DC Microgrid and Control System

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Lecture-39
DC Microgrid Stabilization using Nonlinear Techniques

Welcome to our lectures on NPTEL on DC microgrid and control. Today we are going to discuss application of the microgrid with the non-linear control. We have already discussed with our linear control system today we are going to discuss with the nonlinear control. Now our; as we have seen in our previous presentation that once you go for the different kind of control technique you have a different kind of switching stability limits.

But this since if you are taking considerations of the linear model you are averaging and now the stress lot of information is lost. And for this reason we require to reinvestigate the microgrid with the nonlinear control. Now so why nonlinear control.

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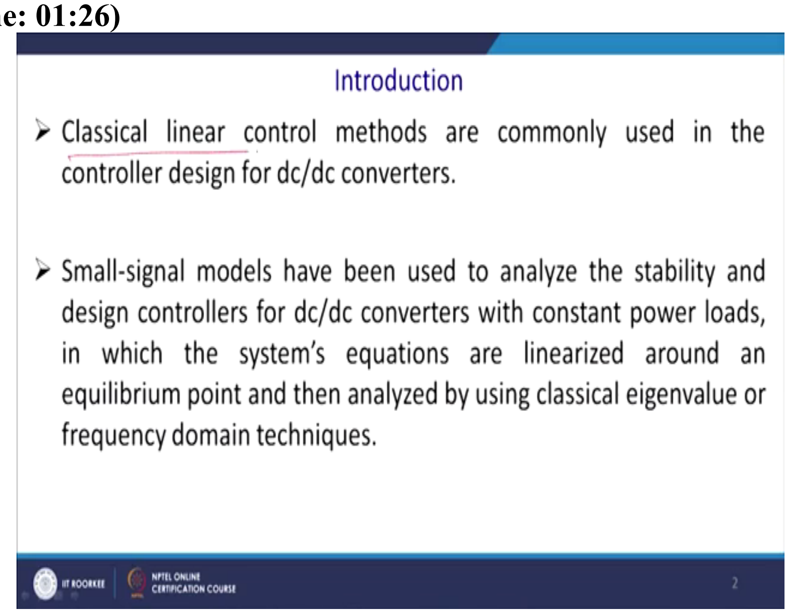

If it is classical or the linear controls methods are commonly used for the DC to DC converter design that we are studying for many more days. But with more knowledge on the non-linear control and the switching technique we have enhance the stability and other performance of this DC to DC converter with the nonlinear control. And thus this nonlinear control strategy can also be applied to our DC microgrid.

Small signal model has been used to analyze for considering the small perturbation in the input and the load disturbance to analyze the stability and design controller for DC to DC converter with constant power load. This is one of the problematic entity CPLDs. In which system equation and when linearize around an equilibrium point and then analyze by the classical eigenvalue and the frequency domain technique.

We have seen that bode plot gain margin phase margin and we have come out to the solution we have applied out and if it is all that control system you have studied in your linear control classes that has been applied here.

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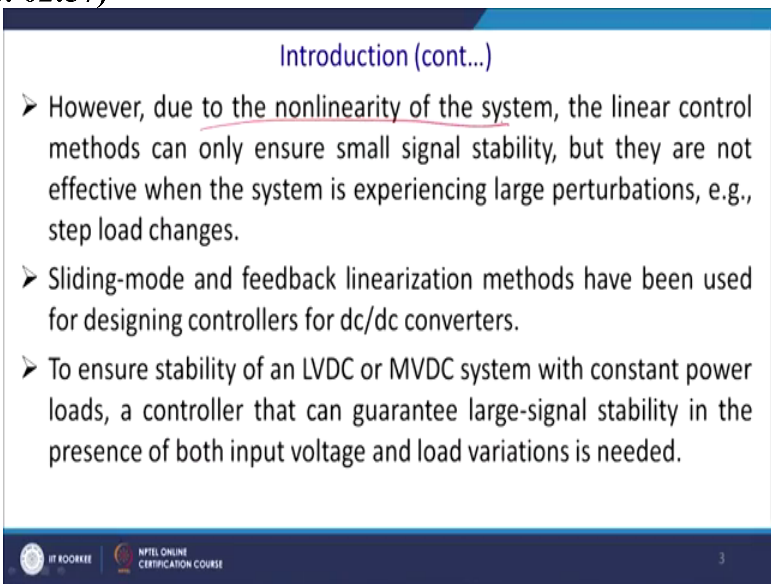

But or, however due to the non-linearity of the system this linear control methods are or can only ensure a small signal stability. So, there is a large change so equilibrium point itself changes and thus you cannot apply a small signal analysis technique analyze the stability with a large change signal. But they are not effective when the system is experiencing the large perturbation for example sudden high load change.

For example all of a sudden irradiations come down drastically clouds comes and you irradiation drastically falls to maybe a 1000 watt to 200 watts or you may have to have all of a sudden fault has occurred you have gone into the your grid connected mode to islanding mode. These are the large change into the system. And one of this solution can be thought up is a sliding mode control or feedback linearization the slide.

But it itself is a big chapter sliding mode control for this is my request those who does not have a knowledge of this linear control strategy of course I can touch upon. And basic a sense that how it can be given how gate can we fit in the DC microgrid and this sliding mode and feedback linearization that itself is a multi rate control that itself is a very chapter by itself, anyway. The sliding mode and the feed mechanism thought has been used for designing controller for the DC to DC controller.

For many days we can find plenty of papers on it and thus this concept can we attributed here also in the microgrid to address this large change. To ensure the stability of this low voltage DC or the medium voltage DC system with constant power loads a controller that can guarantee a large signal stability in the presence of the both input and the output voltage. Input both input voltage and the load variation is stated.

So, linearizations, linearizing a nonlinear plant about an operating point ensure the stability only in the neighbourhood of the equilibrium. So, if there is a large change over so equilibrium point itself changes so all the studies which is applicable in the small signal analysis are null and void. And for this reason we required to go for the nonlinear control and well feedback linearization is a nonlinear control approach where you take the feedback and linearize it use for to compensate the constant power load effect that is the CPLD.

I told you this is one of the very nasty entities in our DC microgrid. Effect in distributed power systems and its effect in a distributed power system like this microgrids, where when in the cut; in a nonlinear feedback is chosen to cancel the nonlinearities introduced in the system due to the presence of this CPLD. Because if you have a constant impedance load that is a linear kind of load. But CPLD essentially is a nonlinear load and it has got a negative resistance.

So, this is something it is a very detrimental in controlling and thus this involves our non-linear coordinate transformation which allows to access the system nor nonlinearities through input channel and thus it try to make the system linear. You have overall system and nonlinear you have a feedback non-linear and thus you try to cancel the non-linearity by the feedback linearization this is the concept.

And so then you can apply your traditional control method or you can apply your non-linear controls.

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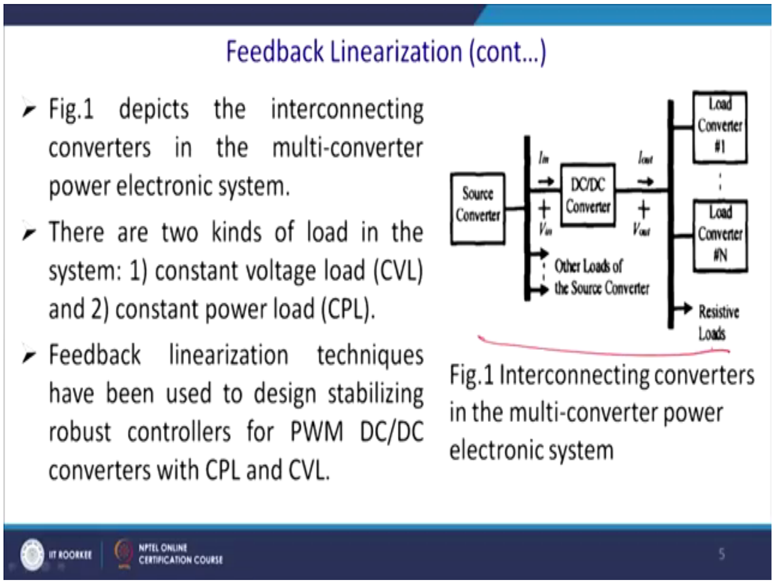

Now let us discuss about this figure 1, interconnecting converters with the multi converters in the multi converter power electronic systems. So, you have a source converter it can be solar MPPT something like that then you may have exchange of the power between the two buses by the bi-directional DC to DC converter. And you have a converter load one it may be the CPL and it all in and this is a resistive load that is the constant impedance kind of loading.

And other load to the source converter and power can be bi-directional here. Let us see that how you can apply nonlinear control in this scheme. Figure 1 depicts the introduct; in the interconnecting convertor in the multi converter power electronics system. There are two kind of load in the system constant voltage load or this is called a CVL. So, it will always try to take a constant load if it is trying to maintain the MPPT voltage or something like that.

Or you need it this voltage required to be fixed and another type is at the constant power load. It will always consume a constant power respective of the voltage with respect to a some amount of range. And within range current will fluctuate. The feedback linearization technique has been used to design stabilizing the robust controller for the; robust means it is insensitive to the change of state. So, that is called robust controller for PWM and DC to DC converter with constant power load or the constant voltage. So let us see that how we can employ it here.

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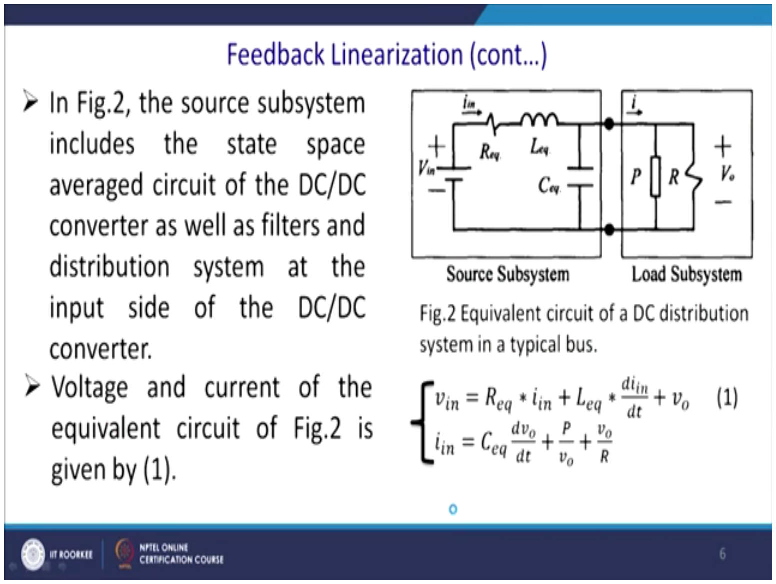

So, we just split it we have done it in a separate way so we have you were you know that this is the input then this is the equivalent resistance has been coupled. Thereafter you have a bit may be you may have a filter to wipe out these high frequencies and thus it can be model this Lq and the Cq thereafter you got a constant power load and you got a resistive load that is a constant impedance load. So, in the figure to the source subsystem includes.

This is the equation the state space average Circuit of DC to DC converter as well as the filter and the distributed system at the input side of the DC to DC converter. So, this is the source subsystems or the input subsystems and this is a load subsystems. The load the voltage and the current of the equivalent circuit of figure 2 is given by the equation 1. So, it is V in equal to R eq into I in + L q di by dt + V 0. Similarly i in equal to C eq V 0 dv 0 dt + P by v0 by R this is the constant power and this is the constant voltage. So, anyway so this will be the current in the system.

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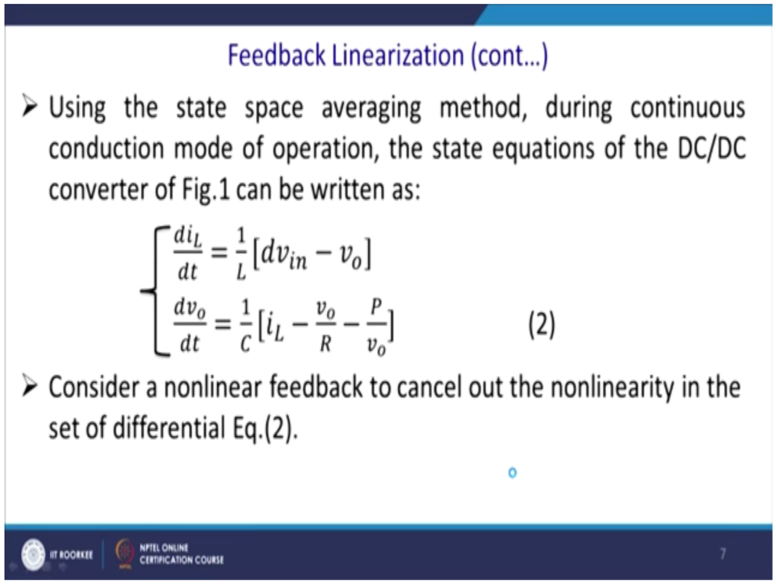

So we can write and we shall do the here feedback linearization using the state space averaging we thought during the continuous conduction mode of operation and please mind it you know all our discussion we have restricted ourselves for a continuous conduction mode. And all those equation is valid for the continuous conduction mode our equations and the strategies everything will change and system will have a degradable performance.

In case of the discontinuous conduction mode that we have not taken into the consideration and it is also a type of the great research when it when it is a light load. And all of a sudden it was I know it was a discontinuous conduction mode or the changeover between the CPLD is to the conduction mode to the discontinuous conduction mode how that control strategy will work. And it is also a great research challenge. So, anyway so we are now dividing this aspects from our present discussion.

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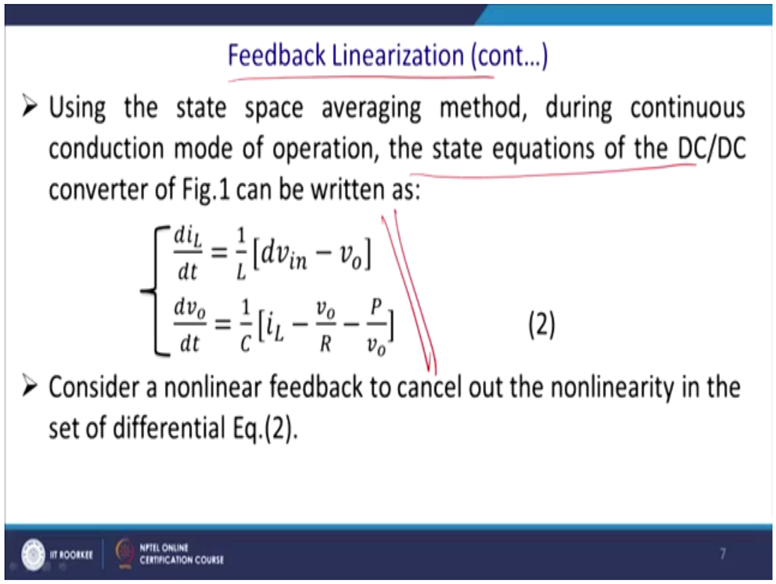

And that is the state equation of the DC to DC converter of the figure is L di dt equal to 1 by L V in - v0 so similarly dv0 by dt equal to 1 by C i L - v0 by R - P by v 0 and now consider a linear feedback to cancel out the non-linearity in the system of equation 2. So, you can see that this will have a non-linearity because you can have a v 0 in denominator as well as the numerator so, how you will tackle it.

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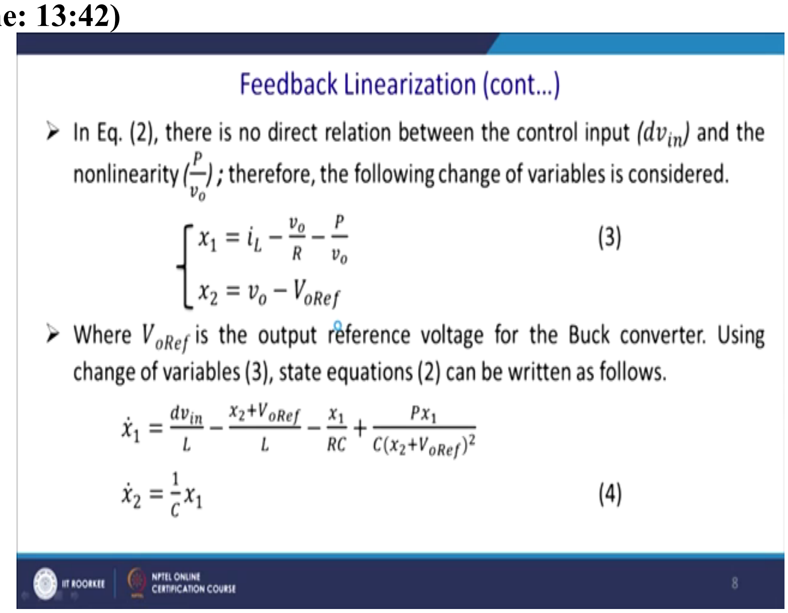

So, for this reason you the equation 2 please refer to this previous equations and the previous slide and there is no relation between the input that is V in and that non-linearity there and the non-linearity that is this CPLD that is P by v 0 therefore the following change of variable is been considered. And thus we can write this one as the state we know that always the current through the inductor and the voltage of the capacitor at the state in a linear system but this state has to be modified to accommodate these control logics.

So, it is iL - v0 by R minus P by v 0 this will be considered as a state and as it is controllable. Similarly this output voltage error of the output voltage is v 0 - v0 ref is considered as a x2 this is another state where v 0 ref or the reference voltage is the output reference voltage of the buck converter or but any DC to DC convertor you will consider here and using the change of variable 3 the state equation 2 can be rewritten as follows.

So X 1 becomes V in by L X 2 + v 0 Ref by L - X 1 by RC by P X 1 by this C into X 2 + V0 ref and X dot equal to 1 by C into X 1. So, that is the; so thus you have your state you have choose in such a way you form a again a state equation so but in a non linear way.

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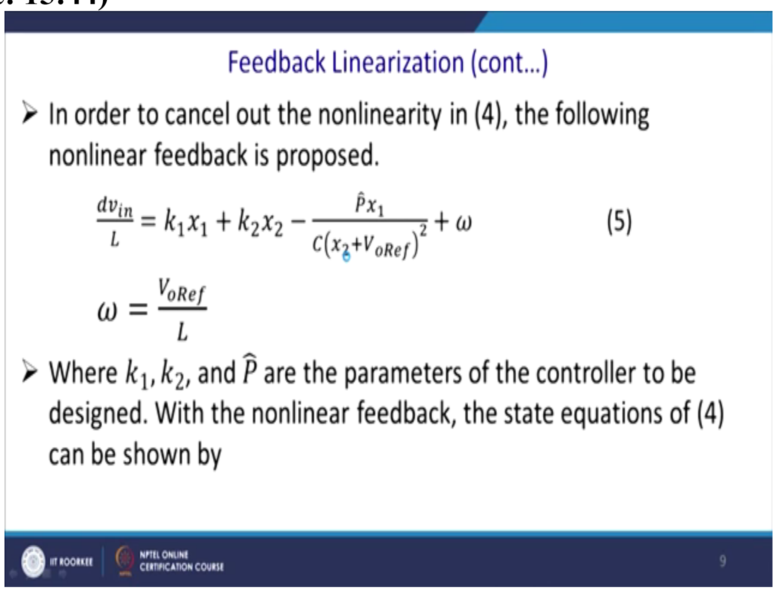

And thus we can rewrite it that V in by L assume that input voltage to be constant then another complexity we will add on what if you take the input voltage to be constant is anyway. So, the; but generally what happened you can write it down in terms of dv in by L that is something is unknown to you it is k 1 into x k 2 into x define k 1 and k 2 little later k 2 into x 2 - at P Delta that is not it any deviation of the power into x 1 into C x 2 + V 0 ref + Omega where Omega is just Omega V 0 by L and where k1 k2 and pre perturbed are the parameter of the controller to be designed so that system becomes controllable.

With an earlier; so what happened with the non linear feedback the state equation 4 can be shown by;

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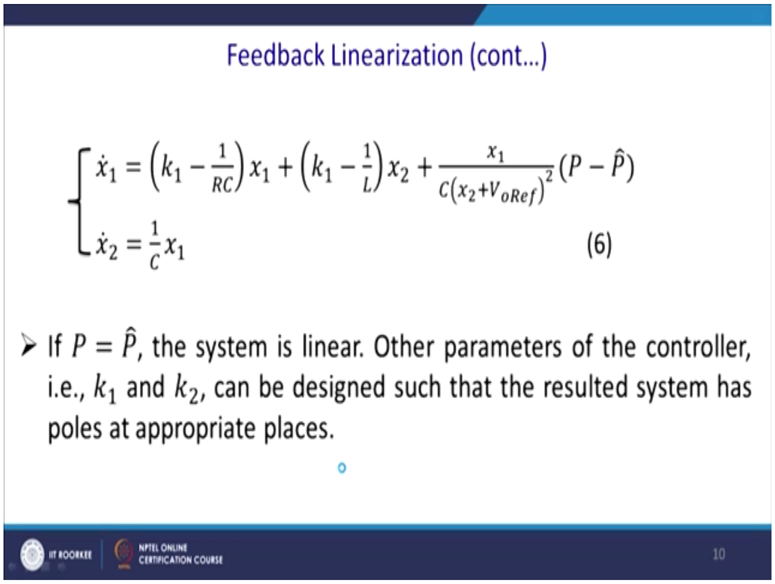

So, this as 6 so this equation can be rewritten in 6, so that is your x equal to k1 - RC into x1 so this one k1 - 1 by L into x 2 into x 1 into this denominator C into x 2 + V 0 Ref square P - P Delta where x dot 2 equal to 1 by c into x 1 and where P equal to p Tilde then the system is linear because this part vanishes and other parameter of the controller we can we require to design properly. So, that this system has an appropriate pole so considering the stability limit of the system.

So thus you can have a writer state space and you can apply you can go to the transfer function then apply to the eigenvalues and find it out the range of the k1 and k2 within that the system will work. So, this is the one of the way of designing by the feedback linearization.

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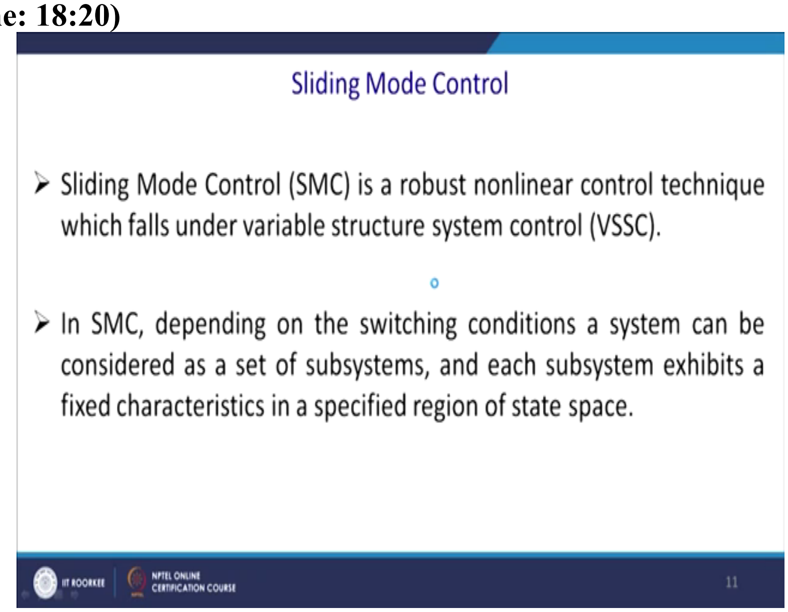

Now let us come to the; another interesting topic so that is called a sliding mode control. Where you will have a chattering, we have to design the stateless. Sliding mode control SMC is a robust nonlinear control system so there is no concept of feedback linearization. It is a hardcore nonlinear control so system is nonlinear and you apply nonlinear. It is not that you design the controller you take the non-linearity you give the feedback that is non-linearity cancels out.

And ultimately you zero down to the conventional linear system but it is a totally you accept that system is nonlinear and give a solution with a non-linearity. And thus we generally say that it is more robust and which is falls under the variable structure control in a short form of VSCC. So, students are required to do the nonlinear courses to understand this subject better. So, anyway we are if you do not have idea of the nonlinear control.

Then you may find that how it will be difficult it is quite difficult to design for this is not it to apply in DC microgrid a sustaining mode control you require to understand this sliding mode control very well. So, anyway those are assuming that you have a preliminary knowledge on the sliding mode control we are studying the discussion. So, this variable structure system control is a is a bigger set within that one of the said is sliding mode control.

The SMC depending on the switching condition a system can be considered and a set of the systems. And such subsystem we can subdivide one system into many subsystem input subsystem output subsystem control your switching subsystem like that. Each subsystem exhibit a fixed characteristics in a specific region of the state space. Thus you split it instead of looking at a holiest in the system you split and write a different kind of state space no of state space equation for each of the sub system.

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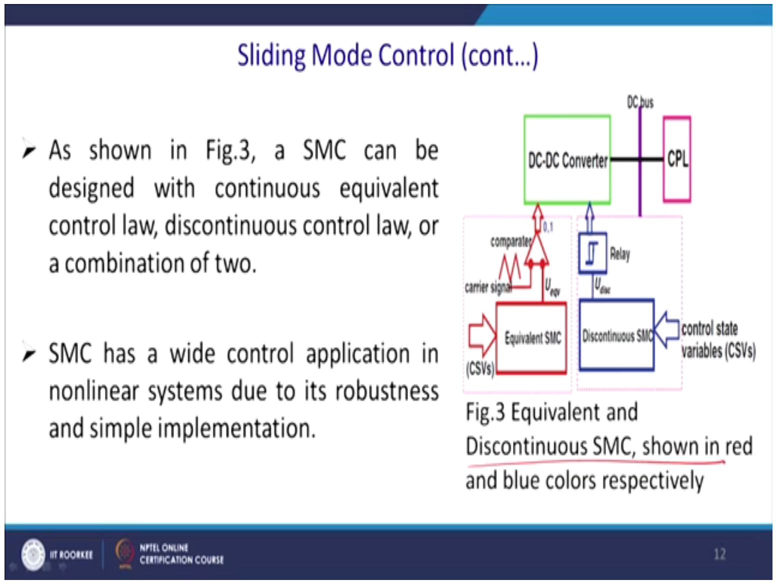

For example in this figure 3 equivalent and discontinuance is simply shown in the red and the blue colour respectively. I am coming to this point little later this is a DC to DC converter and this is a CPL this will be; so this red one is an equivalent SMC and it is in a constant domain and these may be operating in a discontinuous conduction mode. And you put it to the separate system and apply a separate controller.

So, what we can say here is that as shown in the figure 3 the SMC can be designed with a continuous equivalent control law as well as for the since comma discontinuous control law or the combination of the two. So, here it is a continuous conduction mode we assume and all those things. And CPLD maybe in a discontinuous conduction mode and this SMC sliding mode controller has a wide control applications in nonlinear in a system due to the robustness.

So that is something it is more stout in a change of this input signal or noise. So, it does not show any perturbation when we subjected were noise and it come back to the equilibrium point. And it is simple in implementation mind it you know it is simple and implementation if you know the subject. So, for this reason we required to study the SMC quite well and ultimately whole challenge slice to design the sliding surface well any way I am coming to it.

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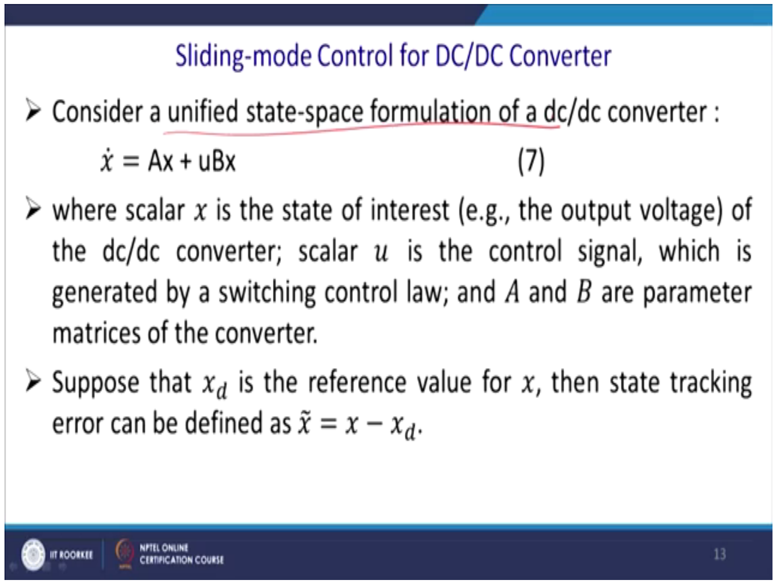

Consider the unified state space equation of the DC to DC converter again and you have X dot equal to Ax + Bu where as scalar x is a state of interest it can be generally current through the inductor and the voltage across the capacitor. For example the output voltage of the DC to DC converter scalar u is the control signal which is generated by using a switching control law. And A and B are the parameter matrix of the converter.

So, suppose your x d is a reference value of x, so you know it is generally synonymous with whatever the rating. Then state tracking error can be defined as x Delta so you want that this voltage to be this 48 volt thus x Delta equal to x - xt and accordingly you will switch it and switching logic will be such that you switch equal to sw 1 by half 1 + sign s. So, if there is a converter voltage required to be high the duty cycle required to increase.

So, according this law will be followed where s is a function of the state taking error define s is s is equal to ct transpose of the x Delta where X tilde is the error well and this vector C denotes the gradient of gradient of s with respect to the state. More generally and any other ace function can be defined as x, x dot of T equal to d dt of lambda n -1 this will be a polynomial of n - 1 into x Delta and when lambda is a positive constant define as a candidate of the Lyapunov function. And having this property that Vs equal to 1 by s square by 2 this is an energy function.

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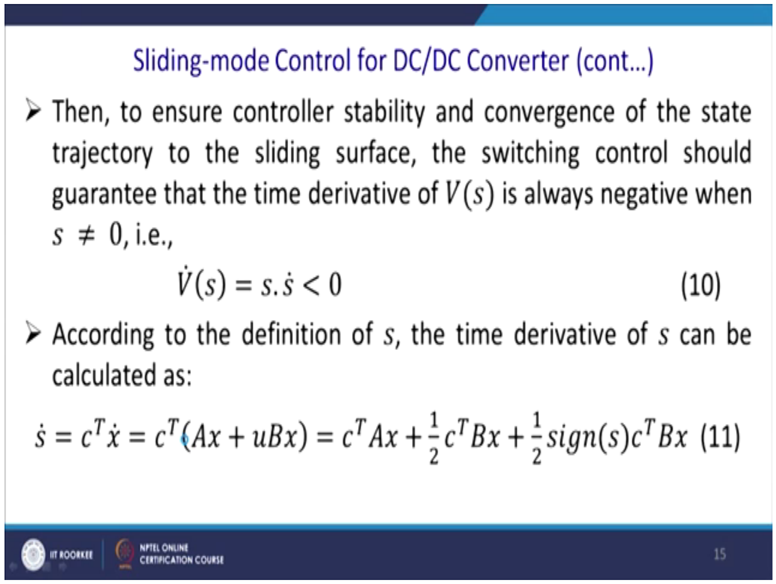

So, then what we required to do then to ensure the controller stability and the convergence of the states trajectory you know that desire point strictly to the sliding surface the switching control should be should guarantee the time derivative of Vs is always negative that when energy is decreasing and it is coming to that close to the inner point s equal to is not equal to 0 and s s dot should be less than 0 there is a Lyapunov of energy criteria.

According to the definition of s the time derivative of s can be calculated as s dot equal to c T of s so user differentiate it so c T A x + u B u x so that is equal to c T Ax + half c T B x + half of sine c T Bx this will be the x dot.

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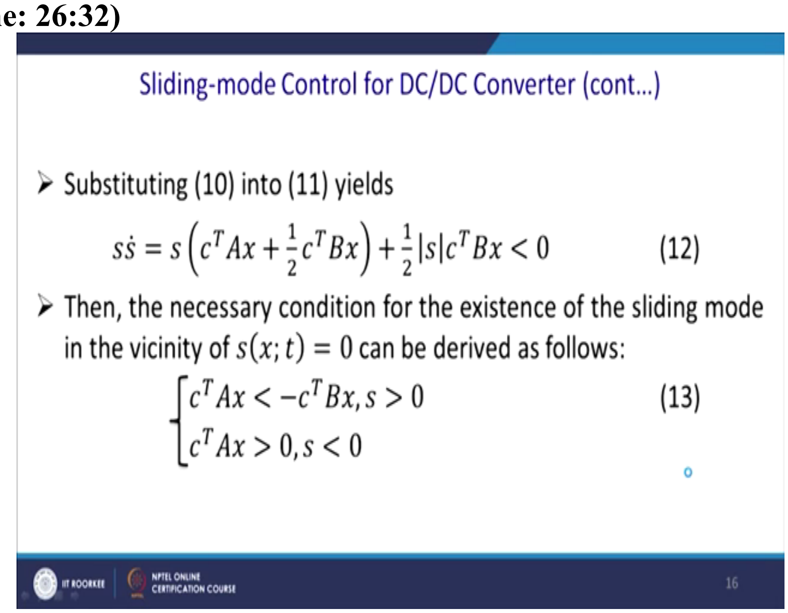

So, thus s into s dot this is the condition of the stability we have to ensure that this has been ensured and accordingly you can design the parameter. So, this in this equation 12 is a necessary and sufficient condition for the stability. So, the necessary condition for the existence of the sliding mod in the vicinity of the surface x function of x and T should be 0 and can be derived as follows should C transpose A of x should be less than - C transpose B x where s is greater than 0. And C T Ax should be greater than 0 when s is less than 0.

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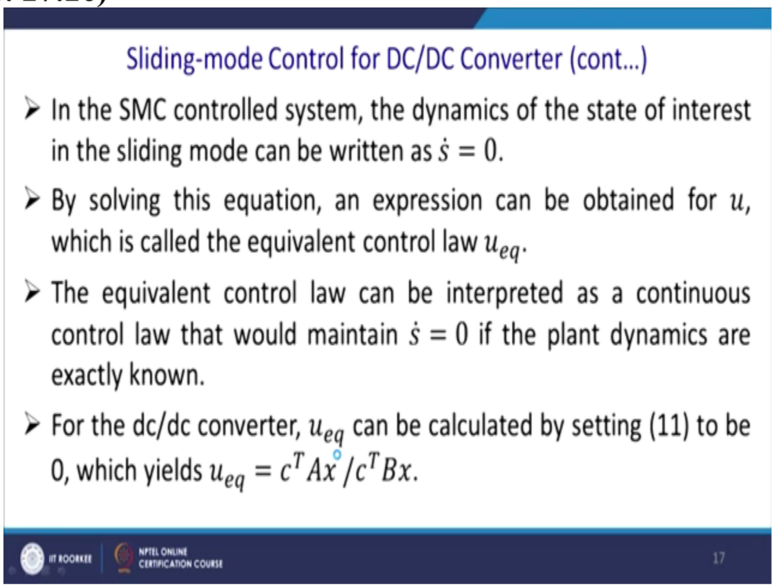

Thus what we can say here see SMC in the sliding mode control system dynamics of the state interests in the sliding mode can be written as s dot equal to 0 by solving this equation and expressions can be obtained for the initiated on the u, which is called the equivalent control law or EQ. The equivalent control lock and we interpreted as a continuous control law that would remain as s dot equal to 0 if the plant dynamics are exactly known that is one of the challenges.

So, you may not know some of the parameters of your plant and for the DC to DC converter you equivalent can be calculated by the by setting this EQ equation number 11. Please refer back to the equation number 11 to be 0 and yielding this EQ equal to C T A x by C T B x.

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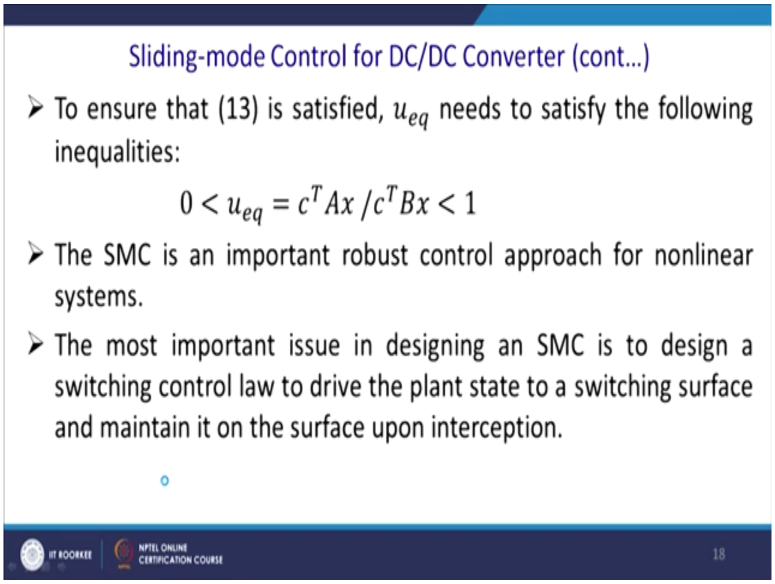

So, and thus please go back to the equation number 13 so this is the equation number 13 so this is a necessary and sufficient condition also. To ensure that 13 is satisfied EQ needs to satisfy the following equality's so this is the equalities EQ should be greater than 0 equal to C T A x by C T B x equal to is less than equal to 1 thus SMC is an important control approach, an important robust control approach in a nonlinear system.

There are so many methods and I have chosen one of the very typical and very interesting control techniques. So, DC microgrid also you can apply lot of control techniques or you can analyze the system or you can enhance the stability by designing a proper control logics. And what is important issue in designing the SMC is to design the switching law or the siding we generally in terms of them we said is a sliding surface.

The switching control law to derive the plant state to a switching surface and maintain it to the surface upon interpretation or reception, so this is the one of the application of the nonlinear control in DC microgrid we have so many technique to be applied and studied so that it is we can push more on the control logic and take care of the large-scale variations. And due to the time constant we cannot discuss all the topic thank you so much for your attention.

Students are requested to while doing this courses has to be very thorough f with the different control technique as well as the sliding mode control then only they can understand or appreciate this course better. And next class is our last class and that will be your conclusions. Then we try to speak about ultimately what we have discussed that we will try to summarize there. And also will see; will show you the scope of; scopes as a practitioner engineers as a researcher and different stakeholder.

What is us; why you should study the microgrid that is something we try to justify in our next class as a conclusion class, thank you so much indeed.