

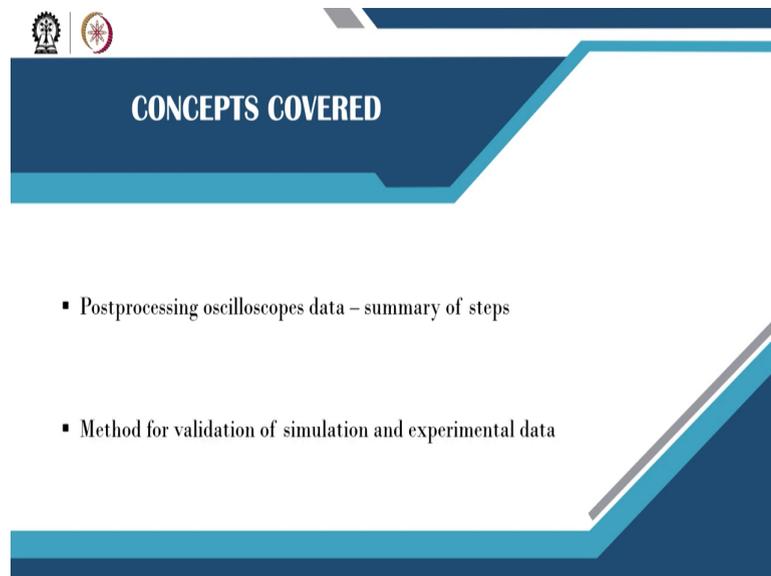
Digital Control in Switched Mode Power Converters and FPGA-based Prototyping
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Indian Institute of Technology, Kharagpur

Module - 11
Design and Validation of Case Studies using DVMC and DCMC
Lecture - 102
Data Acquisition and Steps for Validating Simulation and Experimental Results

Welcome, this is the continuation of the previous lecture where we have shown a realistic MATLAB model and then we have shown the image file of the simulation result as well as an experimental result. In this lecture we are going to show the step for data acquisition through oscilloscope using a CSV file and how can you know plot I mean how can you plot both simulation and experimental results using a single graph? And then we want to see how much they are matching.

And if I mean it is expected there will be some deviation from experimental and simulation results. And we want to you know try to you know understand what may be going wrong.

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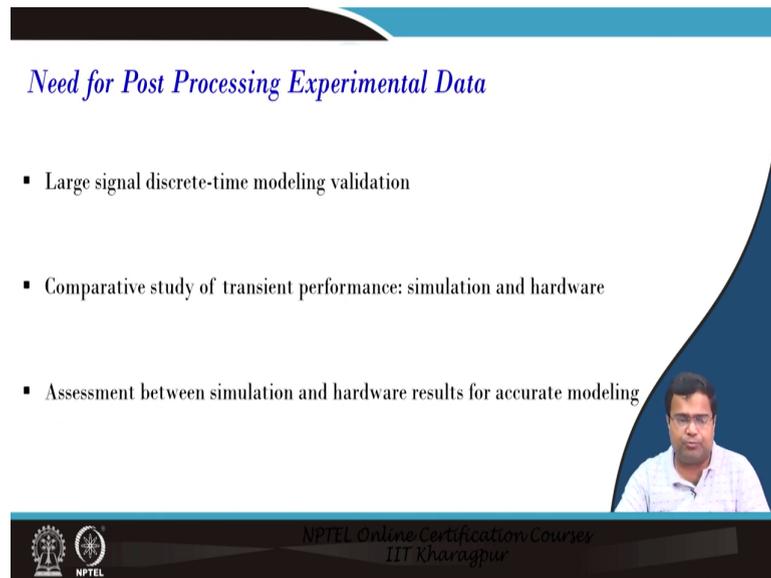


The slide features a dark blue header with two logos on the left and the text 'CONCEPTS COVERED' in white. Below the header, there are two bullet points in a list format. The slide has a decorative blue and white geometric design on the right side.

- Postprocessing oscilloscopes data – summary of steps
- Method for validation of simulation and experimental data

And that is why the difference is coming. So, here we will be talking about the post-processing of oscilloscope data and the summary of the step and then we will show the method of validation of simulation and experimental data.

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Need for Post Processing Experimental Data

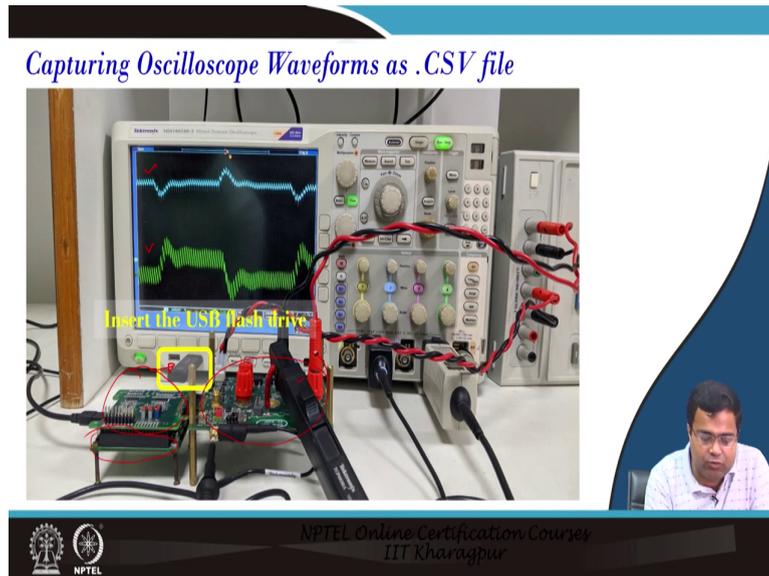
- Large signal discrete-time modeling validation
- Comparative study of transient performance: simulation and hardware
- Assessment between simulation and hardware results for accurate modeling

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So, first, we need to understand the need for post-processing. So, one of the purposes of the need we want to post-process the experimental data we want to match sometimes the discrete-time large signal model for validation. We also want to study the comparative transient performance of both simulation and experimental results. This will help to fine-tune our simulation model. So, that it can more or less capture the hardware result. It may not be possible to exactly match, but how far we can match?

So, once we can capture that in the model then we may not need to do a lot of iteration in the hardware. So, we can do the design process using our analytical model, and we can check in the simulation before going to the experimental validation. And that we will be discussing this week in the subsequent lecture. And we will also show some assessment between simulation and experimental results whether the models are accurate or whether there is a need for scope for improvement.

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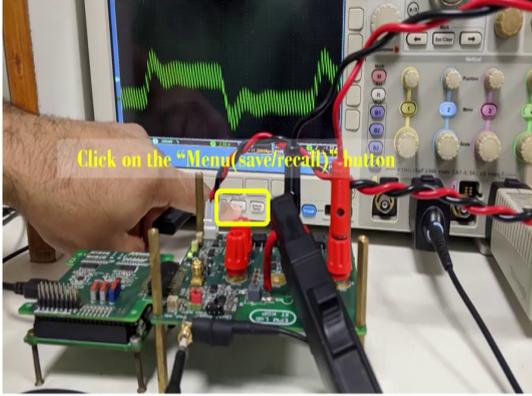


So, first, we will show that step for capturing the oscilloscope waveform as a dot CSV file. So, here I am showing the screenshot of the oscilloscope you can see this is the pen drive you know the oscilloscope will have a USB drive and this is the running waveform where we are showing the output voltage wave from here and the inductor wave from here live.

And this is the current probe and this is our you know signal conditioning board and this below is our FPGA kit and this is our power stage board we are trying to take the result earlier we took the image file, but now you want to take the CSV file. So, you have to insert the USB file then you have to select the menu option; that means, if you go to the previous there is a menu option here.

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Capturing Oscilloscope Waveforms as .CSV file (contd...)



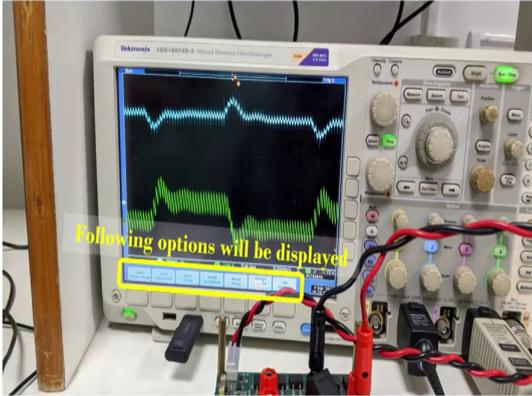
Click on the "Menu (save/recall)" button



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Capturing Oscilloscope Waveforms as .CSV file (contd...)



Following options will be displayed



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You can see there is a menu option here. So, you have to select the menu option if you select the menu option then click the menu save and recall there you will get an option that what type of thing you want to save. So, assign it to whether it is an image file.

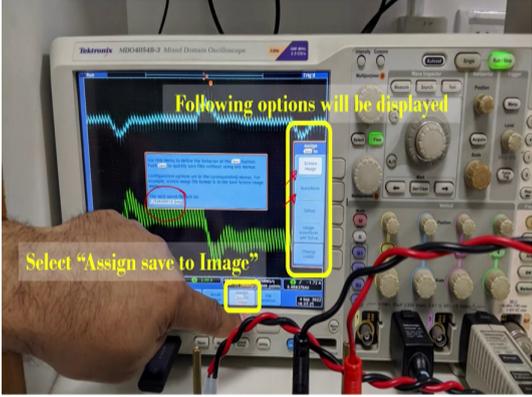
So; that means, when you option the menu it will come up the same screen image. Right now it is the screen image, but we want to take the data file rather than the image file. So, then you have to click here, if you click here then you know when you click this option particularly if

you click this button, particularly this particular button then you will get the option. So, here by default, we are getting the image file.

But we want to take the waveform if it is an image file it will we can save it in a dot BMP file typically we take the data in BMP.

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Capturing Oscilloscope Waveforms as .CSV file (contd...)



Following options will be displayed

Select "Assign save to Image"

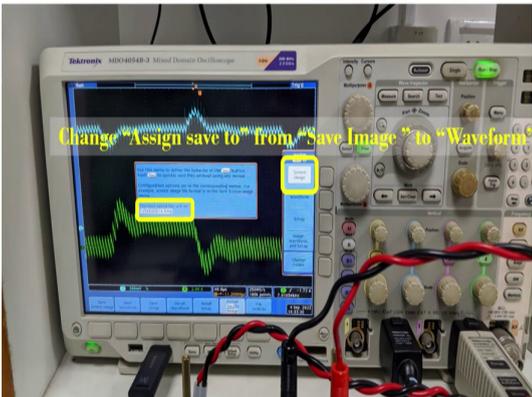


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Now, so, we have to assign save to the image if it is an image then it will be saved as a BMP file ok.

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Capturing Oscilloscope Waveforms as .CSV file (contd...)



Change "Assign save to" from "Save Image" to "Waveform"

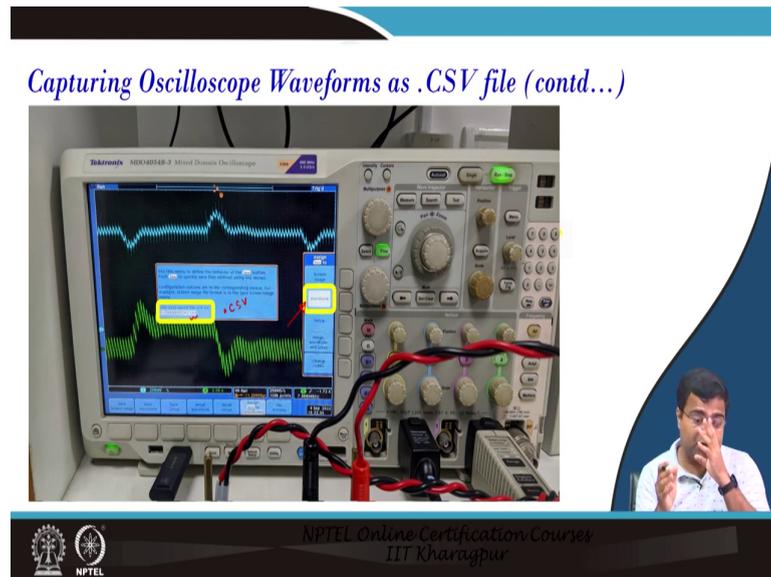


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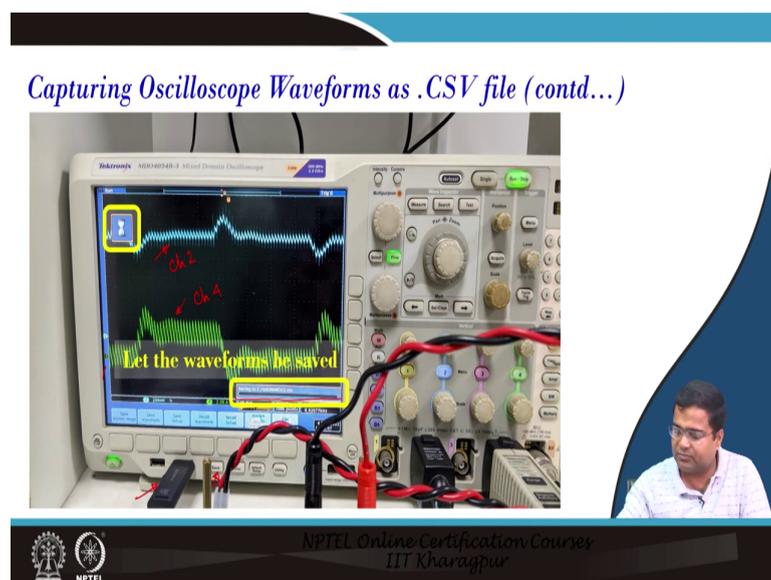
Now, so, this will save as an image now we want to change the image because of the image we have shown in the previous lecture. The image of the simulation result and the image of the experimental result.

But now we have to take the data and plot it in a single command.

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So, then we have to change to the waveform when we change to waveform then the extension file will be shown as dot CSV. That is like an excel file dot data file. Then you get the savings

when you say save; that means, this is the button that you have to press when you press save, it will show the status that it is saving.

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Typical .CSV File for Oscilloscope Waveforms

Row	Column A	Column B	Column C	Column D
1	Model	MS2005A11		
2	Manufacturer	VM	5.02	
3	Manufacturer IANAID			
4	Point Format			
5	Horizontal Div			
6	Horizontal Div	4.00E-05		
7	Horizontal Div			
8	Horizontal Div			
9	Sample Rate	4.00E-05		
10	Record Length	100000		
11	Cursor	0.00E+00		
12	Probe Delay	10	10	
13	Vertical Chan1	A		
14	Vertical Chan2	0.00E+00		
15	Vertical Scale	0.2	2	
16	Vertical Posit	2.00E+00		
17				
18				
19				
20				
21				
22	Time	0.0	0.00E+00	
23		2.33E-04	1.052	0.8
24		2.33E-04	1.075	-0.56
25		2.33E-04	1.06	-0.8
26		2.33E-04	1.075	-0.64
27		2.33E-04	1.042	-0.6

So; that means, the data is saved when the data is saved then you open this USB file; that means, you remove that USB pen drive and connect to your computers once you connect to your computer then you will get a file name called dot CSV accordingly and if you double click this file open in excel sheet. So, there will be a lot of information it will show the model name of the oscilloscope, then waveform, probe attenuation all this information will be there.

But this is where your actual waveform will start this is where. So, the first I will say the first column will be the time vector. The second column will be channel 2 because we are only showing 2 channels. Channel 2 and channel 4. If you go we are showing this is in channel 2 the output voltage is in channel 2 and channel 4 you can see here channel 4 is my inductor current ok.

So, channel 2 is my output voltage and channel 4 is the inductor current. And this is captured by the probe. So; that means, this will show the original currents and voltage. So, this time series data start from here; that means, start from here.

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MATLAB Plots from .CSV File

csv_data_plot.m

```
data=csvread('tek0005ALL.csv',21,0); % skips first two one rows
time=data(:,1); vo=data(:,2); iL=data(:,3);
figure(1)
plot(time*1e+3,vo,'r','Linewidth',3); hold on; grid on;
set(gcf,'color','w');
set(gca,'FontSize',15,'FontWeight','bold','linewidth',3,'FontName','Times New Roman');
xlabel('time (ms)','FontWeight','bold','FontSize',15,'FontName','Times New Roman');
ylabel('voltage (V)','FontWeight','bold','FontSize',15,'FontName','Times New Roman');
figure(2)
plot(time*1e+3,iL,'g','Linewidth',3); hold on; grid on;
set(gcf,'color','w');
set(gca,'FontSize',15,'FontWeight','bold','linewidth',3,'FontName','Times New Roman');
xlabel('time (ms)','FontWeight','bold','FontSize',15,'FontName','Times New Roman');
ylabel('current (A)','FontWeight','bold','FontSize',15,'FontName','Times New Roman');
```

Handwritten annotations in red: 'time' with an arrow pointing to the first column of the data matrix; 'C1 → time', 'C2 → vo', and 'C3 → iL' with arrows pointing to the respective columns in the data matrix. A small sketch of a plot is visible in the top right corner.

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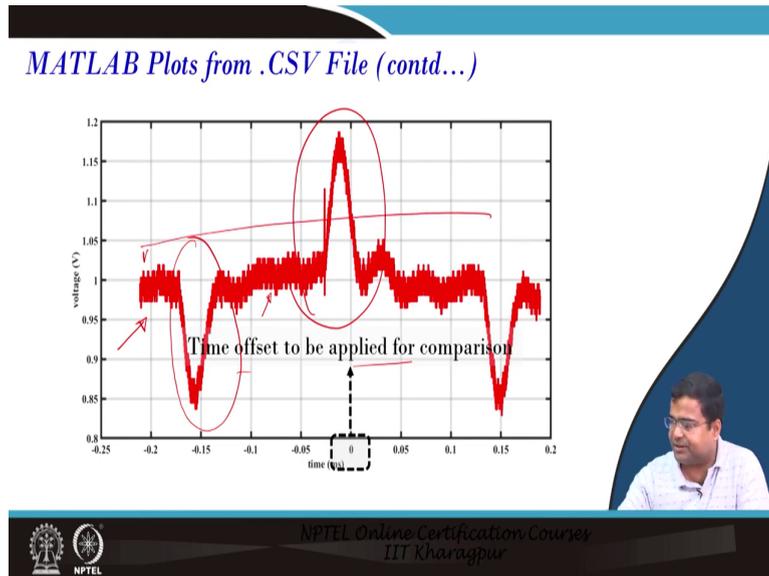
Then when you have to read the data; that means, you start from 21 or you can remove this then you recall the file name is stored as tek0005ALL dot ok dot CSV.

Now, in this CSV file you know we have discussed how to capture the walk space data in MATLAB. So, if you remember that we have saved our waveform of the simulation result in a dot you know in the walk space and walk space we saw it is a structure where we have the first vector which column vector which was time then we got a data vector the first column data was current depending upon which column you are using.

So, here we have 3 vectors the first column vector column 1 is a time vector the second column vector is known this will link with your time it is a time vector. Column 2 is linked with your output voltage it is channel 2 and column 3 is linked with your inductor current ok. That we know. Once you get then you are ready to plot. So, we are plotting the data will be by default in the second we can multiply in 1, 10 to the power 3.

So, we can show in ms, because you want to show the data in a millisecond which is why you are scaling the time and you are plotting the output voltage waveform. So, this will plot the experimental data and we have to hold and grid it. Then on plot 1 there similarly we can do plot 2 which is the inductor current waveform. Now, we want to hold the data and we want to plot the simulation data.

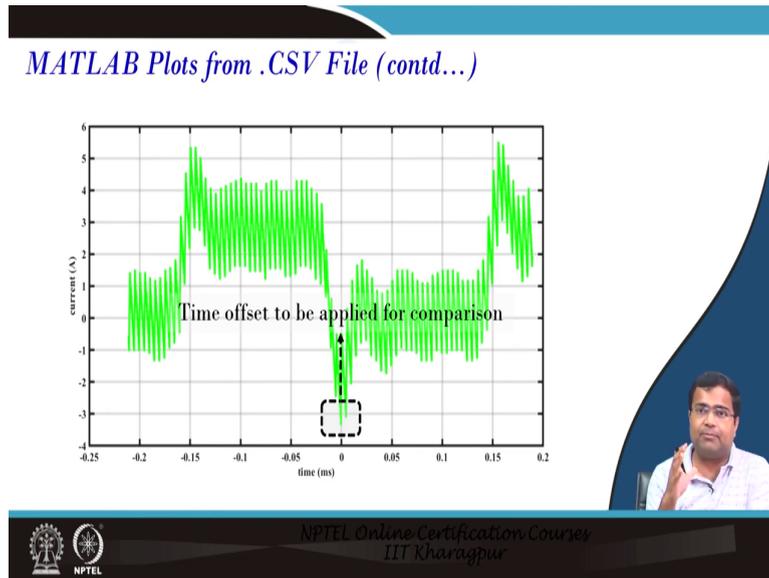
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So, this is the experimental data; that means, we are plotting the experimental data output voltage and here there will load step-up transient and there is a load step-down transient and the experimental data naturally there will be some noise you know these are not deterministic signal. So, these are stochastic signals that will have some noise also. Then and this noise since you are using a digital storage oscilloscope is why the data will look like quantized data.

Next we actual experimental data you will see it is starting with some negative values. So, we need to apply some time offset. So, that you can start this waveform from 0. So, you have to shift to the right side. So, you have to add a time offset.

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This is the inductor kind waveform it also has a time offset that you have to consider and this is the experimental plot we are showing in MATLAB because we have already accessed the data.

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Steps for Comparing Simulation and Experimental Results

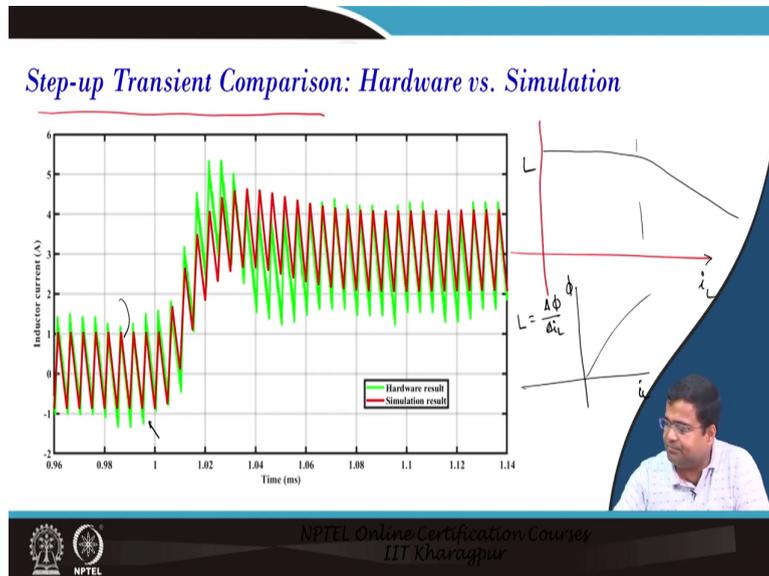
- Plot the oscilloscope waveforms from ".csv" file
- Apply the load step-up transient in simulation and select "csv_data_plot_stp_up"
- Select proper time-offset to compare the step-up transient in " v_o " and " i_L "
- Apply the load step-down transient in simulation and select "csv_data_plot_stp_dwn"
- Select proper time-offset to compare the step-down transient in " v_o " and " i_L "

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Now, next step we want to compare this experimental result with the simulation result. So, first, you plot the oscilloscope waveform from the CSV file, which we have just discussed then apply step-by-step load transient simulation in our MATLAB file and just apply step-up transient ok. First, we have to show the step-up transient. So, we need to properly set the time

offset so, that both transient steps up should happen at the same time for both simulation and the experimental case.

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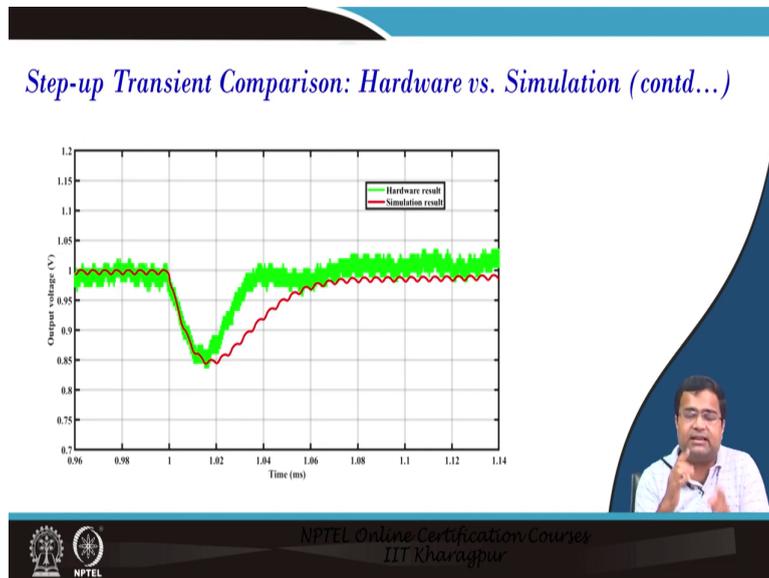
Then we will apply to step down we can show the step down separately and we too again consider the time offset and this is the step-up transient. So, this is the step-up transient comprehensive study where the red one is the simulation result and the green one is the experimental result. So, we will see the experimental result the current ripple is slightly higher; that means, whatever inductor we have compared considered in the simulation is a little bit larger than the actual hardware.

And this might happen because in actual hardware the inductor can slightly vary. If you increase the current the inductor variation may be large, because if you take the data sheet of any inductor you know if you go to the datasheet the inductor value may be the same then it will start degrading and this is concerning the current and this is the inductor value.

Because it all comes goes down to the flux, because if you go to the flux. The flux will enter into a non-linear region where what is the definition of inductance? It is a change in flux by the change in current. If this is the current axis this is a flux axis naturally as it enters into saturation region the flux change will be less.

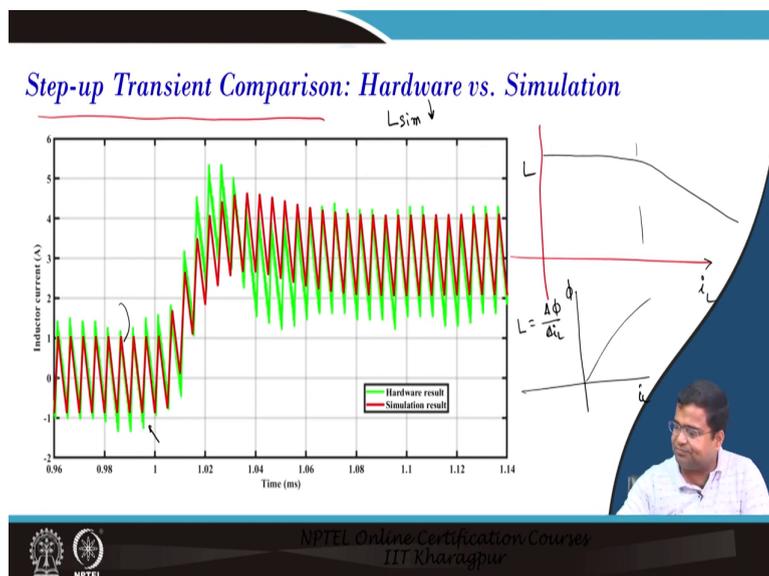
So, the value of the inductance will go down. So, at practical inductance, there is a scope for actually further tuning our simulation inductor value by taking into account this inductor. So, I think we may reduce the inductor value a little bit.

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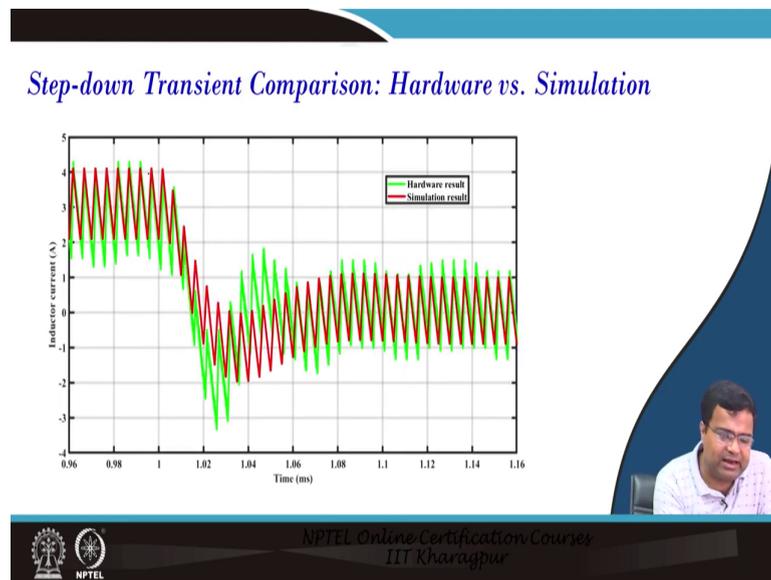
Now, since we are using a slightly larger inductor in our simulation, as a result, we are getting a little bit of sluggish transient response to step up transient using simulation compared to the hardware result; that means, there is a slight difference in their undershoot remains more or less same, but there is a slight deviation in the I would say the recovery time.

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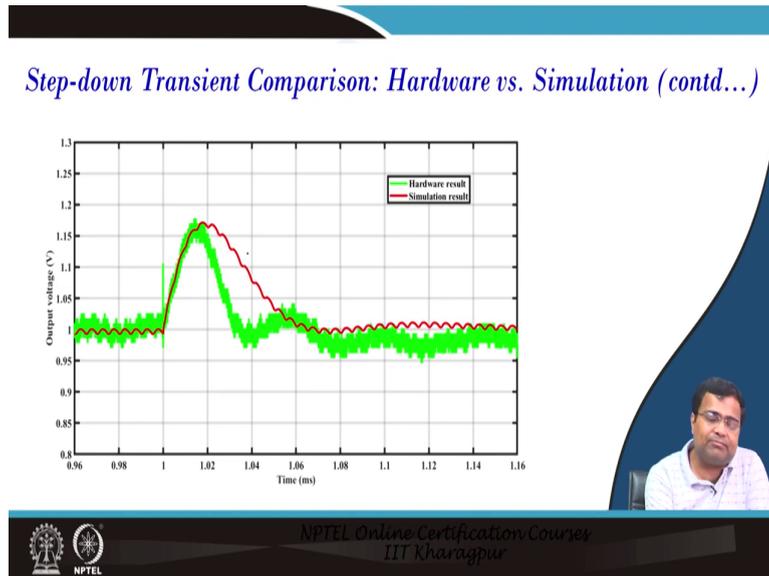
And; that means if you go back to our simulation result. I would say the simulation inductance value we may have to increase maybe by 5 percent or 10 percent. We may have to reduce sorry we may have to reduce the inductor value in the simulation case study.

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So, that we can match the current ripple of the measured inductor current. So; that means, we can play around with the data and we can fine-tune our simulation parameter so, that we can match ok. Now, this is a step-down transient again you can see there is a division in the measured current ripple and the simulated current ripple. So, we can increase we can change the simulation inductor current by slightly decreasing the inductor value.

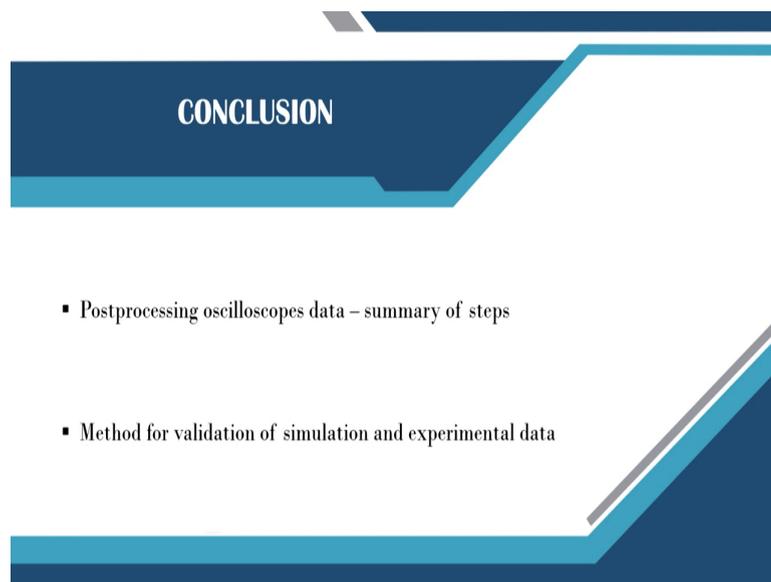
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Again we are our simulated parameter experimental simulated low step-up transient step down has a slightly higher recovery time or the settling time compared to the experimental result. So, there and we have discussed they may not match exactly. So, there is a source of you know deviation and this may be attributed to many you know unmodelled dynamics like we have not considered the parasitic of the inductor in the like an ESL effect in the capacitor.

We have not considered the dead time effect in our simulation that can also be captured. We have not considered the other trace parasitic and also we have not rightly modeled the inductor which we can model by slightly decreasing the inductor value. And I hope if we do that we may come further closer to the hardware result, but it is almost impossible I would say very difficult to exactly match.

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CONCLUSION

- Postprocessing oscilloscopes data – summary of steps
- Method for validation of simulation and experimental data

So, in summary, we have shown the technique for post-processing of oscilloscope data. We have shown the summary of steps and we have discussed the method for validating simulation and experimental results.

And we have discussed some aspects of the mismatch between simulation and experimental results and we have also discussed there is some room for improvement. And this may be the motivating case and this kind of validation and further upgrading the model will help us to design the converter suitably. And so that you can you know the design in your simulation or analytical model and you can plug in simple to the experimental result. So, that you can meet the desired performance requirement that is it for today.

Thank you very much.