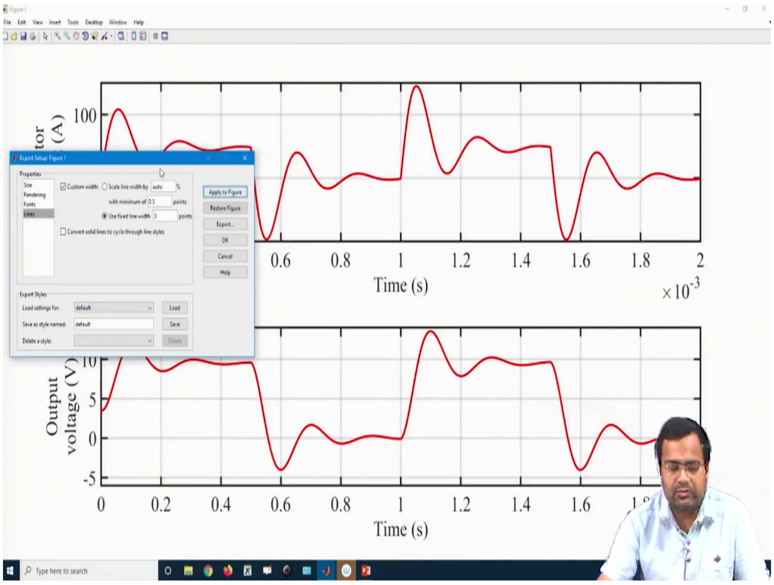

Now, we can go to export set up where we can set the font size bigger, and we should use Times New Roman and line size. You can increase to 3 if you want yes and it will show like this.

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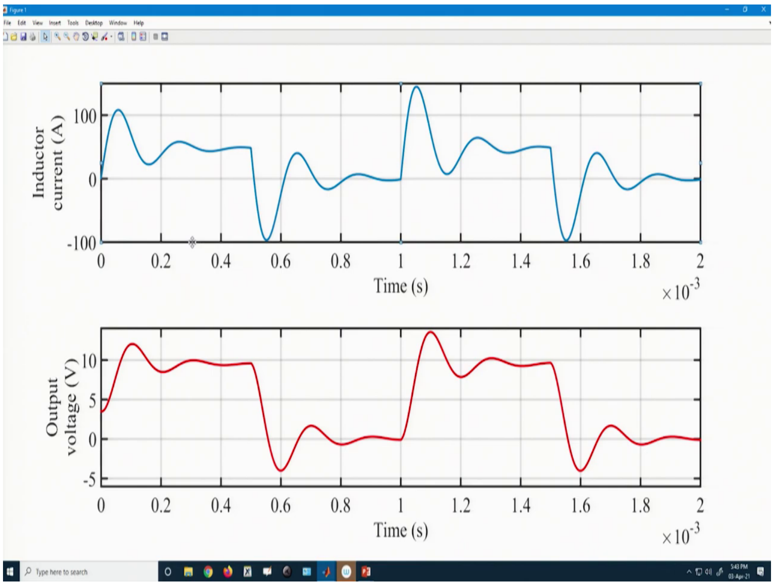

If you want to change the color of this scope you can select, you can select the color say you want to use a blue color. You can use it, that we go. So, this shows that, how to simulate inductor current and output voltage from that, which block we are talking about? We are talking about this block parallel and this kind of result you can see from the scope.

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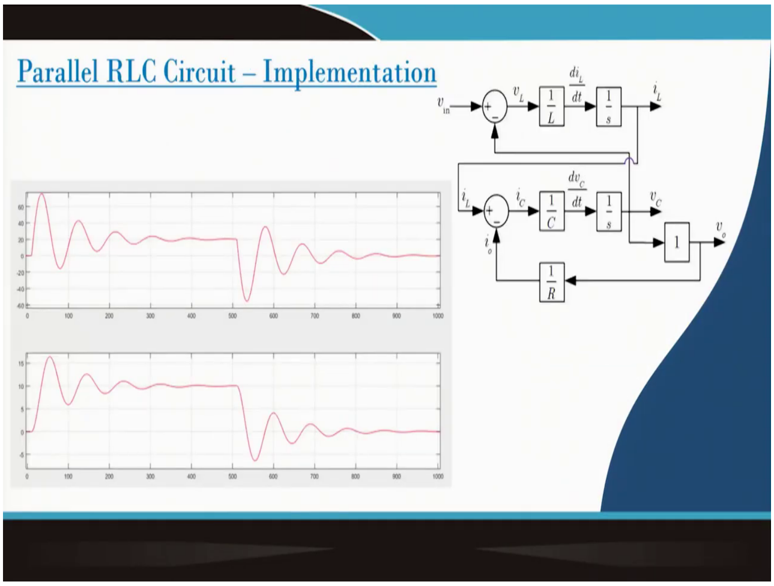

So, this is the parallel RLC circuit implementation using MATLAB.

Now, we need to do like a modular block; that means, let us go back. And, we know that how to make, how to create the subsystem block right? So, what we will do we will keep those outside and this entire block we select and we create a subsystem. So, we have to first select this block and make subsystem create subsystem.

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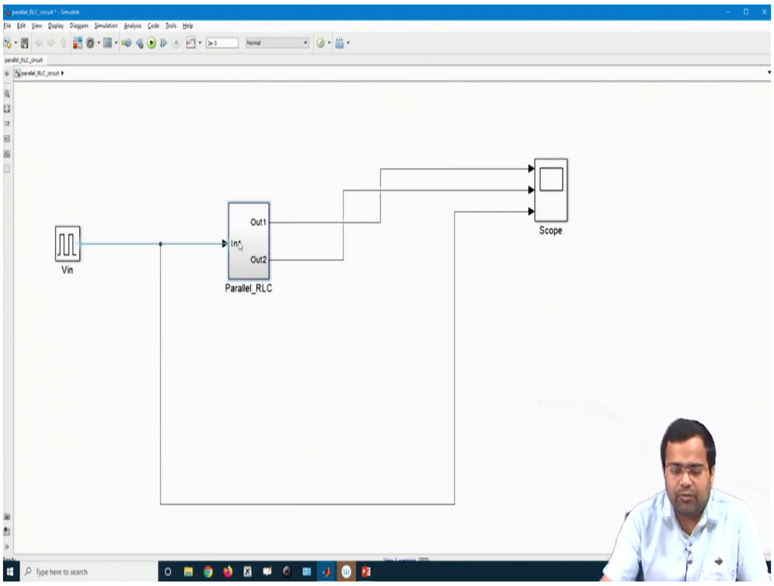

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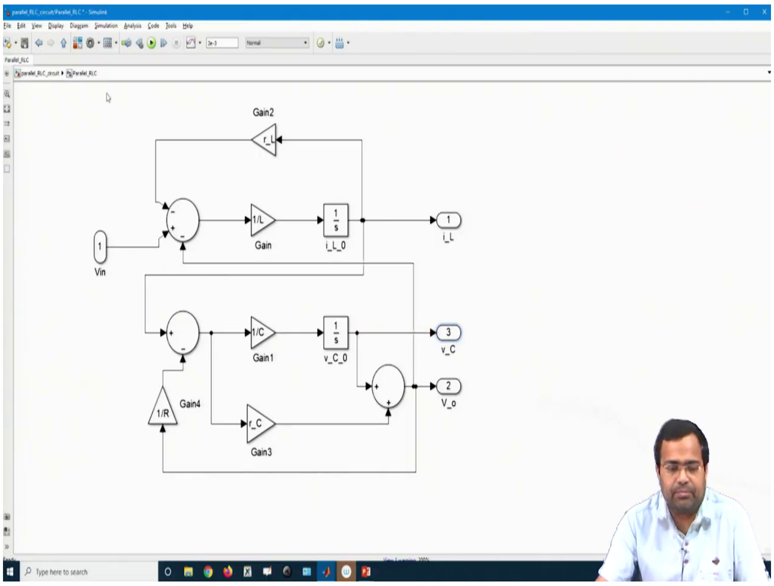

Once you create subsystem, then we need to write like a Parallel RLC block. Parallel RLC block, ok. Now, we go inside. What is the input in this parallel RLC block? So, we have to specify the inputs and output; that means; let us write down I think, ok. So, the first block here, what was there it was our input sorry. So, this was our input voltage V in and the second block output we want to see.

Yeah. So, we want as many numbers of output you want. This is my inductor current i L and the third block is my output voltage, not the capacitor voltage. I can write V 0 and if we want to place another you know block, another output which is an optional, because I want to check the capacitor voltage as well.

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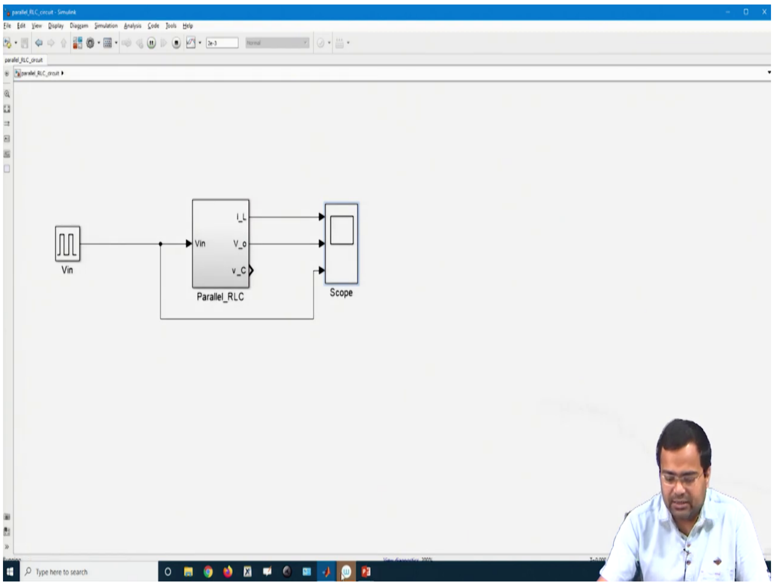

So, I can create another channel I just plug in and go back. And, you will see now my parallel RLC circuit building block is completed. Now, this building block is much more easy to you know to simulate ok, this is the scope. So, whatever we did earlier it will remain same. We can run it and then we can repeat. We can repeat this waveform and it will show the same results.

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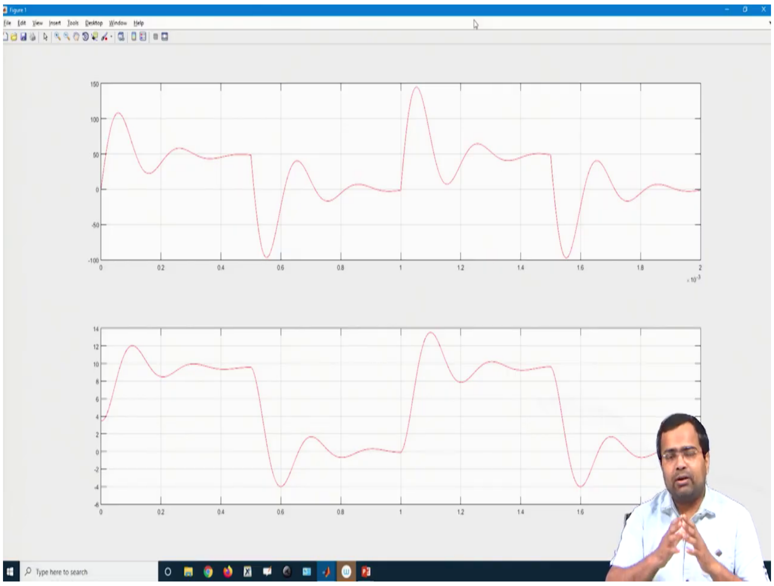

That means, what we learn, we learn how to block build Simulink block from our block diagram representation mathematical, which was derived from mathematical model. And, we have created subsystem and that subsystem we can call it in my subsequent blocks ok. Now, our next task, what is our next task?

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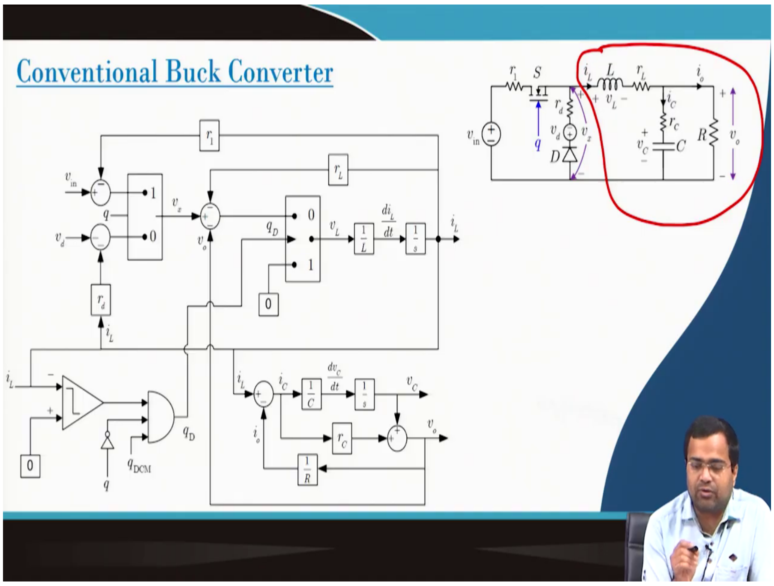

So, next task is to implement a conventional buck converter. So, now, it is a complete diagram. If, we look at the parallel RLC circuit, if we take that you know this part is common this part is common, but this part is common. So, we can use that parallel RLC branch without any hesitation. We can use it. But, you have to be careful about the selection of that inductor voltage, which is a very crucial, because we know that inductor voltage if you want to enable that discontinuous conduction mode of operation.

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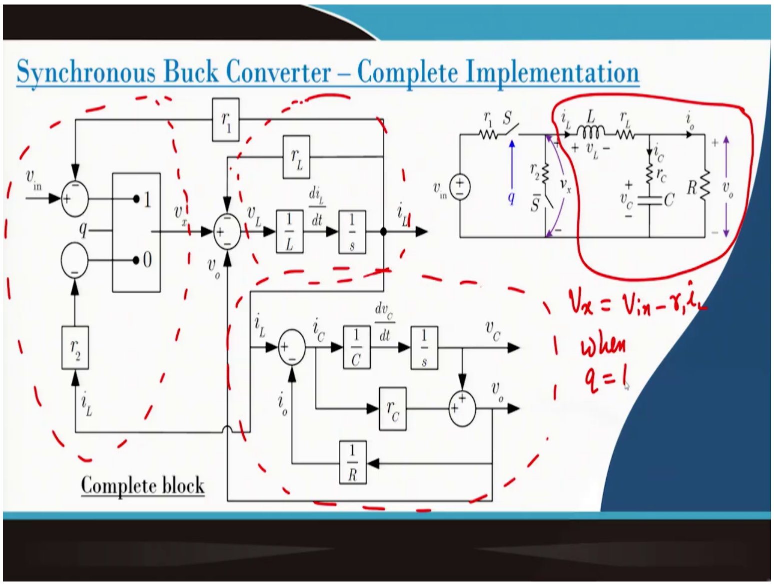

In fact, instead of starting with conventional buck converter, let us start with the synchronous buck converter that will be much more easy. So, the synchronous buck we have again implemented this block ok.

So, here only difference is why where is the difference, these block we have already made that means these block we have already made in our Simulink is a parallel RLC branch, this block is also we made in the parallel RLC branch like this branch. So, if we look at this diagram compared to the parallel RLC branch and this circuit, what is the difference? It is a v x; that means, if we retain the parallel RLC branch and if we incorporate this v x then our job is done.

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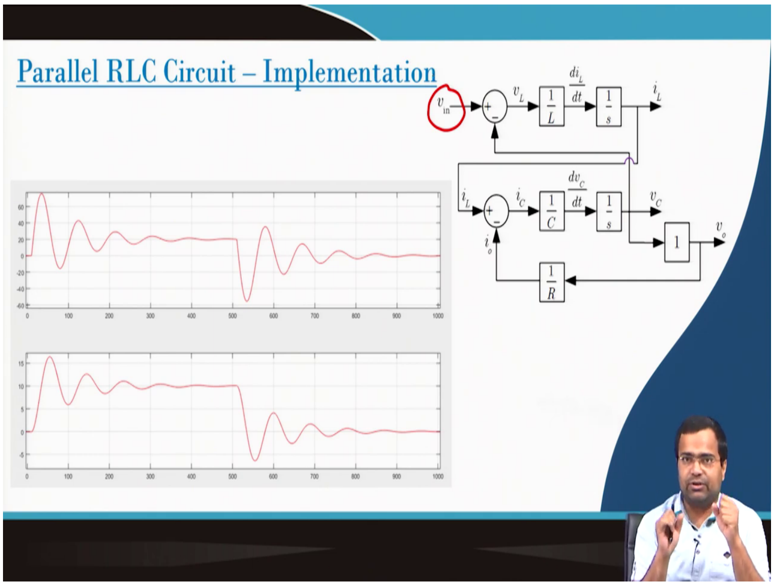

That means, if you go back in this block, we want to replace this V in with v x; that means, that is a switching voltage, switch node voltage. So, our job will be done using this block. So, then what is our next task ok? Let us go back, go back and we want to build this model. Now, we want to develop now synchronous buck converter.

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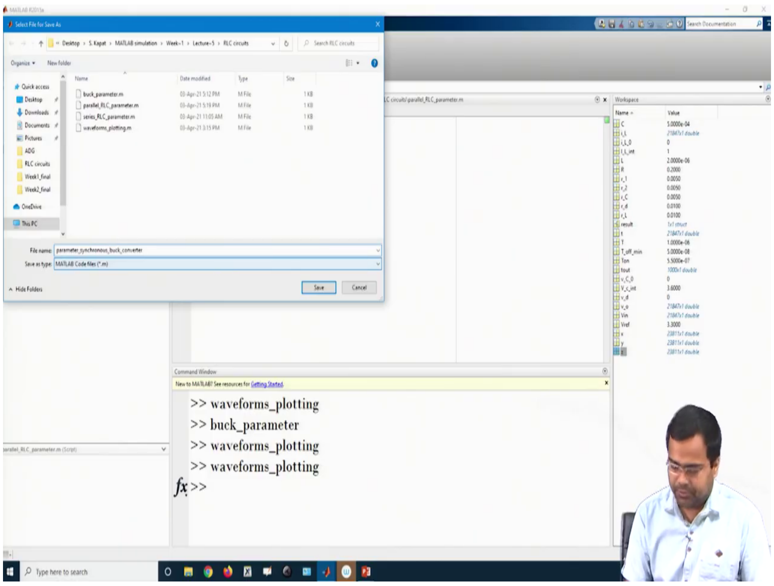

So, let us save as a synchronous buck. Now, I want to show you that these blocks are much more flexible. I also want to show you a synchronous buck; I want to set the parameter value.

That means, let us say whatever parameter of the RLC we have chosen we will save as there is another file is a synchronous buck and this is my parameter file, parameter para file ok.

So, in this parameter file we are keeping the same a L C R load resistance everything similar value, let us say we can change this value there is no problem. Now, let us go back. So, in the synchronous buck, what is now input? So, this we call it as a v x, the other branches are common. So, you can use this block. This is common and this block we need to create. This block is not very straightforward, because it has to come from a switching block.

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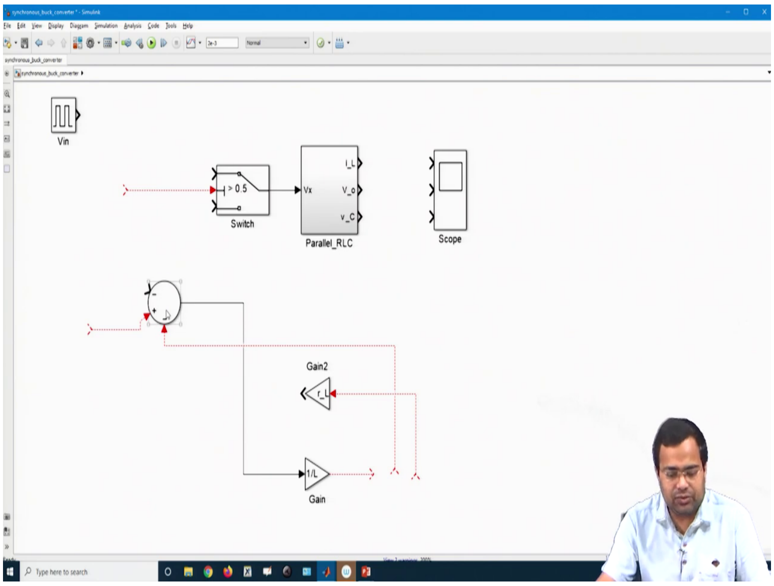

So, let us disconnect for the time being. So, we already have a parallel RLC branch. Now, we have to create a block. So, how do you make this block, if we again go back? So, here this is the block I am talking about. I need to implement this block now. So, this block consists of v x which. So, I need to define 2 additional parameter r 1 r 2, which are the r 1 is the on resistance of the high side switch, r 2 is the on resistance of the low side switch.

And, this v x will be generated using a switch block, when the switch is on, then if you look at this v x terminal, the v x will be V in minus r 1 i L, when the switch is on. And, that is when my q is equal to 1 right. And, it will be minus r 2 i L when q 2 q is 0. So, this switch block we have to use ok.

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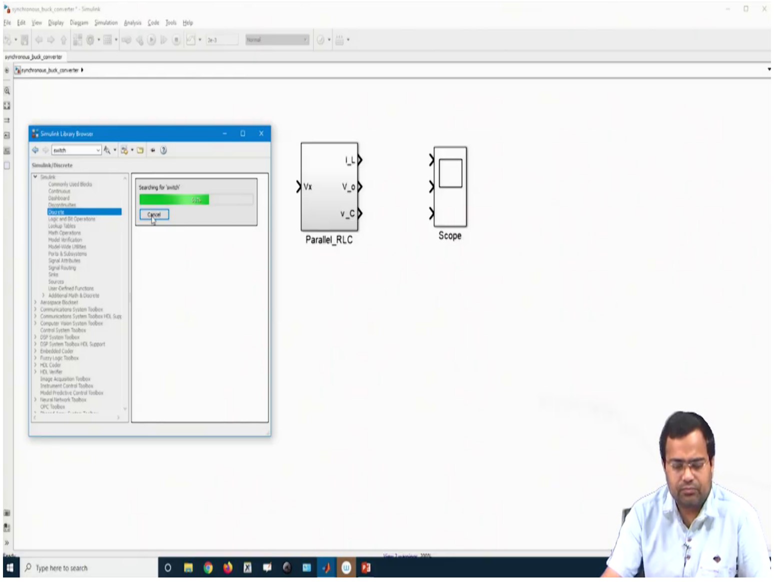

So, let us go back to this block. And, if we look for switch we should start for a switch block, switch should be available in the simulink, let us wait for a switch block, it is a continuous block and yeah. In fact, we do not need to look for, we just have to cancel. The switch block should be because it is a general purpose simulink block. So, yeah we can use you know switch block from here, ok, I think it was about to come.

In fact, we can in fact, we can use a function block MATLAB function either can you switch or you can use a function block that may be better. So, whatever we want because now the simulation is a bit slow here. So, our only purpose is when the q is on 1. It will take this block, the switch lock.

So, I think it is getting yeah. So, you got now you got switch block, that is it. So, this switch block we have connected here ok. Next, we got switch block.

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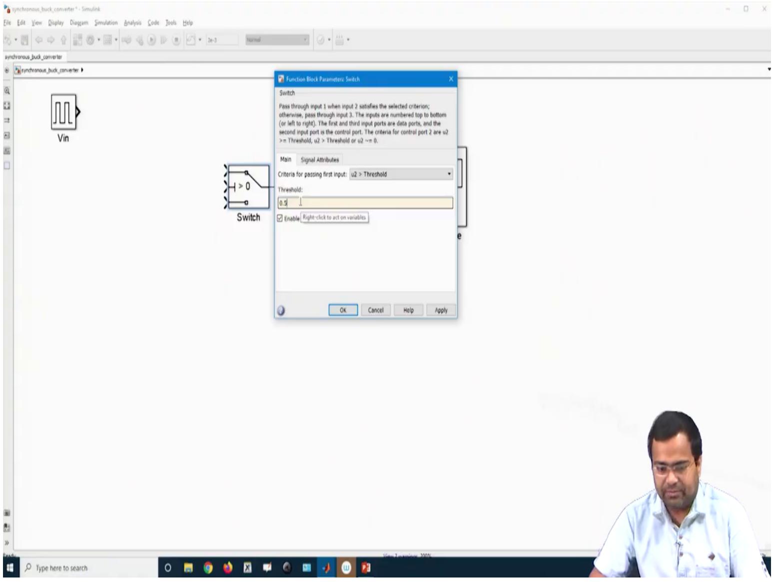

So, as I said we have to put a threshold value of the switch. Let us put 0.5; that means, if my this input is just a minute, if my the input to the middle channel, which is the input. If this input is greater than 0.5, then it will take channel 1. If it is less than 0.5, then it will take channel 2 ok.

So, we will select some basic blocks and we will select some of this block. Let us take, we need some of this block just for ok. So, what we need for the first block? That means, when the switch is on ok, it will take V in minus r 1. So, I need only 2 block ok I need V in ok sorry 1 minute.

So, this is my first block where I have to define what is the on resistance.

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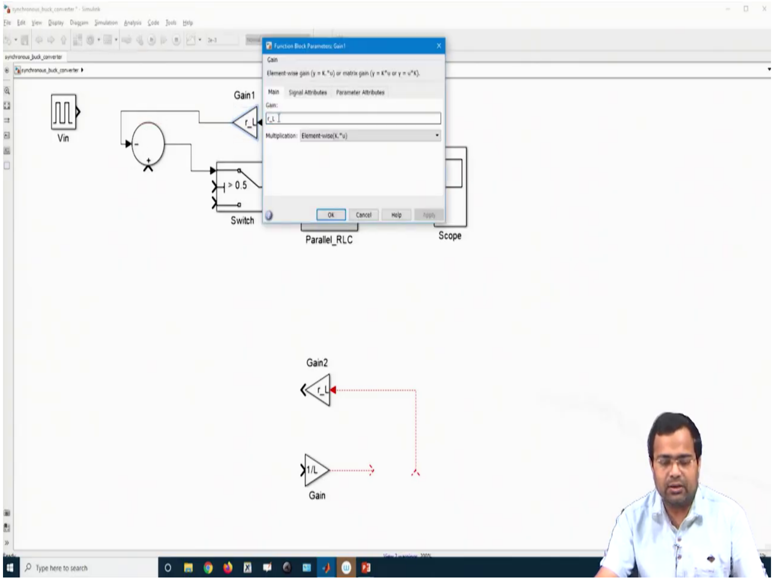

So, this is coming from inductor we can simply connect it like this. And, this is my r 1 or underscore 1 that is my on time resistance of the high side MOSFET ok. And, this is now my new V in ok. And then when this is off, it is simply a minus sign. Sorry, another gain block will be this will be what? It will be equal to i L minus r 2 for this channel. ok got it.

Now, input channel will create separately. And, we will create another channel, let us say so, sources. So, commonly used block, we can use a constant and that will use as a constant. So, that will use as an input voltage, because input we need a DC voltage and you can use a switch block here, that is for my generating the gate signal and that we go.

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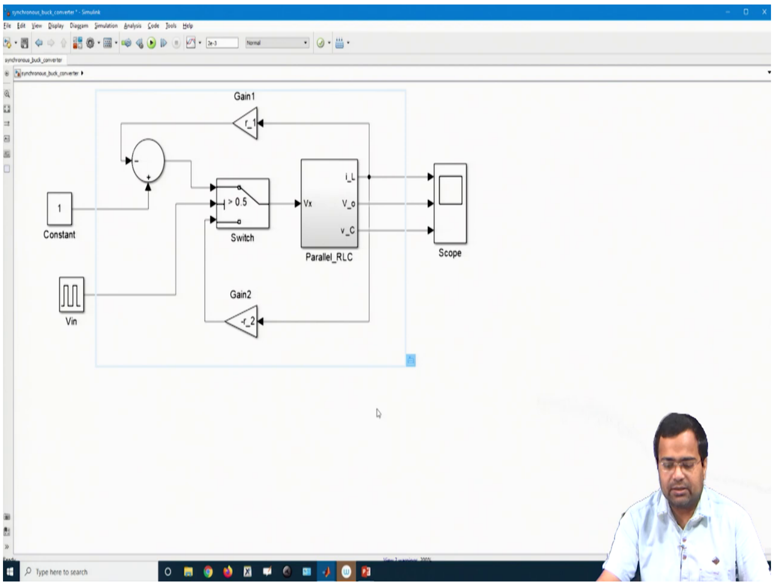

So, yeah. So, now, we have all sorts of blocks which are coming out. We need to see the output voltage; we need to see the capacitor voltage. So, these blocks now we can create a subsystem calling as a so, we are creating a subsystem this particular block.

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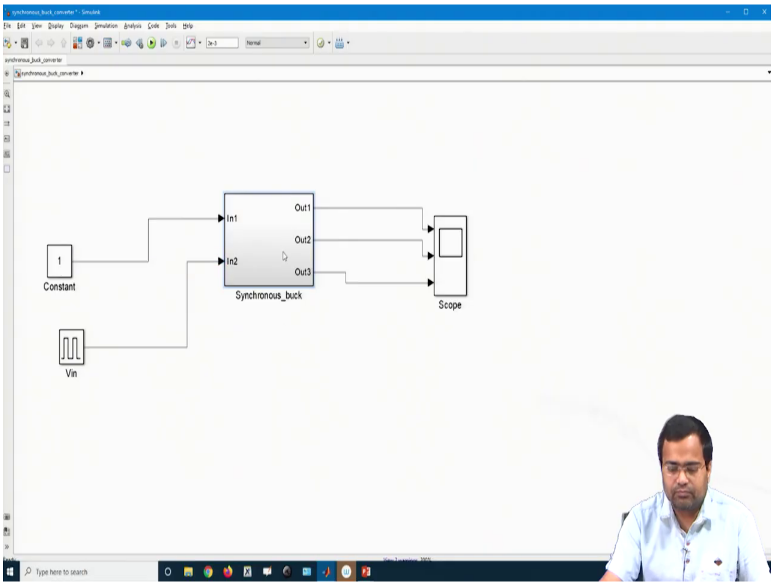

Create subsystem and this will call as synchronous buck ok, and we actually expand ok. So, what are the blocks? The first one is in V and this is my gate signal.

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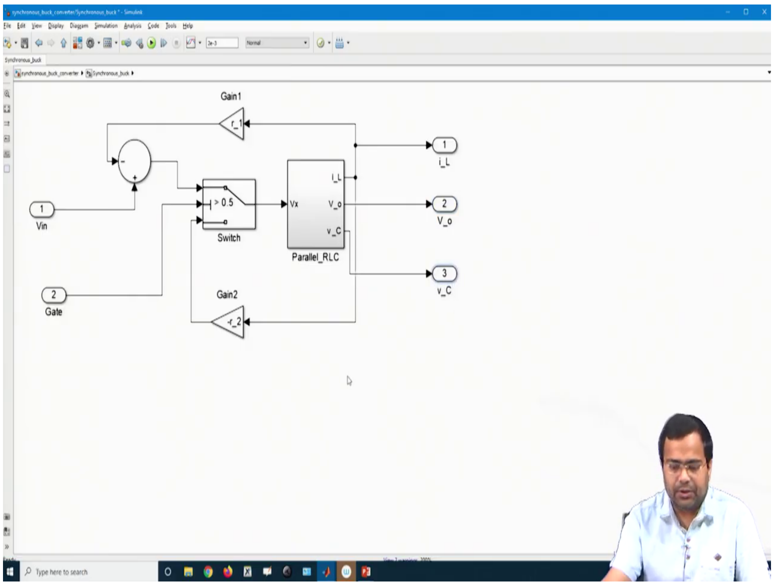

And, these are my output. This is my inductor current, this is my V out and this is my v C alright. So, we got input voltage V in v C, now we can set input.

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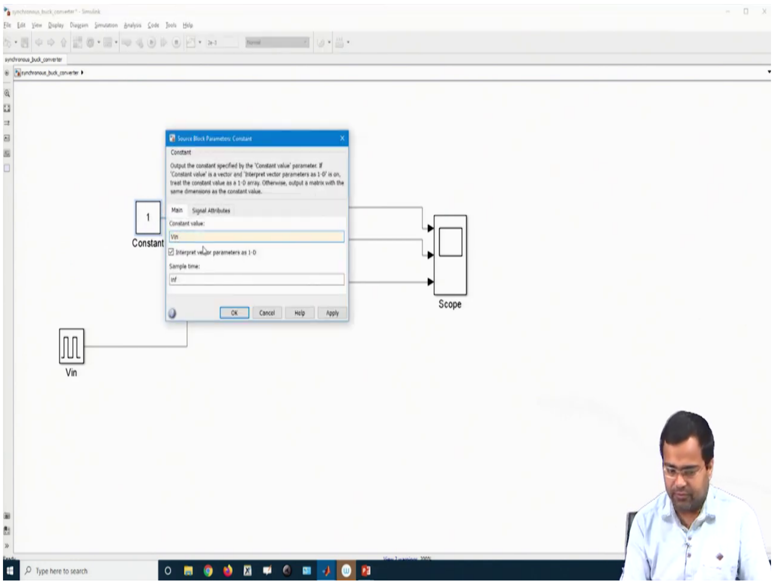

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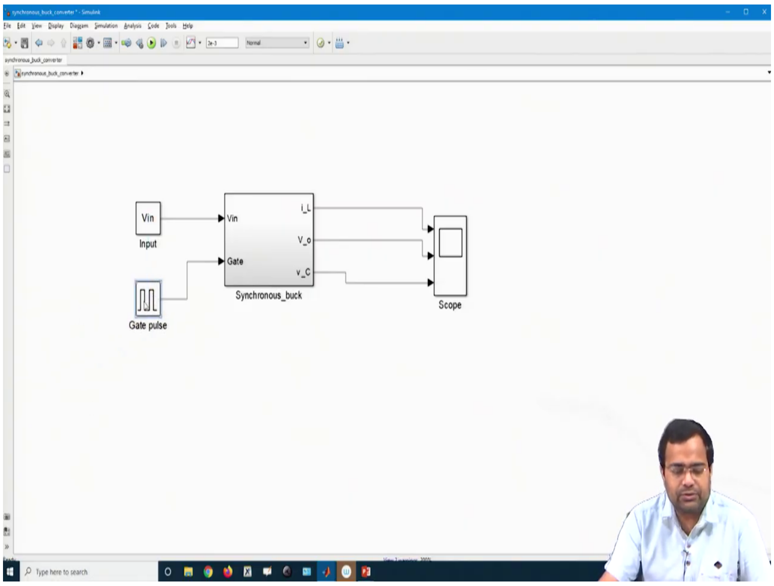

So, here we can choose a V in voltage that you want to select which is my V in ok or Vin is already there. So, input we can say input and this is my gate pulse ok.

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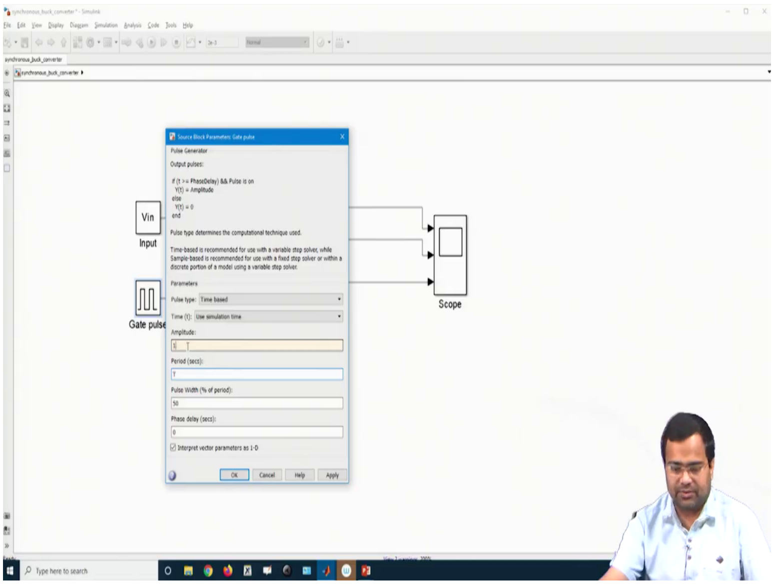

Now, suppose if I set a get pulse time period T, that I am going to set and with let us say 50 percent and amplitude is 1. Because gate signal will either high or low, logic 0 and logic 1. Now, we have to define all this parameter inside my this file.

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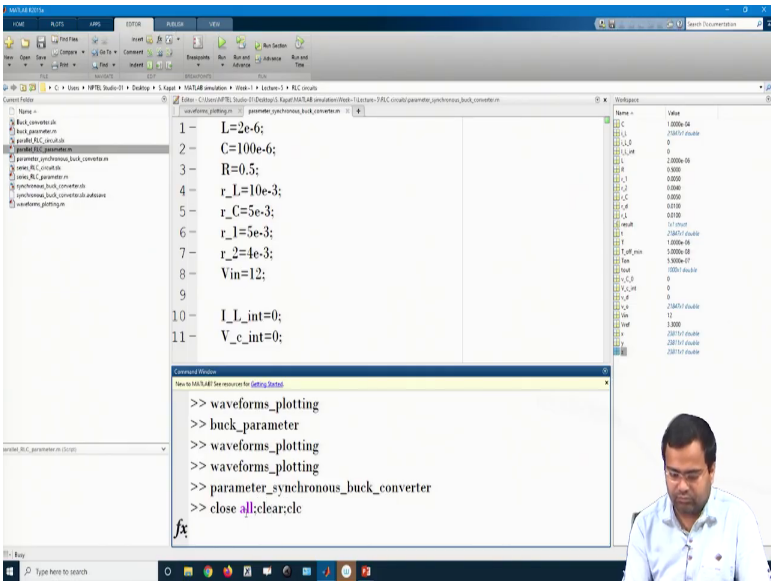

So, what is missing here? Here is missing term is r 1, let us say which is maybe 5 milli ohm e minus 3; r 2, which is let us say maybe 4 milli ohm you can customize what you want. And, other parameter V in let us say we say 12 volt, an initial voltage we have set 0 and 0 ok.

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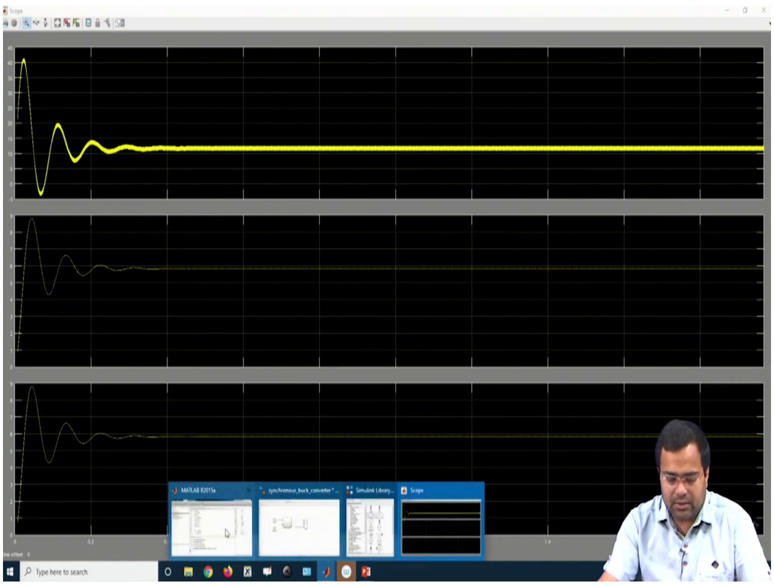

So, now I hope we are ready to go for simulation and let us see, but ok close all.

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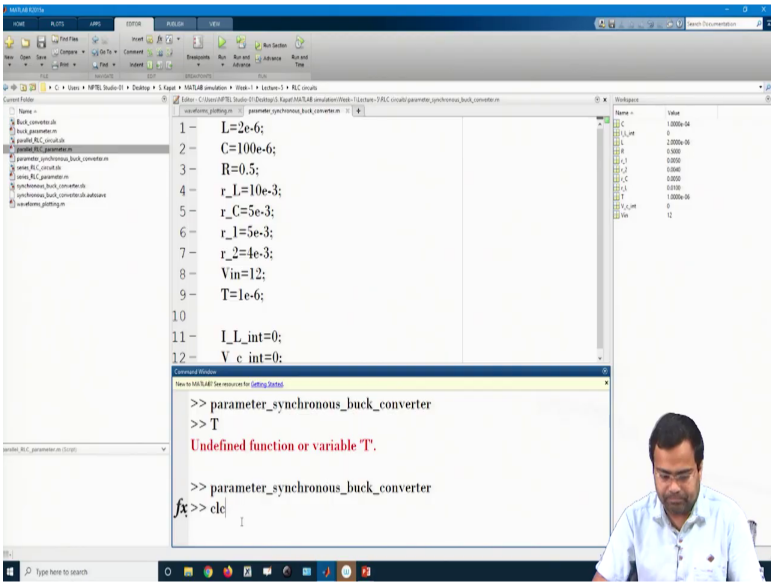

So, what is missing? If we run it will give error, because of time period is not set, time period is not set, but how is it taking the time period T ok? So, somewhere the T is there, where is the T? Undefined. So, we need to provide T, which is equal to 1 e minus 6, because that is my yeah. Now, let us go and simulate yeah.

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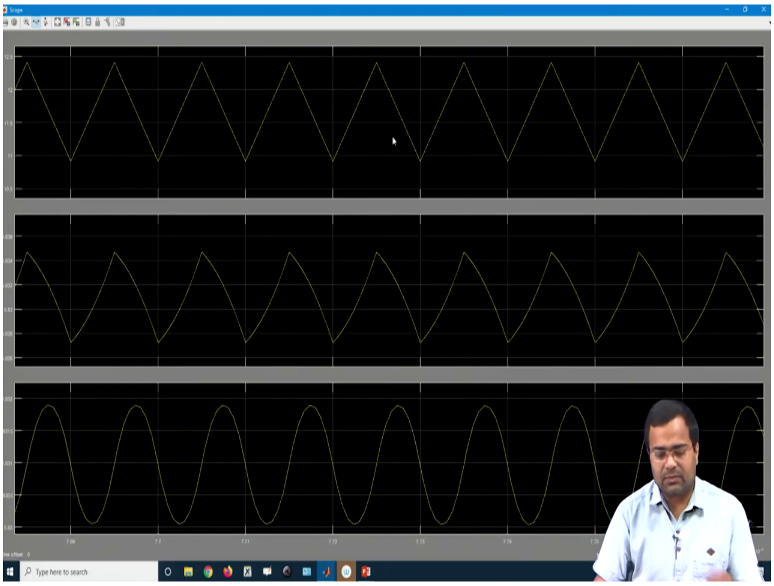

So, you can say that output voltage these are my inductor current for the given inductance value. And, this is my output voltage, and this is my capacitor voltage. These are my curve.

So, what I can plot it here? That means, now in the good waveform, I think I have used this result block. We need to check that is name is fine. Now, we will go for this one. So, first title was v L v 0 and this is my v c, so, v c ok alright.

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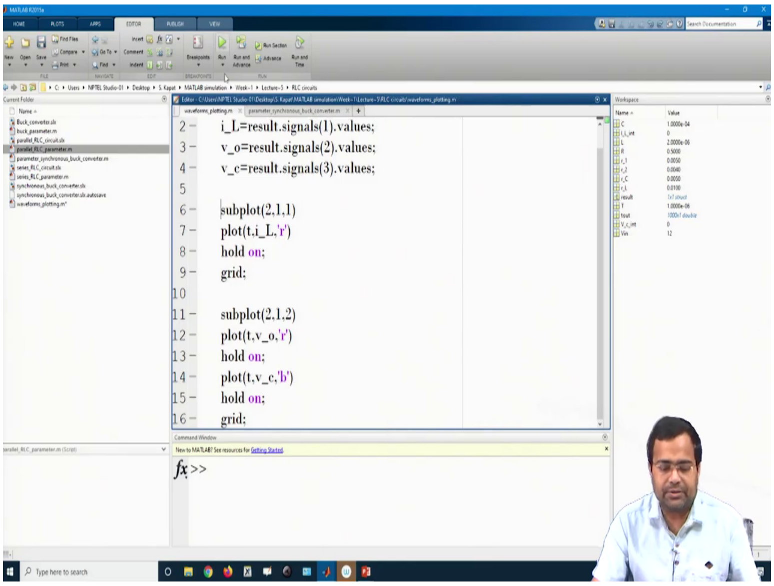

So, again, we will do subplot, now in this subplot 2; that means, we have to plot output voltage and capacitor voltage as well. I want to show you how the capacitor voltage looks like. Now, what is the difference between these two using a blue color and we can do hold on ok. Now, we will simply run it yes.

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So, if we run it, inductor current is showing like this, output voltage is shown like this. And, if we look at closely, we look at this wave form; that means, if we closely see around this time frame let us say, we choose like in between 3.8 to 3.9 microsecond.

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So, 3.8 to 3.9 microsecond if we choose, this window ok, so, in between 3.8 and 3.9, 3.75. So, I can choose this 3.9 to 3.8 like this and here also I can choose 3.8 to 3.9, 3.82. So, these are my wave form where the blue one is the capacitor voltage and the red one is the output voltage. So, due to the ESR the output voltage and the capacitor voltage are not identical. So, there is a slight difference in this waveform that is visible.

Now, so, we are able to implement this buck converter and I will leave it to for the next session you know I will present, that how to incorporate the DCM enable operation. How to incorporate DCM enable operation? I will make that presentation in the next one where I want to implement when we want to consider, discontinuous conduction mode there we want to show that.

Because, right now, we are only running the synchronous buck converter where we do not care about the discontinuous conduction mode, it will always operate in continuous conduction mode. But, if we want to incorporate DCM then we need to add a block where the 0 current detection will happen.

Because, if you look at this waveform, the inductor current actually is also going in the negative direction. If you go to this wave from, if you plot it you will see. At some point of time, the inductor current is going in the negative direction and which is not possible when there is a diode.

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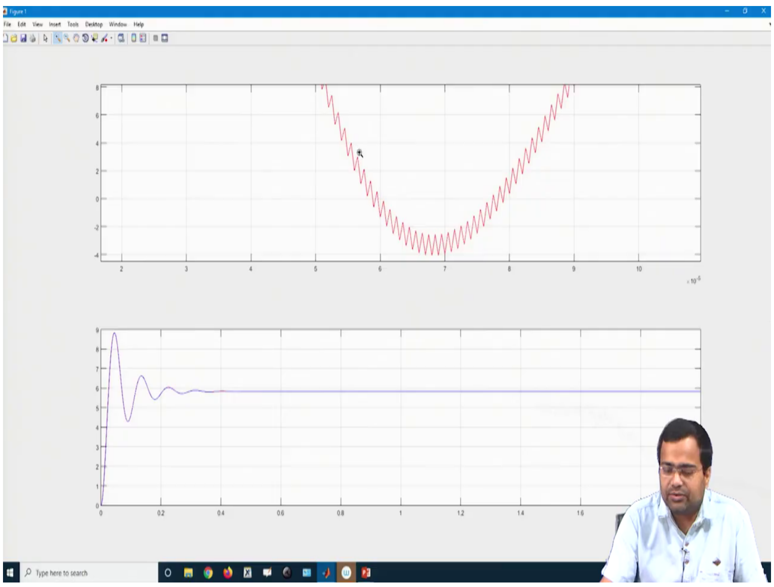

So, here it is fine, this is fine ok. So, I think that is all for today. So, we have learned about how to implement a switching converter. And, that we have derived based on you know if you go inside the synchronous buck converter, it is a parallel RLC circuit.

And, there we just added the switch block and that implement our synchronous buck. A same model. If we add some more feature it will become conventional buck. In fact, we can also slightly modify this block to create a boost converter.

So, all this model; will be shown at this point, but here I want to show from future onward we want to show the building block directly, rather than developing from the scratch. Because, last two presentation this one and the previous was aimed to show that we can develop custom building block, using MATLAB Simulink.

Thank you very much.