Control and Tuning Methods in Switched Mode Power Converters
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Module - 09
Large-signal Model and Nonlinear Control
Lecture - 41
Dynamics of SMPCS and Overview of Model-Based Nonlinear Control

Welcome this is lecture number 41; in this lecture, we are going to talk about Dynamics of Switch Mode Power Converter an Overview of Model-Based non-linear Control.

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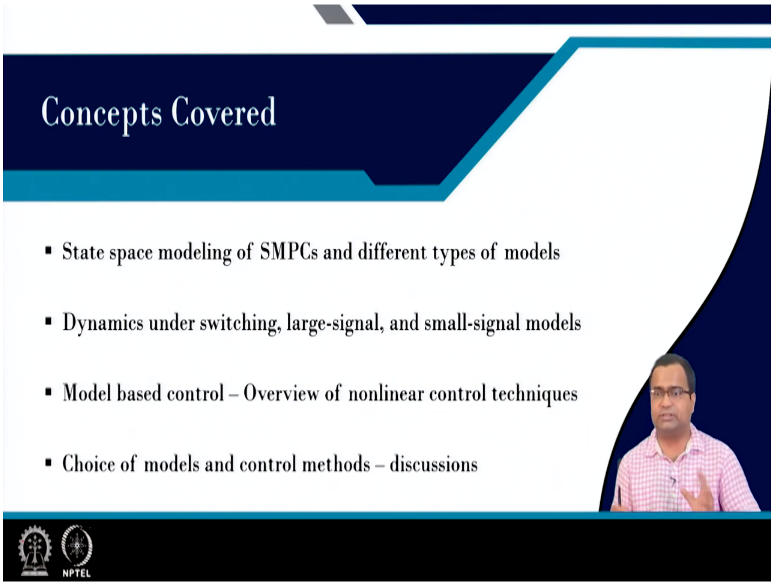

So, first we will talk about state space modeling of switch mode power converter and different types of model under state space modeling. Also we will get different types of model. Then we will talk about dynamics under switching large-signal as well as small-signal model.

So, switching model, large-signal model and small-signal model, then we will you know I will talk about the overview of non-linear control which can be; I mean, you know relate which can we can relate the different type of non-linear control based on what type of model we use ok. And then choice of model and control method with some discussion.

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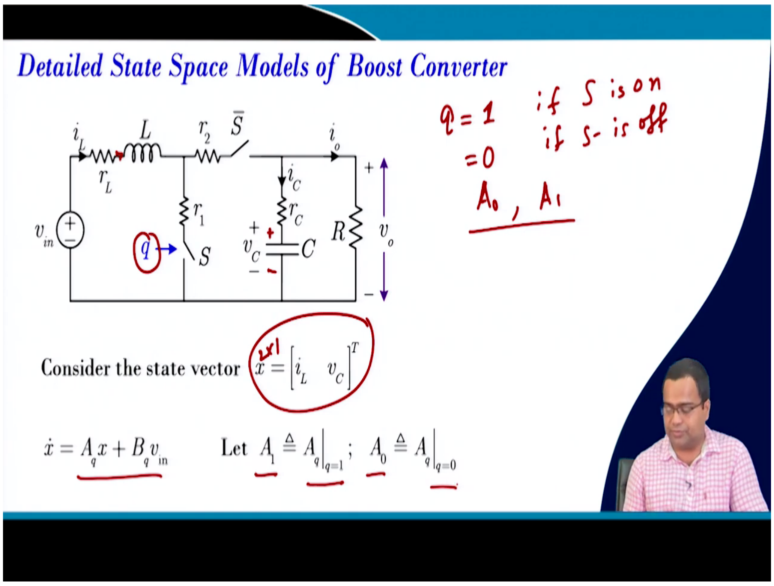

So, first let us consider a boost converter although we are talking about a practical boost converter first. So, we know that the state vector we consider generally, the current through the inductor we generally consider and the voltage across capacitor this we are taking at the state vector is a 2 cross 1 right it is a 2 cross 1 matrix.

And we want to obtain x dot equal to A q x B q v in. What are A q and B q? Because we have A q variable here right and q can take it can be either 1 if S is on the switch is on right so; that means, if we take S is on it is equal to 0 if S is off right.

So, depending upon the switch state, we will get q 0 or q 1 based on q 0 and q 1. Uou will get A 0, A 1 matrices based on q 0 q 1 value right. We are talking about A 1 when q equal to 1 and A 0 when q equal to 0 right.

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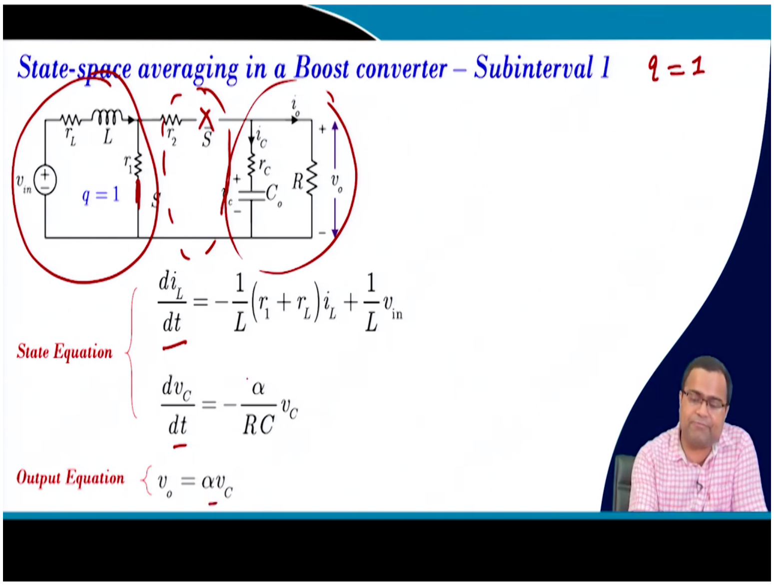

So, sub interval 1 when q equal to 1; it is like in a boost converter when this switch is on and this switch is off right. So, this part does not carry any current. So, you will have a separate circuit rc branch and we have a separate r L circuit right. So, we can write down the state equation, the dynamics of the inductor current and the dynamics of the capacitor voltage can be derived and that we have discussed in sufficient detail.

So, I am not going to repeat because under state space modeling we have discussed this, then we can write the output voltage equation right and this can be in this case the output voltage is simply a function of the capacitor voltage.

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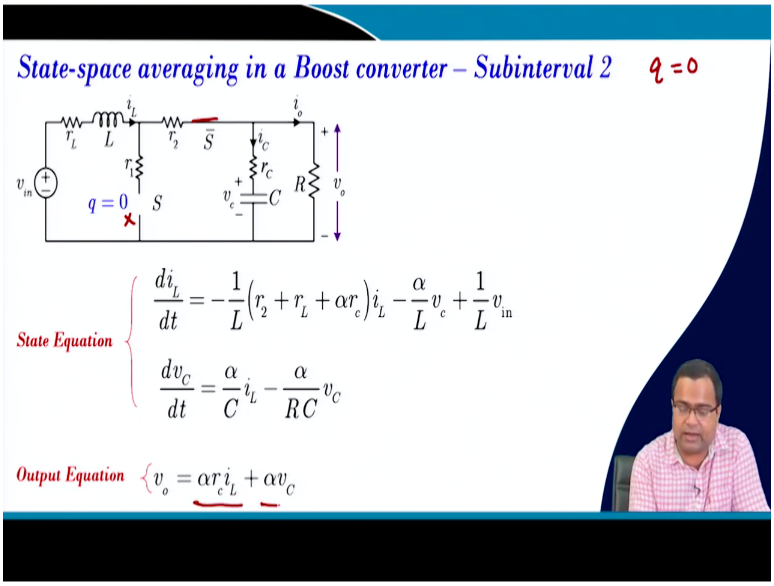

If we go to subinterval 2 when the switch is off, we will get the circuit. So, this path is off, but this is now on right. Again, we can write the state equation inductor current dynamics, capacitor voltage dynamics and we can also write the output equation, which is a function of inductor current and the capacitor voltage.

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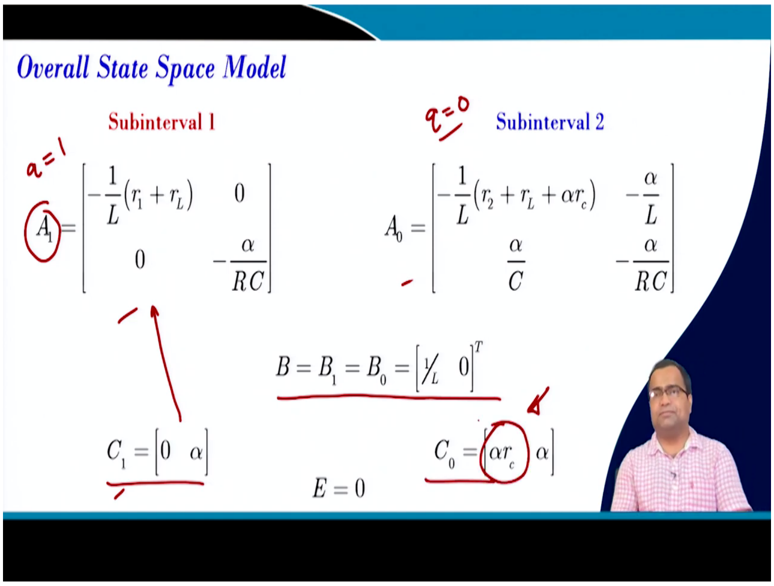

So, overall state space model we already know A 1 when the switch q equal to 1 which is a sub interval 1 and the sub interval 2 when the switch is 0. So, two matrices we found similarly, but interestingly B matrices are common weather switch on and off the B matrix is always the same. This is because the input is always connected except for the discontinuous conduction mode when the inductor is turned off; because it is not carrying any current, then only B matrix will change, but we are talking about continuous conduction mode.

But C 1 matrix are different both A 1 A 2 A 1 A 0 are different C 1 in this case the output is direct function of the capacitor voltage, but in this case the output voltage is a direct function of output voltage as well as a part of the inductor current.

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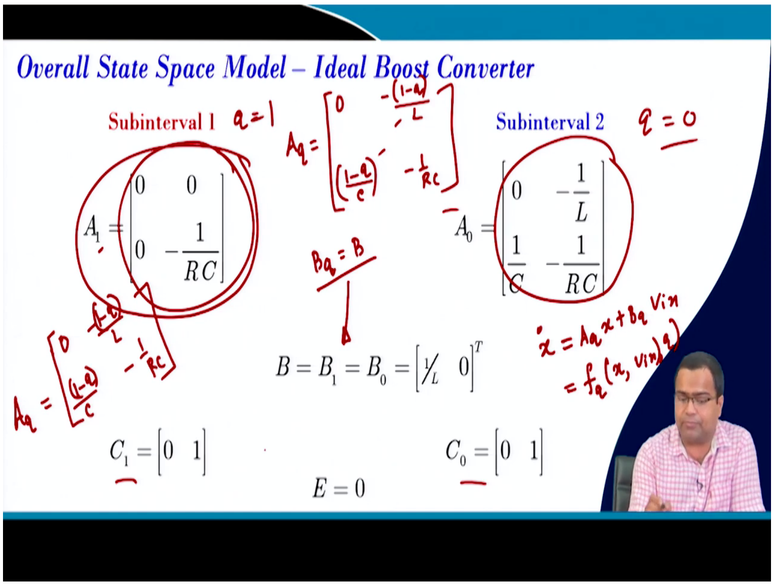

So, now, if you take an ideal buck-boost converter so, A 1 matrix; that means, when the q is 1, we can get A 0 matrix when q equal to 0 we can get ok. So, B 1, B 2 matrix also you can get C 1, C 2, C 0 matrix.

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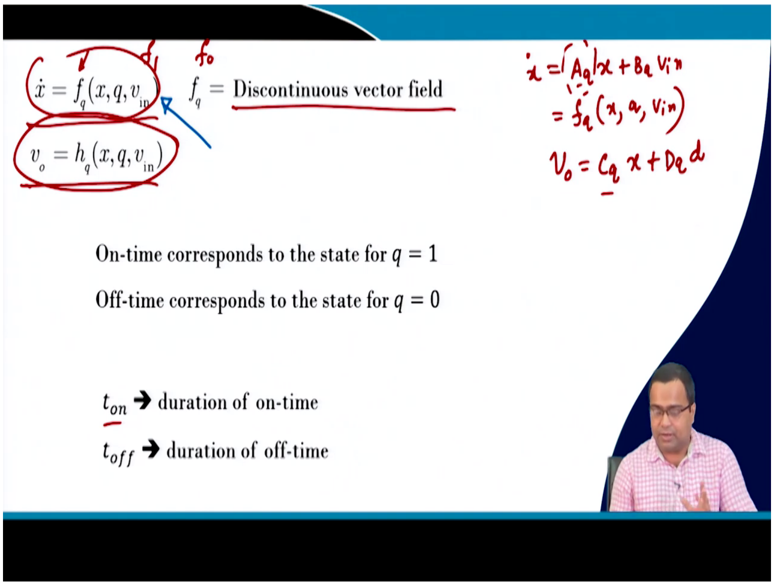

So, now we can combine this into vector form; that means, what is that vector form that we are going to discuss; that means, if we try to write A q what is A q? So, A q in this case is nothing, but if you see this two matrix first term is 0 second term is 1 minus q by L, 1 minus q by C minus 1 by R C ok and B q is simply your B matrix this is your B matrix.

So; that means, A q if we write once again A q if you write neatly 0 minus 1 by q by L 1 by q by C minus 1 by R C; that means, when the q is 1 this is 0, this is 0. So, we are getting A 1 when q is 0 then you are getting this. So, we can get the overall matrix x dot equal to A q x plus B q V in and which we will call as f q function of x v in.

And this is exactly we are writing is a function of ok it is also a function of q sorry also a function of q because q is a switching gate signal which can take either 1 or 0. So, this is a function of this ok; that means, again, we write x dot equal to A q x plus B q V in since this matrix we have A q function.

So, we can get x, q, v in, but this is a discontinuous vector field because A q matrix is discontinuous they are totally different structurally when q equal to 1 and q equal to 0 if you go back, you see this matrix and this matrix are fundamentally different. I mean, if you take the rank of the matrix in the position of this element, you cannot relate them right. So, they are structurally different.

Similar as a result of this vector field; that means, if you take f 1 and f 0 they are fundamentally different so, that is why this is a discontinuous vector field at the point of discontinuity when your q changes from 1 to 0 or 0 to 1. Similarly, the output voltage will have a discontinuity because in the output voltage, what is the output voltage expression? We wrote that C q into x plus D q into d or you can say V in whatever. So, C q is a discontinuous matrix and that also C 1 and C 0 are different. So, for an ideal converter, they are fine.

In the ideal converter, the output voltage is not discontinuous it is not discontinuous, but if you go to the practical boost converter, you know we talked about the practical boost converter that C 1 and C 0 are different because this term is causing discontinuity ok.

So, in general, we can think of the vector field where this is a discontinuous. The output can be also discontinuous in general. So, where q equal to 1 is the on state and q equal to 0 is the off state and their duration of on and off is nothing, but t on and t off.

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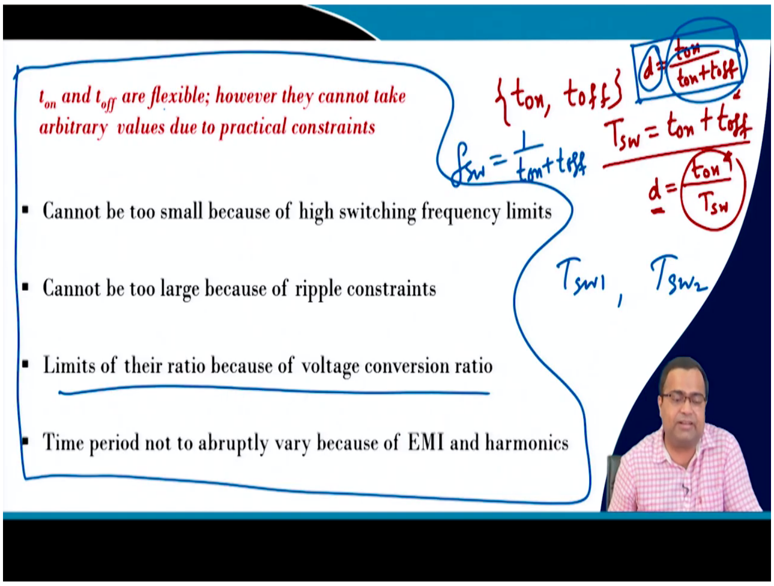

Now, t on and t off are flexible because under steady state, we need to achieve a set of t on t off; that means, t on and t off I can think of it is a set right. So, for s w is nothing, but sum of t on plus t off right. So, suppose if we choose and if duty ratio is the duty ratio if we take t on by T sw.

If you want to maintain the same duty ratio, we can choose a different t on and different t off. So, that the ratio of this will be; that means, what is my d? It is nothing but t on by t on plus t off. So, if you want to maintain the t on plus t off ratio to be same, we still can vary t on and t off to achieve in such a way the ratio will be same.

So; that means, in principle, we can get an infinitely large set of t on t off which will satisfy my steady state requirement. During a transient, the choice of t on t off play a significant role in the control because what is my desired transient response? We want to make it fast we want we want to avoid overshoot undershoot how fast we can achieve. so, that t on t off will come either from a closed loop or in some cases, the designer also uses a time base control.

But whatever it is there it is flexible. I mean, you can flexibly choose t on t off, but there is some practical constant. T on t off cannot be too small, it cannot be too small even though you keep the ratio same because if you decrease t on t off, then time period will decrease and your switching frequency which is 1 by t on plus t off right.

So, if you decrease their value the sum, then the switching frequency is very high. So, there is a limit on the switching frequency other losses will be there you know there are many other practical aspect they cannot be too large because switching frequency will be too low and the ripple will be too large the ratio cannot abruptly change because the duty ratio has a limit.

So, upper limit and lower limit and we have discussed in the steady state loss analysis even if a boost converter we cannot achieve in a practical boost converter voltage gain more than three, it is very difficult because again that the gain will fall. So, there is a similarly for a buck converter step down if you want to achieve a very high step down using a single buck converter with a low duty ratio. There are practical constant and the losses can be very high.

And that is why people try with different architecture to extend the duty ratio either at low or high, whether it is a buck or boost and there are different topologies. So, there is a practical limit on the ratio of the converter as far as the simple buck and boost converters are concerned.

And time period cannot change abruptly; that means, in under one steady state you have one time period, you choose one set of time suddenly for another steady state you choose another set of time period. So, we cannot change abruptly because we have to design input filter. So, we need to achieve certain desired time period.

So, these are the constraint that are imposed by the practical converter which will limit the choice of t on t off during transient we cannot have even very large t on t off that can result in very high current overshoots and so on. So, it can damage the devices.

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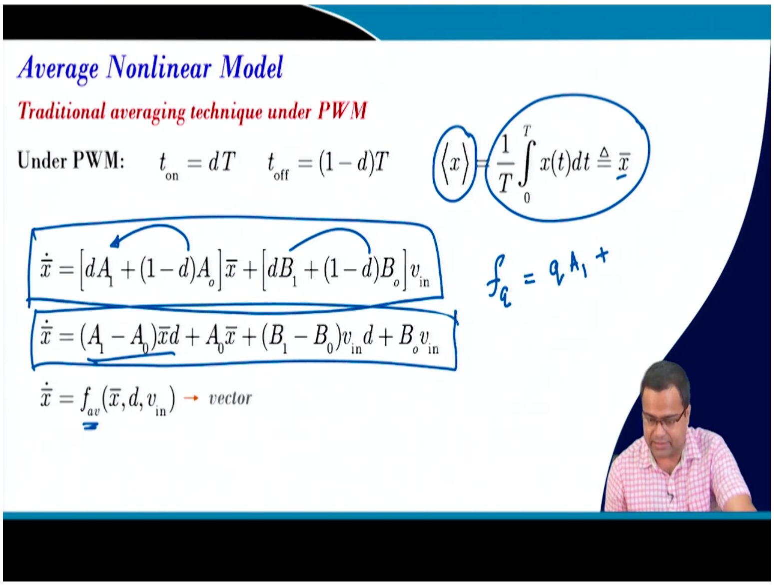

So, now before you go for the average non-linear model; that means, whatever we discuss is the t on t off. They are basically sorry if we take a standard pulse width modulation; that means, ok. So, if you consider our this one is a discontinuous vector field which includes switching dynamics.

Now we are talking about the average dynamics and we have discussed lot of average model, state space averaging, circuit averaging where we have considered the average quantity of anything over a time period right and we denoted this as a x bar it can be inductor current, it can be output voltage state variable right. So, we can write the dynamics of the DC-DC converter, particularly the average dynamics in terms of this is a standard for PWM.

Then we can separate out A 1 A 0 and then from here itself you can separate out you take d part here d part here. So, A 1 minus A 0 into d x then you can separate out and this whole thing we can write this whole thing we can write as a vector now this is average dynamics.

Now interestingly if we consider f q which was what was that? f q was a discontinuous vector; that means, we have considered q into A 1 plus you know if we go back if you recall our a matrix sorry if we consider our a matrix it was nothing but A q into x plus B q into v in.

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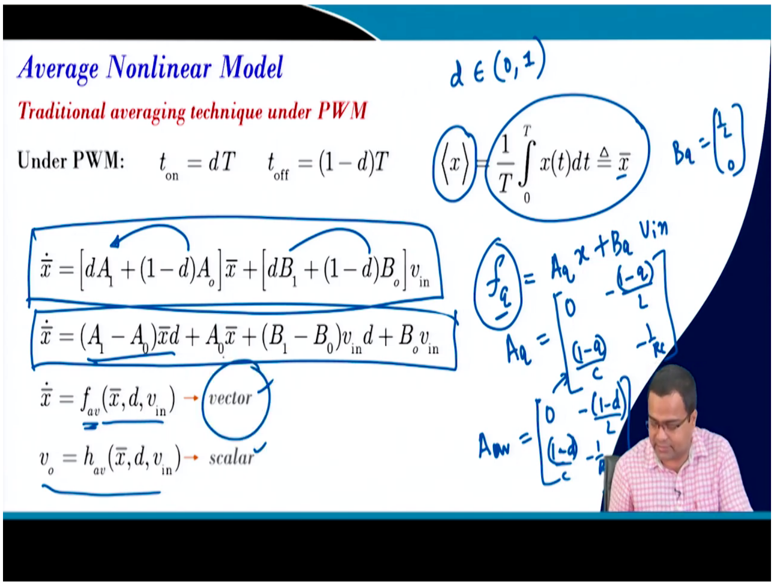

And what was A q for an ideal boost converter? 0 minus 1 by q by L, 1 minus q by C minus 1 by R C and what was B q? It was nothing, but 1 by L 0. So, there is no dependency of q.

So, this f q is a function of q and is a discontinuous function. So, this is also a vector, but it is a discontinuous vector, but after you apply averaging; that means, you are averaging over a cycle, then this discontinuous q is replaced by duty ratio d; that means, I can say A average is nothing but 0 1 minus d L, 1 minus d C 1 by R C right.

So, this is our vector field where q is replaced by d where d basically a continuous variable which can take the value typically in the open interval between 0 to 1 because if you set it is 0 or 1 then again we are talking about saturation duty ratio saturation.

So, in general, if you do not consider duty ratio saturation, it is the open interval between 0 to 1. So, this is a vector. Similarly, we can write the expression of output voltage and, though this is a scalar, this is a vector.

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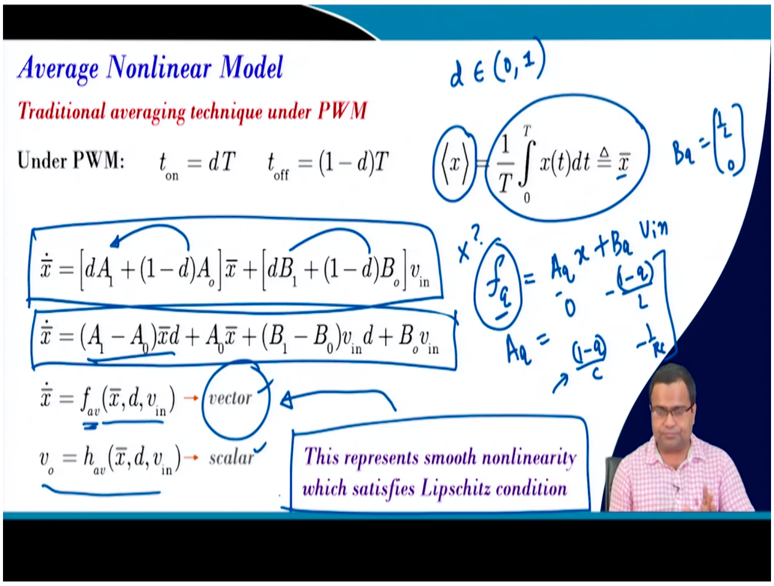

But this is a smooth vector. So, this is a smooth vector and where it satisfies what is called Lipchitz continuity so, that we can apply Taylor series linearization. We cannot apply Taylor series here because it is a nonsmooth vector field and discontinuous vector field due to the discontinuous control input.

But when you apply averaging technique now, it becomes a continuously differentiable function and then it satisfies the Lipchitz continuity where we can apply our traditional way of terror series or other control technique where the continuous vector field or the smooth vector fields are used.

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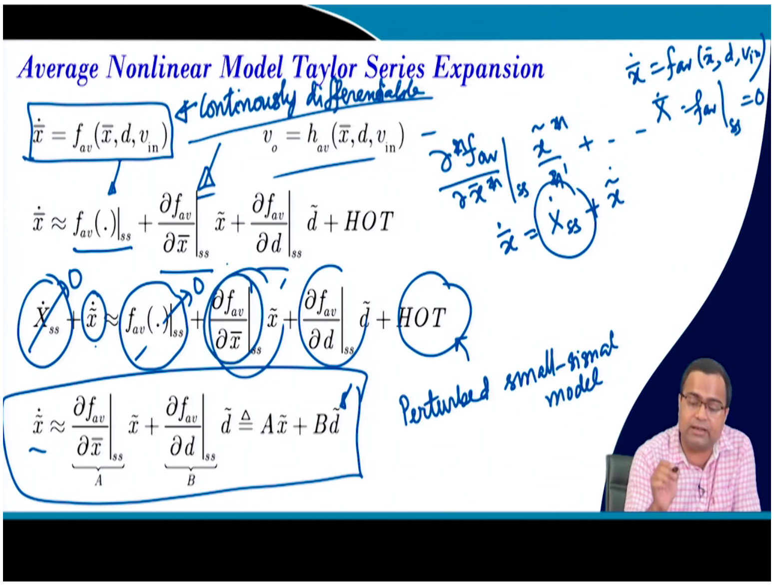

Now, we want to do Taylor series. So, any differential equation in general if it is a non-linear and if it is continuously differentiable continuously or at least at least the first derivative must exist and it will finite and the output voltage also can be written, then we can approximate if it is continuously differentiable then you can approximate using Taylor series.

So, this function can be approximated under at some steady state condition. It is a partial derivative this and higher order term right and what are the higher order term if we take the next higher order term here it will dou 2 f average, dou x 2 steady state x tilde square by factorial 2 and so, on right so, n factorial.

So, you can take you can take these two be in general n this is n this is n this is n. So, you can think of nth term similarly for this term. Now we generally replace that x average can be replaced by the steady state quantity plus a perturb quantity right. Now what is the derivative? We can take differentiate and the steady state derivative is 0.

So, this is 0 and steady state quantity. Again, this term will be 0; that means, we started with x dot equal to f average x d v right. So, under steady state if we take replace all steady state this will also be at steady state right. So, this should also be 0 whole thing 0.

So, this will be 0 this will be 0. So, you will leave it you will leave with this term. This term and higher order and if you ignore the effect of higher order term, then this can be approximated and this will look like a linear system model x dot equal to a x plus B u where e u is nothing, but the duty ratio here is the control variable ok.

And this is the perturb model remember perturb called small-signal model. Why? Because we are ignoring the effect due to the higher order term and if you take large-signal mode, large variation, this term will come into picture your model will drastically deviate and that we have discussed.

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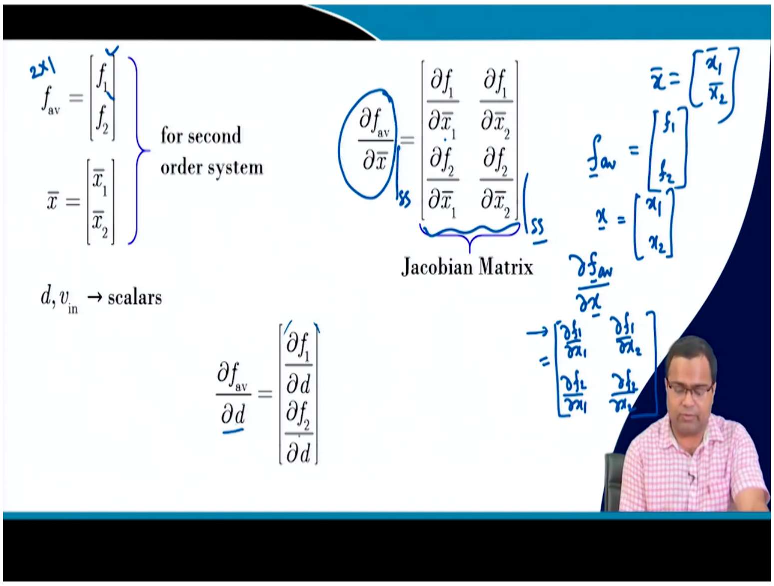

So, we can take the vector. How can you find this quantity dou f v; that means, f f a v has two component it is a vector. It is 2 cross 1 right. So, if you take it is 2 cross 1. So, it has 2 component f 1 f 2. Those are scalar and similarly we have x which will also have two component x 1 bar x 2 bar right.

Now how can we obtain x 2 bar second order system thus these are scalar. So, how to get this one? This is called Jacobian where dou f 1 dou x 1 dou f 2; that means, if I take a function f a v which is let us say f 1, f 2 initially you consider.

And I take another vector which is consists of x 1, x 2 for example. This is a vector, and I want to get this vector partial derivative with this vector. This can be written as the first term dou f 1 dou x 1, dou f 1 dou x 2; that means, in this line f 1 should be there in the numerator dou f 2 dou x 1 dou f 2 dou x 2.

So, this is exactly what we got, and this is called Jacobian matrix, ok. So, you can find out this Jacobian matrix at some steady state point if we want to find you have to find this value. Now, if it is a scalar, if you differentiate, then it is very simple: just dou f 1 dou dou d dou f 2 dou d.

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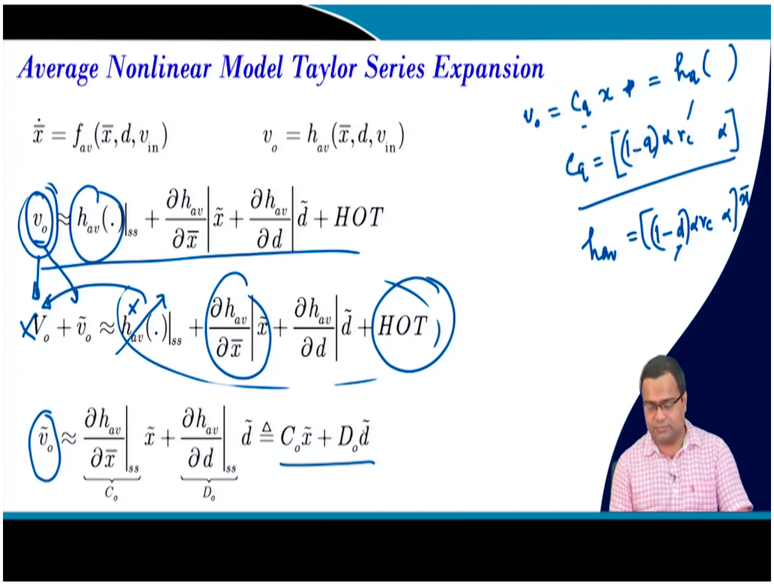

So, using that we can obtain the Taylor series. Next output voltage, which also we saw in boost converter, the C equivalent matrix C q so; that means we got v 0 was C q x plus you know something into in this case there was no other term. So, it was fine. So, this C equivalent what was C q? We got that it was 1 minus q into alpha r C into alpha.

That means, when q equal to 1 it has a different value is a for a practical converter, q equal to 0 it is different. So, this function can also be different and that my that is why in a boost converter when you consider esr this is due to the esr, there will be a discrete jump in the output voltage at every switching instant and this discontinuity is coming due to the switching event.

So, then we can again write the Taylor series, but here we are talking about the average quantity. This is the average; that means, this we write like h q, but when you take average when we write this quantity is replaced by 1 minus d alpha r c alpha into x average.

So, there now there is no discontinuity because duty ratio is a continuous variable again we can write Taylor series and again output voltage can be replaced by steady state quantity and the perturb quantity, again you can expand in terms of Taylor series and now this steady state quantity is equal to this steady state quantity.

So, you can cancel these two terms from both sides. Then what is left? If you ignore the higher order term, then you will get that output perturbation. The ac excitation is nothing, but this term into x m and this is exactly what C 0 and D 0; that means, the output voltage perturbation can be a function of perturbation of the state and can also be a function of perturbation of the duty ratio ok.

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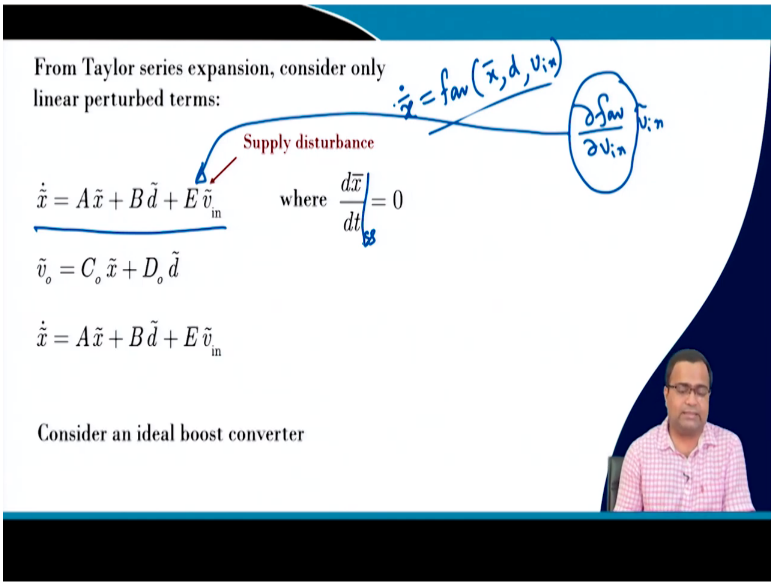

So, now we have considered the perturbation. In fact, we can also consider input voltage perturbation which you have not considered, but you can follow the same process right that means, we can follow that we can obtain that x average dot in terms of f average dot we have considered only duty ratio but you can also write V in and again what you will write?

You have to add consider another term dou v f by dou v in into v in tilde. That term we have to consider and this particular term if you compute at steady state this will give you the equivalent matrix E matrix supply disturbance. So, now average quantity if you set 0. So, this could be at steady state. At steady state it is 0. So, we can get this perturb model and we can take an ideal boost converter.

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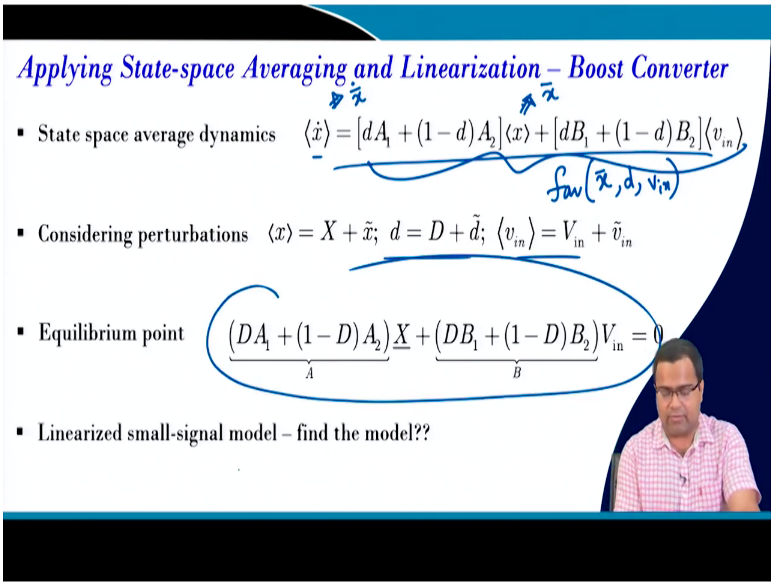

So, now, we want to consider linearization; that means you take x perturbation average dynamics, which we call this whole right-hand side. We call as a f average, which is a function of x average. We also replace with this quantity right here also you can write x average. So, this is a function of average quantity d and v in. We can now consider the perturbation and we can separate out the steady state quantity and we can get the linear. So, find the model now we consider a boost converter.

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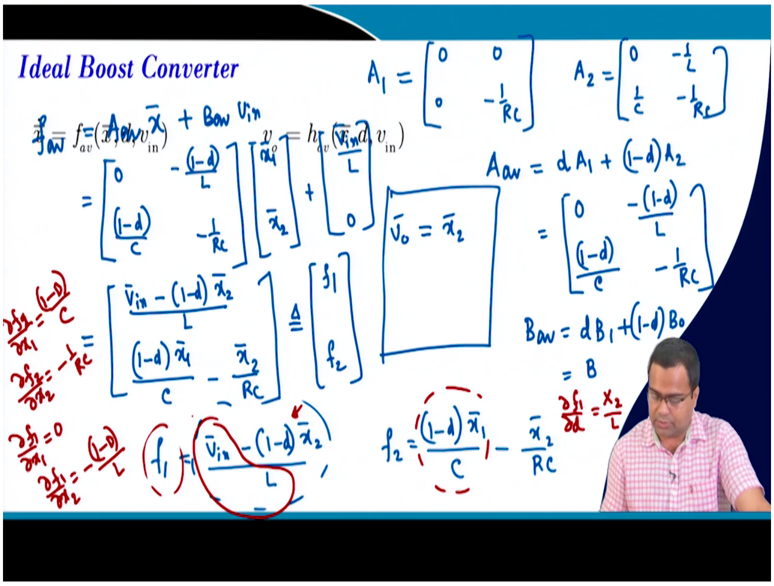

So, in an ideal boost converter what is our A 1 that we consider it is like a 0 0 0 minus 1 by R C what is our A 2? Our A 2 was 0 minus 1 by L, 1 by C minus 1 by R C then what is our A average? An average is nothing, but d into A 1 plus 1 minus d into A 2 and which we can write 0 minus 1 by d L ok 1 minus d c minus 1 by R C correct.

Then what is my and what is my B average? Again d into B 1 plus 1 minus d into B 0 since these two matrix are same. So, it is simply B which is either B 1 or B 0 whatever they are all equal.

So, f average in a boost converter is nothing, but it is nothing, but A average into x plus B average into V in what is that? This is nothing but. So, if we consider this 0 1 minus d by L, 1 minus d by C, 1 by R C into x 1 x 2 plus V in average by L 0 So, which can be written as if you write it down.

So, we will get V in average minus 1 minus d into x 2 average by L and this side what you can write? 1 minus d x 1 by C minus x 2 by R C so; that means, if I write in terms of f 1 f 2 then what is my f 1? It is V in average minus 1 minus d into x 2 average by L and f 2 is 1 minus d x 1 average by C minus x 2 average by R C ok.

Now, we want to get the Jacobian matrix; that means, what we want to get obtain ok. So, we obtain this. What is the output voltage expression? So, if you take a space here in output voltage since we are taking ideal boost converter. So, it is simply nothing, but your x 2 average. So, there is no discontinuity, there is no problem.

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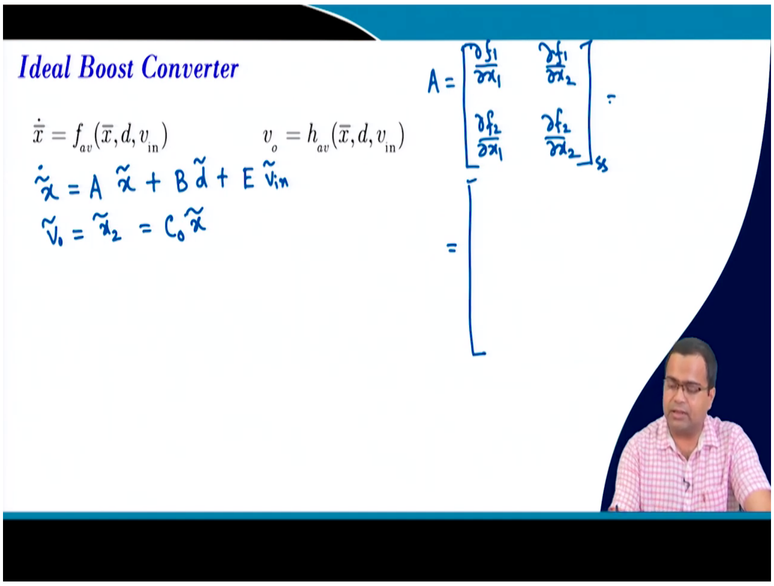

Now, we are. So, what I am trying to get? I want to get x tilde of a boost converter is A into x tilde plus B into d tilde and if you want to achieve the input voltage perturbation d tilde ok and then V 0 tilde is simply your x 2 tilde so; that means your C matrix is I mean it is already there.

So, what is your C matrix? That means, we can get C into C 0 into x tilde now we want to find out what is my A? It is the Jacobian dou f 1 dou x 1 dou f 1 dou x 2 dou f 2 dou x 1 dou f 2 dou x 2 computed at steady state. Now we want to find out what are these. Let us find out what is this quantity if you go back ok. So, what is my f 1?

So, you can say this is my f 1e; that means, if I differentiate with respect to x 1 it will be 0 right. So, we will we will get 0; that means, my dou f 1 dou x 1 is simply 0 what is my dou f 1 dou x 2? Dou f 1 dou x 2 is simply minus 1 by d correct what is my dou f 1 sorry dou f 2 dou x 1? So, it will be 1 minus D by C this is coming from here and what is my dou f 2 dou x 2? It is simply minus 1 by R C correct. So, what we are going to do get?

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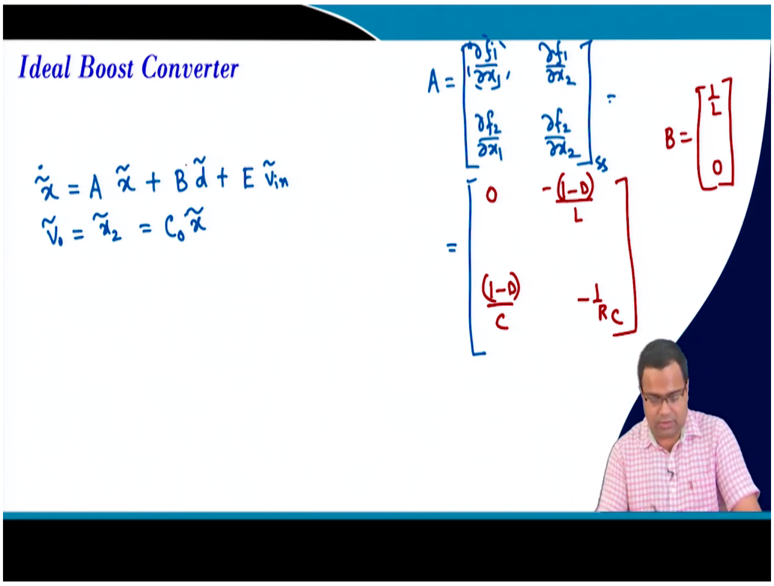

So, the first term will be 0, second term will be minus 1 by D into L, third term will be 1 minus D by C minus 1 by R C? This is my A matrix B matrix since it is common. So, it will be simply 1 by L because B matrix is common right what is B matrix ok? No here it is not it is not that B matrix it is the B matrix sorry.

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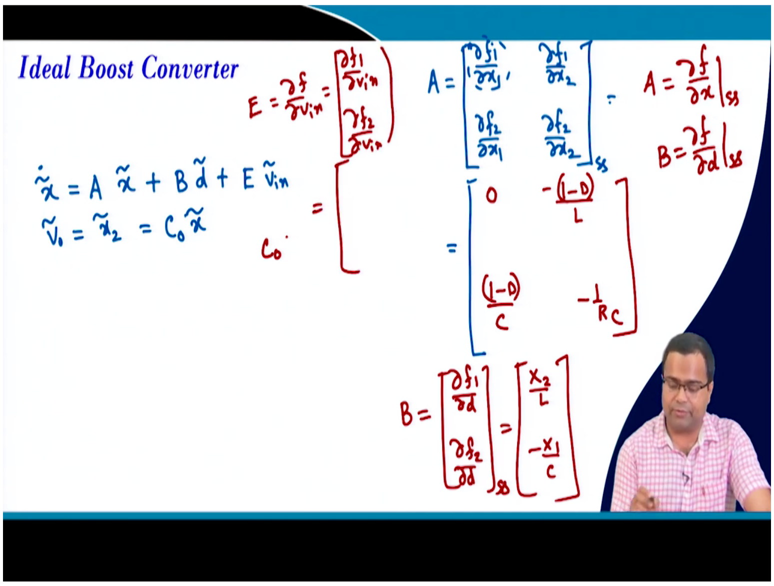

So, here what is A matrix here A matrix is dou f dou x computed steady state similarly B matrix dou f dou d computed at s. So, now, that means, B matrix will consist of dou f 1 dou d dou f 2 dou d at steady state and what is this let us find out. So, under steady state. Again, if you take this function. That means, what is my dou f 1 dou d?

So, if we take this particular term, it will be x 2 steady state by L correct positive sign. So, it is a x 2 by L dou f 1 dou d dou f 2 dou d it is minus x 1 by C minus x 1 by C. So, x 2 is the steady state value of the capacitor current voltage and x 1 is the steady state value of the inductor current.

What is C 0 and what is E? E what is E? E is nothing, but dou f dou V in right which is nothing, but dou f 1 dou V in dou f 2 dou V in and if you go back dou f 1 dou V in we can get it from here, but there is no V in term in the f 2.

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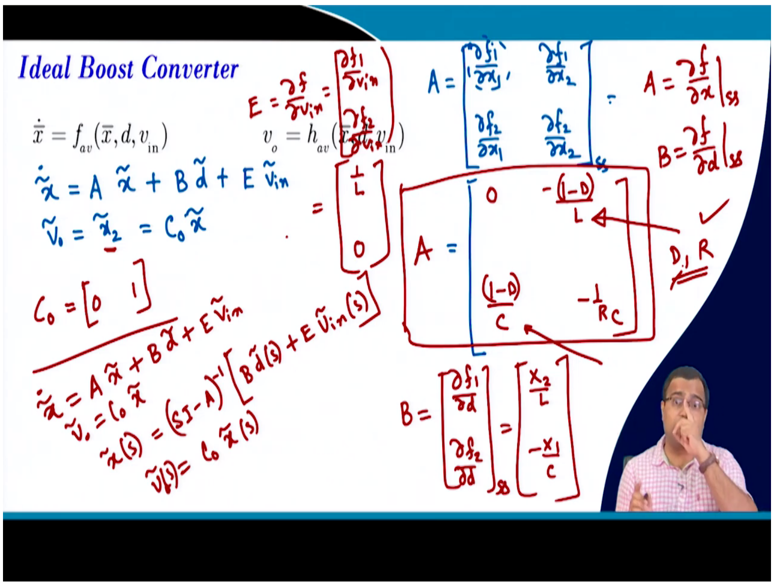

So, this will be straightaway 0 this is straight 1 by L right. So, you got it E matrix. What is C 0 matrix? C 0 is nothing but what? It is very simple because here it is 0 1 that is it. So, you got all these matrices and you can get a different type of transfer function right. So, you can get it ok.

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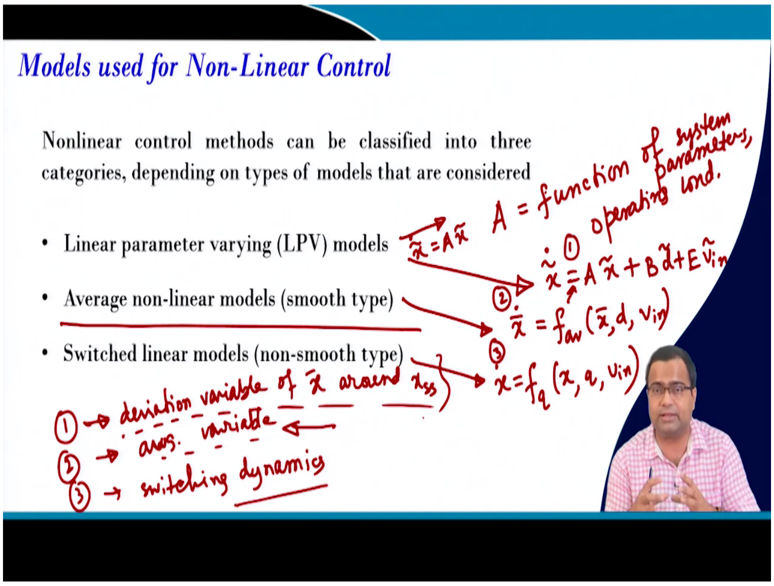

Now once you have that x tilde dot is equal to for any trans any converter x tilde plus B into d tilde plus E into V in tilde and V 0 tilde is C 0 into x tilde. I can take Laplace transform x s will be S I you can minus A inverse B into d tilde S plus E into V in tilde S right and then V 0 tilde S is simply C 0 into x 0.

So, then we can obtain a different type of transfer function from here. So, finally, the model used for non-linear control we have three types of model; linear parameter varying model because if we go to the A matrix for this boost converter, what I found this is my A matrix right.

So, A matrix depends on the value of the inductor which is generally fixed once the converter is designed unless there is a variation of inductance when you operate close to the saturation point. Otherwise, they are more or less closely like you know more or less constant capacitor is also more or less constant, but D and R they vary. This is the operating point; that means, duty ratio will vary based on the input output voltage relationship.

Even for practical converter, we saw that if there is a load transient R will definitely vary and in addition to that there will be a variation in duty ratio because the practical duty ratio will be slightly different from ideal. So, in order to anticipate that additional drop due to the finite dc output impedance, you need to you know increase.

Suppose, if there is a load step of transient, your effective duty ratio has to be slightly higher than the ideal duty ratio to get the desired output voltage so that the duty ratio will also vary with the load current as well ok.

So; that means, that is why this is called linear parameter varying model where A matrix is a function it is a function of system parameter system parameters operating condition. Now the system parameters are generally L and C; the operating conditions is the load resistance and the duty ratio because that changes with the load current change because those are the external parameters right.

In the change in input voltage right we also discuss average non-linear model where here we directly obtain x tilde dot is equal to A into x tilde ok let me write it down here we got x tilde equal to A into x tilde plus B into d tilde plus E into V in tilde.

In this case, we got x dot average is nothing, but f average x tilde and there is a duty ratio and input voltage. So, the difference between these two this is this one the first one and the second one and what is the third one first let us. So, third one is x dot which is the actual switching converter with q v in.

So, there are certain perspective the number 1 input. It is only the deviation variable deviation variable is considered. Around deviation variable of what deviation variable of deviation variable of x average around x steady state. The model 2 it considers the average variable average quantity and model 3 considers switching dynamics.

So, in an effect the third one is the most accurate one, but it is one of the most complex one because you are switching dynamics second one is a moderate is reasonably good because you can vary the duty ratio you know except for the saturation limit we can widely vary and this model can capture reasonably,.

But the first 1one is the simplest one, but it cannot capture for a duty ratio variation during transient. Thus variation should be very very small, but this we can apply our linear tools right because and here this is a linear parameter varying model. So, we can design compensator using our classical linear control theory toolbox.

But model limit is a concern. This one is better than the first one, but it is a non-linear model smooth non-linear model. Here we can apply the traditional like a lyapunov base passivity based control feedback linearization ok different type of control which may be better than the linear control, but if we can tune the linear control properly then you can get some close behaviour at least somewhat better.

But this may be better you can get better transient response, but the switching dynamics is the one which takes care of the switching behaviour and it can get the performance the fastest performance which cannot be achieved either of these two technique using either these two models I would say. So, the types of non-linear model control depends on the model.

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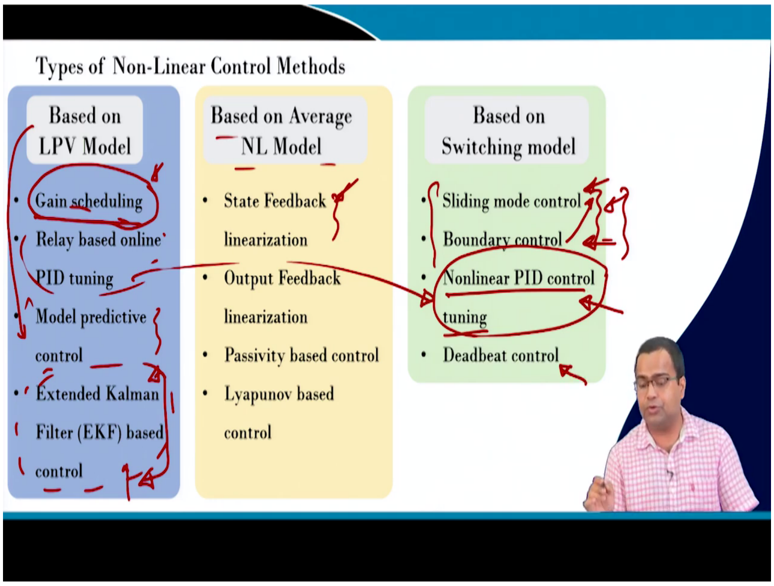

So, first if you take linear parameter varying model, then we will take the average non-linear model and the switching model. So, gain scheduling is a very popular technique. In fact, we have discussed the PID controller tuning using relay based tuning Jiggler Nicole.

So, the gain scheduling means we have talked about analytical controller design, right? In voltage mode, current mode control, we have taken the small-signal model we have derived analytical way of compensator design to achieve certain crossover frequency, phase margin. We can tune the parameters in real time to get reasonably fast transient for a wide range of operating condition.

Another is the relay based tuning, but this is something like an offline tuning and you have to put a kind of lookup table and update the parameter. Whereas, the relay based tuning and something similar they use online tuning. That means, you can during the transient in the real time, you can create an event where you can inject like you know you can insert a on/off non-linearity and using a control oscillation you can get the PID controller tuning parameter and then you can plug in to get the transient response,.

But again, all these are somewhat complex method the model predictive control. Once you get the linearized model, you can use a model predictive control for optimization. But the model predictive control can also be used in switching dynamics as well as average dynamics ok, but you know in many papers actually the model predictive controls are used because as if we are getting a linear model.

So, you can apply you can obtain the discrete time model of the linear model and you can obtain model predictive control for further optimization because you can use the kind of state space based control technique and you can optimize by creating some performance index. You can also use the extended Kalman filter based method because you know if you consider the stochastic system with unmodeled dynamics as well as the process, you know the measurement noise.

So, then you can use the extended Kalman filter concept, but this technique again you can use you can linearize the system around some operating condition and then apply Kalman filter right. So, its an extended Kalman filter; that means, linearize around it consider the non-linear average model, but you need to linearize.

So, the model based I know average model you can use a state feedback linearization full state feedback you can use output feedback linearization you can use a passivity based control you can use Lyapunov based control and there are many other control techniques are there.

So, I am just touching these two. I will discuss these two techniques in the subsequent lecture. Now in switching control you can use directly using switching like a sliding mode control and that also we are going to discuss in the subsequent lecture. The boundary control is a class of switching, like a sliding mode control where we need to design the switching surface and the switching surface can be the target trajectory itself.

That means we can we want to design the switching surface in a way so, that it will be the target trajectory itself. So, there will be no sliding motion I mean the sliding motion itself it will reach to the steady state then we will also talk about the PID control or non-linear tuning and this is one of the important topic which will be much simpler. You can still use PID control.

But we can incorporate the ripple parameter to get the performance, which can be achieved by very fast like a sophisticated non-linear control. But here we can simply use the same you know PWM controller because all this technique require like a variable frequency operation or something like you know the structure the surface of the controller can be higher order.

So, it can require more resources and most of the time we interface with this kind of control with a PWM control under steady state. So, they combine a non-linear and linear control to achieve the desired response. But here what we are going to talk about is a single PWM control can achieve the whole performance you do not need to do a separate controller and you can also use the deadbeat control like a time optimal control you can do to achieve fastest response.

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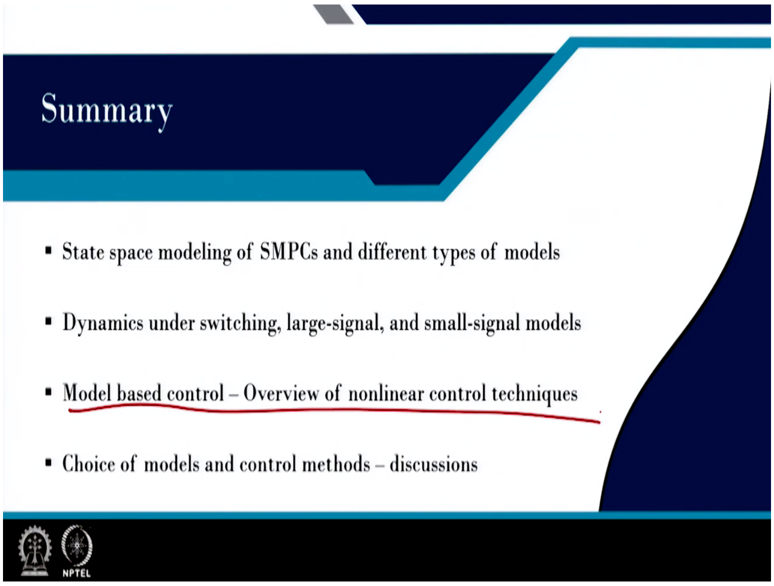

So, with this, I will summarize state space modeling of switch mode power converter. We have discussed, different types of models we have discussed, we have discussed dynamics under switching as well as large-signal small-signal model and we have also given some overview of the non-linear control using different model and we have also discussed that if we want to simplify our control, then we can you start with the simplest you know linear parameter varying model, but we need to update the parameter,.

But still the design is based on small-signal we can do average model non-linear model and we can achieve something better and then we can use non-linear model switching model and we can get now the fastest response and all these we will discuss in the subsequent lecture. So, with this I will finish it here.

Thank you very much.