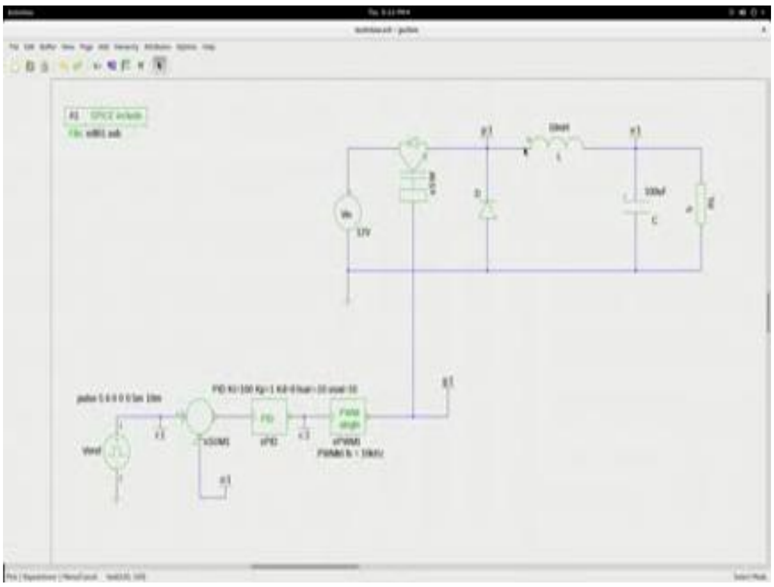
Design and Simulation of DC-DC converters using open source tools
Prof. L. Umanand
Department of Electronics System Engineering
Indian Institute of Science, Bangalore

Lecture – 22
Simulation examples

We shall now look at the simulation of buck converter in closed loop. What we will do, like before we will go to this folder where I have now created the schematic and I am naming it as buck close dot sch. And I have updated custom dots of file and there is a buck closed dot cir and we will come to that later.

(Refer Slide Time: 00:55)



So, let us open this buck close dot sch which is the close loop schematic for a buck converter. You can use the same approach for any other converter too, let me zoom in yes. You must be able to recognize this portion, you see that this is DC source 12 volts, and this is the power switch which we will be controlling through some duty cycle and you have the buck converter portion l and the c which we used in the open loop simulation and the inductor will free wave when the switch is off or switch is on in that in that troll chart.

So, all those things you know and have some load of 5 volts stack which will give me around somewhere around 1 amp of current. Now the changes that we have made are here, in the control portion which ultimately is going to control the gate drive of the switch. So, what is it that we have done? We had actually included the PWM in the open loop itself and we had given a constant voltage here. Now instead of the constant voltage we are now having a controller, the comparator and the feedback. Now the feedback is given through this label and you see that when we discussed in theory we had connected this directly to the output.

But then instead of flattering up the schematic you recall that we had given a label here called o and the same label if I copy it and put it here it is equivalent to saying that I have made a physical connection between these two points. So, this output voltage is actually now fed back to this point, so here you are having a difference amplifier plus and minus to the plus and giving a reference voltage. The reference voltages as you see here is not a constant I have given a kind of a pulse load disturbance so that we will actually see that the output is tracking this pulse to decide disturbance. But however, in actual practice you will see that this will be pure constant set point value.

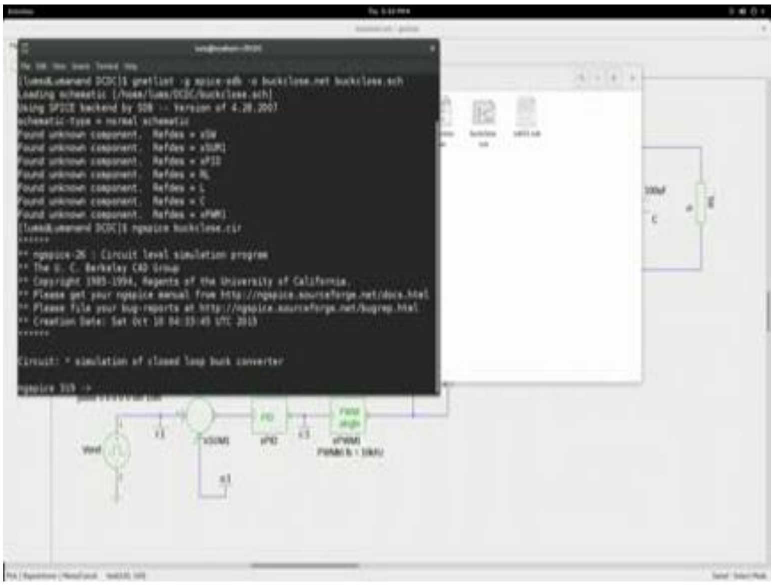
Now, the difference between the set point and the red buck voltage the error is fed to the PID controller. And the PID controller has some parameters k i parameter for the integrator, k b parameter for the proportional, k d for the differential I am not utilizing it I am setting back to 0. There is a l sat there is a lowest saturation limit set it to minus 10, u sat the upper saturation limit setting it to plus 10. You have control on setting it to still lower values too. Now this output is final effect to the PWM which will generate the appropriate duty cycle pulse and give it to the power semi conductor switch here.

Now, this is the total gross loop circuit of the buck converter and this is the closed loop portion and this in fact is the controller with these parameters. Now let us see what happens when we simulate. All these things you know how to input the pipe and this is the inclusion of the edt 0 1 dot sub. Now before we go to the simulation what is said that we have added, we have this is 1 block, this new block that you would not have seen till now and this is another block that you would not have seen till now; is nothing but summer. This is one of this has been built using the analog behavioral model of Ng spice.

Likewise PID is also built using the analog behavioral model of Ng spice. I will just show you how that model for that block has been incorporated in edt 0 1 dot sub.

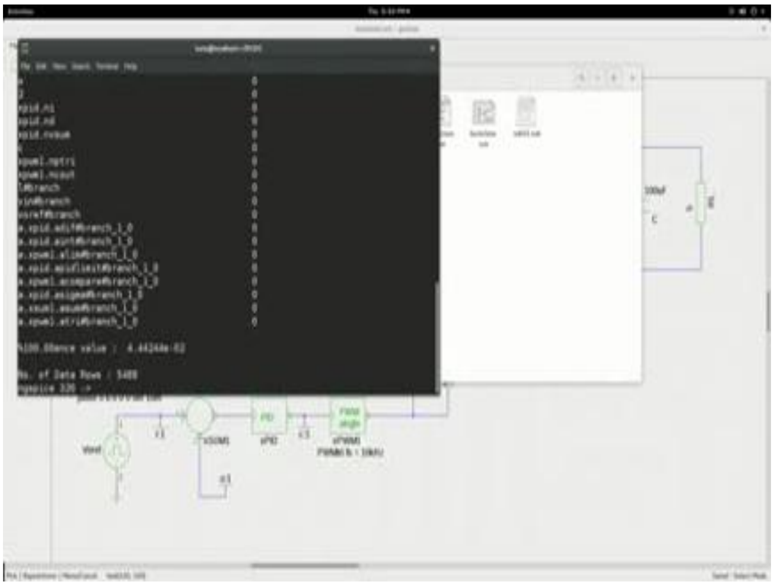
Now, these two blocks are available in the A block library. So, in the A block library you see add. This is the symbol and that is what we have pulled and kept it there the symbol we will recognize that. Then the other file is the PID. This is the PID and this is what we have used here. So, this is available in that A block folder of the library. Now let us save all this.

(Refer Slide Time: 06:22)



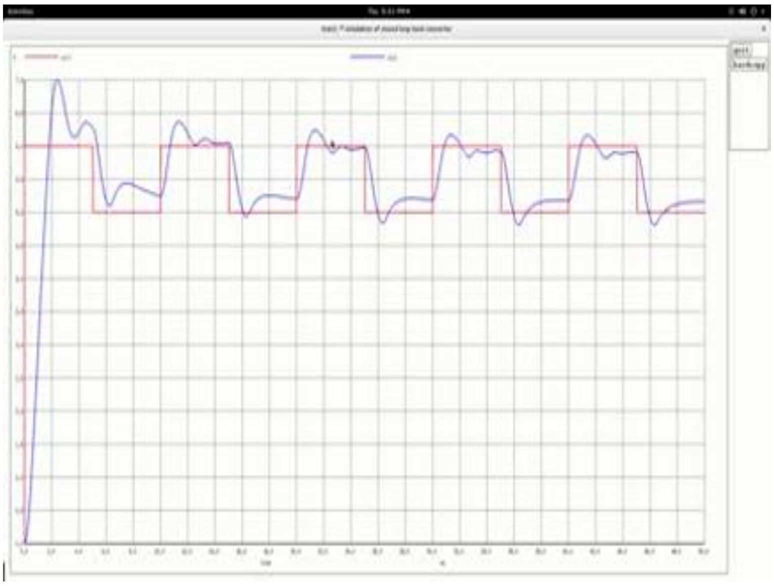
And this schematic let us use our well known process which is first we go into that directory and generate net list, so this is the net list command I think you recognize this and using the buck close dot sch and generating the buck close dot net. So, let us generate the net list and you would see here that the net list has been generated. And now let us go and do Ng spice environment and call buck close dot cir. Now what is there in cir? Cir is nothing but a drop tran statement at (Refer Time: 07:19) statement with steps of 10 microseconds and 15 mill seconds UIC, include the buck close dot.

(Refer Slide Time: 07:39)



So, going into Ng spice and doing the run command will execute the simulation. Now let me do set color 0 equals white set color foreground as black. I want to plot the reference and the output, just to see whether the output is tracking the reference.

(Refer Slide Time: 08:15)

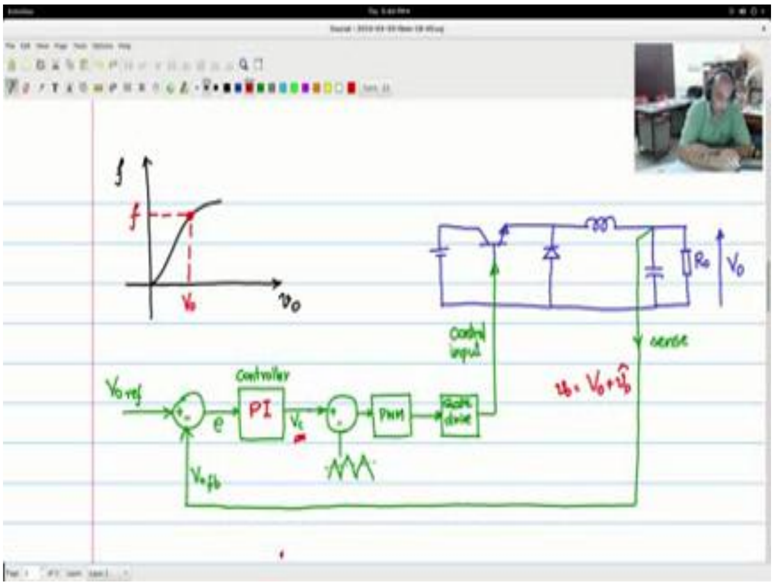


So, let me put r and the output o. You see the red wave form is the reference wave form and the blue wave form is the output wave form it is trying to track the reference wave form. Of course, the tracking is not too good we may have to tune the PID parameters; there is some measure of control you see that it is taking control between 5 and 6 volts. Now what I would like to do is put down this environment, I will go and adjust these parameters. Now k i is the integral, constant k p is the proportional constant and let me change the proportional constants to larger value so that the dynamics is improved.

Now, you had to do all these thing step by step, but I am trying to do it in one big step just so that we save some time, but you can play around with these parameters here. Now let me save this and then let us go back and generate the net list and go into the Ng spice environment along that and let me do these settings. And we can now see same wave form v r and V naught. So, you see much better, you see that the wave form is more closer in tracking the dynamics are better, basically because you have improved the dynamic response by the choice of k p. Of course, I will leave it to you to play around with all the different parameters and also the parameters of the buck converter L and C's and just try out to the end.

This pulse the kind of reference is just for this purpose of learning so that you see that there is some affect the output is trying to track the input and output is coming to a desired value. In practice it will be constant let us say you want to give an output of 5 volts your set point will just be 5 volts it will reach the set point 5 volts and continue to stay here without all this jigly wigly wave shapes. So, this is just to show that the buck converter output can be regulated.

(Refer Slide Time: 11:14)



So, this is the close look buck converter system that we saw and we discussed previously. I would like to suggest a small improvement in the control structure so that there is less strain on the controller here. At present in this type of topology you will see that this controller has to handle the entire swing of V naught. For example, when we consider; let me make some space here and let me have the axis that is a one axis like this and another axis like this.

Now I just (Refer Time: 12:07) here I just said this is the V naught axis. And let me explain in the sense here let us say v c or some function at I just put some function here I will explain what the function is. Now let me take this up like that V naught versus f. Now let us say the operating point is somewhere here, now this is V naught, this is f. This f would be it can represent the v c that we are talking of the controller voltage, so it is hovering at this point. If you are talking of the error of the f can represent the error and you can say what is the relationship between the V naught and v c. So, V naught and f f is a general equilibrium.

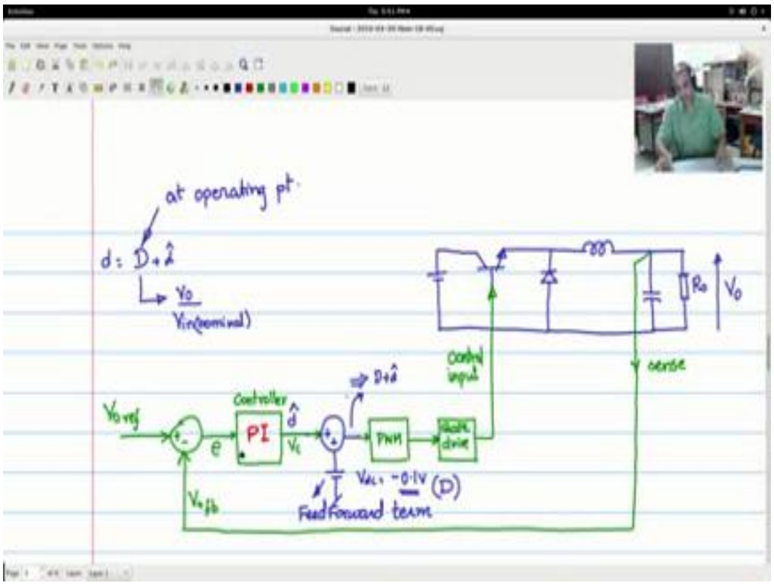
Now V naught is not a constant, V naught is actually; I will write it here V naught is composed of two parts one is a constant part representing the operating point plus a very small signal part. This is the variation which is called load disturbances load changes and all those things. And this small V naught hat is the one which is making the system to deviate from it is operating point V naught.

So, other entry there is a small zone as we say something like this, and I will call this small zone as V naught hat. Now this leads to a deviation can be see R e variants, so I will say this is f hat. So, the f is also composed of f which is operating point plus f hat. If it is b c that we are talking of the control voltage it is having b c, so operating point value plus variation of the neighborhood of the operating point.

Now, the point is in this particular topology as we are seeing it now the controller is handling the entire large signals swing from 0 to the operating point and the neighborhood of the variations in the neighborhood of the operating point. Whereas, if we delegate through the controller a very small section and that section being only. If variations and the neighborhood of the operating point, then the stress and the strain on the controller will be less and not only that the controller can be quicker. So, you have a stable operating point let us say we are able to take care of the stable operating point as a feed forward component and take care of only the disturbances in the neighborhood of the stable operating point with the help of a controller. Then such a controller will be much simpler and it will also have less strain and it will also have better dynamics.

So, how do we implement such a controller? And generally that would lead to improved control action and I will just in a short while redraw this and show you how to implement that.

(Refer Slide Time: 16:45)



So, this is the controller as we known. First of all I will try to make some space here, so this portion let me take it into the PWM. So, I will erase this portion here. Now think of the open loop case. Now I am going to use the blue color to show the portions which now I am going to introduce the differences. Now in the case of the open loop case at this point we use to give let us say we are studied it is a voltage of around let us say 0 volts or minus 0.1 volt so that you have some 40 percent of duty cycle. Now, this used to give open loop constant fixed duty cycle kind of a drive.

Now let us say we know the input output spec of the converter. Now one have to know the input output spec of the converter, you know the input voltage nominal value and what is the output voltage supposed to be regulated you know and that is why you are setting the reference here. So, output voltage is known what you want input voltage nominal value is known, so the nominal duty cycle would be V naught by V in nominal. So, if I say that the duty cycle d is composed of two parts d plus d hat to components. Now d is coming from V naught by V in nominal value. This d will give you the point the value of the duty cycle at operating point. V hat will be the variation of the duty cycle due to very uncertainties, changes in the load changes in the input voltage and temperature so on.

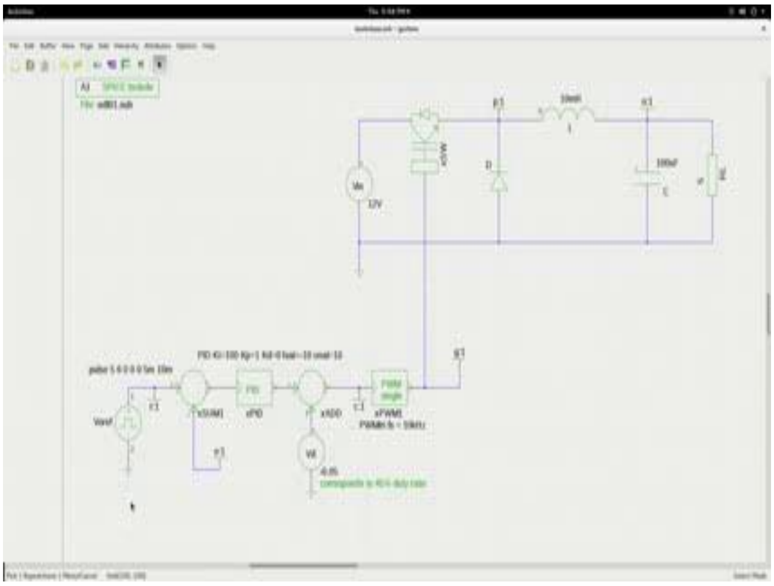
So, let us set this VDC value here to voltage value which should correspond to the nominal operating point duty cycle. Then let the v c that is coming from here correspond to d hat. Then in such a case if I add these two I should get d plus d hat which is the d which is expected by the transistor, so that is exactly what we want to do. So, I will do the following change here, I will introduce a summer, let us say which is plus and it is also plus and to this plus I am introducing a small voltage source or something which gives you a constant and to that you are giving a VDC value which represents the nominal operating point.

So, a voltage output which is coming from this and trying to modulate the PWM should correspond this, will correspond, I am using correspond this is voltage which corresponds to d plus d hat. Now this is what will modulate the triangle within the PWM and generate the data. Now this term is called the feed forward term. So, this is called feed forward term in our control literature. Now what is a controller doing, the job of the controller has been simplified. So, under normal operating point or under normal operation when there is no disturbance then the fix up feed forward term value here is defining the d and then appropriate duty cycle is given and this is suppose to give the output which is (Refer Time: 21:26).

Now, suppose the output is not 5 volts it has deviated from 5 volts due to in the many reasons; it could be due to temperature, it could be due to input output input fluctuation, it could be the output loading and many of these reason. Let us say the output has deviated. Now that deviated value has come in here you would hit this particular summer difference comparator files of that there is a difference between these two there is an error the error will give small value of a control voltage which corresponds to d hat these two will get headed and the voltage are corresponds to d plus d hat and appropriately the control action is taken. And in the steady state when everything is fine and when the output is controlled and regulated and if this output is corresponding exactly to the operating point then the error will able be 0.

So, this controller here is taking care of only the deviations about the nominal operating point and therefore this controller will be faster and have less strain on other. So, that is the concept that we have just introduced to improve this control topology. We shall just see this in simulation also, how it is incorporated and that would give you kind of an alternate controller which has better responses.

(Refer Slide Time: 23:32)



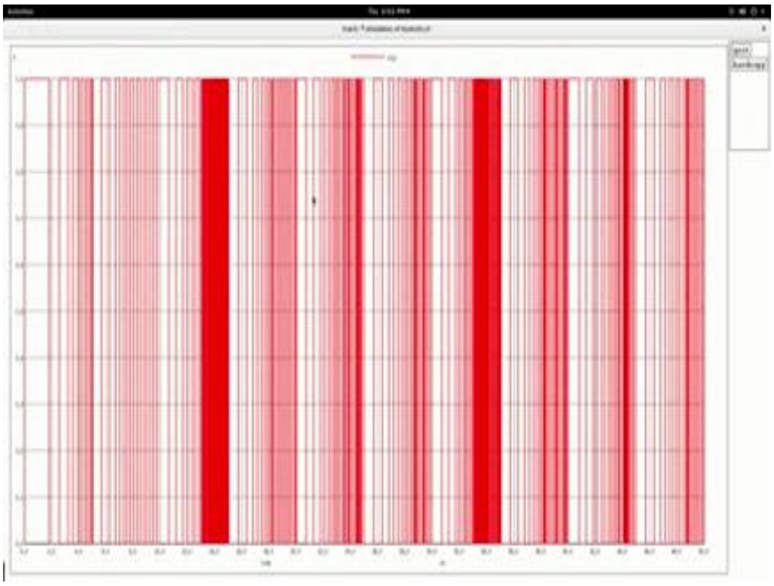
So, let us look at the simulation of this modified controller, I have here the same buck closed circuit and I have done the corresponding modification that I have been discussing with you. Now, here you see that. These of course is the same buck converter circuit we have the PWM block here which is giving you the appropriate duty cycle and on this side you have that reference and then you have the feedback coming from this o label here, o label which is commented at this point, this is the error. Error is passed on to the PID controller and the output of the PID controller corresponds to the deviation in the duty cycle voltage corresponding to hat.

Now, here on the other terminal of the hat ladder you are having the DC voltage and here I give minus 0.05 to correspond to 45 percent duty ratio. So, this is the nominal value or the cooperating point value which I am giving it as a feed forward term and plus this will be this control voltage and this is d plus d hat with even the variation that is coming due to unwanted reasons and is coming from the controller is goes into the PWM and controls the switch. This is this is how we had this feed forward term here. So, I would also like to simulate it and then show it you this will not take not much time, I will put back those numbers which I have put the last time during the simulation of the other buck close circuit.

So, let me say it here. Now recognize that x hat is another new block which I have included PID and x some you saw and x hat is also available in the A block, this is the hat and you can use that and this is the sum which is used here. This is saved and we can go to the folder here. Now here the buck close and dot cir and the edt 0 1 dot sub, I dint show you what is there inside d dt is 0 dot sub you should understand that I have added some things here I have added the t i d is sub circuit. This is again composed of all analog behavioral module elements and these are well defined in Ng spice manual. And then I have made a summer and that is also by the analog behavioral model, I have made a ladder here and that is also Ng spice analog behavior model. I included here a multiplier also, but of course we not using it anywhere which is kept it here for your reference. So, you enforce this.

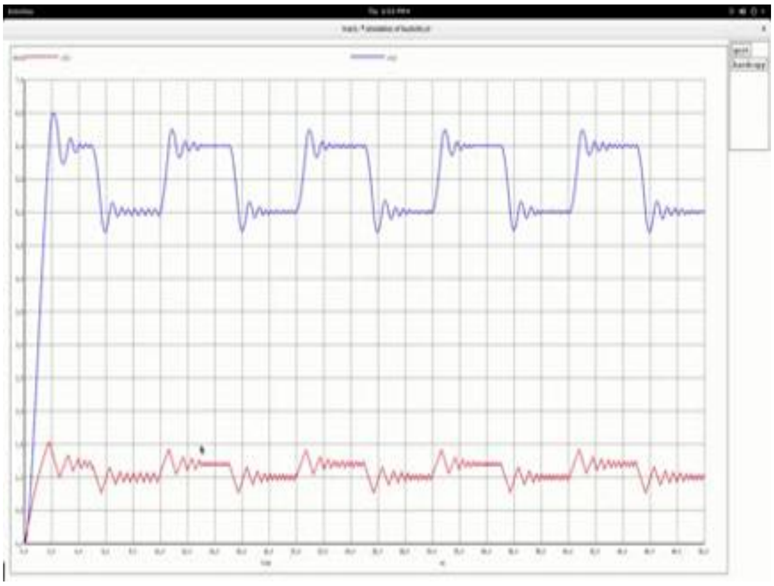
Now let us go to the terminal and let me go to the directory. C d to the directory and let me generate the net list and how the net list generated here you see and Ng spice buck close or cir. Now you are in to the and this part is environment, you run the program and now let me set to the background color to white and set the floor ground color to black. Now block I want to plot as usual the reference and the output. So, you see right it gives you also similar kind of performance measures. You will also see what happens here and what are the gate pulses which are given to the switch? You could probably see plot we give which will give you the data signals.

(Refer Slide Time: 28:19)



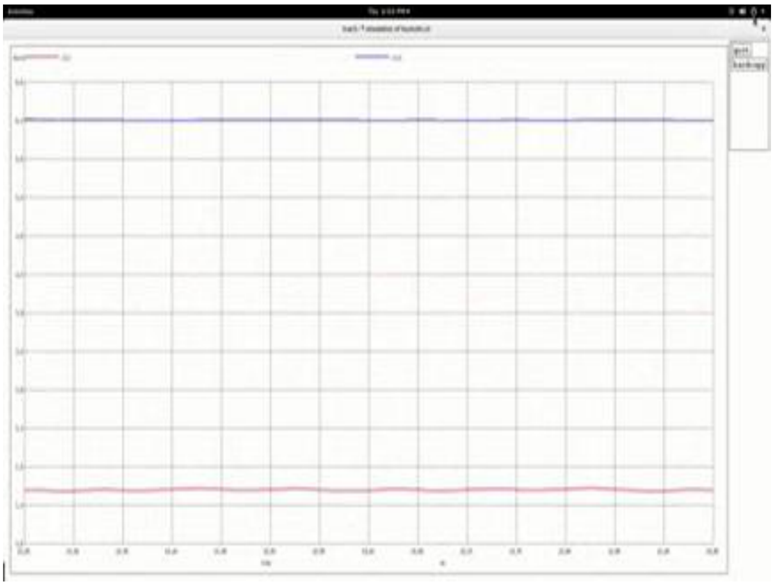
So, this will be the gate pulse which are varying continuously as you see here, and you could also see the inductor current plot i of l along with V naught.

(Refer Slide Time: 28:43)



So, you see that because V naught is no longer constant you see that the induct current is also having lot of variations, but you could see probably in this time span where it is constant it would It will be like what we expect if I increase the amplitude.

(Refer Slide Time: 29:03)



You see this is what we would like expect when it is constant. So, you play around with the wave forms and the values and if you should be trying to on a port inside into this whole close loop system.