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

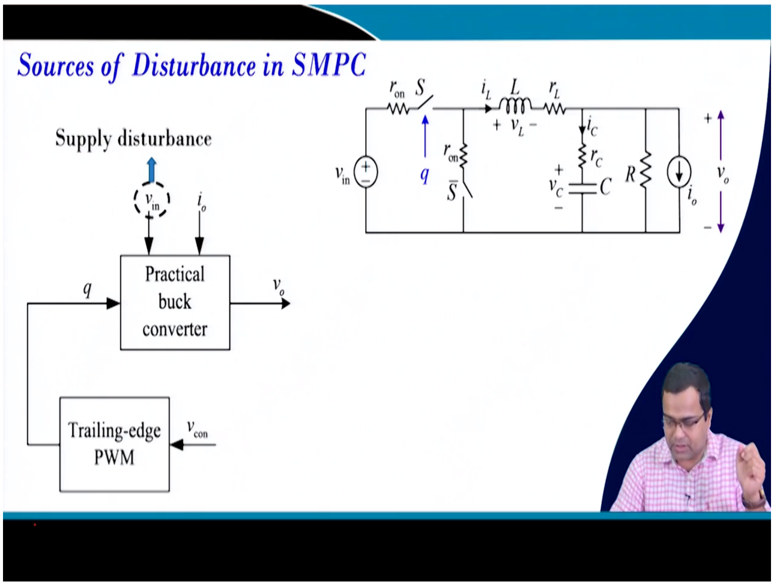
Module - 03
Fixed Frequency Control Methods
Lecture - 14
Feed Forward Control in SMPC and MATLAB Simulation

Welcome, this is lecture number 14; in this lecture, we are going to talk about Feed Forward Control in Switch Mode Power Converter and MATLAB Simulation.

(Refer Slide Time: 00:35)

So, the topic which I am going to cover are sources of disturbance in switch mode power converter, then disturbance rejection using feed forward action, then supply disturbance rejection and MATLAB simulation, then load disturbance rejection and MATLAB simulation, and understanding need for feedback control.

(Refer Slide Time: 01:01)



So, first I want to talk about sources of disturbance in switch mode power converter. So, here I am showing a synchronous buck converter with parasitic, real parasitic.

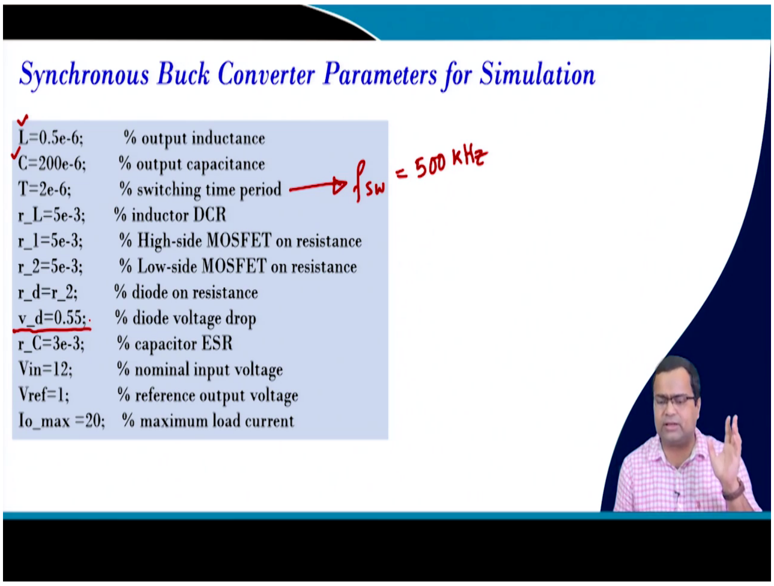
And if we take this converter, the major disturbance which can arise is the supply disturbance. Because you know we have discussed in the previous class that, there can be a disturbance in the power supply, because if it is a practical voltage source and the disturbance can occur, because if multiple converters are connected to the same source and that disturbance can propagate from one converter via the source to the other converter, that is one possibility.

The other possibility is that you know the supply can be a battery, which the voltage can fall; because when you are trying to draw current from it. So, there can be variation in the voltage. So, in spite of this variation, our objective is to how can we reduce the effect of supply disturbance in the output, that is one of the objective.

The other disturbance can occur is a load disturbance; because this power converter will be designed to drive certain applications. For example, if you talk about led driving application; if we talk about you know battery charging or if you talk about processor power supply.

In processor power supply, we need to cater the load transient; because the based on the competition of the processor, the load current or load demand can drastically vary and there can be frequent load changes, load current changes. So, now, the power supply has to you know have to reject the disturbance or basically reduce the effect due to the variation in the load current, because we need to design a regulated power supply, ok. So, the load disturbance is another source of disturbance.

(Refer Slide Time: 02:57)



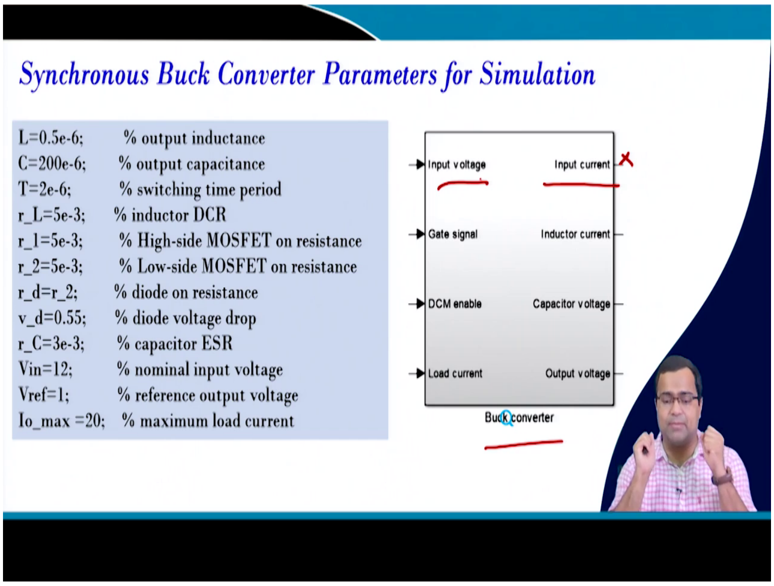
So, in synchronous buck converter parameter, because we are going to talk about MATLAB simulation and we want to show few motivated simulate simulation case study to show that; the sources like disturbance in the supply voltage, how it can affect the output voltage. So, in this particular design, in the previous class we have discussed how to design the power stage of a buck converter.

And we found that if we want to select the switching frequency to be 500 kilo Hertz; because this corresponds to the switching frequency of 500 kilo Hertz and then that relate 2 microsecond time period and we also decided that how to design inductance as well as the capacitor, like in output inductor and the output capacitor.

And here we are considering real parasitic; but since we are talking about synchronous buck converter, so this diode drop will actually not come into picture. But our model is generic, so we can use in conventional configuration when this diode drop will come. The other one is the reference voltage.

So, we are trying to achieve 1 volt; but I am not going to talk about feedback control here, so we may find the output voltage for a desired duty ratio, it may not achieve the same output desired output voltage, ok. Because if you do not connect closed loop control, then naturally the output voltage will not be exactly the same as what we want.

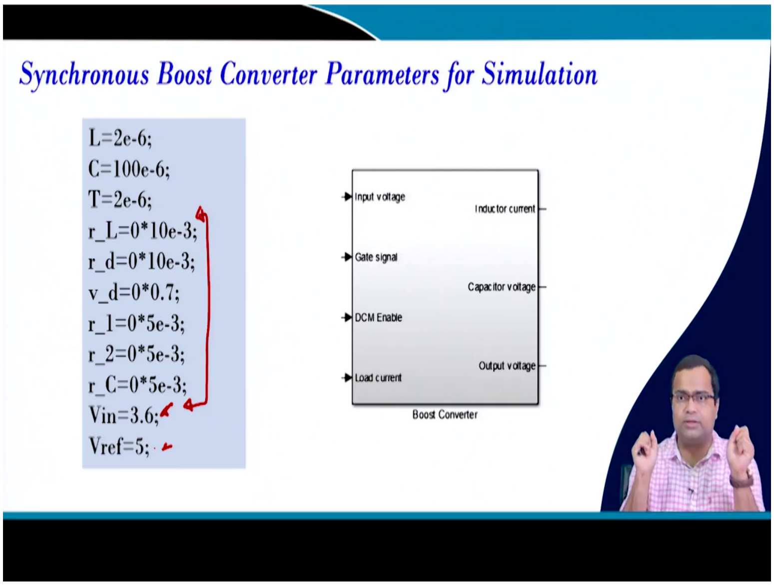
(Refer Slide Time: 04:34)



So, this is the configuration and this is the you know. So, this is the buck converter model, MATLAB model which we have developed in the sub previous subsequent lecture. And in the last class, we discussed about how to also connect or basically tap this input current; because this is very important, if we want to connect an input filter to this converter, then the input current of this converter should be connected to the output current of that particular block.

For example, in filter, what is the output current that should be connected to the input current and that filter output or the supply output will be the input to this input voltage. So, these are like a plug and play type model, ok.

(Refer Slide Time: 05:19)

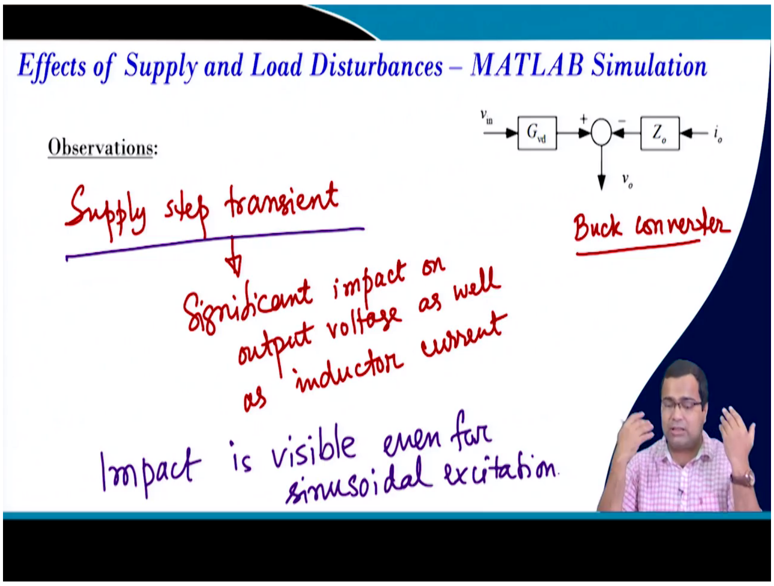


Next we are also talking about a boost converter and we are going to talk about in this class is the feed forward control. Suppose even without feedback control; can we, first we want to observe what is the effect due to the disturbance and then we want to see how can we reduce the effect due to the disturbance by means of feed forward action, ok.

So, here we are talking about first the boost converter is one of the case study and also we primarily consider on the buck converter. And for the boost converter case study we have consider that L C value which are given here like 2 micro Henry inductor, 100 micro Farad capacitor and for the time period of you know 500 micro like 500 kilo Hertz.

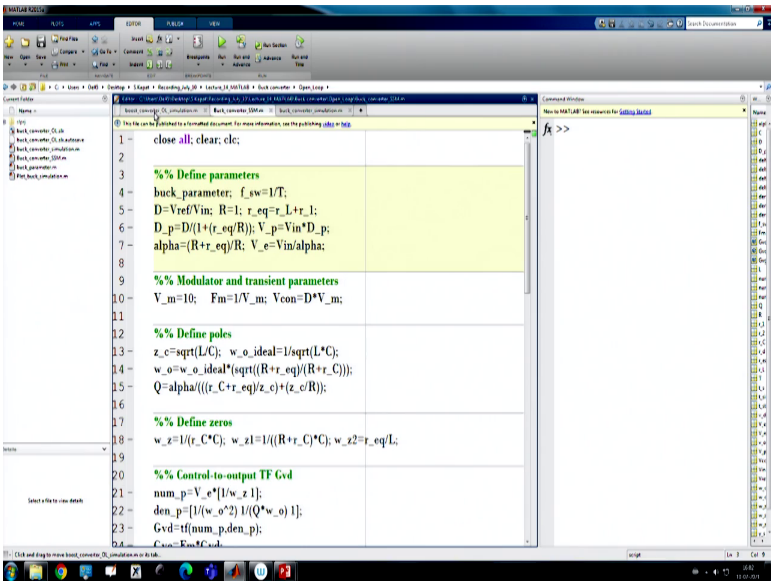
And for the boost converter, initially we have consider you know the ideal boost converter; but we can of course you know go for practical boost converter, that is not a problem. And then we are initially we are considering 3.6 volt input and 5 volt is a desired output; but again there is no closed look control, so your actual output may be different. But in case of an ideal boost converter, we probably can achieve output voltage to its desired value by suitably setting the duty ratio.

(Refer Slide Time: 06:45)



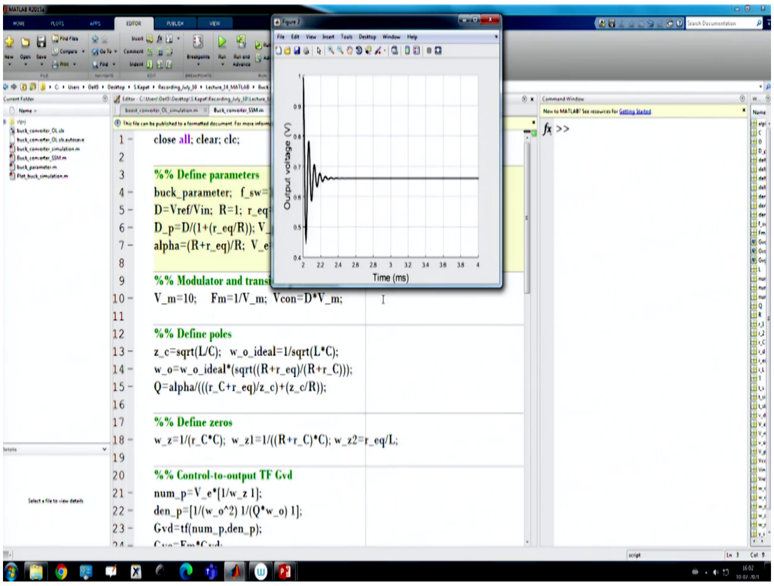
Now, first want to say as we want to observe, the effect of supply and load disturbance using MATLAB simulation. So, we are first talking about a buck converter. So, initially we are considering a buck converter and we want to see the effect. And subsequently we will see the supply disturbance in a boost converter and also we want to develop feed forward control, whether can we reduce the effect of supply disturbance in the output or not, ok.

(Refer Slide Time: 07:18)



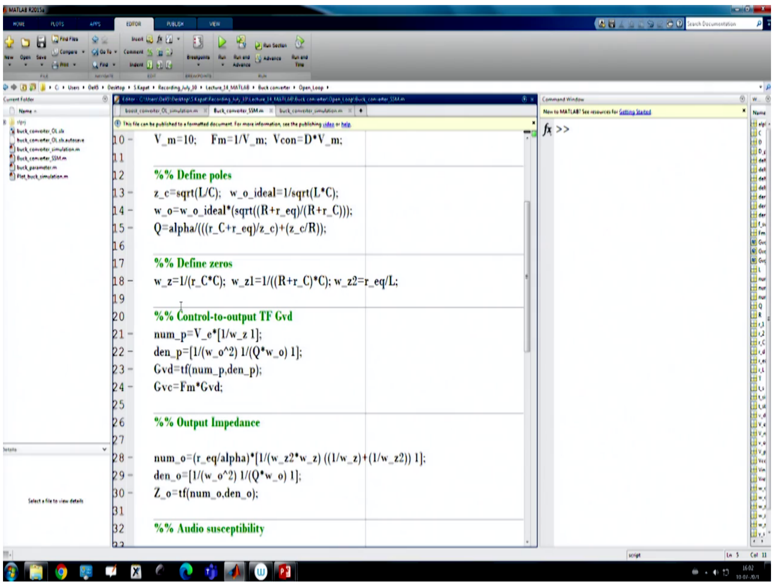
So, let us go to the MATLAB simulation. So, in this particular simulation, ok.

(Refer Slide Time: 07:34)



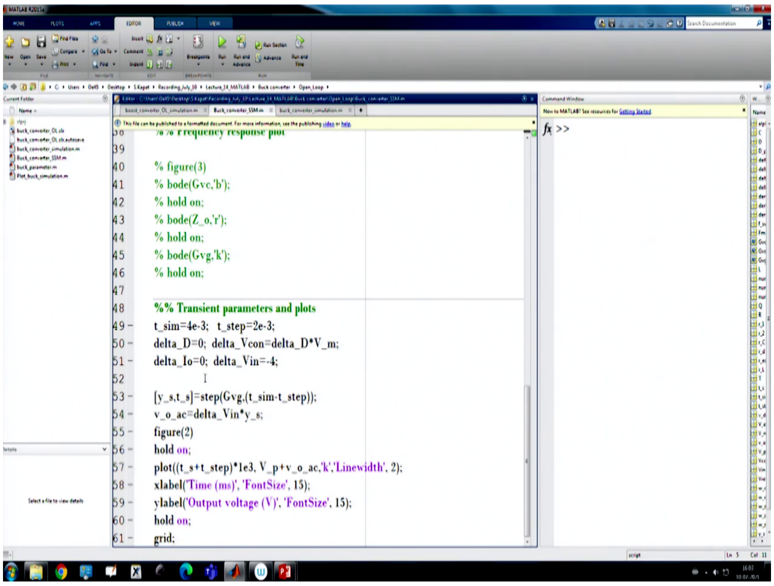
So, first I am going to talk about a buck converter model, ok. So, this particular output voltage.

(Refer Slide Time: 07:42)



Actually this we have derived small signal model; but since I have not covered small signal model, so you do not have to bother about this thing, because we will discuss in detail in the subsequent lecture.

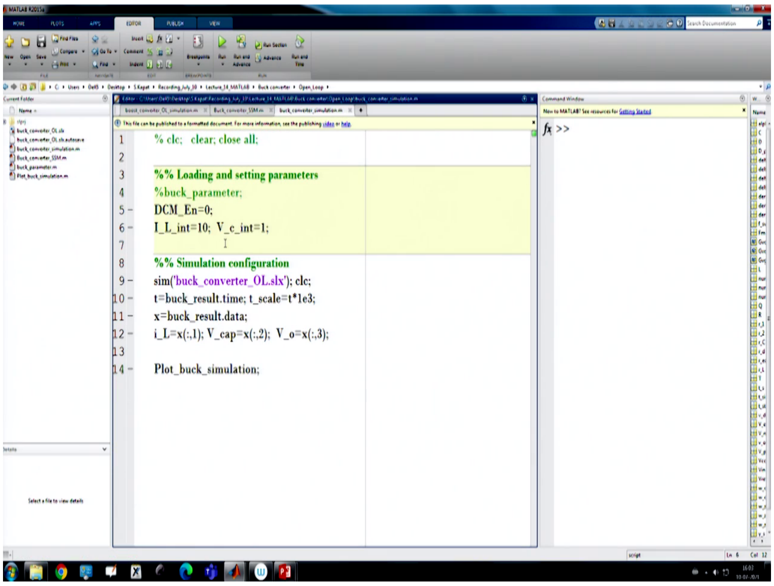
(Refer Slide Time: 07:54)



But today objective is, if we apply initially a supply disturbance of minus 4 volt; that means my original input voltage is 12 volt which is the nominal value and after and we are running the total simulation time of 4 millisecond and after 2 millisecond of time, I am applying a supplied step transient and with a negative voltage of minus 4.

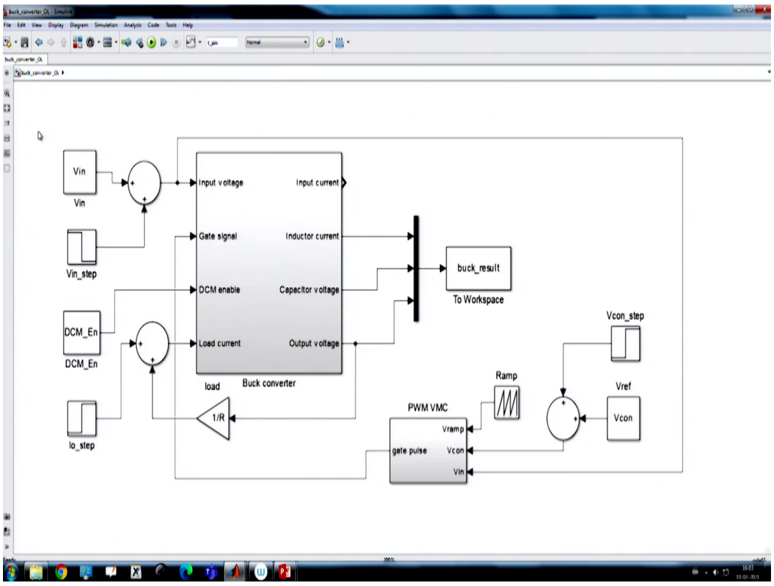
That means, the input voltage will change from 12 volt to 8 volt; because we are applying a minus 4 volt supply transient, ok.

(Refer Slide Time: 08:30)



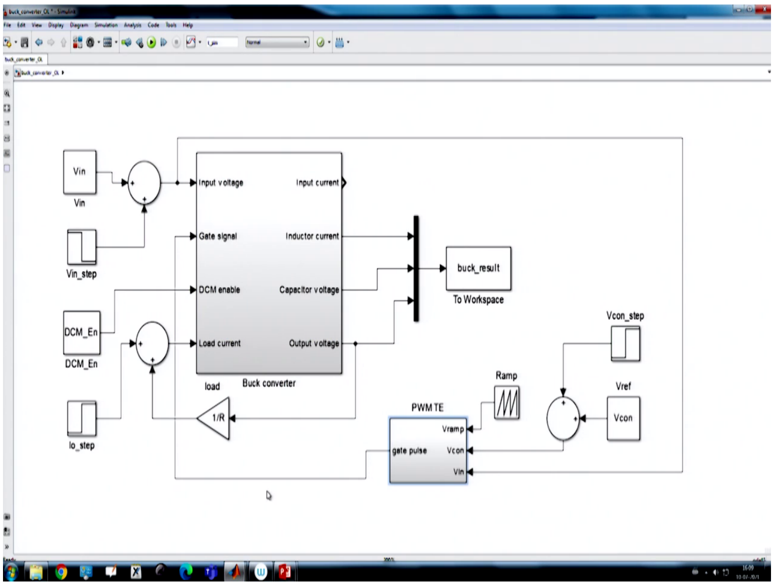
Now, let us go to the buck converter simulation and let us open the file.

(Refer Slide Time: 08:33)



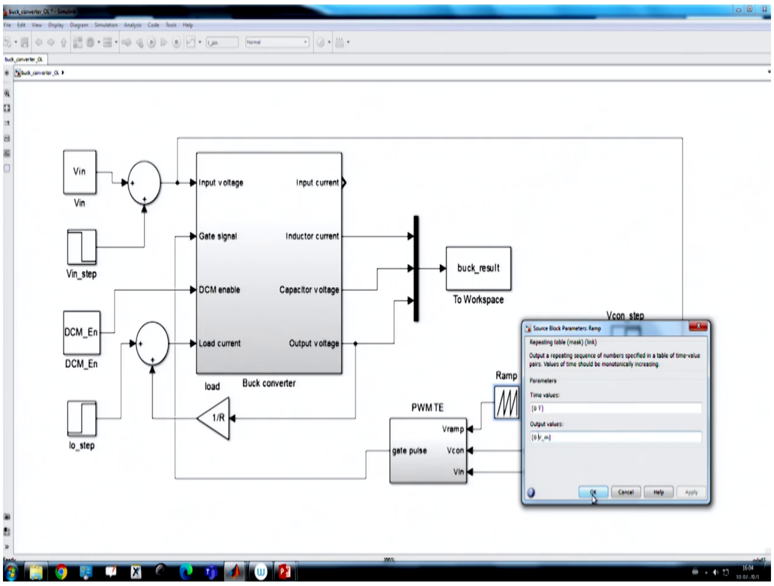
So, this is the buck converter simulation file; in this particular example, I am going to initially consider, this is my trailing edge modulation block.

(Refer Slide Time: 08:45)



This is my simple trailing edge modulation block and you know the trailing edge modulator require two thing; one is the ramp and which we are not defining.

(Refer Slide Time: 08:54)

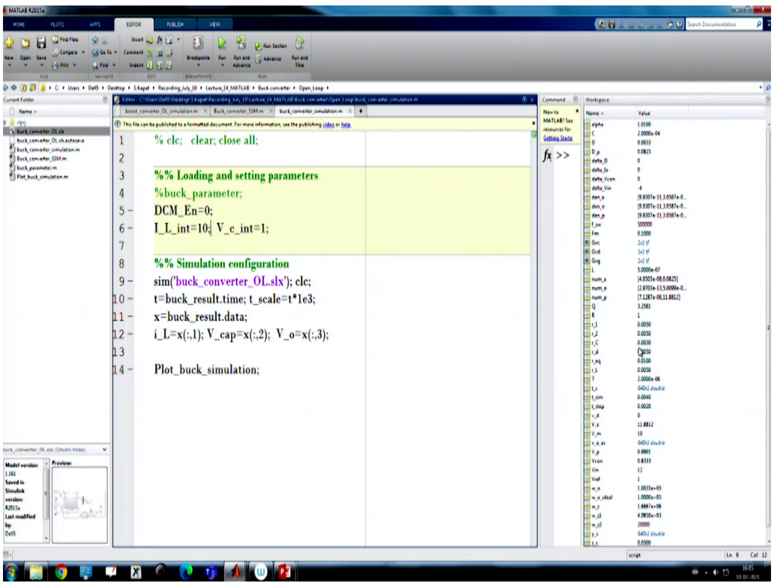


And I am taking 10 volt is the maximum value of the ramp. And then because we have discussed that, if you want to run a DC-DC converter we have to consider a sawtooth wave form. And if you want to generate open loop duty ratio; then one way you take a sawtooth waveform and you compare with a fixed voltage and sawtooth wave form.

If you compare, then it will generate the duty ratio and we also need a latch circuit, those thing we have discussed. Next, so this sawtooth waveform we are giving a constant voltage and we can also apply a step transient in the constant voltage, suppose if you want to apply a duty ratio perturbation. But right now we have presently, we have presently applied a supply transient, ok.

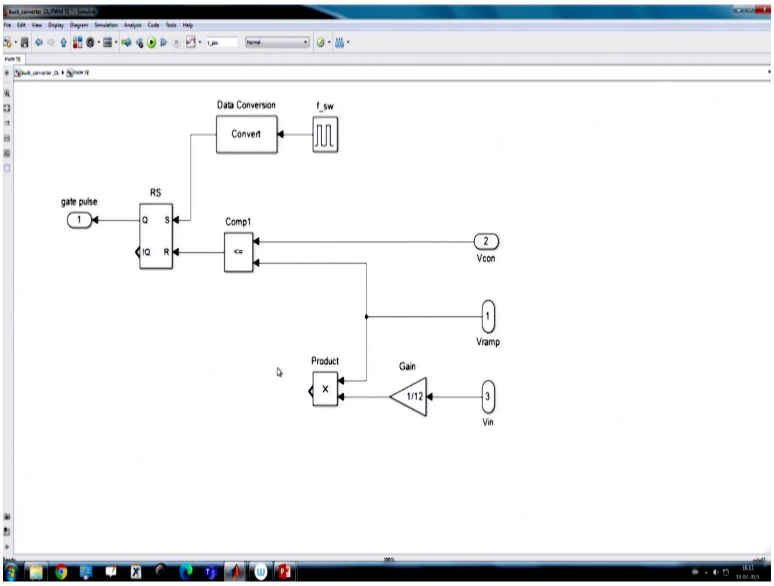
So, in this PWM you know trailing edge modulator, one input is the sawtooth waveform ramp, which has a slope or basically voltage of V, m and which in the program that we have said that V, m to be V, m we have said is a 10 volt, we have said is a 10 volt, ok. So, it is already set from the parameter value.

(Refer Slide Time: 10:06)



And if you go to the you know. So, if you go here, you can see that V, m which is here it is equal to 10, ok. So, this is in the work space we have all these values, ok.

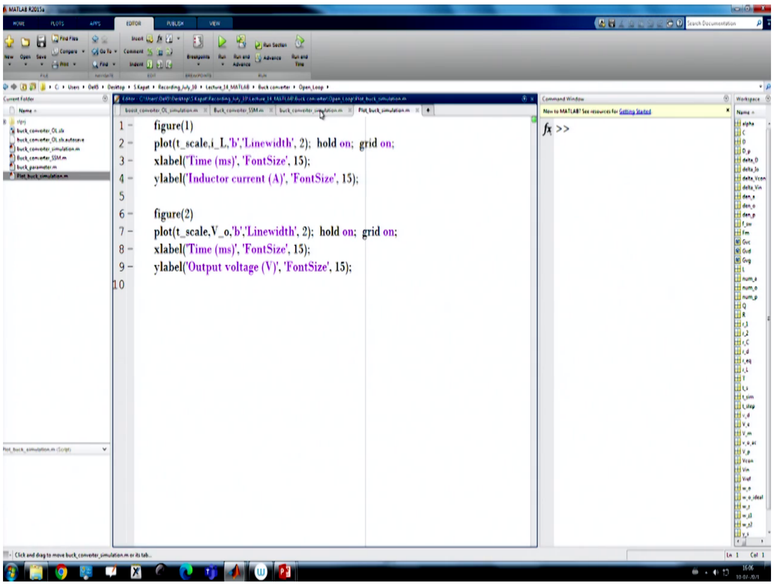
(Refer Slide Time: 10:24)



Next in this particular block, now if we go inside, first we want to compare the control voltage with a sawtooth waveform; that mean initially let us go and check, we want to compare the sawtooth wave form with the control voltage. Because we know that sawtooth wave form is compare, control voltage is compared with sawtooth wave form and the comparative output goes to the reset input of the RS flip flop and where the set input is coming from the clock, switching frequency clock.

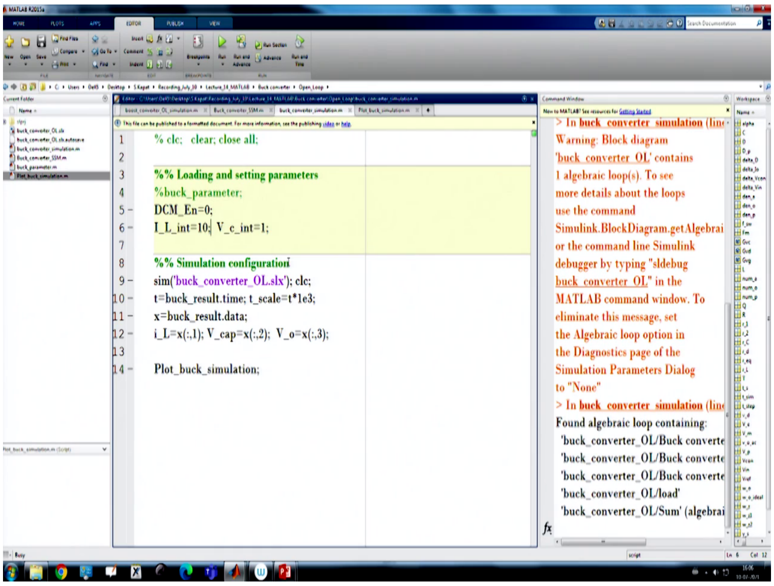
And since it is the trailing edge modulation, so this logic is already explained, ok. Next task we want to run the simulation, this is under open loop condition.

(Refer Slide Time: 11:10)



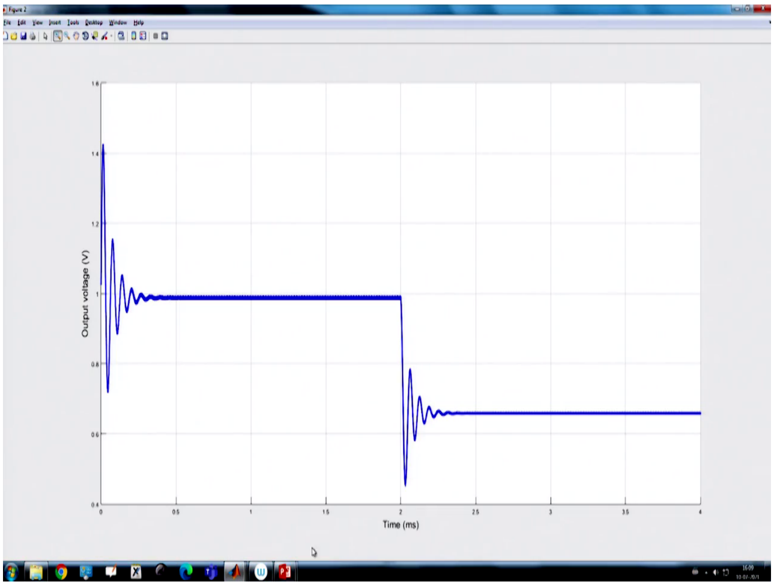
And you know we want to simulate it and check, that what is our response, ok.

(Refer Slide Time: 11:16)

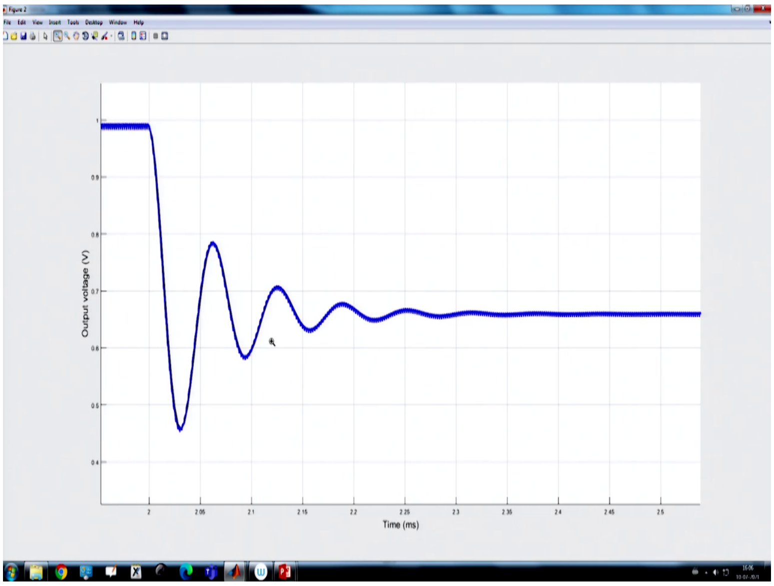


So, if we simulate here, we have applied a supply transient under open loop condition.

(Refer Slide Time: 11:26)

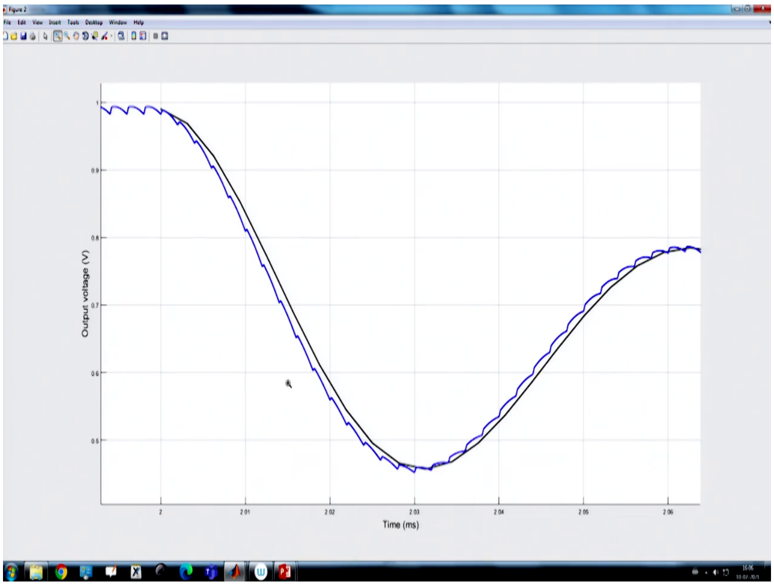


(Refer Slide Time: 11:32)

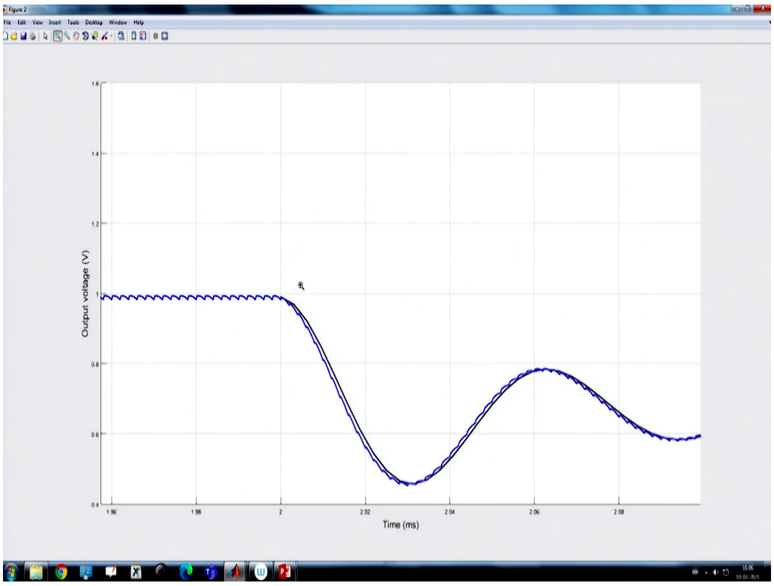


Now, so it shows that, if we go back; here 2 millisecond time, we have applied a supply transient.

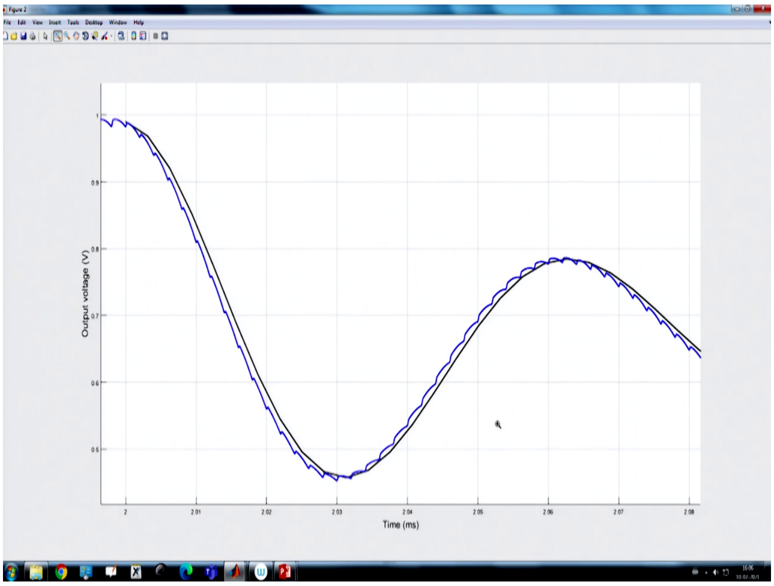
(Refer Slide Time: 11:34)



(Refer Slide Time: 11:37)

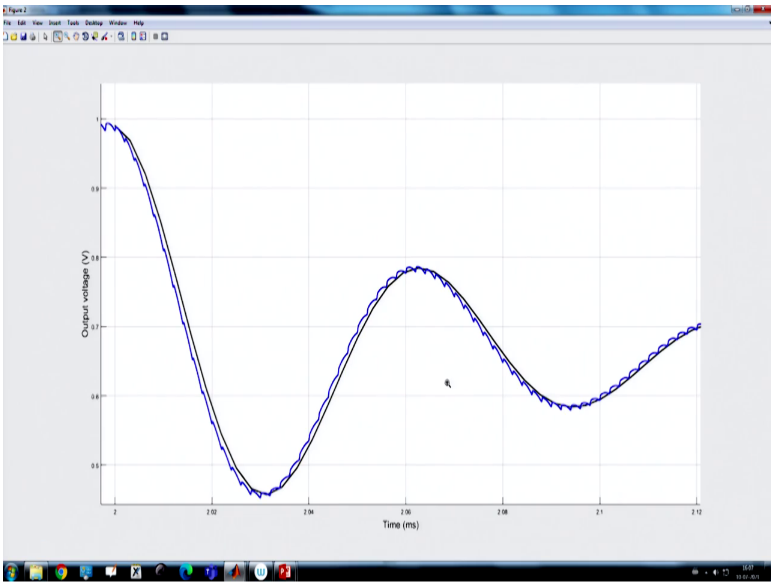


(Refer Slide Time: 11:41)



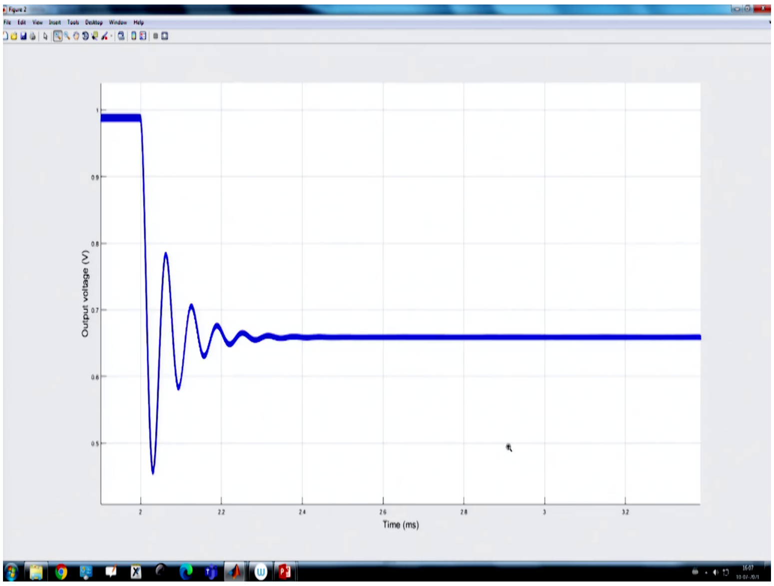
So, the black trace indicate the response of the buck converter from small signal model. And again this model matching thing we will discuss in you know week 6 as well as week 7; so we do not have to consider now. So, here I am just showing. So, the blue traces indicate the switch converter; that means they are buck converter output voltage when we have applied a supply transient of minus 4 volt.

(Refer Slide Time: 12:04)



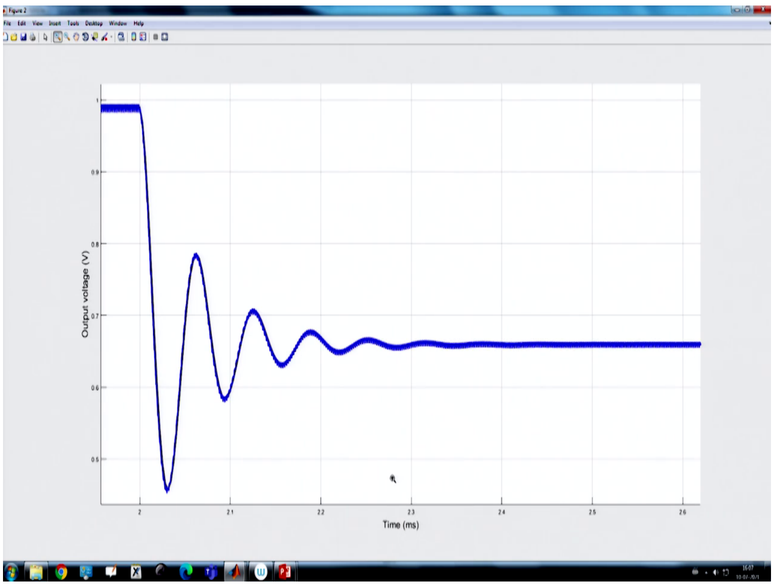
And you can see, because it is open look converter, so the voltage is actually going somewhere else.

(Refer Slide Time: 12:08)



And there is a huge you know; there is a drastic effect in the output voltage, when there is a supply transient.

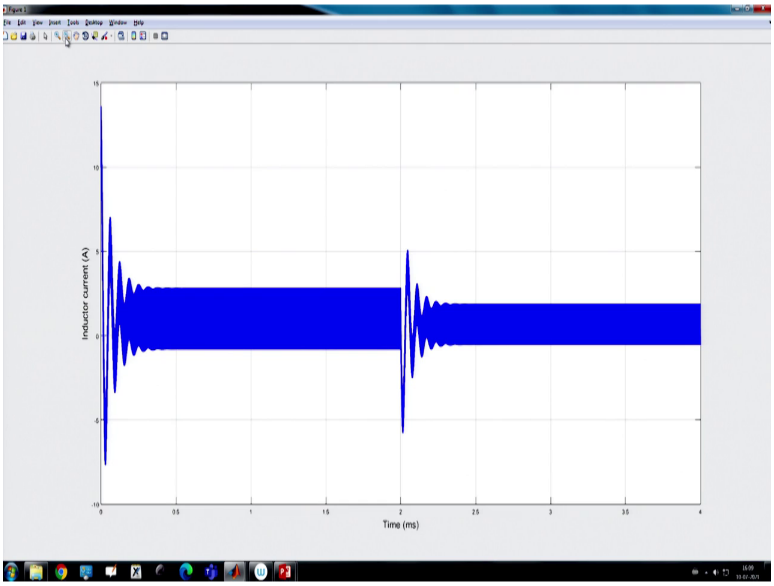
(Refer Slide Time: 12:13)



It has both you know overshoot, undershoot kind of characteristics and the DC point is getting shifted; because it is open loop, the duty ratio is fixed and if we reduce the input voltage, naturally the output voltage will reduce. But another thing the transient effect; that means that you know the dynamic behavior of this is also coming from the model that we are going to discuss and that will be characterized by is known as audio susceptibility. So, right now we are not discussing that.

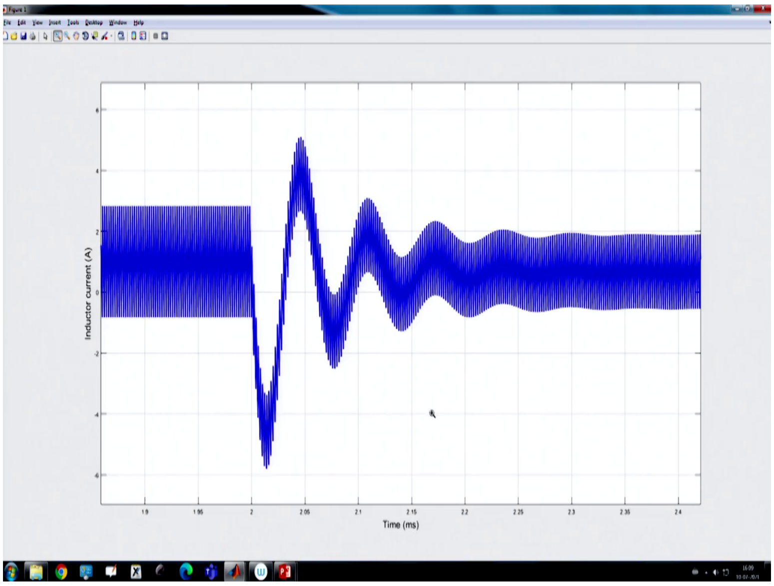
Now, next task that we want to. So, this supply disturbance is a huge impact in the output voltage. Similarly, if we apply a sinusoidal perturbation, it will also have an impact, that we will also see. But now our objective can we reject these supply disturbance or can we reduce the effect, so then let us go back to our presentation. So, what observation we made? That we made that, supply disturbance; that means supply step transient has a significant impact ok, on output voltage as well as.

(Refer Slide Time: 13:43)



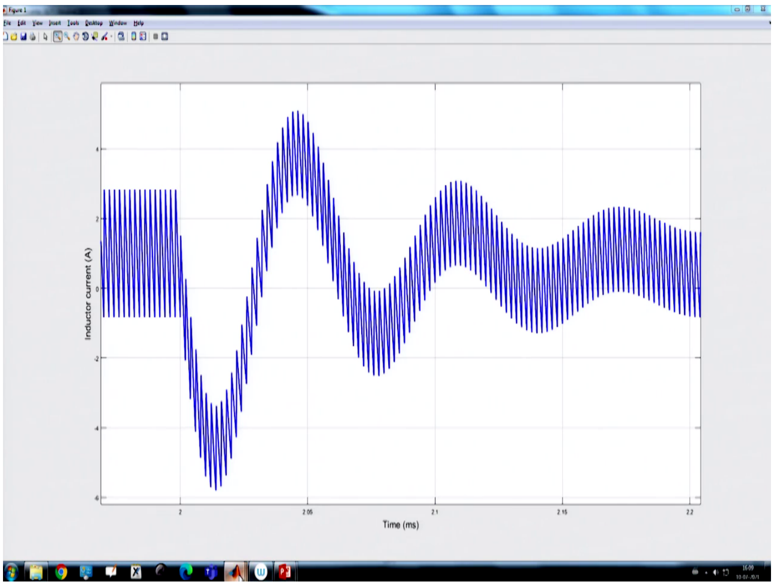
So, we need to check the inductor current also, right.

(Refer Slide Time: 13:48)



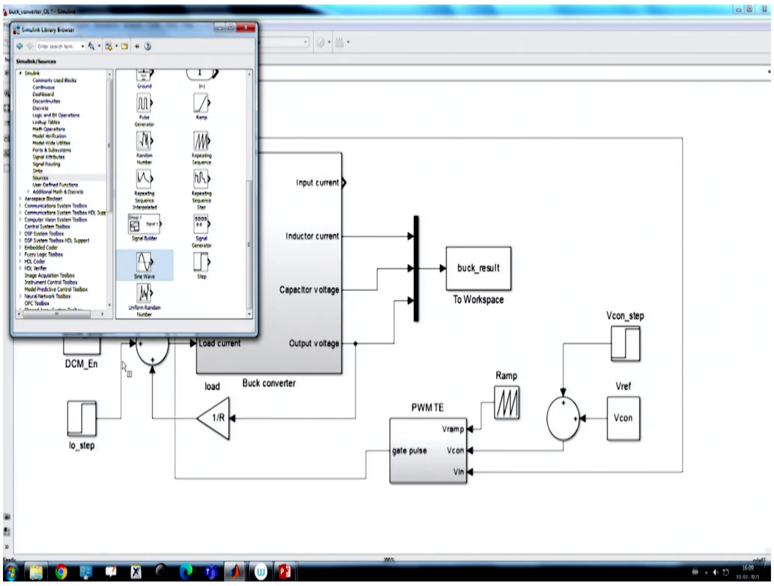
So, if you go to the inductor current waveform, it also has effect like you know there is overshoot undershoot of the inductor current.

(Refer Slide Time: 13:51)



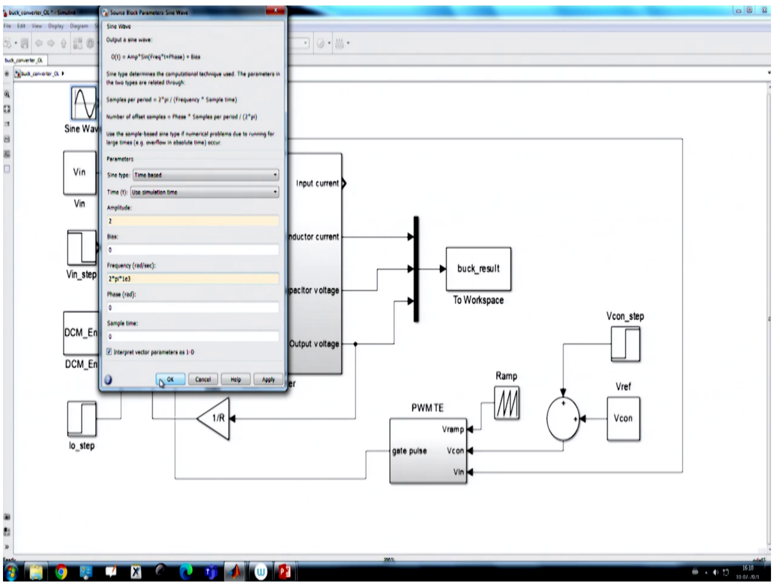
That means what we can write here as well as inductor current, ok. Now, we also want to see what happen if we apply a sinusoidal excitation; that means for the same simulation let us go back, let us go back to the simulation and if we go to the MATLAB file and we want to close this waveform first you know ok, we want to see what will happen if we excite with a sinusoidal.

(Refer Slide Time: 14:30)



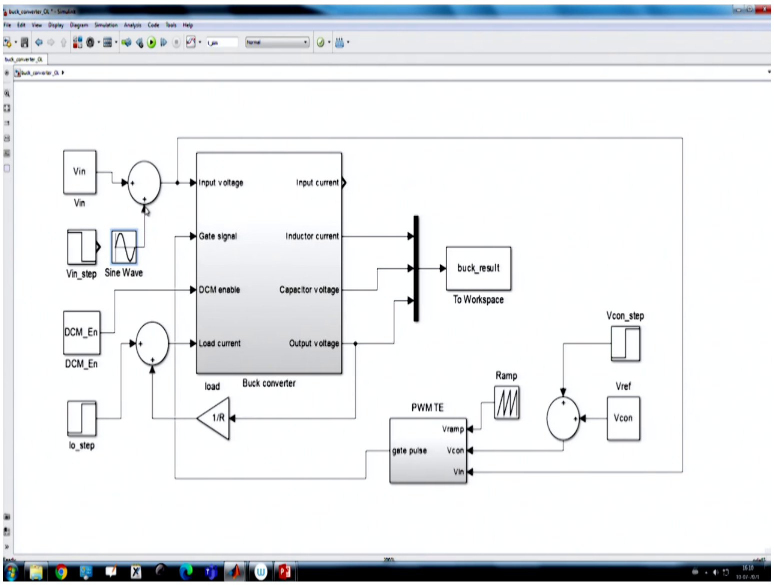
Instead of step, suppose if we apply a sinusoidal excitation; that means let us take sources and we want to apply let us say a sin wave, ok.

(Refer Slide Time: 14:39)



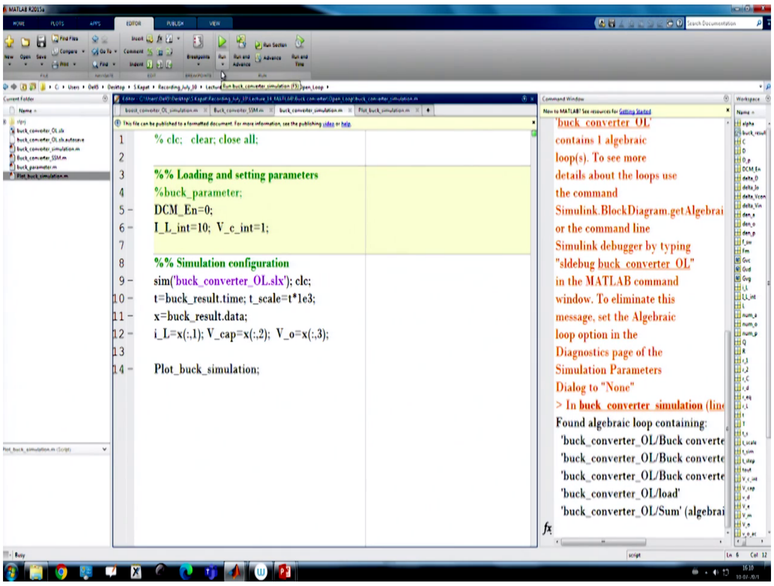
And let us say the sin wave has amplitude of 1 and maybe amplitude of 2 and it has a frequency of let us say 2 star pi star maybe 1 kilo Hertz, 1 kilo Hertz.

(Refer Slide Time: 14:58)



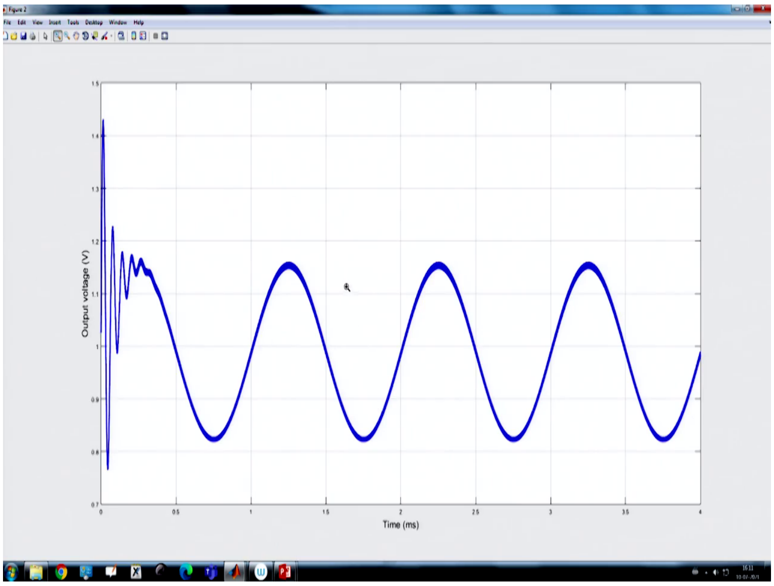
So, we are taking a sinusoidal excitation. So, instead of step excitation, we are taking sinusoidal excitation and we want to run the simulation once again and check what happens.

(Refer Slide Time: 15:08)



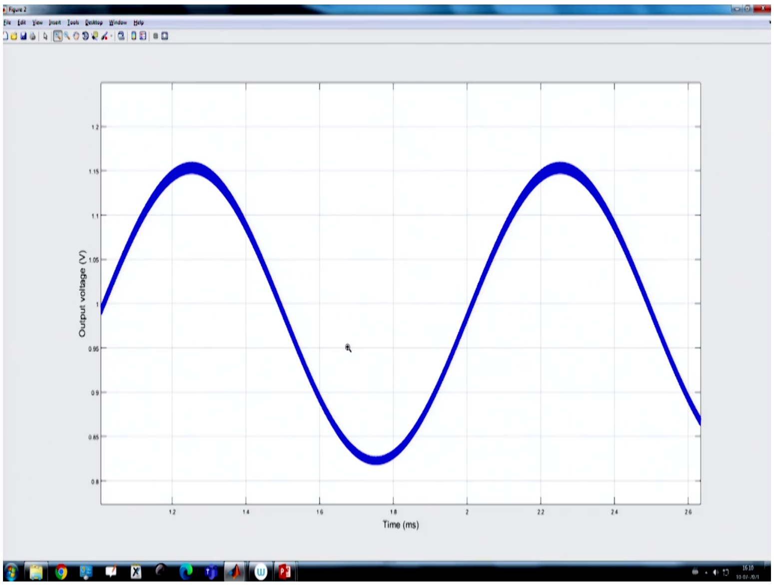
So, right now earlier we have considered step transient and step change in the supply voltage and we saw the effect, now we are applying sinusoidal excitation, ok.

(Refer Slide Time: 15:20)



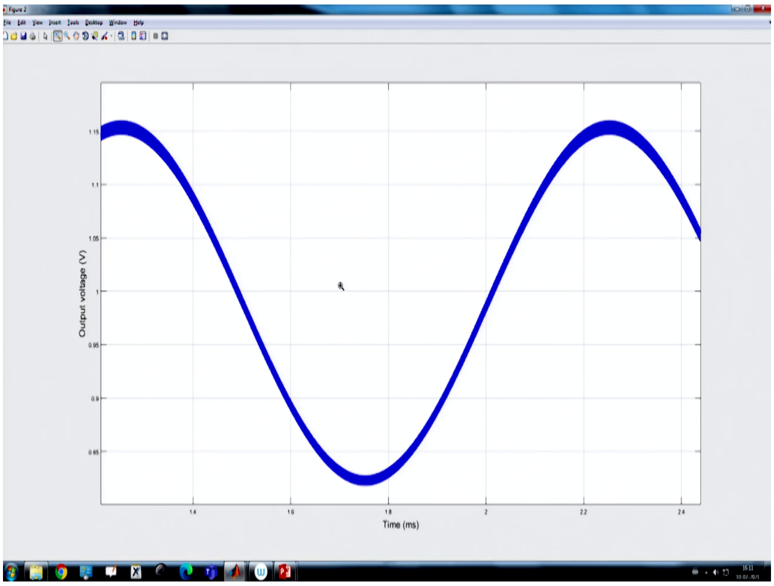
Now, the sinusoidal excitation clearly shows that, there is we have applied 1 kilo Hertz switching frequency of excitation.

(Refer Slide Time: 15:28)



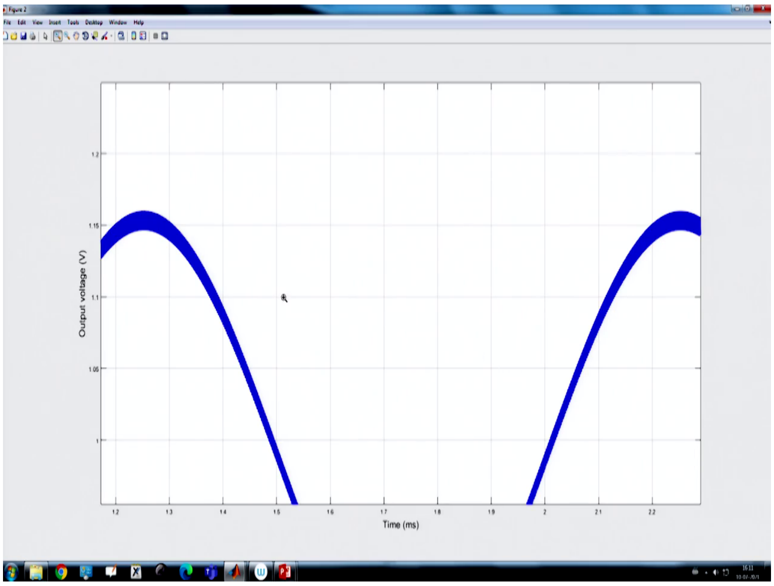
And that 1 kilo Hertz was applied on top of its steady state value; that means it has a DC voltage of 12 volt and on top of that we have applied a sinusoidal excitation of 2 volt peak, that means peak to peak is 4 volt.

(Refer Slide Time: 15:49)



And you can see there is a, that same effect is actually reflected here.

(Refer Slide Time: 15:54)

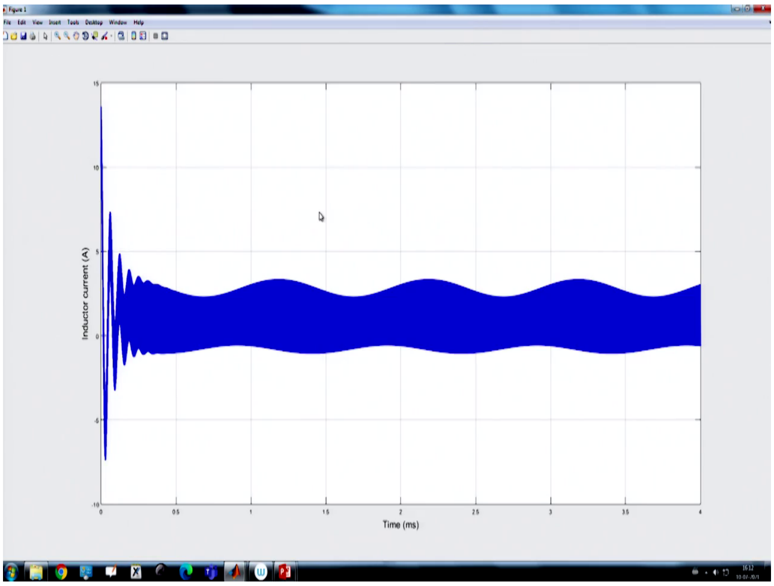


That means, if you see the you know if you take the peak to peak here; if you count from here to here 1, 2, 3, 4, 5, 6, 7, 8, 9, 10. So, 10 into; so that means it is showing 1 millisecond; that means it has a component of 100 Hertz which is the sorry 1 kilo Hertz, which is the supplied, I mean your applied frequency. That means, the frequency is getting, the output is getting affected by the supply disturbance.

That means if there is any disturbance in the source and we saw in the previous lecture; that means if due to the supply impedance or due to the interconnected converter, if there is any sinusoidal or any you know periodic excitation or even it can be a damped sinusoidal, that appears in the source and that will be propagated to the other converter which is connected to this source.

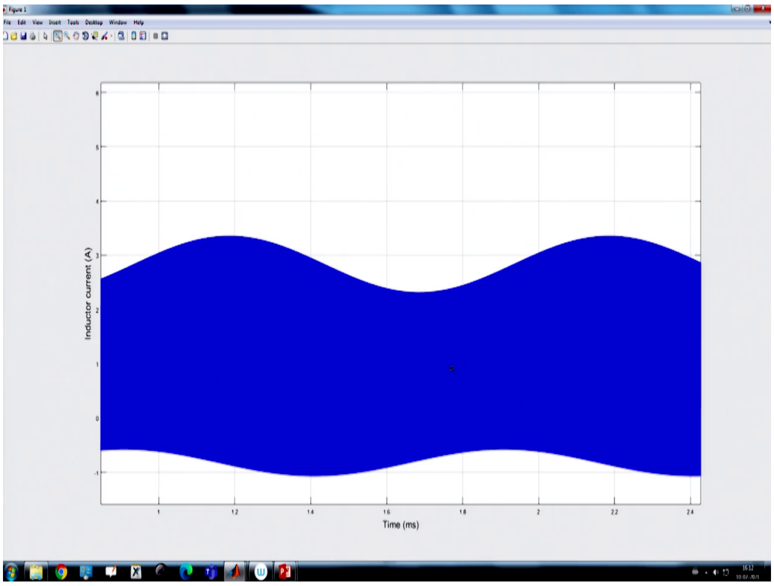
Provided that you know if it is just in open loop control; that means by default the converter cannot reject these disturbance and these disturbance has a significant effect.

(Refer Slide Time: 16:56)

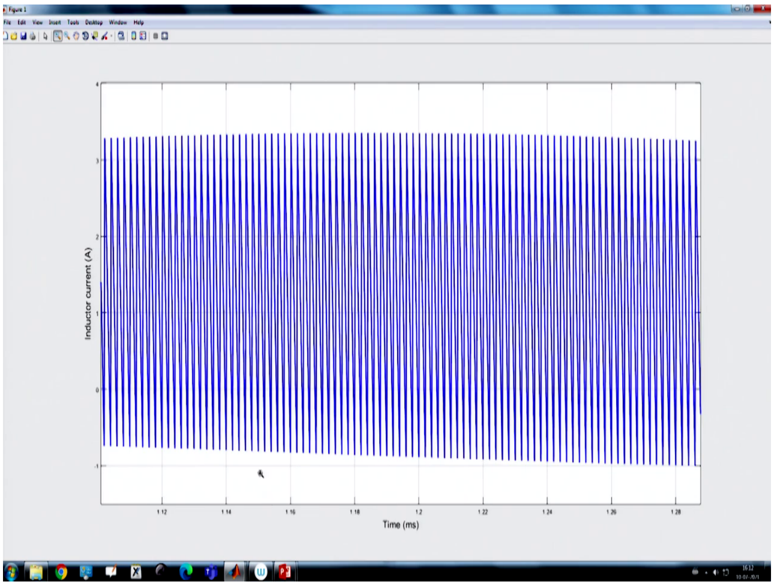


And if you see the current waveform the current waveform also has the effect of these supply disturbance.

(Refer Slide Time: 17:01)



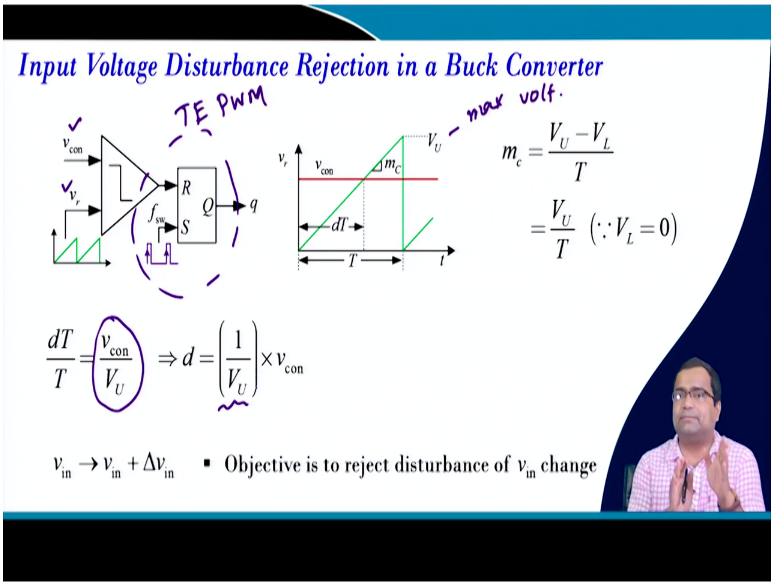
(Refer Slide Time: 17:02)



And it is clear form this waveform, ok. So, that means we can come to this conclusion. So, even if it is step transient, ok. So, it is step transient, the impact also there; that means impact is visible even for you know sinusoidal excitation. That means, this is something which is not desirable; because that a good power supply should have a very good power supply rejection ratio or it is also known as audio susceptibility.

That means we should reject these supply disturbance in the output of the converter, the converter should not respond to this disturbance. While we explore the feedback aspect to reject this disturbance, but we want to see whether can we do something which can immediately reject or not.

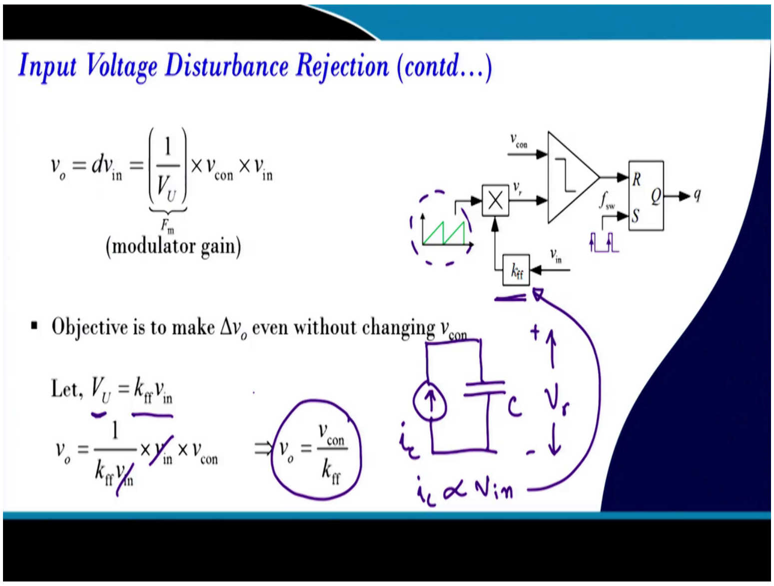
(Refer Slide Time: 18:02)



So, first thing we need to understand that, in this converter I have discussed that, our control voltage is compared with the sawtooth wave form, right. And if you go to the MATLAB block, you know block diagram of the MATLAB; you say this is my sawtooth wave form which is ramp and this is a control voltage and if you go inside, these two are compared, right. That means, sawtooth voltage is compared and you have a latch circuit, because it is a trailing edge PWM right that we have discussed.

Now, if we write the expression of the duty ratio, the duty ratio is simply the control voltage by the peak voltage which is here. So, this is my maximum voltage and we are considering the lower base value to be 0. Now, so that means, the duty ratio is simply 1 by this maximum voltage into control voltage and if we apply any supply disturbance, so our objective can we reject this disturbance or not.

(Refer Slide Time: 19:08)



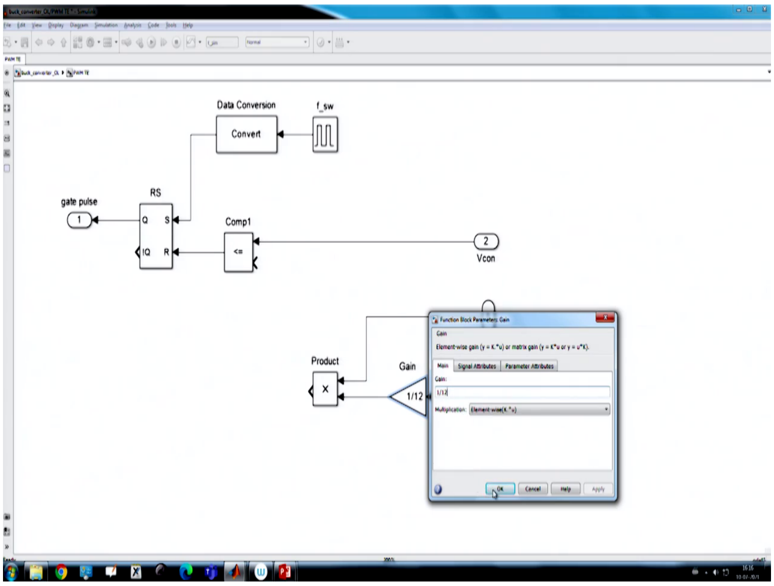
So, in order to do that, let us consider a feed forward action. What is that? So, you want to consider; that means with the ramp slope, I want to change when there is a change in the supply. That means, I want to connect a feed forward action, which will be; that means the ramp slope will be multiplied. So, one thing we have to keep in mind, in practical you know commercial i c generally we use a constant current source to charge the capacitor.

So, this is my capacitor and this voltage is our nothing, but this ramp voltage. And if we use the constant current and if we charge the capacitor to linearly charge and then we have to discharge. Now what I am doing in this process; this constant current I am just making something like a it is proportional to input voltage and that action is taken by this feed forward control, ok.

That means in actual commercial i c, we can you know reduce increase or decrease or basically proportionally vary the constant current you know amplitude in you know along with the input; that means in response to the input voltage. That means, if the input voltage is constant, this current will be constant, the slope will be constant; but input voltage if it varies, then we will change it.

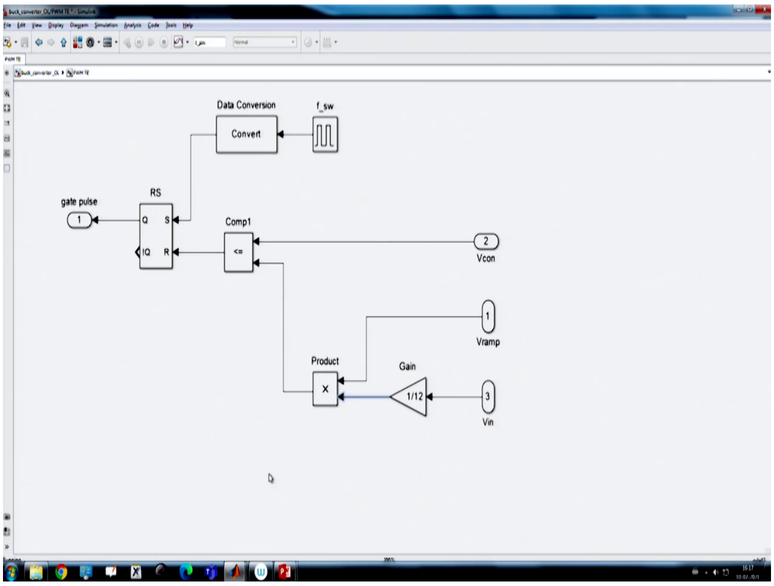
If we do that, then what will happen; that means your maximum value will be k ff into v in, if you replace your v 0 with this and if you write. So, your v 0 now is independent of the input voltage term, because these two term get canceled; that means if we add a feed forward action, mathematically it can show that it can reject the disturbance. Now, we want to see whether it actually happens or not.

(Refer Slide Time: 20:57)



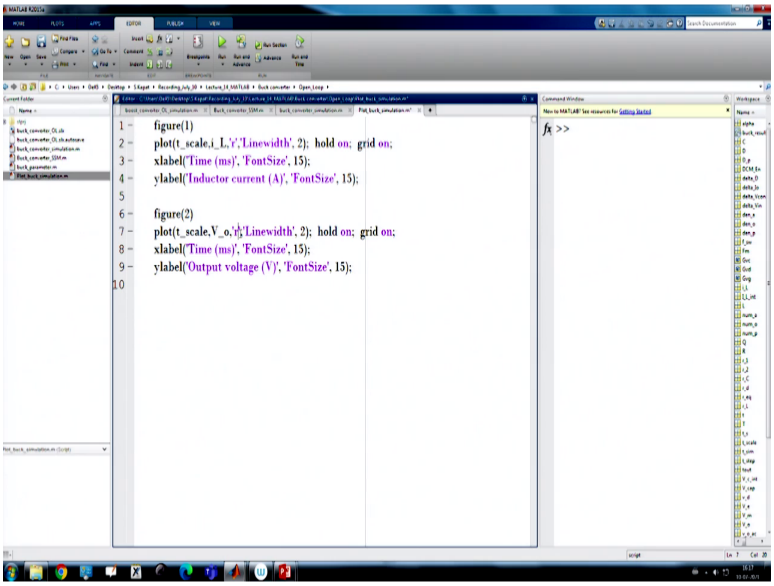
So, again let us go back to the simulation. Now, instead of using direct ramp, I am ramp is multiplied with the input voltage and this is my feed forward gain. Since my input voltage is 12 volt.

(Refer Slide Time: 21:19)



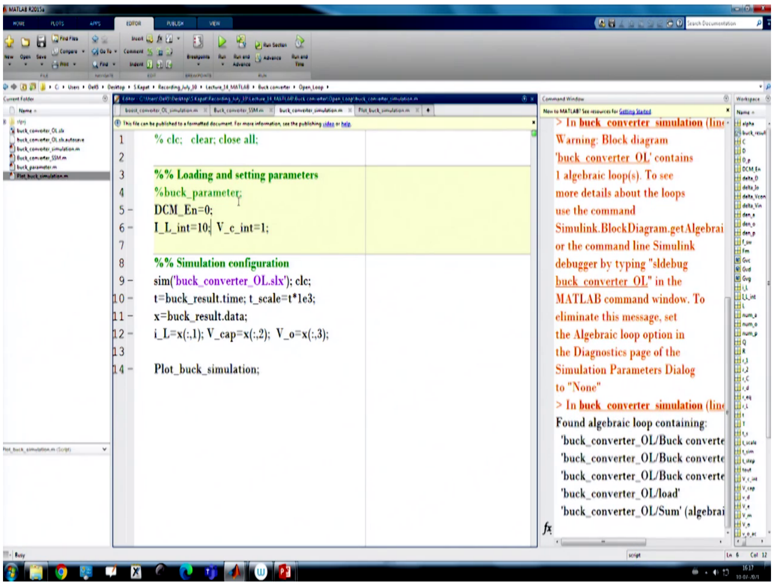
So, initially I am using 1 by 12 in order to scale that at nominal value; this multiplied of this term is basically unity, because its output is unity at nominal voltage, so that at nominal voltage it will retain the same slope, which was connected earlier, ok. So, now, I am connecting this and I want to see what will be the effect when we connect.

(Refer Slide Time: 21:38)



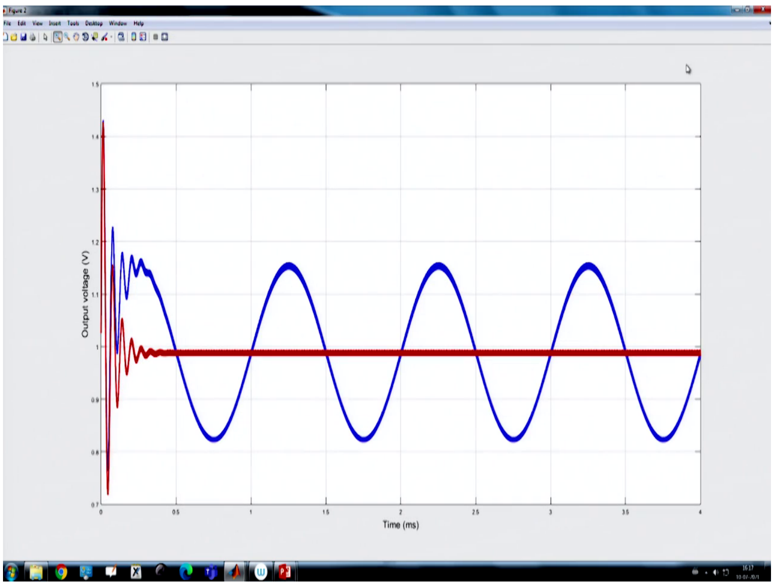
Now, I want to use a different color and show that, whether can we reject the disturbance or not. So, let us run it.

(Refer Slide Time: 21:43)



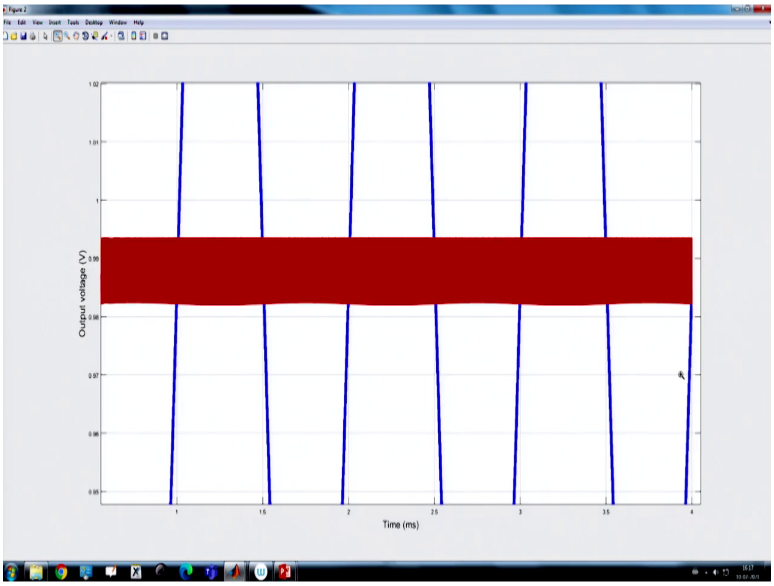
Now, we have consider a feed forward action by virtue of this product; that means the feed forward gain, which is there in this presentation, ok.

(Refer Slide Time: 21:55)



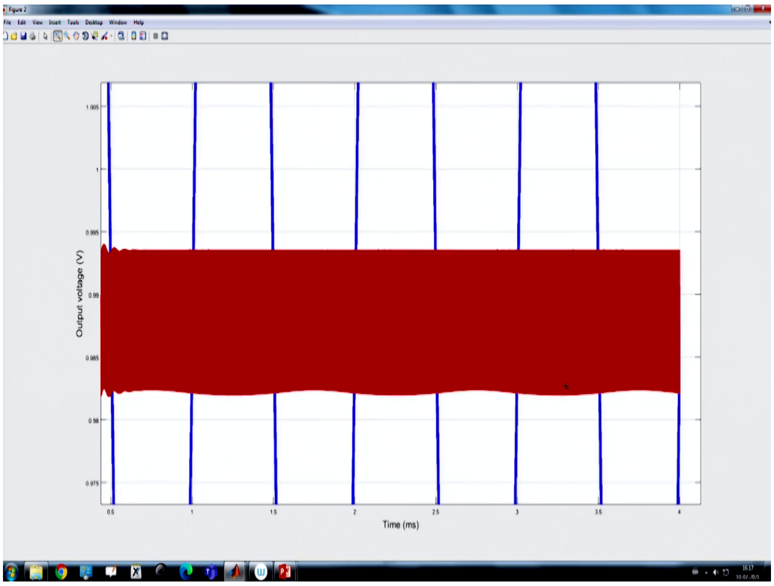
Now, let us go to our simulation result.

(Refer Slide Time: 22:03)



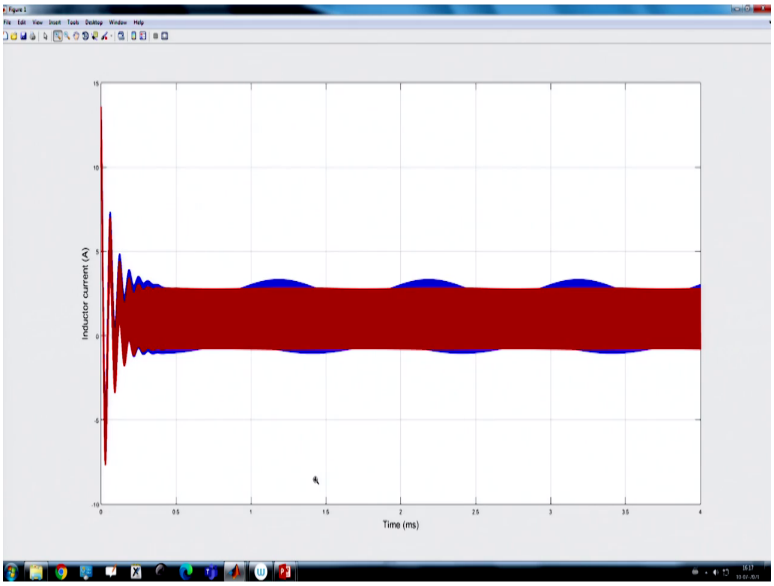
So, you will see, in this case the red color is with feed forward action and it totally reject the disturbance; that means as if there is no impact in the output voltage, even though it has a sinusoidal.

(Refer Slide Time: 22:09)



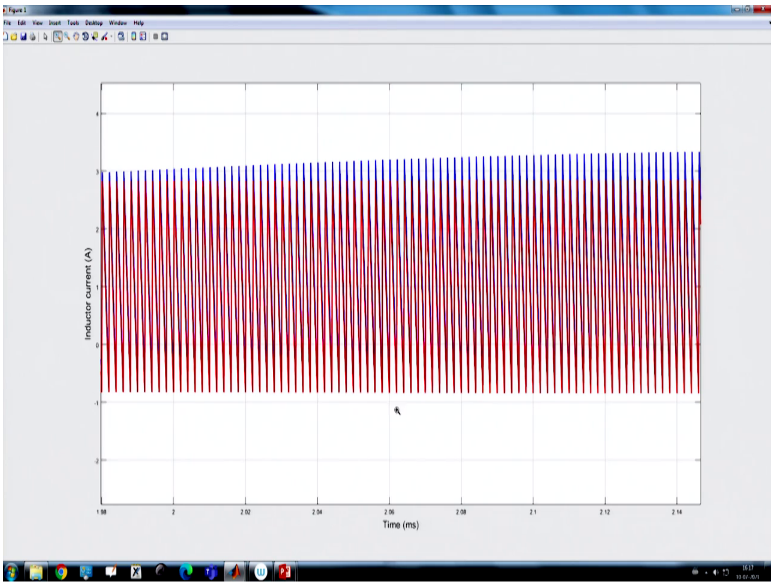
Except for almost in you know kind of a, it is a negligible impact; I would say it is there is no impact, right.

(Refer Slide Time: 22:22)



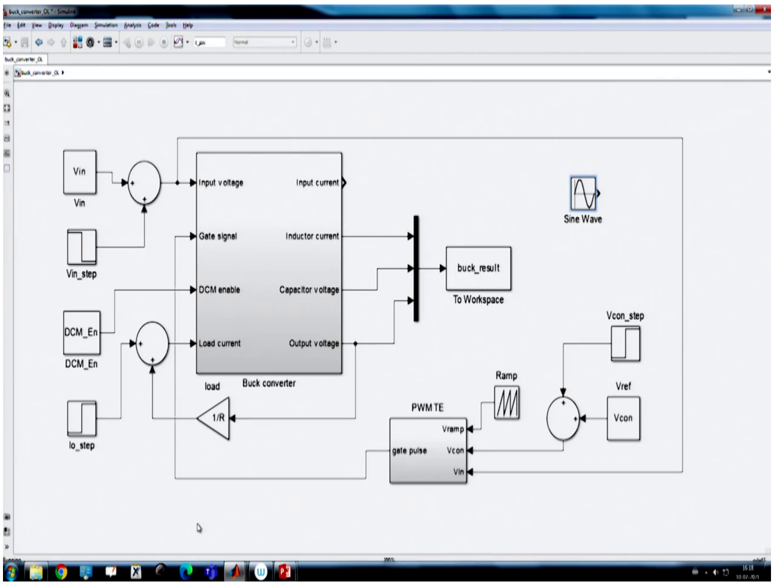
So, that it is totally rejected and if you go to the current waveform and you see the current wave form is clean wave form right, there is no disturbance.

(Refer Slide Time: 22:26)



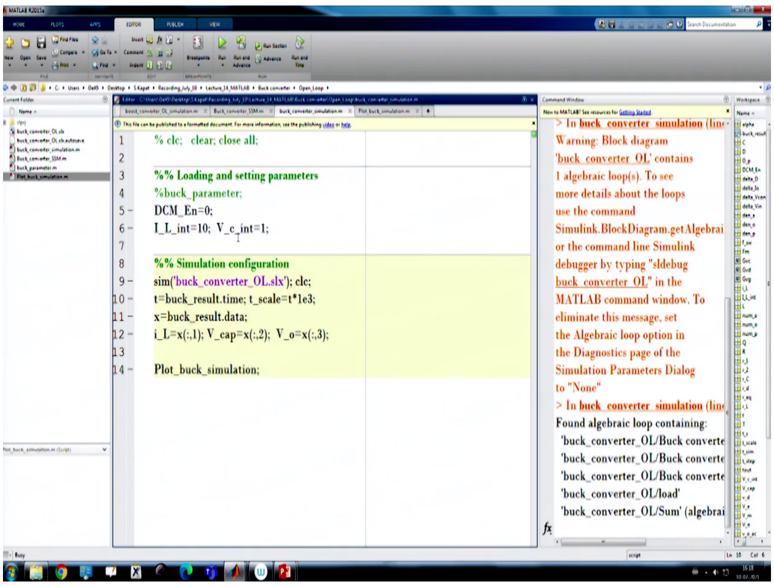
There means, this feed forward action can reject the disturbance. We want to see what happen with our original one, when we have considered you know the step transient, ok. So, now, go back to our simulation and we want to remove this sinusoidal excitation, ok.

(Refer Slide Time: 22:44)



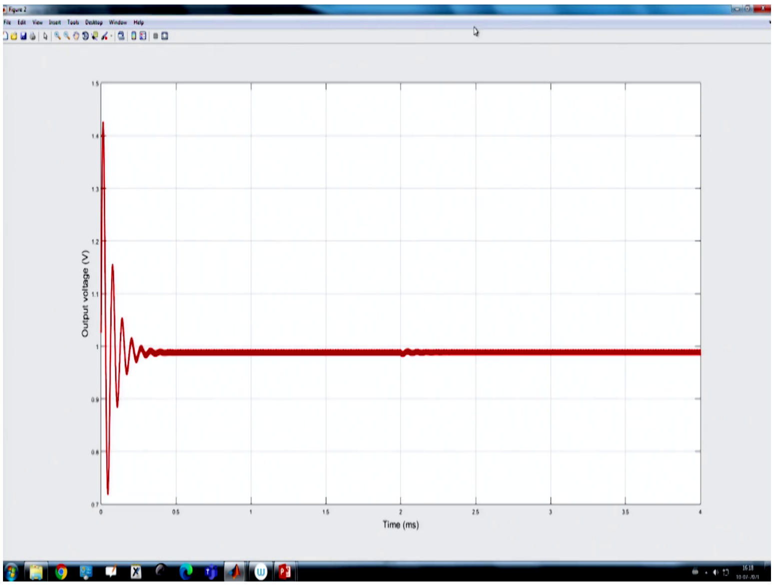
So, we want to remove this sinusoidal excitation and we connect back our step transient and re run this simulation, ok. So, in this case initially we want to plot; that means with this is with feed forward action, let us plot it, ok.

(Refer Slide Time: 23:04)



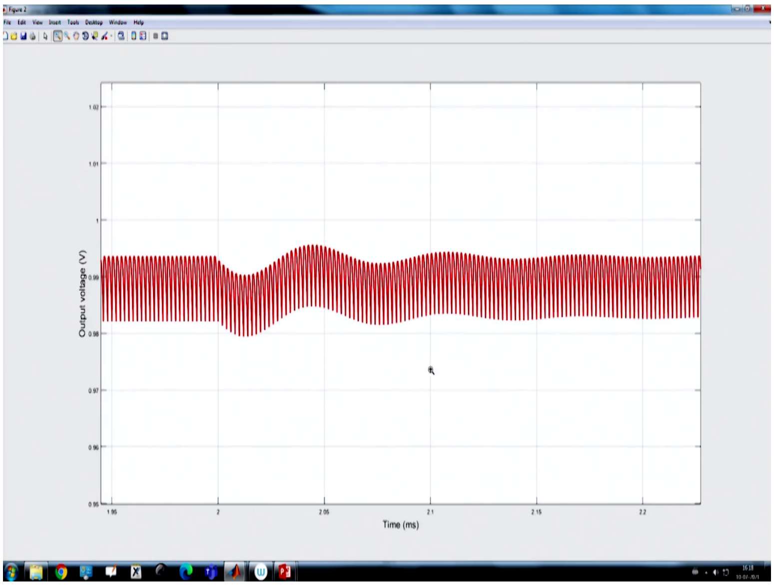
So, with feed forward action and then we want to see without feed forward action. So, here we have applied a step transient in the input voltage and we want to see what is the response; that means, whether, yes.

(Refer Slide Time: 23:16)

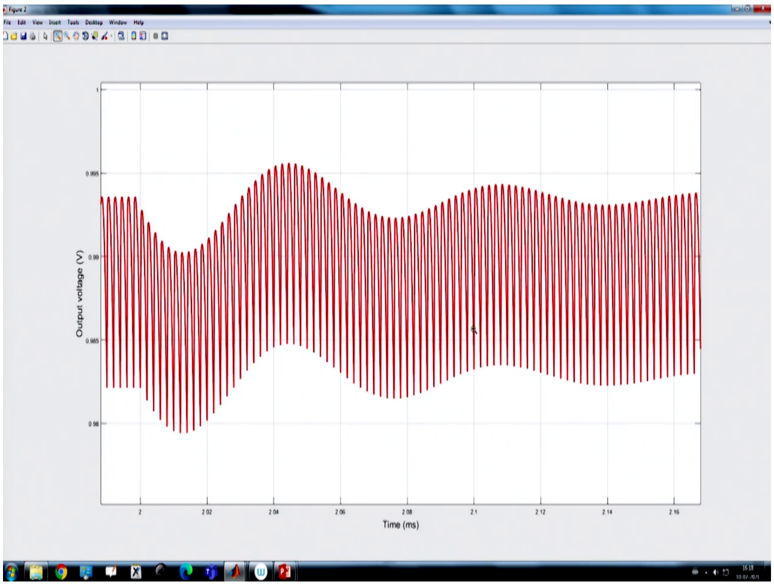


So, you see here we have applied a step transient.

(Refer Slide Time: 23:21)

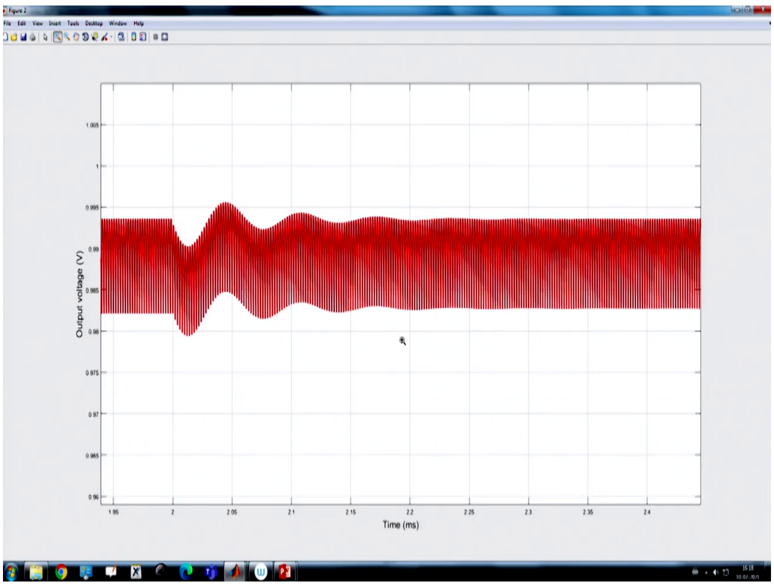


(Refer Slide Time: 23:24)



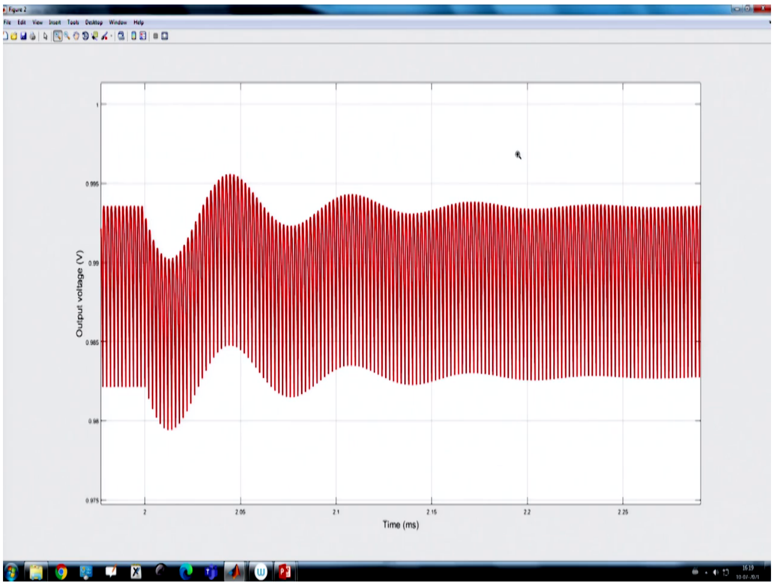
This at 2 millisecond and again there is almost negligible impact, except for you know because the power supply has finite bandwidth, it does not have a infinite bandwidth, which we have discussed in the previous class.

(Refer Slide Time: 23:37)



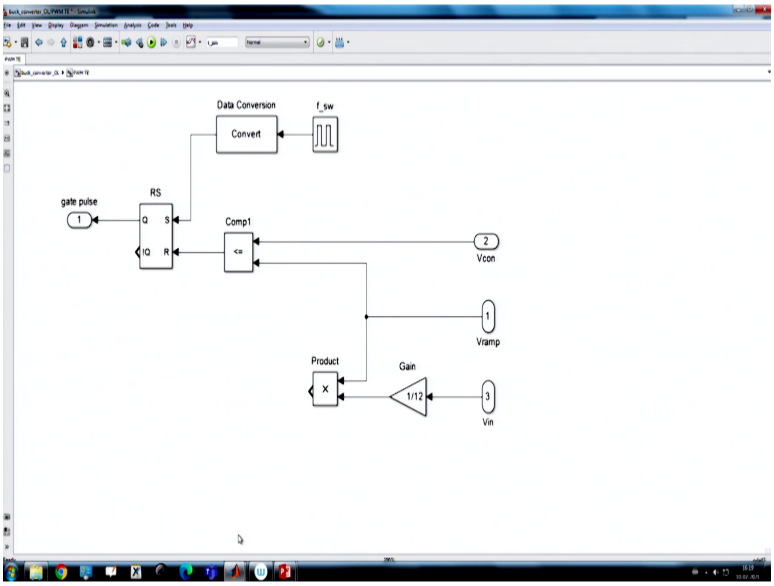
Due to that there is a very insignificant impact.

(Refer Slide Time: 23:39)



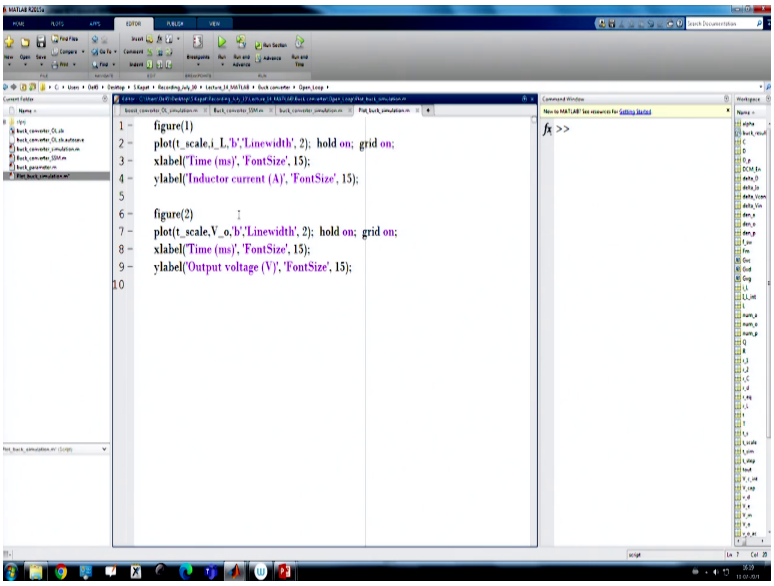
Otherwise, it totally reject the disturbance step disturbance, ok. But on top of that if we simulate without feed forward; that means let us go back, you know let us go back to the simulation.

(Refer Slide Time: 23:54)



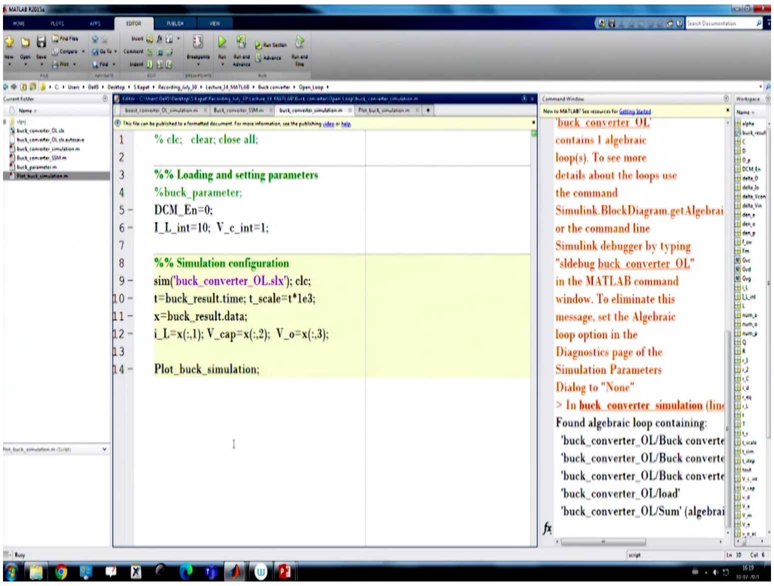
Now, we want to return, we want to connect back the original one, where only ramp is compared, ok.

(Refer Slide Time: 24:04)



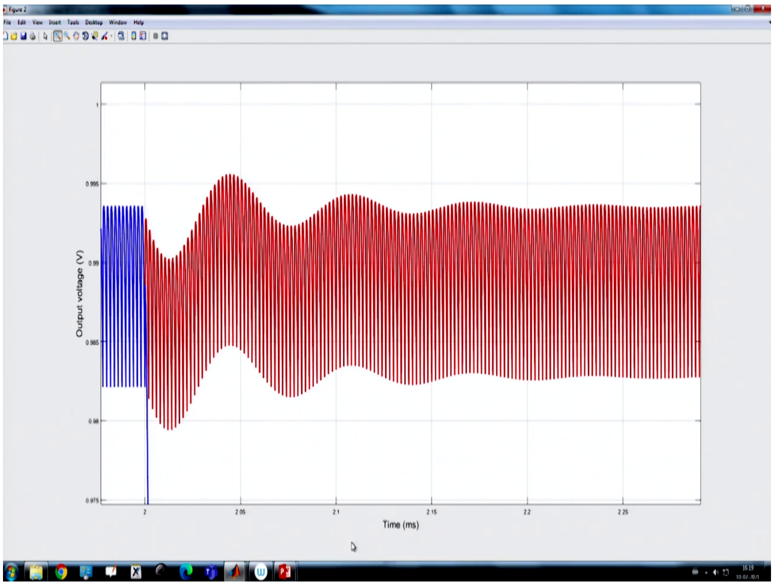
And if we go and change the color ok and then we want to compare what happen with this.

(Refer Slide Time: 24:08)

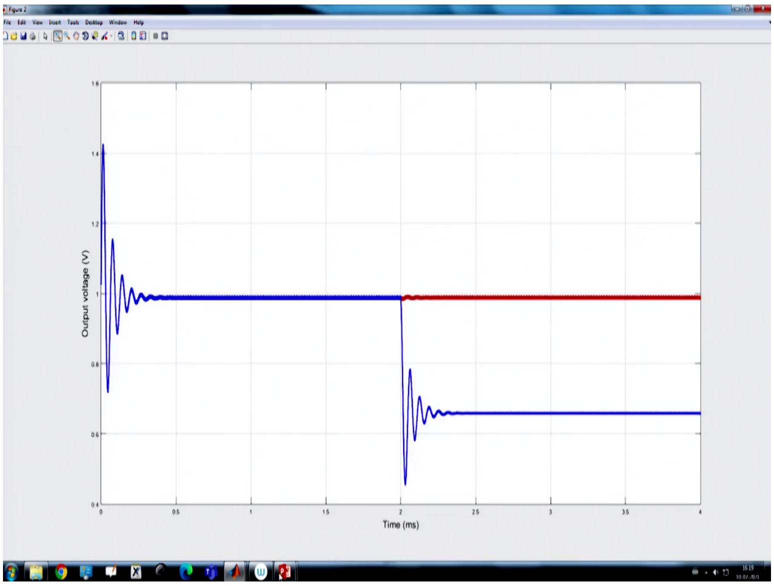


So, in this case we have consider ramp directly and which is compared with the control voltage. So, no more feed forward action is considered; even though it is available, but we have not connected, ok.

(Refer Slide Time: 24:19)

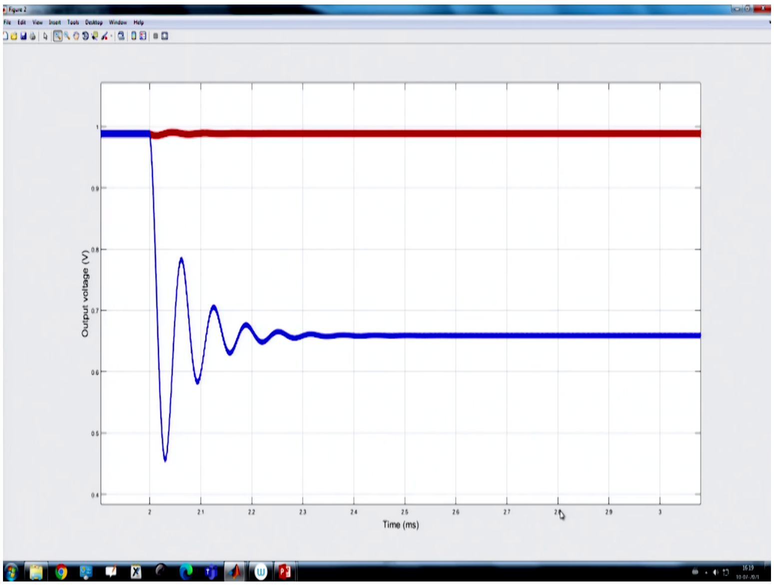


(Refer Slide Time: 24:21)



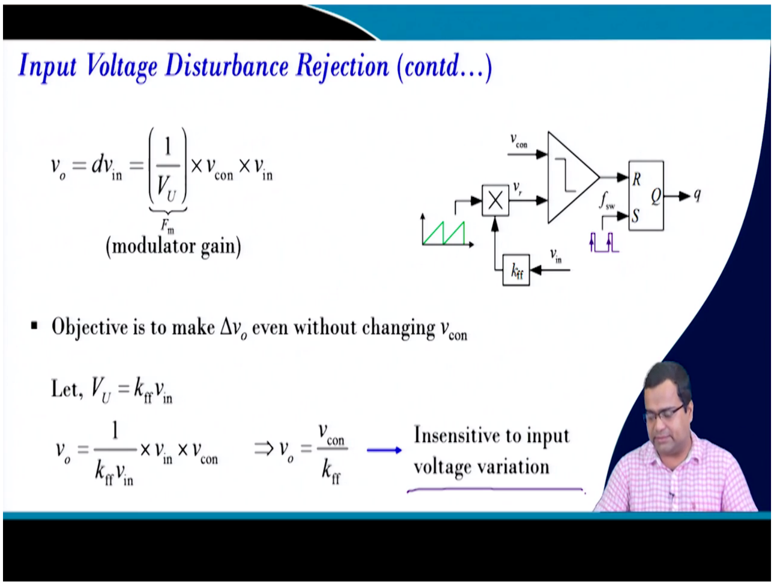
Now, you can see, this one is the original that we have seen, the blue color.

(Refer Slide Time: 24:24)



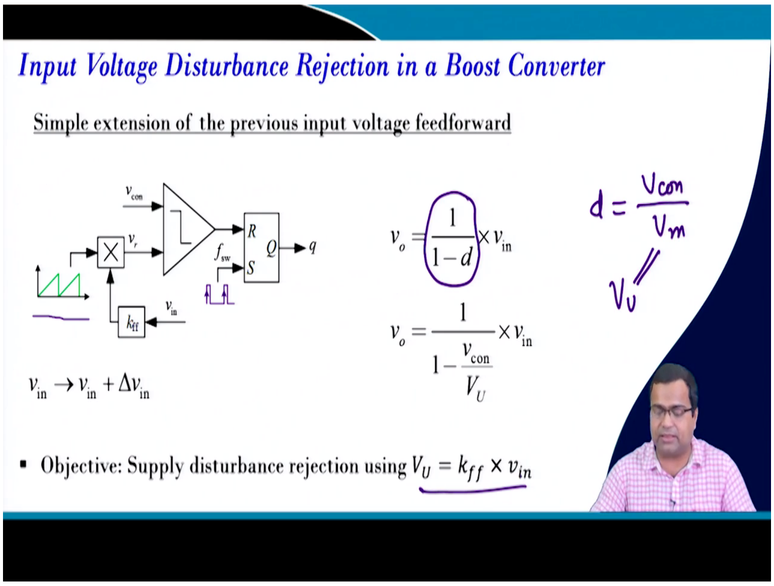
Where there is no feed forward action; it is open loop and it has a significant impact in the output voltage, ok.

(Refer Slide Time: 24:34)



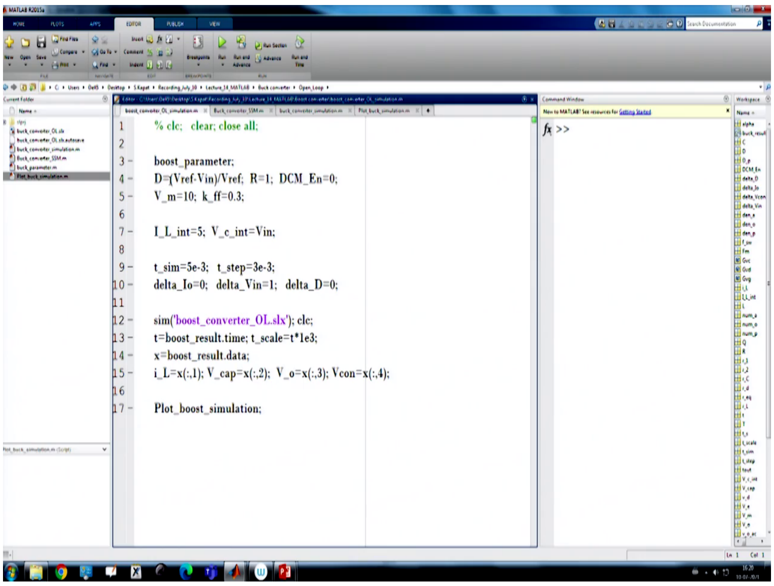
So, that means it is clear that, the feed forward action can drastically reduce; that means you know if you take the, the feed forward action can make the supply insensitive to input voltage variation and that we have seen, in step transient there is a various minimum effect due to finite bandwidth, otherwise it totally reject the disturbance.

(Refer Slide Time: 24:51)



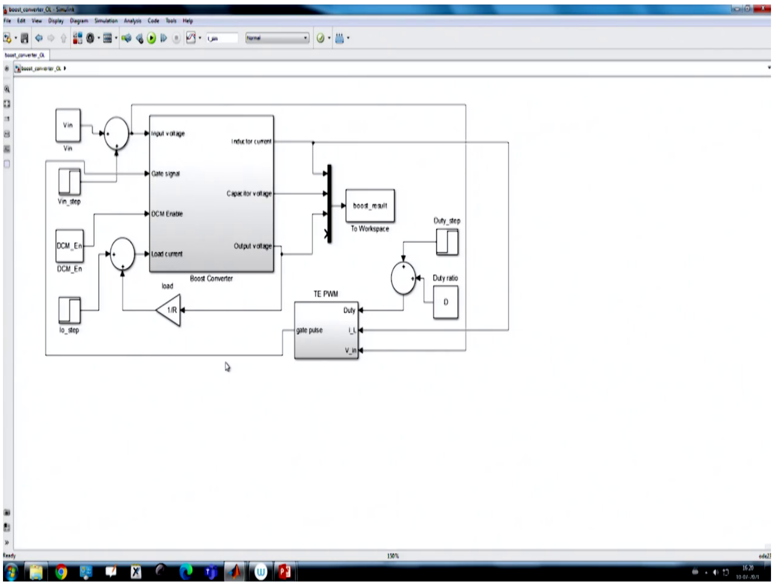
But we want to see whether this technique really work for a boost converter or not. So, in boost converter again we have considered the same technique ok and let us go back to the boost converter.

(Refer Slide Time: 25:07)



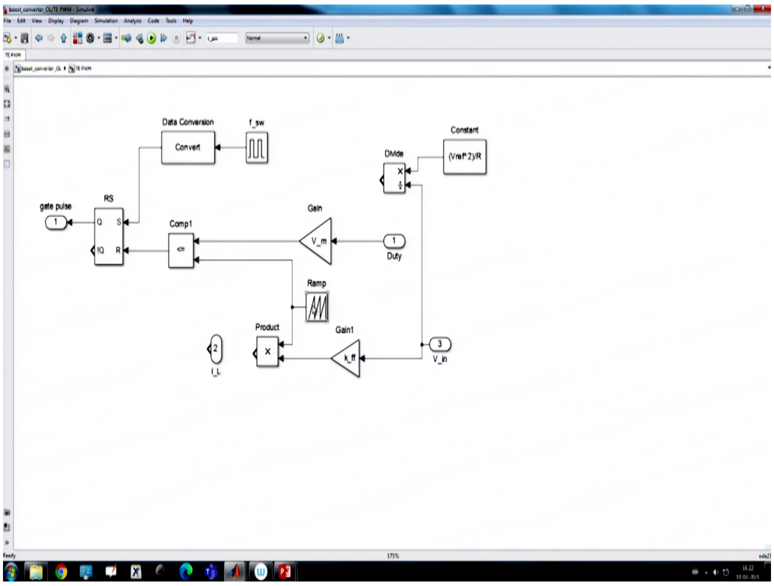
So, if we go back to the boost converter now.

(Refer Slide Time: 25:09)



Now, we are considering a boost converter. In the boost converter what we are doing; we are now directly taking the duty ratio, that means you know, so it is just if you set an open loop duty ratio, let us say d equal to, what is the d? So, I can set it from here, my duty ratio is set in a boost converter; it is from your input output voltage specification and it is an ideal boost converter, ok. So, that means I am setting a duty ratio and I can also apply a duty step transient, ok.

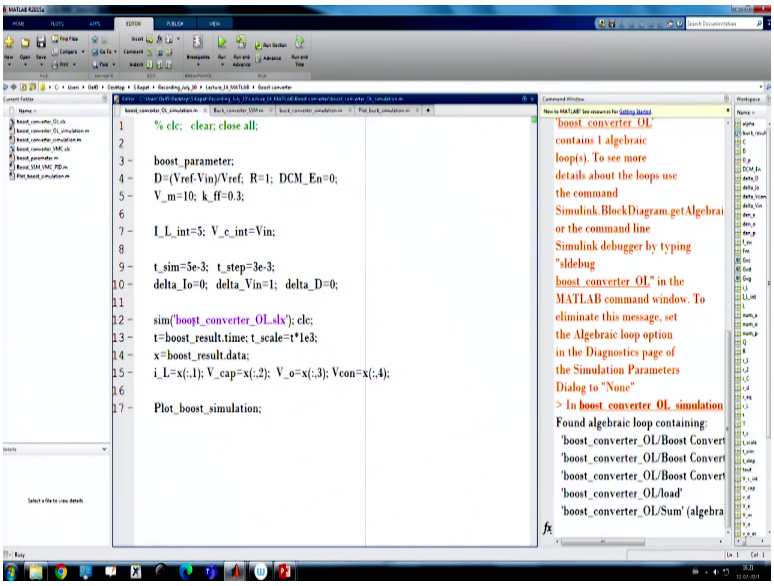
(Refer Slide Time: 25:41)



Now, so if you ignore this you know initially go back, I want to initially connect my sawtooth wave form; because you know what is the control voltage? The control voltage is nothing, but the duty ratio into the modulator voltage, maximum voltage, ok. And I want to initially connect directly with the sawtooth waveform and I want to apply a supply transient in the boost converter.

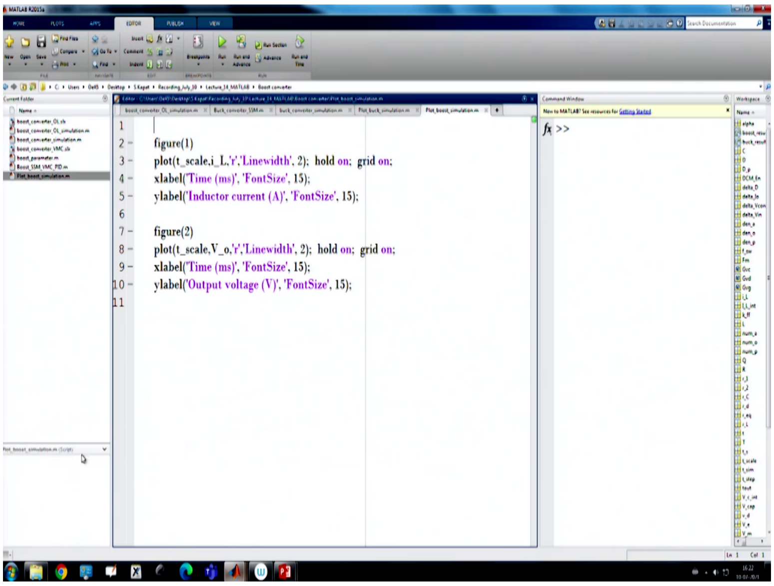
And first want to see, whether the boost converter; so I have applied a supply transient of 1 volt and let us see what happen.

(Refer Slide Time: 26:12)

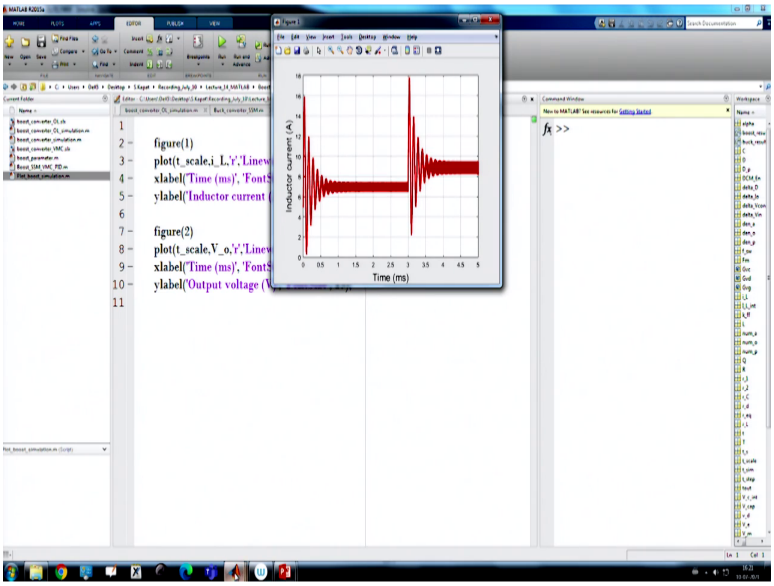


So, here. So, this is the boost converter response, ok.

(Refer Slide Time: 26:15)

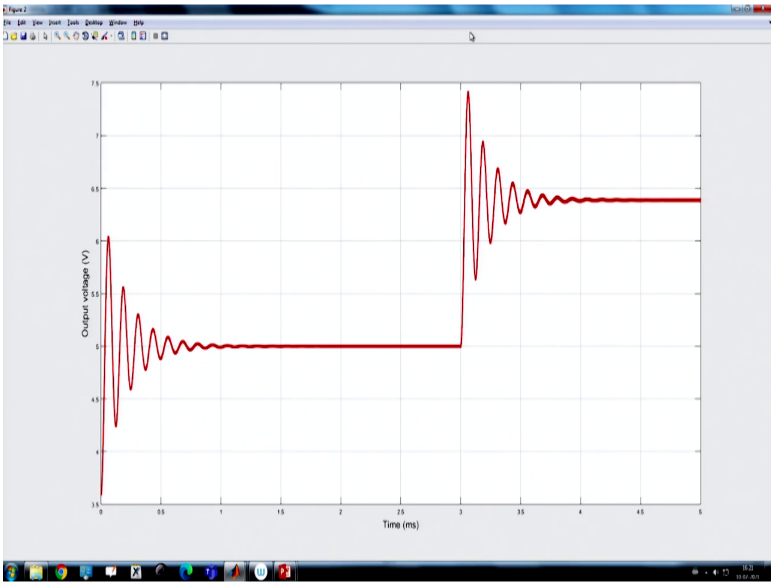


(Refer Slide Time: 26:18)



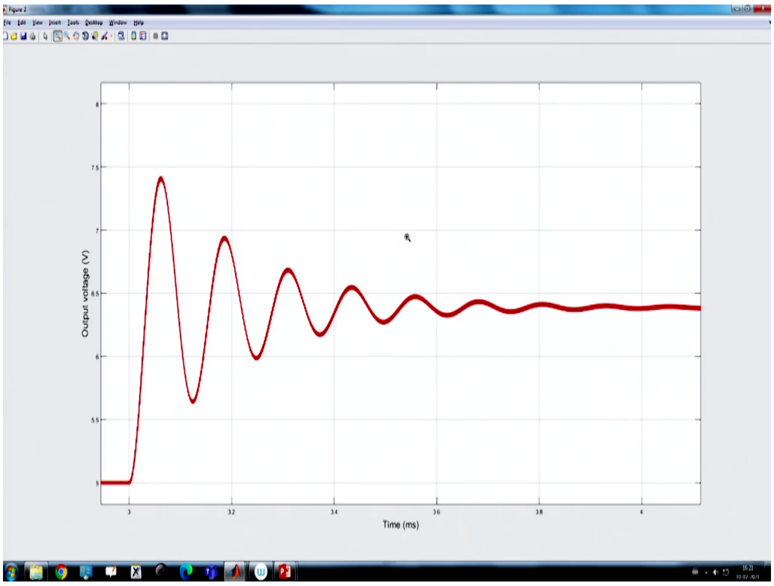
It is the inductor current and output voltage.

(Refer Slide Time: 26:21)



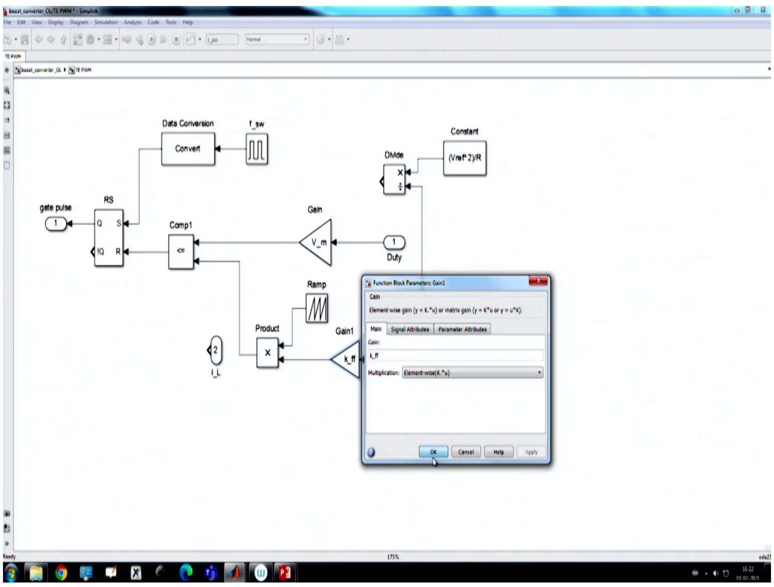
So, you can see the output voltage gets significantly affected, when there is a supply disturbance.

(Refer Slide Time: 26:28)



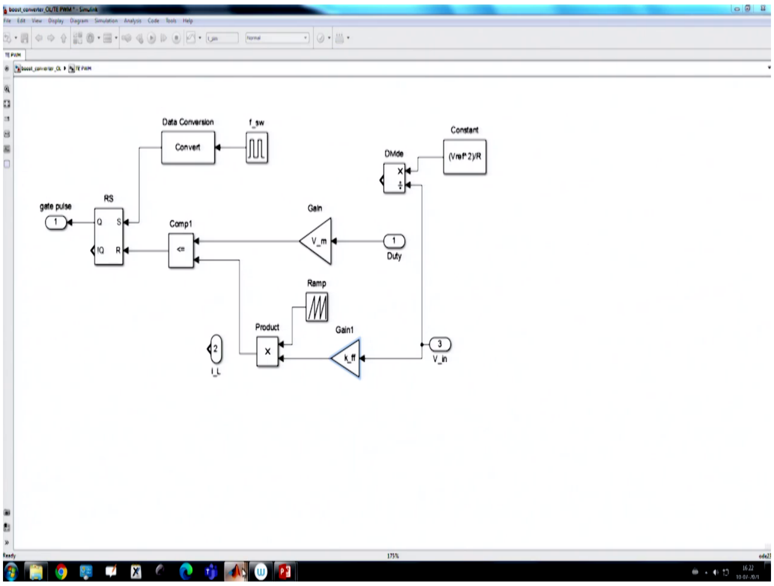
And this is also audio susceptibility for a boost converter. This is open loop and as we have discussed that it is going to affect, so that we can see. Next task we want to consider our technique here, simple feed forward action that we have considered for a buck converter. And we want to see whether this technique is going to work or not. So, if you go to this you know boost converter circuit now. So, here.

(Refer Slide Time: 26:57)



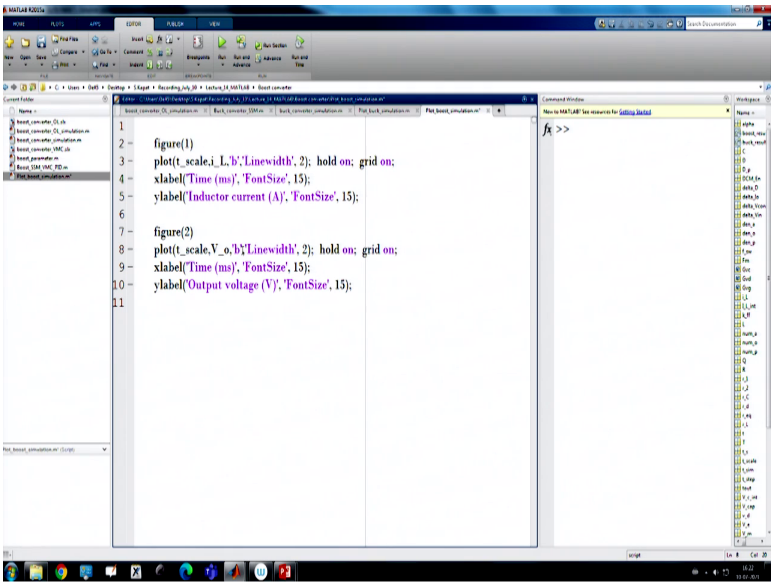
Now, we want to consider instead of this ramp, we want to consider this feed forward action; again feed forward action I have set some gain in my MATLAB file.

(Refer Slide Time: 27:02)



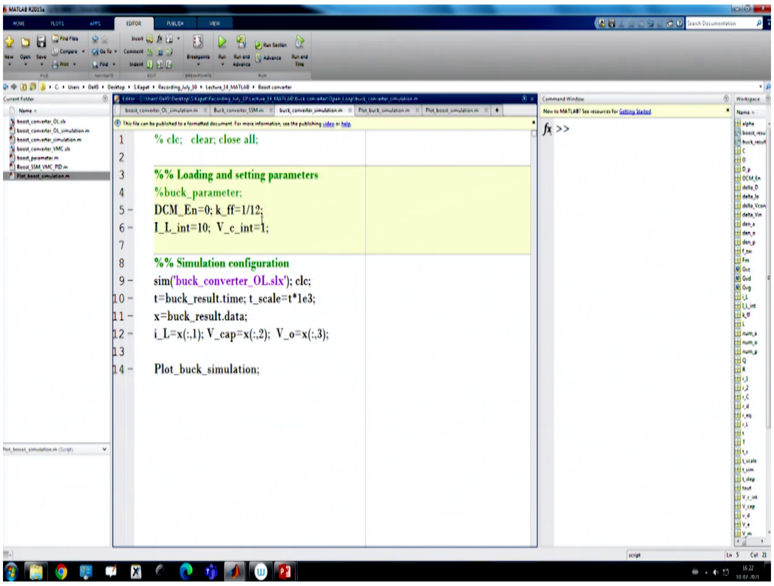
So, I want to use a different color.

(Refer Slide Time: 27:07)



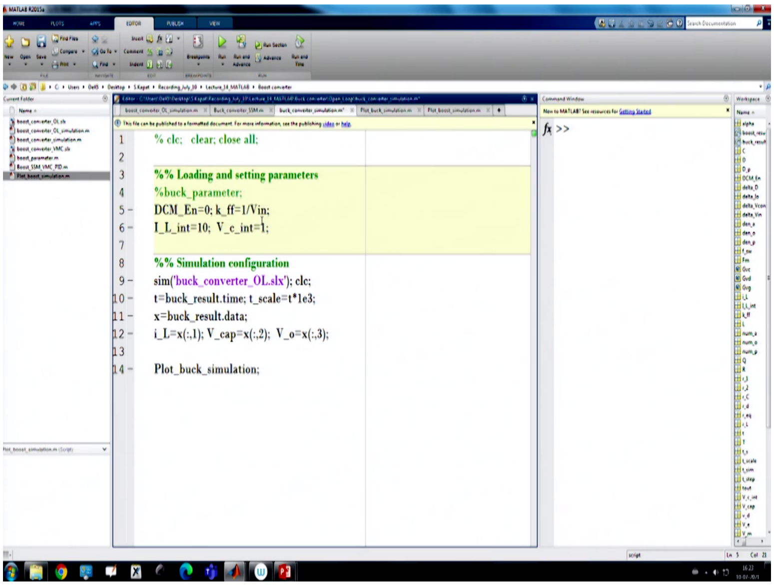
So, this is blue color, where we are using a feed forward action and if you go to boost converter, I am using a feed forward gain, so you can set some k ff gain.

(Refer Slide Time: 27:18)



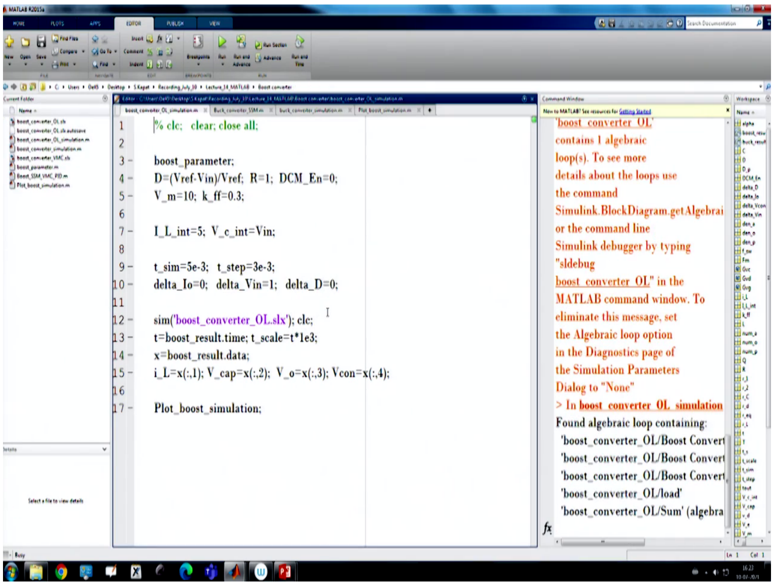
Let us say it is 1 by 12 or something like that, you can set you know.

(Refer Slide Time: 27:28)



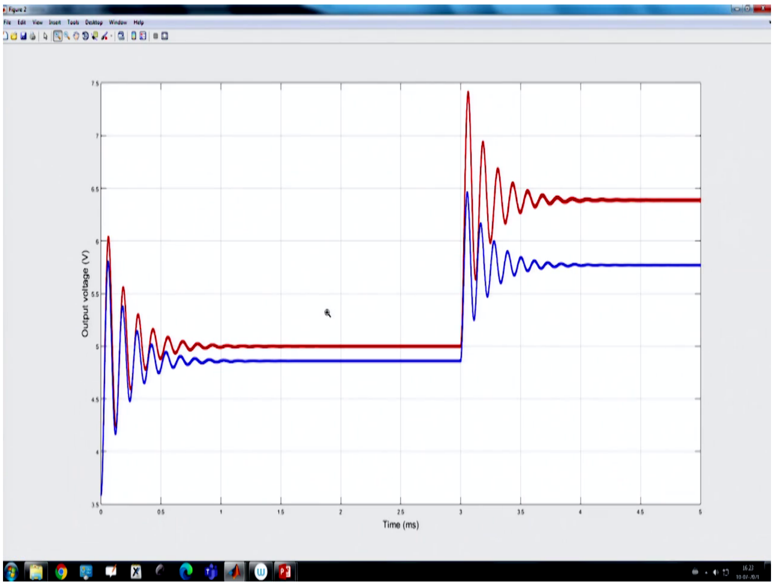
Because it is 3.3, so I will set 1 by V in; because we are multiplying with the input voltage, right. So, feed forward gain is 1 by V in. Now, we want to rerun this simulation and check what happen, sorry actually it should be boost converter, yes.

(Refer Slide Time: 27:46)



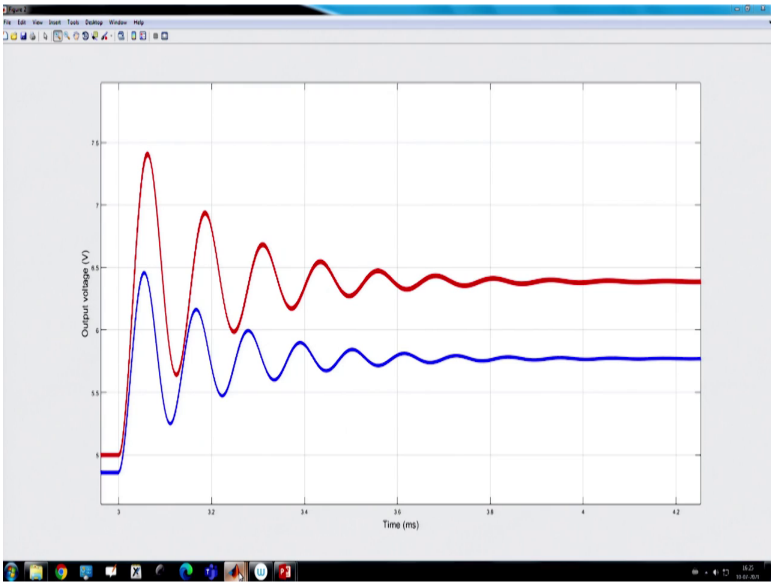
So, we are we are rerunning the simulation, yes.

(Refer Slide Time: 27:59)



And we are going to see what happen now, yes.

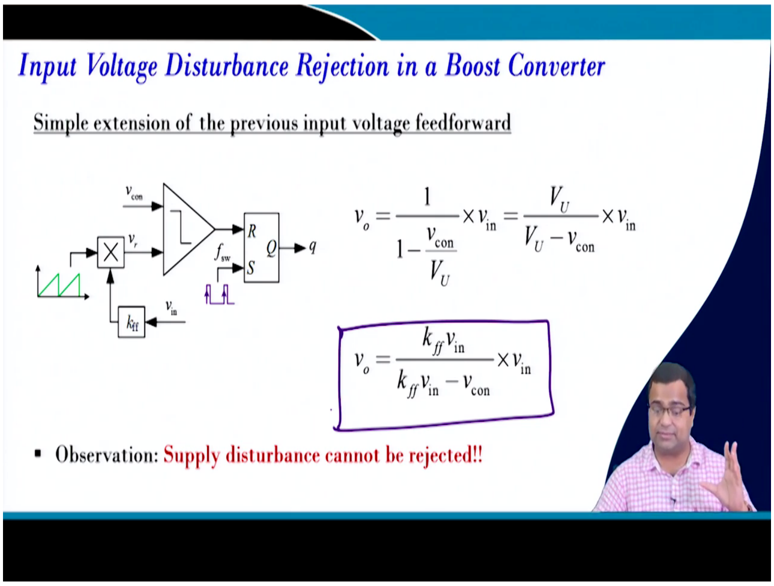
(Refer Slide Time: 28:05)



You see even with the input voltage feed forward the technique that we are applied is simply does not work totally; it got the effect got reduced to some extent, but it simply cannot actually anticipate this input voltage feed forward. That means, this technique if you take the output voltage expression of a boost converter, it has a non-linear relationship with the duty ratio; in case of buck it was simply d to v in.

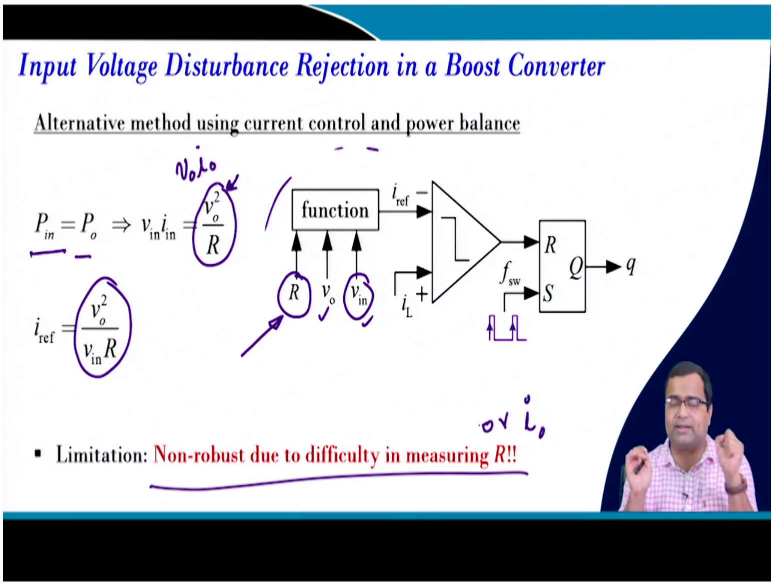
So, and we know that what is duty ratio? We know that it is control voltage by the maximum voltage; in this case which is nothing, but we took V U, that means it both are same, basically both are same. So, if we, that means objective is to reject disturbance using the same method.

(Refer Slide Time: 28:50)



And if we apply the same method, it turns out to be, it cannot reject the disturbance by this equation; that means it is supply disturbance cannot be rejected and that we have seen in the simulation region.

(Refer Slide Time: 29:03)

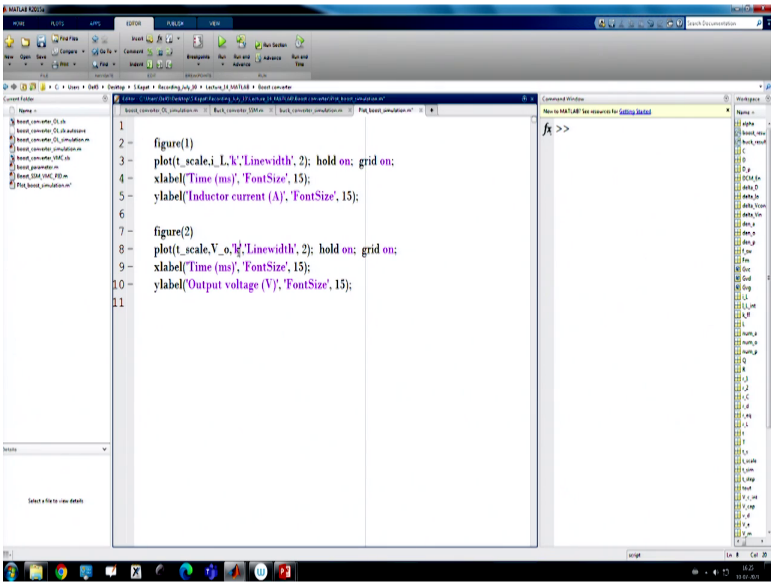


Next can we think of alternative solution? So, alternative method, because boost converter is a indirect converter, where it has a non-linear duty ratio relationship. So, it will not work the way the buck converter work. Now, let us consider if it is an ideal boost converter, we know the power balance formula; that means the input power is equal to output power if it is loss less, because you are talking about an ideal boost converter for the time being.

And you know the output power is simply v 0 square by R and now we can set a current reference; that means we are now bringing current into picture. And we want to make sure that, if we can set the current difference; that means you know for the, because boost converter inductor is in the input side, that means the inductor current is same as the input current. So, we are setting the reference for the inductor current; that means we are setting the reference input current, which is derived from the output power equation from here, right.

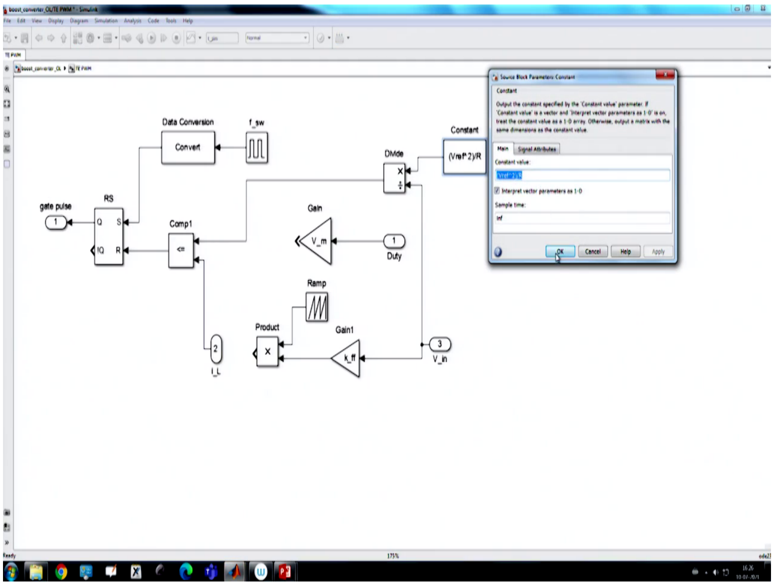
And if you do that and then if we implement this function and realize, can we see the effect or not. So, let us go back to the boost converter.

(Refer Slide Time: 30:17)



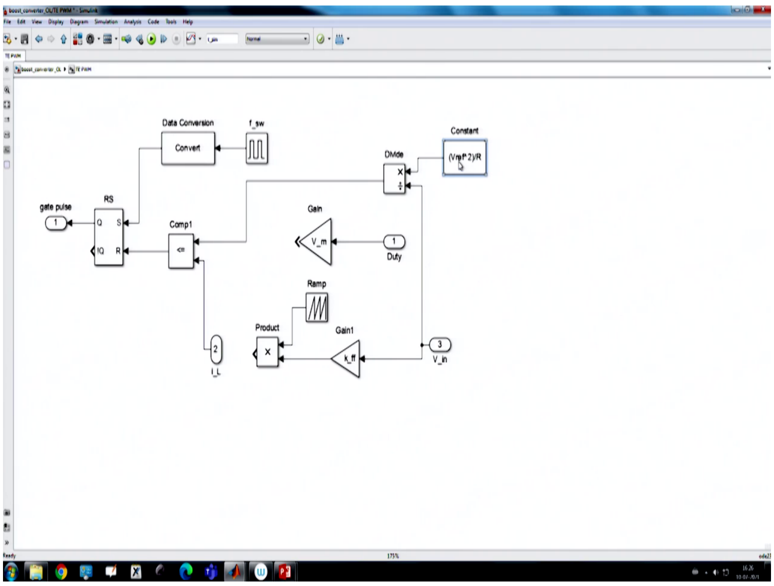
Now, we want to use the different color. So, now, we want to use you know black color and this color is indicated you know to show the.

(Refer Slide Time: 30:27)

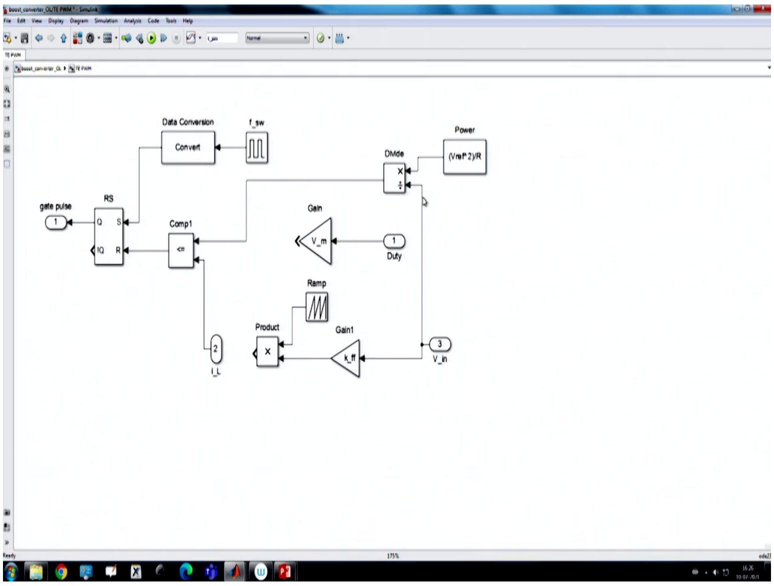


So, now in boost converter, we are taking the third one, where in instead of a now inductor current is compared, instead of sawtooth wave form and we are creating a function which is coming from here and this is giving us you know this is V square by R, which is the power.

(Refer Slide Time: 30:43)

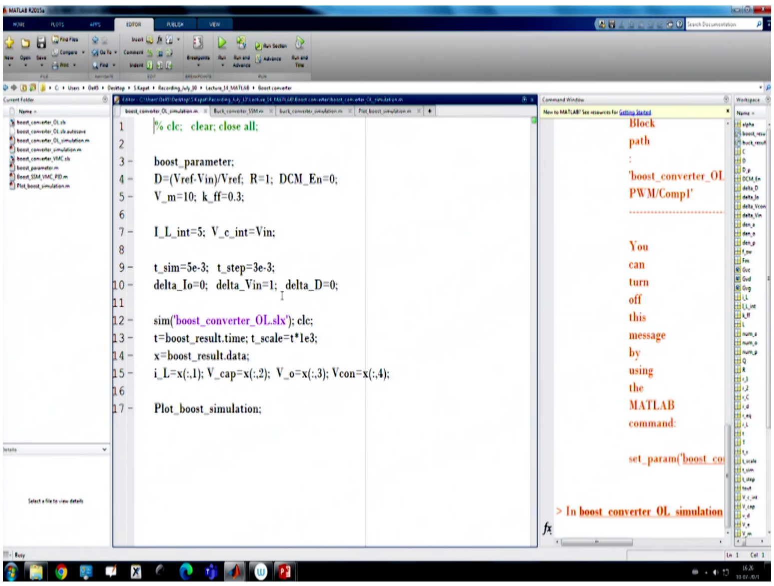


(Refer Slide Time: 30:46)



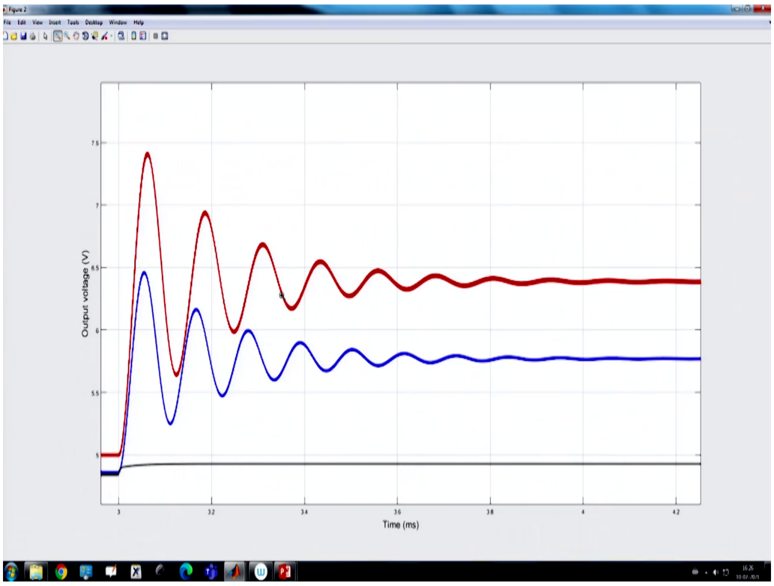
This is basically the power, because we are assuming input power and output power same. And power divided by the input voltage will give us the reference current and that it is a closed current loop, but we are not closing the outer loop, ok.

(Refer Slide Time: 31:05)

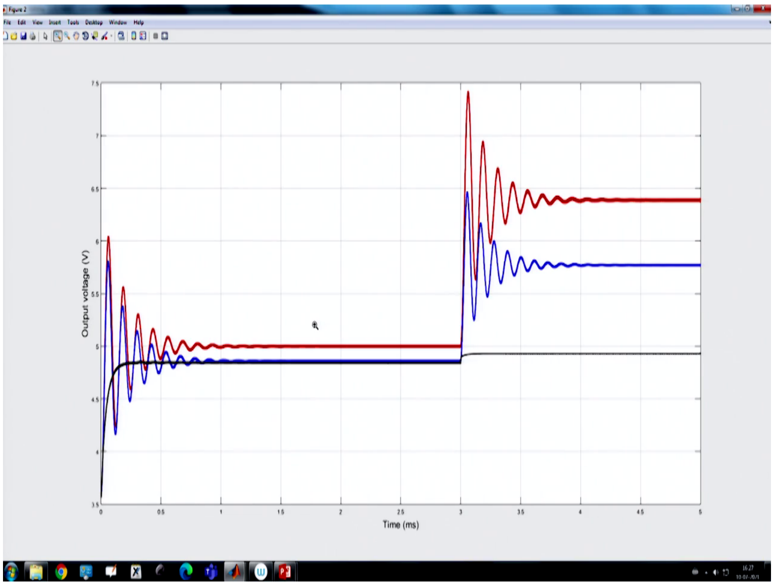


Now, if we simulate in this case and we want to compare what happen, when we connect the inner current loop, which the reference is generated.

(Refer Slide Time: 31:11)



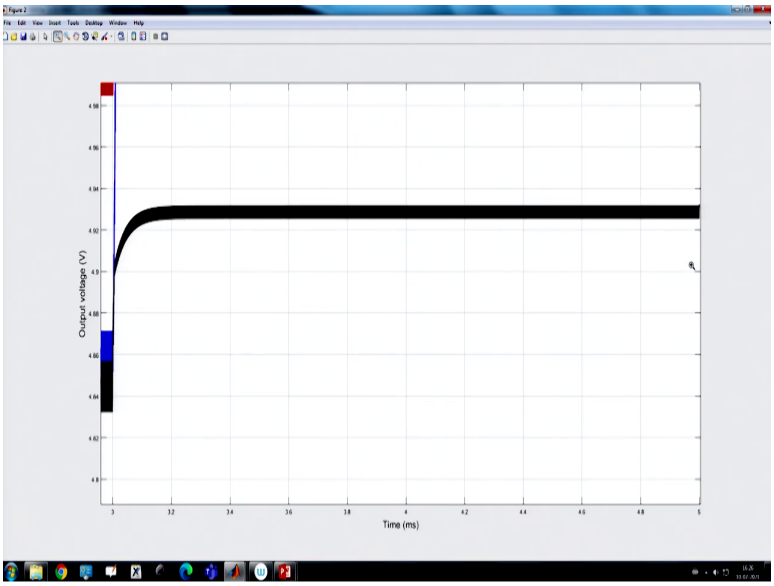
(Refer Slide Time: 31:14)



(Refer Slide Time: 31:17)

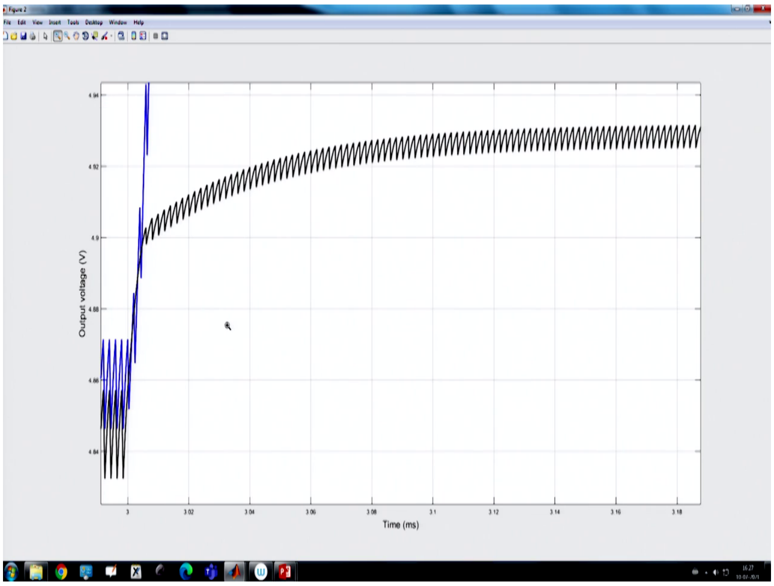
And you can see that the effect due to supply variation is drastically reduced by this technique.

(Refer Slide Time: 31:20)

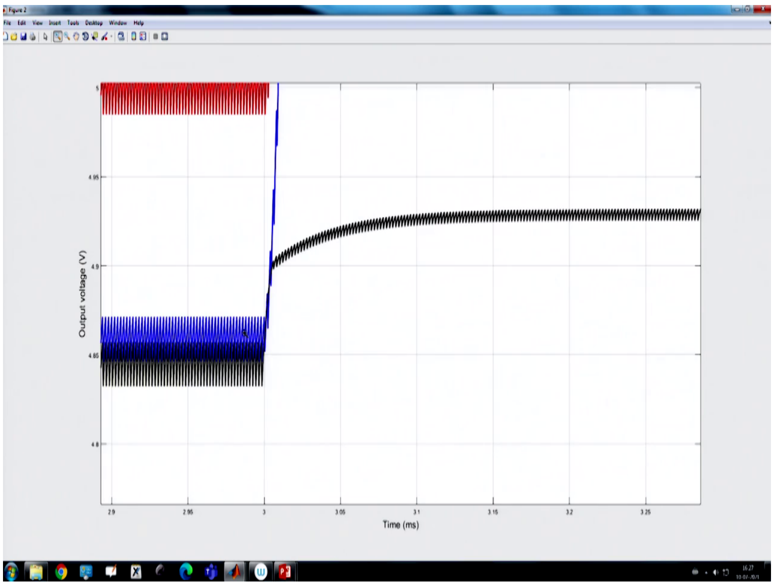


But this is also kind of feed forward technique, but only we are considering the current loop. But you can see there is a shift in the DC, because we are setting the current difference; we are not setting the actual average current, rather we are just setting the peak current. So, you can implement also average current control.

(Refer Slide Time: 31:30)

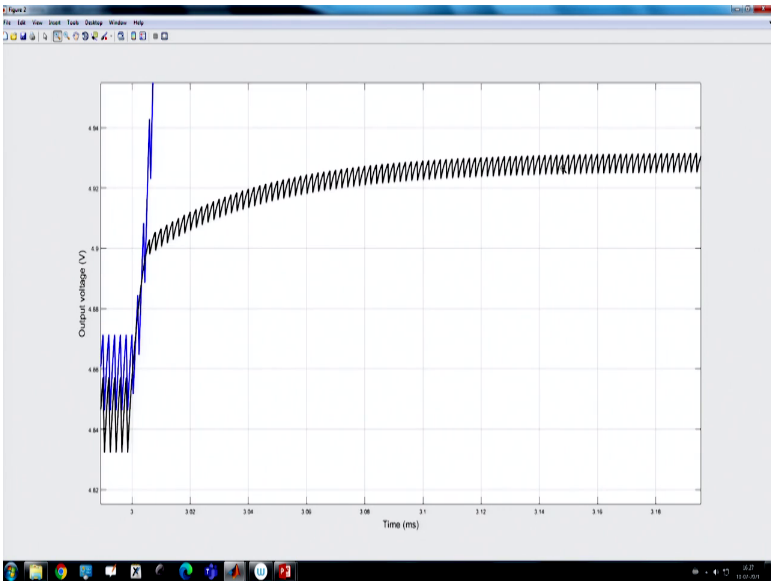


(Refer Slide Time: 31:40)



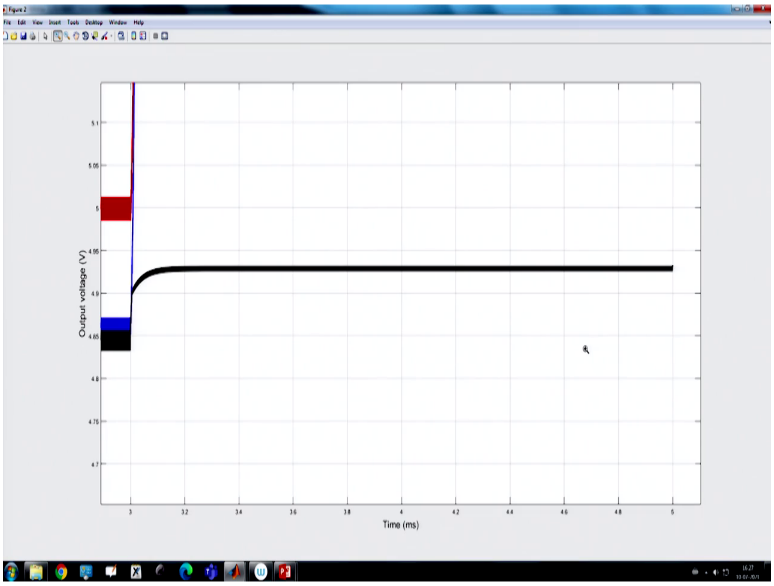
But one thing is also we can see, because it is in inductor is in the input side; so we will see in the subsequent lecture in a boost converter even current mode control, that audio susceptibility in a boost converter also has a fast order effect.

(Refer Slide Time: 31:56)



And that is why it is slowly rising and reaching to 0.

(Refer Slide Time: 32:02)

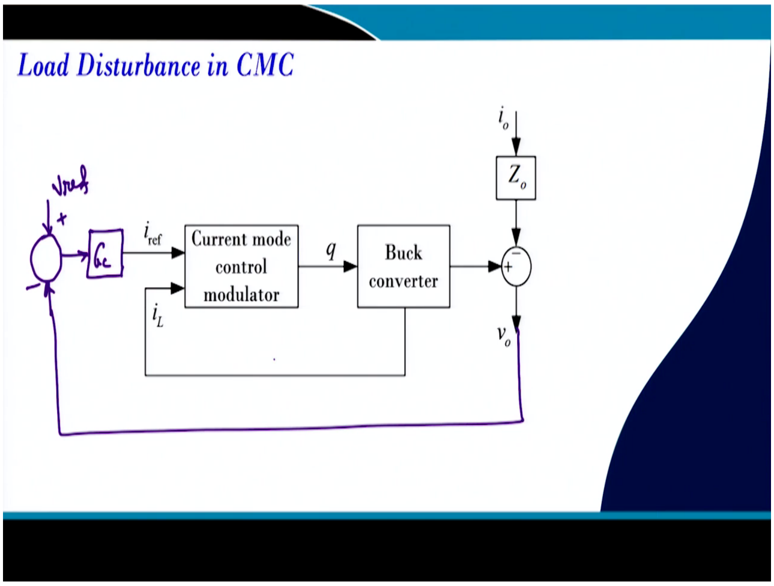


But that actually, but still I can see, we can significantly reduce the effect due to the disturbance ok; that means we can achieve very nice you know performance from here. So, that means what we learn that, we can reject the disturbance, we can drastically reduce; we cannot reject, reduce. But the problem, we need the information of load resistance, we need the information of input voltage; though we are sensing output voltage that is available, even the input voltage sensing is not a big deal.

But the problem is the load resistance, because you do not know; either you have to sense the load current, then you can multiply with this, because this can be also v 0 into i 0, but even that require load current sensing. So, this is a non-robust method due to the you know difficult in measuring load resistance or I can say the load current or load current. So, this require, ok.

But still this technique can drastically reduce the effect due to the supply disturbance in a boost converter.

(Refer Slide Time: 32:59)

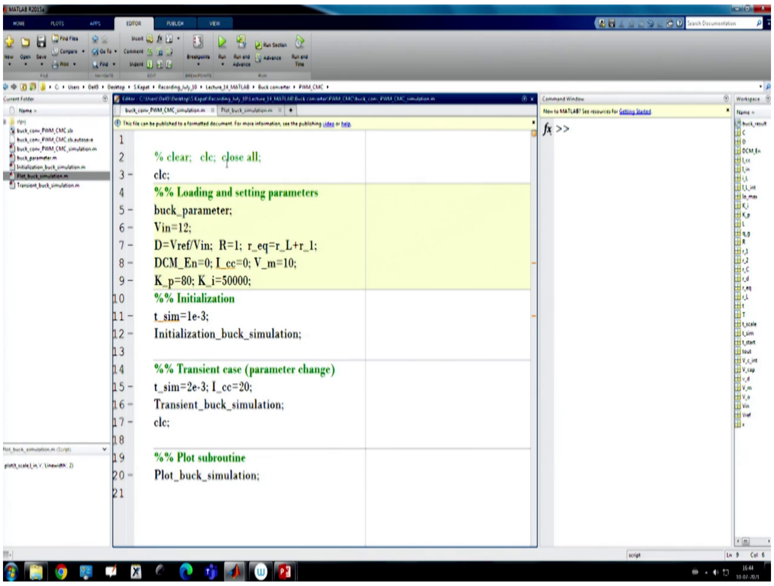


Now, we are going to discuss load current disturbance in current mode control. So, in current mode control, we have two loop; inner current loop and outer voltage loop. And inner current loop, the current reference is generated by using a outer loop, which has a controller and then the controller takes one is the reference voltage v ref and another is the output voltage, which is coming from here.

So, here it is important to, because we want to see load disturbance; if we do not close the outer loop, then what will happen? We need to actually change the reference current, otherwise the voltage will not be regulated, ok.

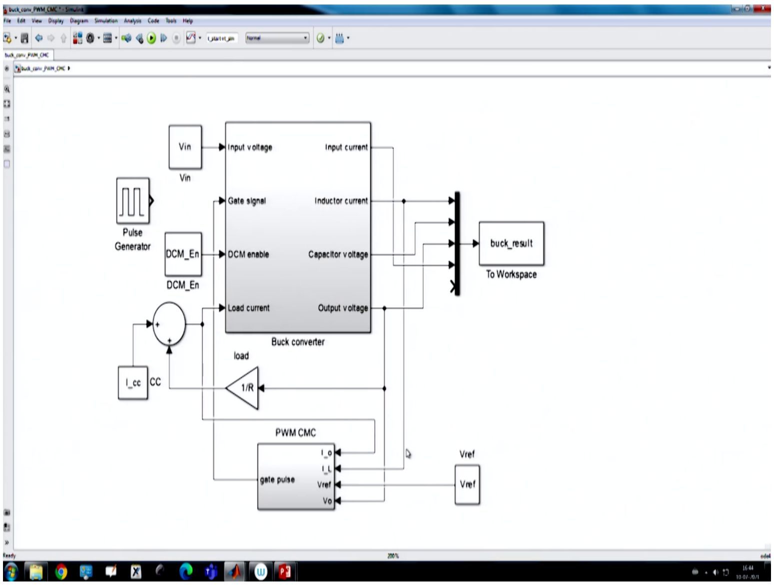
So, one thing we want to see first, that in current mode control; if we simply use you know like a load transient behavior, then what will happen? That means, there is a load disturbance and how can we you know reject the load disturbance in or reduce the effect of load disturbance in current mode control, ok?

(Refer Slide Time: 34:09)



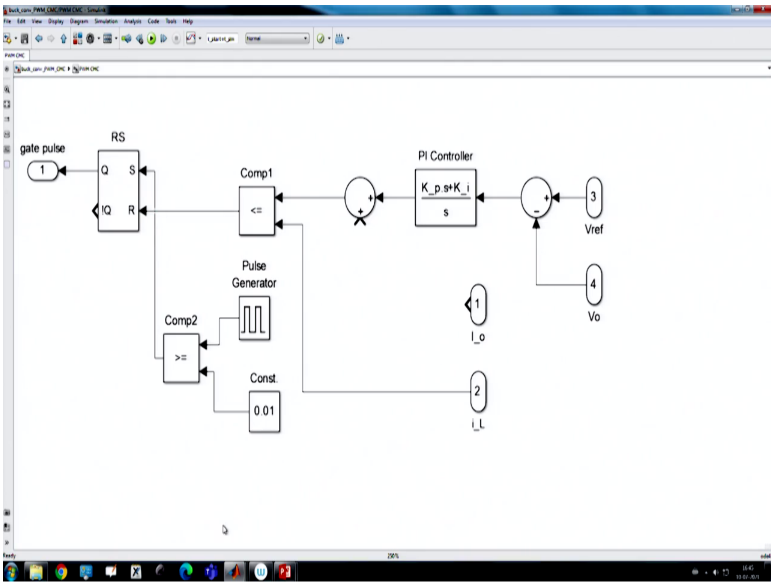
So, let us go to the simulation and in this case we are talking about a current mode control where you know this is the model.

(Refer Slide Time: 34:13)



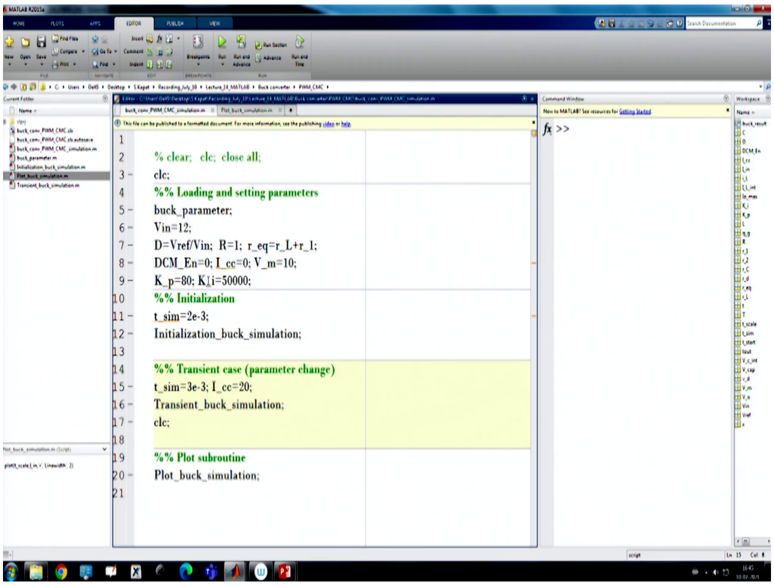
So, you know we have discussed about current mode control, but we will take more detail of current mode control in the future lecture; but for the time being let us assume that current mode control; that means we have to compare inductor current, because we have discussed in week 2 lecture peak current mode control, valley current mod control, different architecture, ok.

(Refer Slide Time: 34:35)



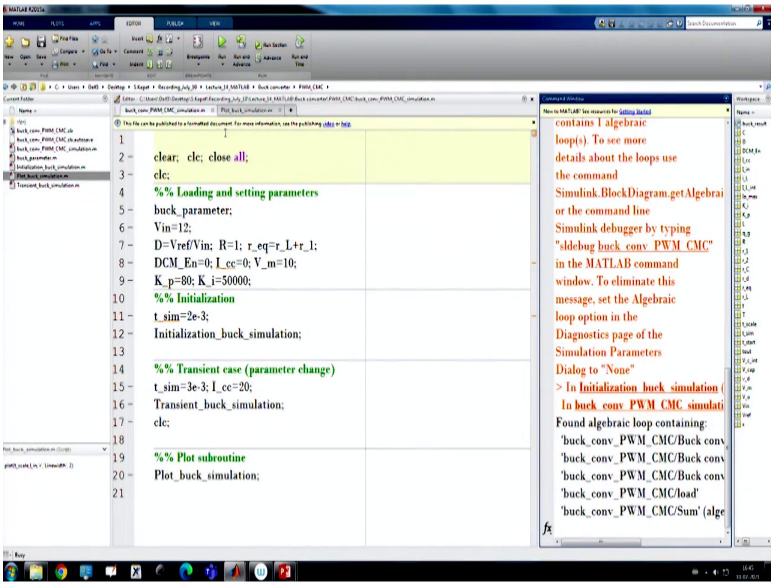
So, here we are consider a PI controller outer voltage loop and sorry outer voltage loop and we also have an inner current loop, ok. So, we have inner current loop and outer voltage loop and PI controller is used as the you know outer voltage loop ok and this is the inductor current reference.

(Refer Slide Time: 35:06)



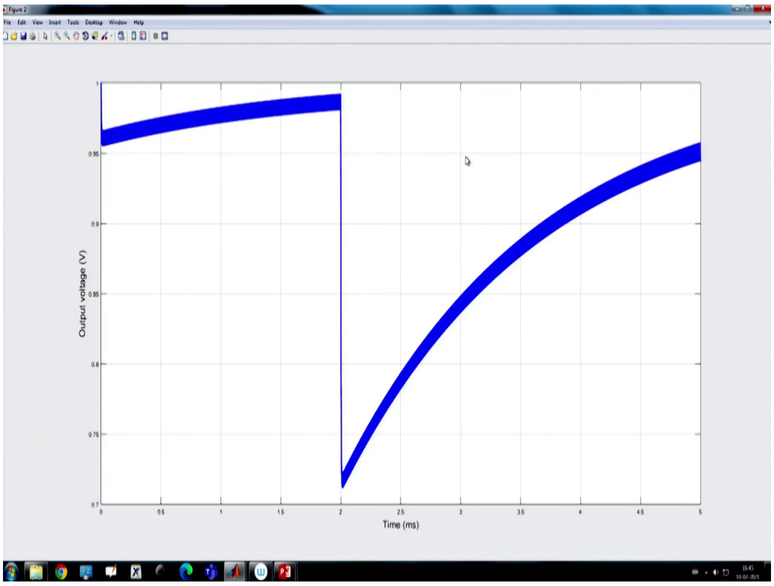
So, in this first case what I want to simulate that, if we you know run for let us say, we want to apply a load transient response. So, initially there is no you know, just it is a simple current mode control, ok.

(Refer Slide Time: 35:19)



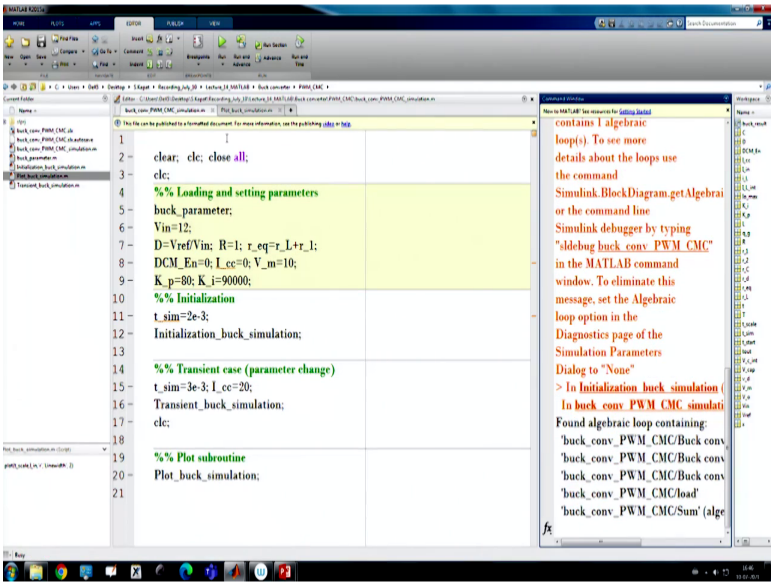
We want to evaluate the performance of this current mode control with both current inner loop and outer loop close, but we have applied, here we have applied a load step transient.

(Refer Slide Time: 35:34)



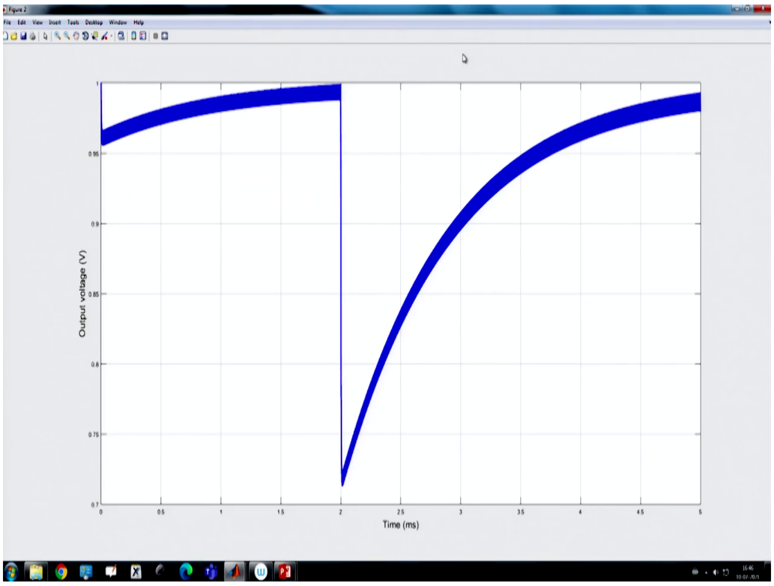
And here it is showing that load transient response seems to be is not satisfactory; that means it we have to wait long time. And in fact, you can achieve better performance simply by you know increasing the integral gain; because integral gain does not seem to be sufficiently high.

(Refer Slide Time: 35:55)



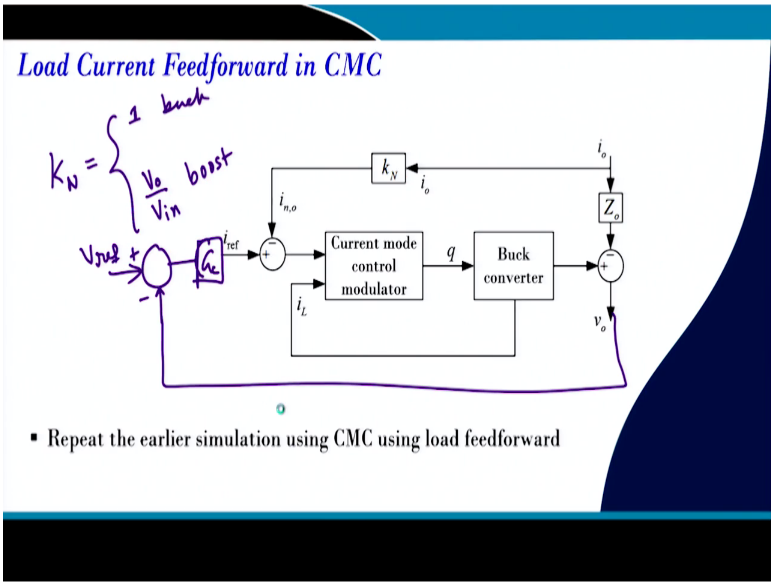
So, if you increase the integral gain, then we can achieve somewhat better transient performance; because we need to you know get rid of the steady state error. And, but higher integral is required to.

(Refer Slide Time: 36:10)



So, this is somewhat like it is reaching steady state close to that with a higher integral gain. So, if we increase the more and more integral gain, we can make it faster; but still it looks like a first order behavior and it takes a longer duration load disturbance.

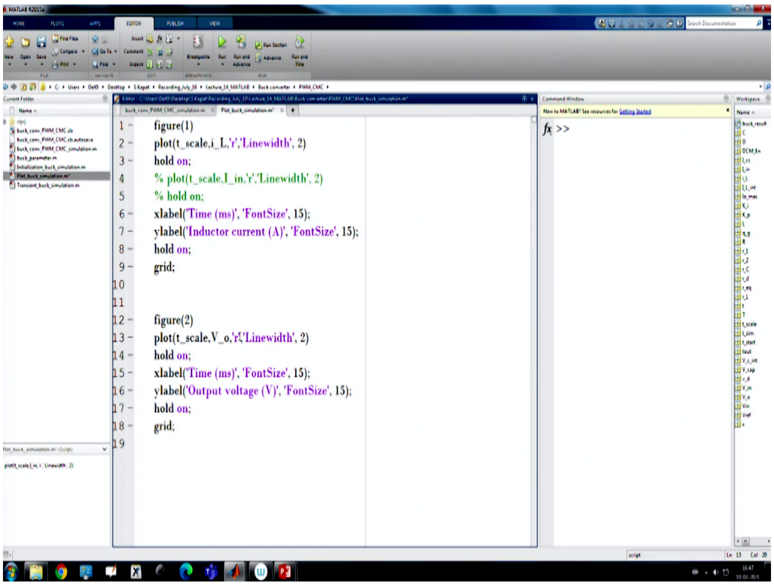
(Refer Slide Time: 36:27)



Now, how to reduce this effect? So, we can consider a load current feed forward, ok. And this normalization factor load current feed forward, this K N is called normalization factor which is equal to 1 for buck converter. Because this normalization factor, it normalize the load current with respect to the inductor current average; for buck converter, both average inductor current is same as average load current, so it is 1.

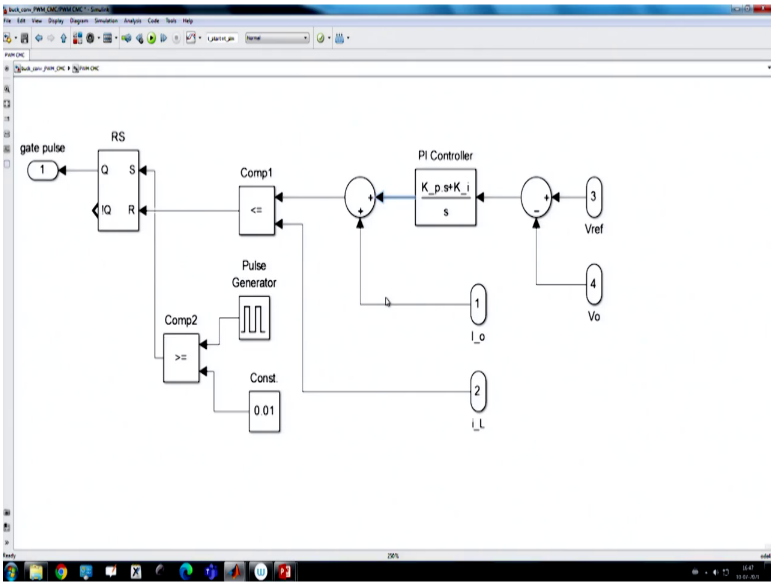
In a boost converter, it has to be v 0 by v in; that is for a boost converter, so that your inductor load current can be mapped to inductor current in the normalized sense, ok. So, if you repeat this closed loop and again we have closed loop control here; that means we have a controller here G c and the controller has one v ref here and we also have an outer voltage loop here ok, and same controller we are comparing with load current feed forward, ok. Let us go back to the simulation and run it.

(Refer Slide Time: 37:29)



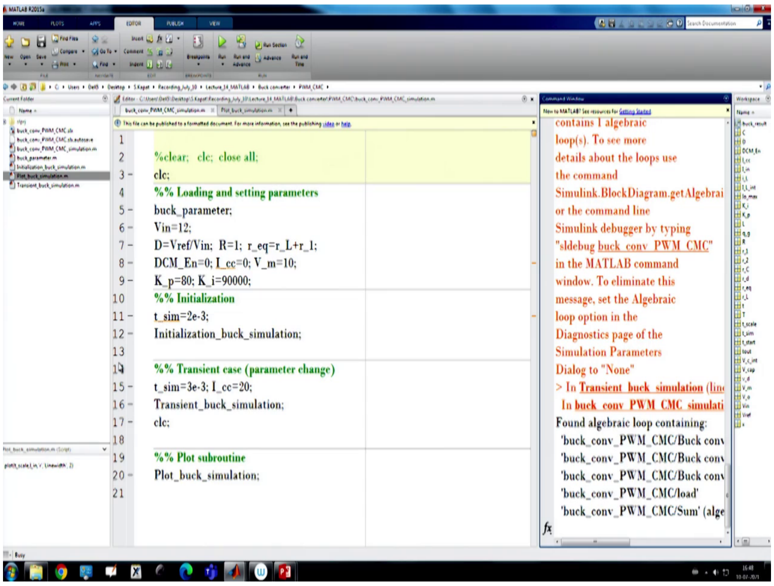
So, now we are changing the color. So, what are we doing here?

(Refer Slide Time: 37:55)



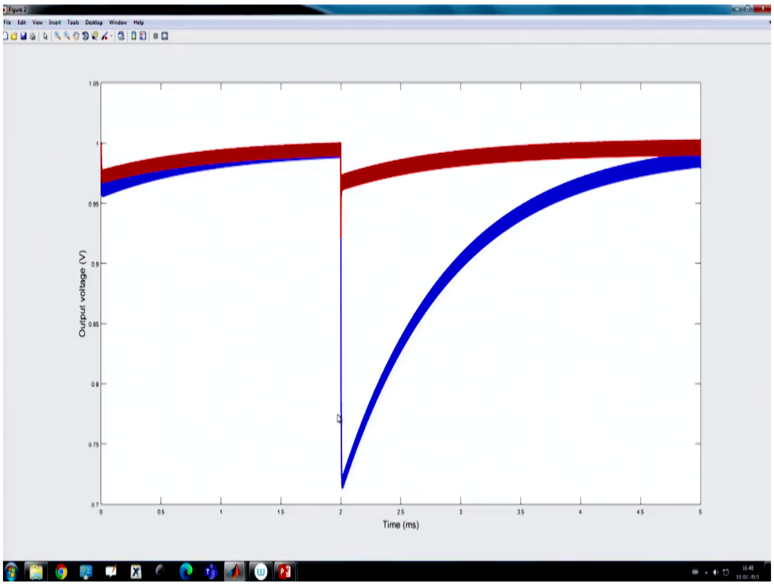
We are we are essentially now taking a load current, either this load current can be added with the reference current; because this output is a reference current or it can be subtracted from the inductor current, ok.

(Refer Slide Time: 37:48)



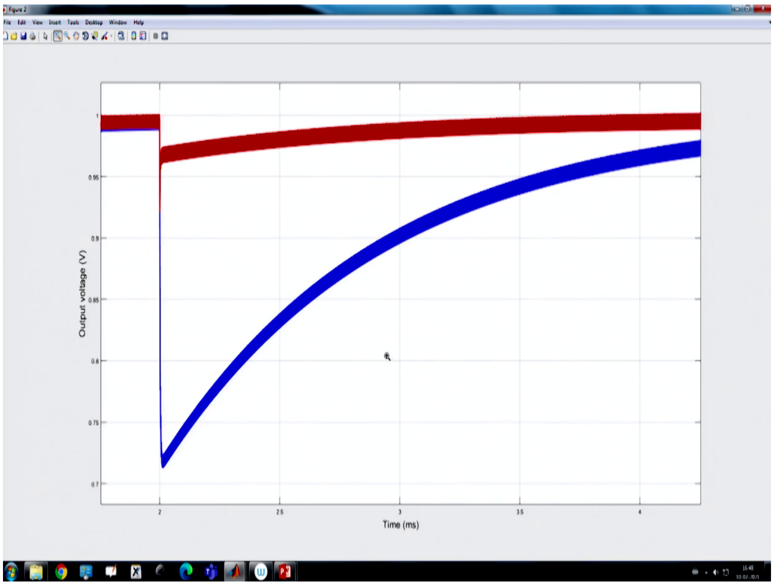
Now, if we rerun this simulation, ok. So, if we rerun the simulation and we want to check, whether this load feed forward can improve the performance or not; because we already have the result for, because here we are considering a load current feed forward, ok.

(Refer Slide Time: 38:03)



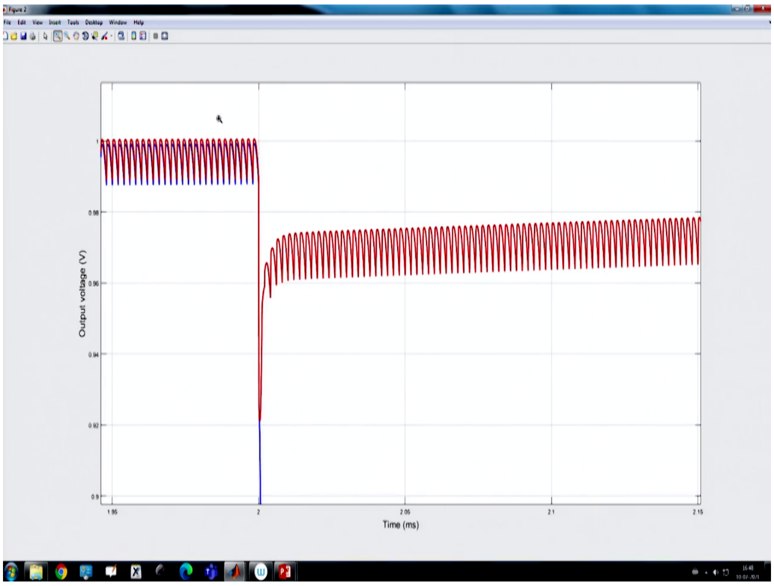
Now, if you see the response of this simulation results, so it will show; that means, if we take the grid here.

(Refer Slide Time: 38:20)

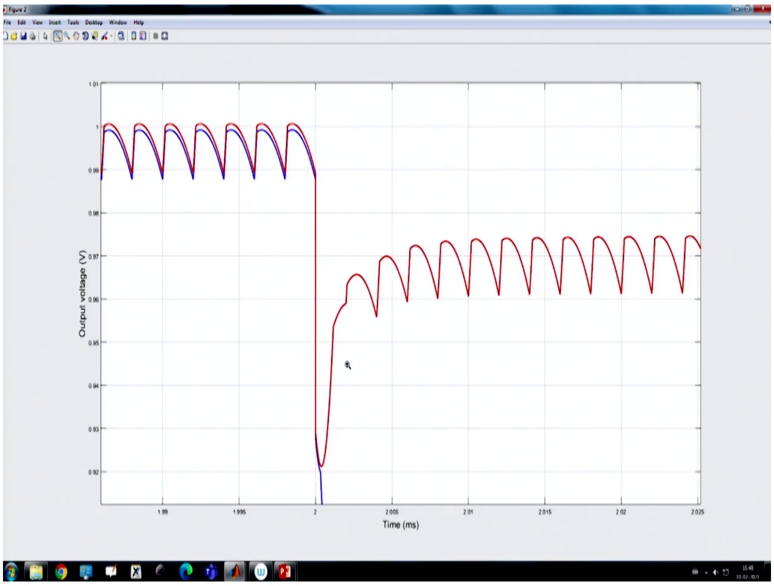


So, you can substantially reduce the transient, improve the transient performance by means of a feed forward control.

(Refer Slide Time: 38:22)

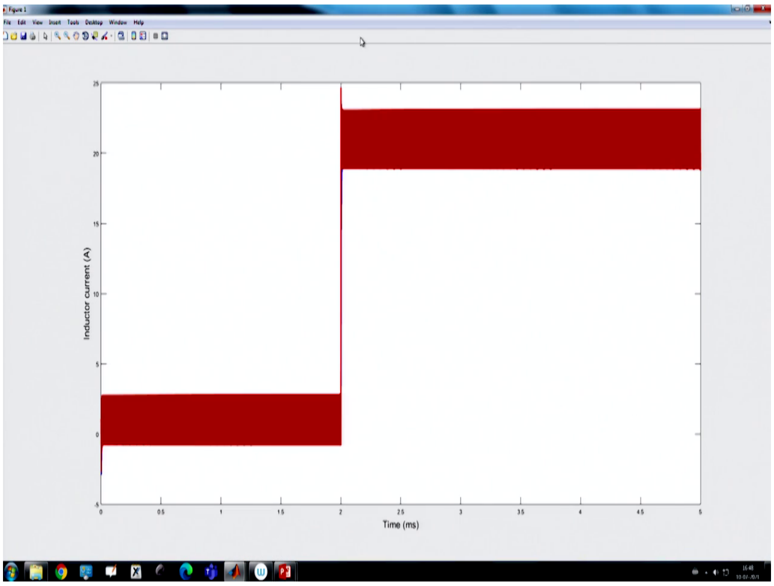


(Refer Slide Time: 38:24)

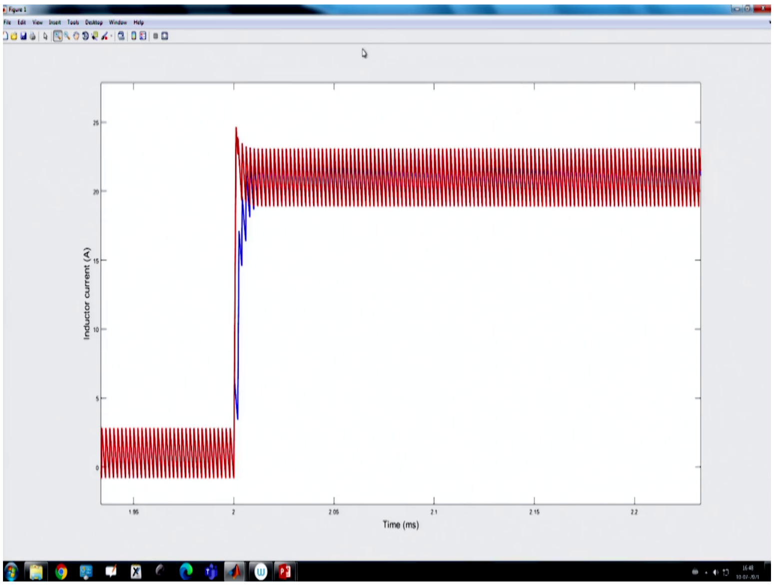


So, you can see the impact can be drastically reduced by means of a feed forward control, ok.

(Refer Slide Time: 38:28)

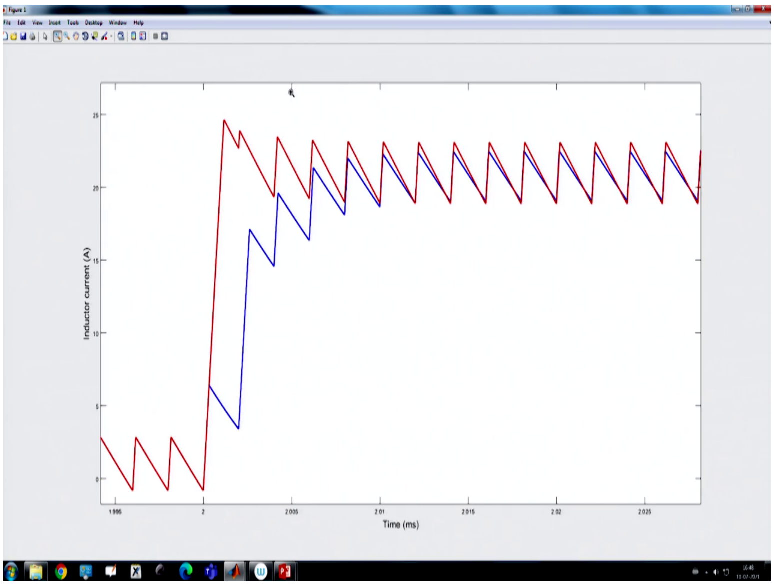


(Refer Slide Time: 38:13)



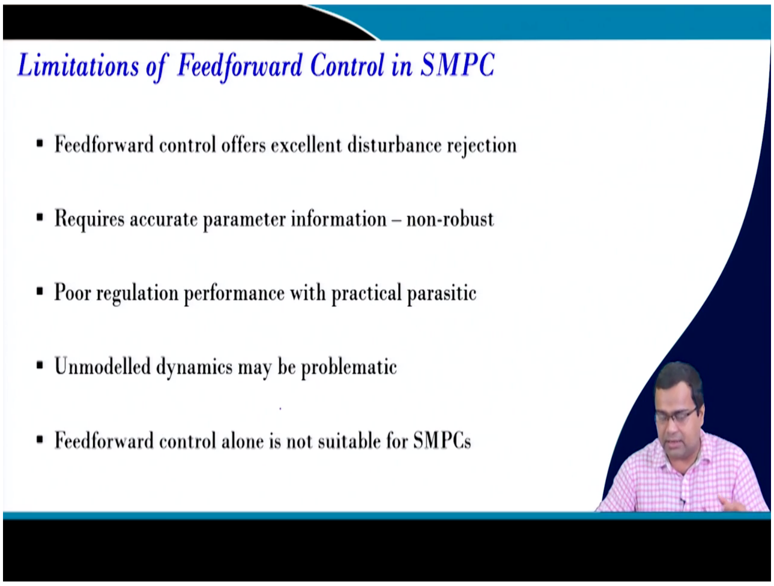
And if you see the inductor current, the response difference will be visible from here.

(Refer Slide Time: 38:35)



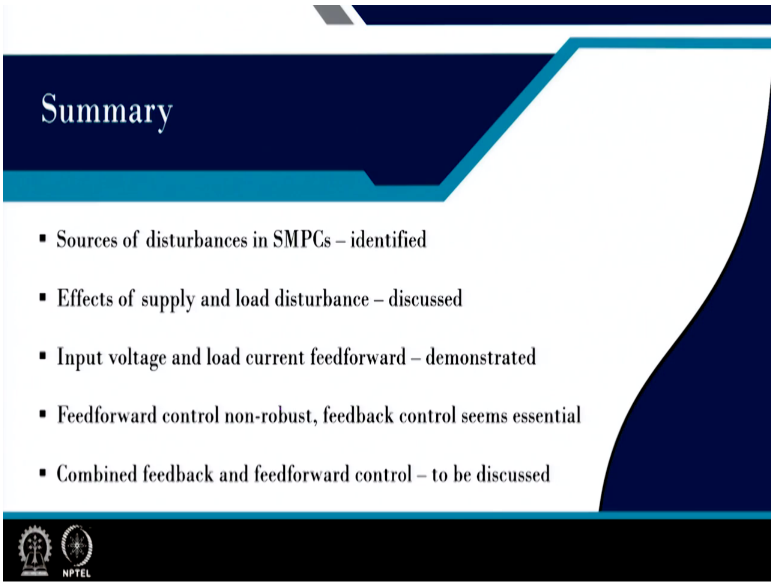
So, if we apply a load feed forward, the response can be improved drastically, ok.

(Refer Slide Time: 38:40)



So, limitation of feed forward control, the feed forward control offer excellent disturbance rejection; but it require accurate parameter information. In some cases they are non-robust; that means poor regulation performance we saw that, we cannot get perfect output voltage regulation, particularly for practical with practical parasitic and unmodelled dynamics in practical system may be problematic.

(Refer Slide Time: 39:11)



So, the feed forward action alone is not sufficient for switch mode power converter. So, we need to consider feed forward control along with the feedback control. So, in summary, we identified sources of disturbance, we discussed supply and load disturbance, input voltage and load feed forward control we have also demonstrated. And we also demonstrated that feed forward control is good, but it is non robust and you need a feedback control, it is essential to regulate the output voltage and make the design robust.

So, we will discuss in subsequent lecture that, how can we incorporate such feed forward controlling, feedback control to achieve fast response as well as tight voltage regulation. So, with this we want to finish here.

Thank you very much.