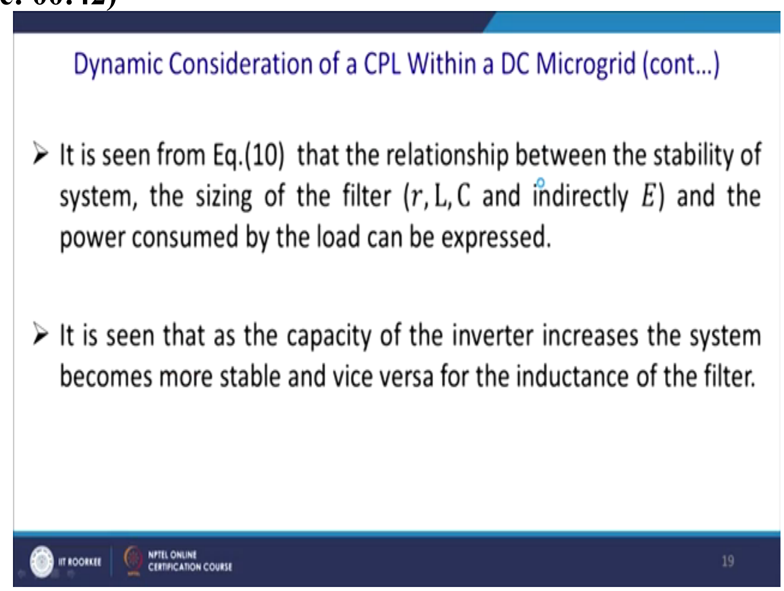
DC Microgrid and Control System
Prof. Avik Bhattacharya
Department of Electrical Engineering
Indian Institute of Technology-Roorkee

Lecture-36
Stability Analysis of DC Microgrid (cont…)

Welcome to lecture on the DC microgrid and the control system we shall continue with our stability analysis also in the DC microgrid. So, negative microgrid so what was discussing that with a problem with the CPLD in our previous lecture.

(Refer Slide Time: 00:42)

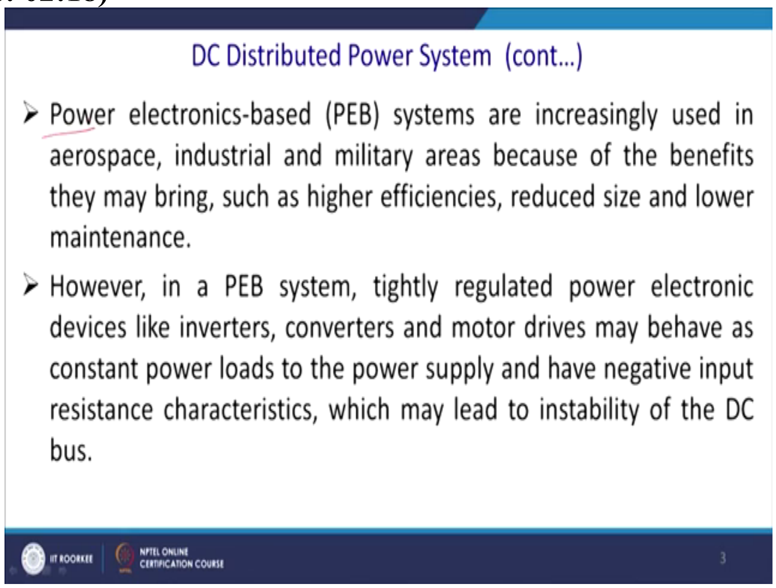


So, that the DC microgrid facilitate the integration of the emerging DC renewable energy sources that is we have to; you mean to get the fuel cell not only solar and wind or any other sources of the power energy sources example photovoltaic and the fuel cell or the energy storage devices the battery ultra-capacitor or the super capacitor as well as modern Power Electronics loads by eliminating the redundant energy conversion.

The development of the DC microgrid can overcome the practical issues of AC network. Such as you have a; no problem of the frequency synchronization, concept of the P L is missing, reactive power flow, active power control those are all missing, inrush current from the transformer, current harmonic and other all the nasty power quality issues. You get rid of all the entities in AC microgrid.

And unfortunately at the time of Edison so those power quality issues was not very prominent otherwise I more than sure Edison would have been win the battle over the other counterpart.

(Refer Slide Time: 02:18)

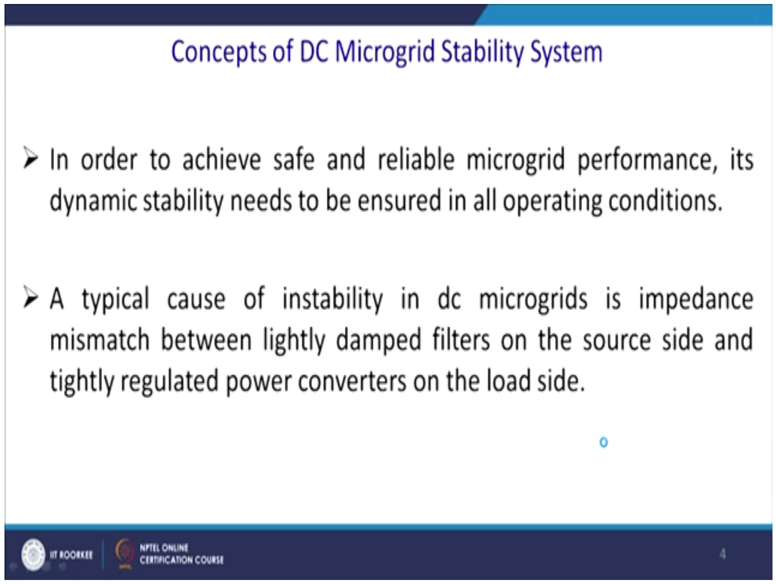


The electronics; so let us come to the discussion about power electronics based system mostly this converters are power electronics based system. And increasingly used in aerospace industrial and military area because of the benefit of being many, such as higher efficiency you may have a high frequency high efficiency DC to DC converter. Reduce size and the lower cost of the maintenance. So, if you increase the size if you are flying is a cost.

So, if you more compact if you can make sure that will be and advisable and that has to be practiced. However in case of this electronic based system tightly regulated power electronic devices such as inverter converter and the frontend motor drive AC DC conversion maybe in case of the AC microgrid behaves as a constant power load not only those DC CPLD. This also behaves as a cost and power load to the power supply and have the negative input that is why detrimental.

If your negative input resistance is 0 so that is disadvantages which may lead to the instability of the DC bus that is something we required to observe and find out the solution for the same to healthy operation of the DC microgrid.

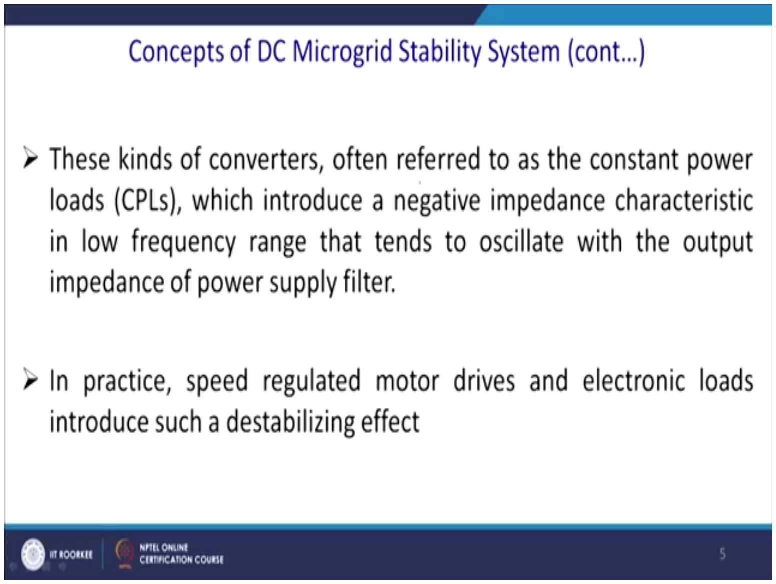
(Refer Slide Time: 04:01)



So, in order to achieve the safe and reliable microgrid performance its dynamic stability dynamic stability needs to be ensure in all the operating condition that is something we require to do. A typical cause of instability in the DC microgrid is the impedance mismatch. Source impedance is a load impedance for this I was telling that the maximum power theorem please recall. And generally converter has a high input impedance like OPAM and low input impedance that is what we want.

The for this reason there is a problem of the mismatch between the highly damped filter to the source size and the tightly regulated power converter on the load side. So, source size you are allowed to vary the solar irradiation will change and you have IV characteristics of the Solar Panel will change. But what is essential you are doing in your output you are keeping your voltage constant load constant. And thus there will be a buffer in between the power electronics space ultimate with that leads to the mismatch between the impedance. So how will you ensure the stability there that is a challenge?

(Refer Slide Time: 05:44)



So, this kind of converter often referred as the constant power loads which introduced the negative important characteristics in a low frequency range that tend to oscillate with the output impedance of the power supply again this has the quite nasty phenomena please understand it. The CPLD what it does was introduced in is the negative impacts characteristics in the low frequency range that when the supply frequency range.

And tend to oscillate with the output impedance of the power supply filter. So, it will be sometimes may be gives you a low frequency oscillation also. So, in practice speed regulated motor drive and electronic load introduces such destabilization effect and where you will find that it will oscillate with the power supply. So, because what happened please understand it why there is a mismatch you are feeding DC to AC.

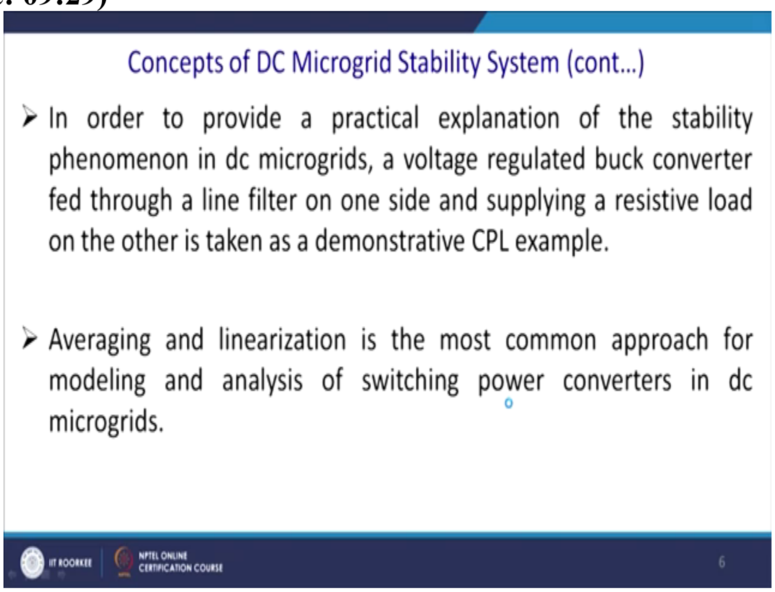
So, you got an inverter and what happened you know this is your average power that you are supplying for the DC and over all you have this power is oscillating double frequency oscillation. Because when you are crossing 0 then current is very low or if you have quite heavily loaded then it is almost power factor is .8 or .9. So, what happened there, so you are feeding a very less amount of power and when voltage and current both are very close to the peak then also what happened you are taking huge about the current and power.

So, there will be a low frequency oscillation into the system and that will be reflected to the DC microgrid and ultimately capacitor voltage will have a swing. And that is what I was saying, so it will tend to oscillate the output voltage impedance of the supply filter. And this causes lot of; and again if you are huge amount of this kind of load in the DC microgrid. You may have it AC's that you are now reading, you ever see that inverter for essential input DC.

Because when you are planning from the grid you may rectifying it and you are feeding to a inverter. But when you already have a DC you do not justify it you put it to the inverter and what, so this kind of nasty phenomena will come across and we required to stabilizer grid in those circumstances. One of the advantage of this grid is that it is because of its huge inertia its more or less stable. If some; if you do something does not happen to the grid much.

That is in India we have a power utility of the power corporation will tell you whole power it is it handling the tear what amount of the power so it is quite natural that it is sudden change in some portion of the grid does not affect. But in microgrid if you have huge amount of the CPLD it is a big concern and is a great challenge for the power electronics and control engineer to address it.

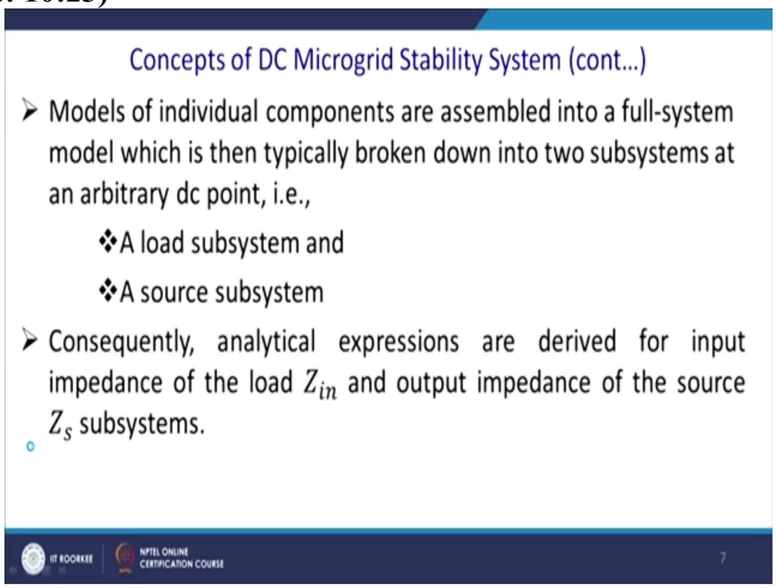
(Refer Slide Time: 09:29)



In order to provide the practical explanations of the stability phenomena that is what I try to do in our my next slide; previous slide. In the DC microgrid a voltage regulator and buck converter fed to the line filter on one side and supply a resistive load on the other side is taken for the case of the demonstration of the cost and power load concept. And we shall apply the averaging phenomenon also linearizing in a newer route. The averaging the linearisation is a most common approach for modelling of the DC microgrid.

We have seen the analysis of the switching power converter in DC microgrid. Students are advised to pay for my previous lecture on advanced Power Electronics on DC to DC Converter there this average model at linearization other aspect has been covered in details.

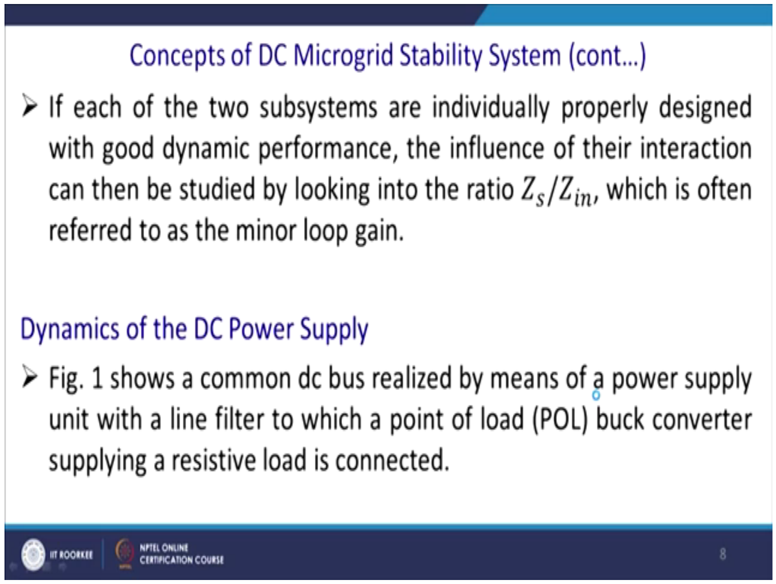
(Refer Slide Time: 10:23)



And the models of the individual components are assembled in a full system model which then typically broken into 2 subsystems at arbitrary DC point. So we will break it since you know that when switch is on, your one set of characteristics equation when switches off another set of characteristic equation but we just say in a different manner here. So, we have a load system and sources subsystem. One switch is on, that power is transmitted from the source to load so you got a source subsystem.

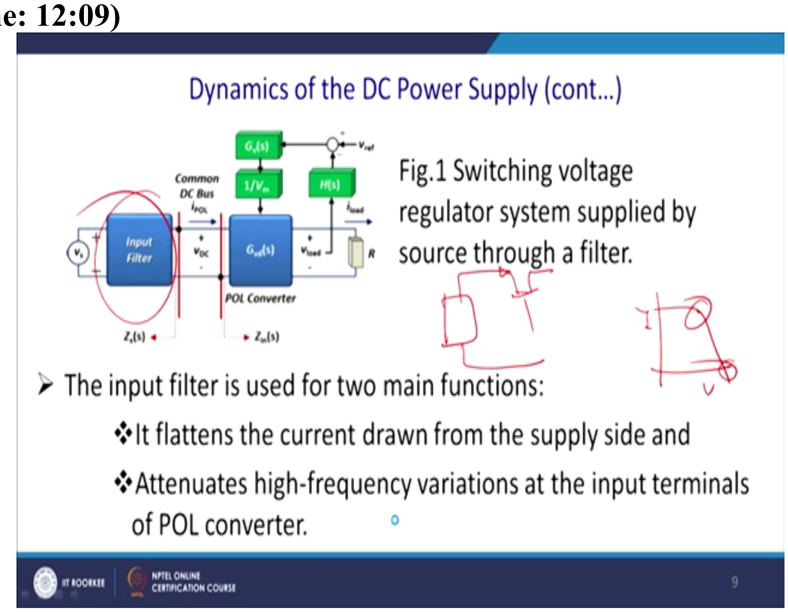
And when switch is off ultimately capacitor has to feed the load so thus you have load subsystem and that importance of the changes in this two circumstances. Consequently the analytical expression are derived for the input impedance for the load input impedance that is Z i and output impedance of the source subsystem.

(Refer Slide Time: 11:30)



Each of the two subsystems are individually properly designed with the good dynamic performance. The influence of the interactions can then be studied by looking into the Z s by Z in which is often referred to as the minor loop gain. So that is something you have to keep in mind that it is Z s and Z in is that import impedance.

(Refer Slide Time: 12:09)



And so, dynamics of the DC power supply this is the figure 1 where it is consisting of the input filter. Why input filter is given because you know you talk about your MPPT, solar MPPT. In solar panel you are taking power all of a sudden if you are breaking circuit then you are making your current 0. So, this is not allowed and thus you will be huge shift of the PV curve in the IVPB curve of the Solar Panel. So, you are operating here you are supposed operating here.

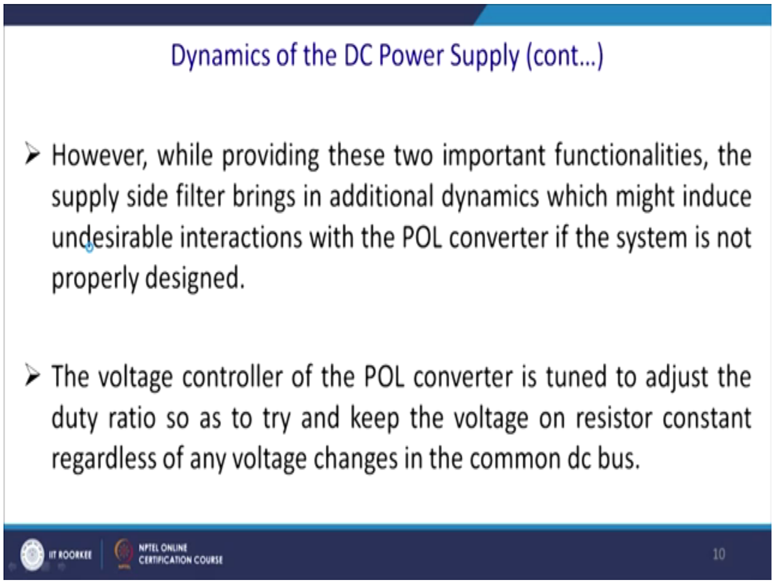
And all of sudden you will switch it off what happened this is I in this is V moving this to this point. And that it is not allowed again your turn from this point to this point is not possible. And for this is reason you required to put an input filter I am coming to this point litter later. So, this figure 1 shows the common bus was realized by means of the power of supply unit with the line filter which is a point of the load or an abbreviation we shall use it POL buck converter supplying the resistive load and disconnected like this in the figure has been shown.

So you got a filter then you got a common DC bus this portion is common and this side we say that it is the Z s and other part from this side which is truncated are the keep it as scissor and decide you say that is a input impedance here. Of course you know you have to match this impedance this has to be this then only you will have a maximum power transfer to be takes place any way. So, if there is a mismatch between these two impedances then there is a challenge of stability.

So input filter is used for two main function as I was explain it slackens the current drawn from the current side that it was I was saying. You see the example of assuming that is the solar MPPT this is the problem all of the sudden the switch is off current will go to the 0, again you cannot track and moreover it attenuated the high frequency variation of the input terminal of the POL converter. So, since impedance is varying once switch is on the impedance is something else and when it is off that is something else.

And thus what happened due to that thinking impedance that you know it is high frequency variation of the input terminals and for this reason that will access a buffer to the source so that it will be not affecting the change of impedance to the source.

(Refer Slide Time: 15:27)



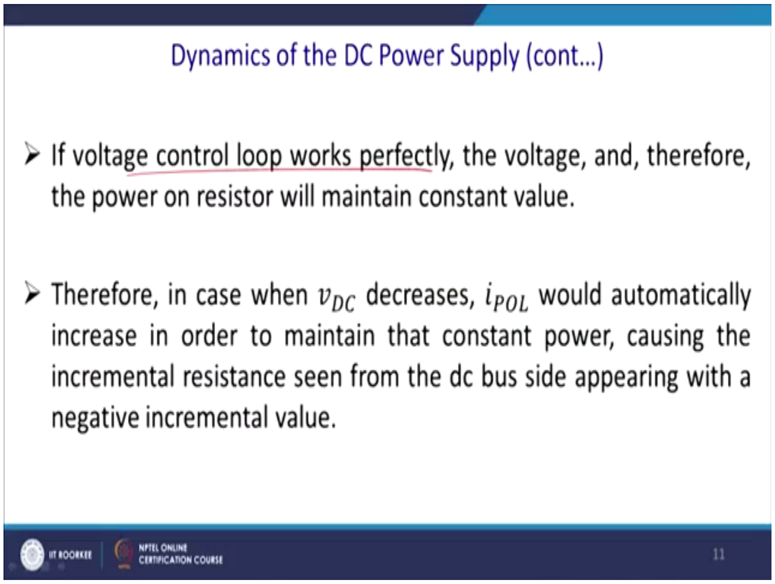
So, while providing that is a challenge though you required to heat because of it. However while providing this to import functionalities the supply side filters also brings additional dynamics. Because it is AC you are having a step change everything every time it will response. So, the supply type filter elements additional dynamics which might be introduced unreasonable characteristics with the power electronics or the disk converter that is the abbreviation of it is called POL converter,

Parts of loading that is the points of load, what happened in changing stay with you know you cannot expect that load will be constant. It is something the prerogative of the consumer. I switch on light one side of series what happen I will be move out one point to another point maybe it is a automatic sensor based and other lights are switch on, so while load changed and this dynamics if it is not properly dumped out will give your sustained oscillation.

This is in layman's language this is the problem. So, the voltage controller of this POL converter is tune to adjust the ratio so that it tries to keep the voltage on the resistance constant regardless of the any voltage change of the common bus that is something that it takes some amount of insulation. That is voltage controller of the POL converter it is tuned to adjust the duty ratio such a way to keep the voltage on the resistance constant.

So, irrespective of the change in the input regardless any change of the voltage in the common bus that is the task of it. A voltage may be coming down the common bus 48 to 46 but this converter will maintain that are regulated voltage to the resistive volt.

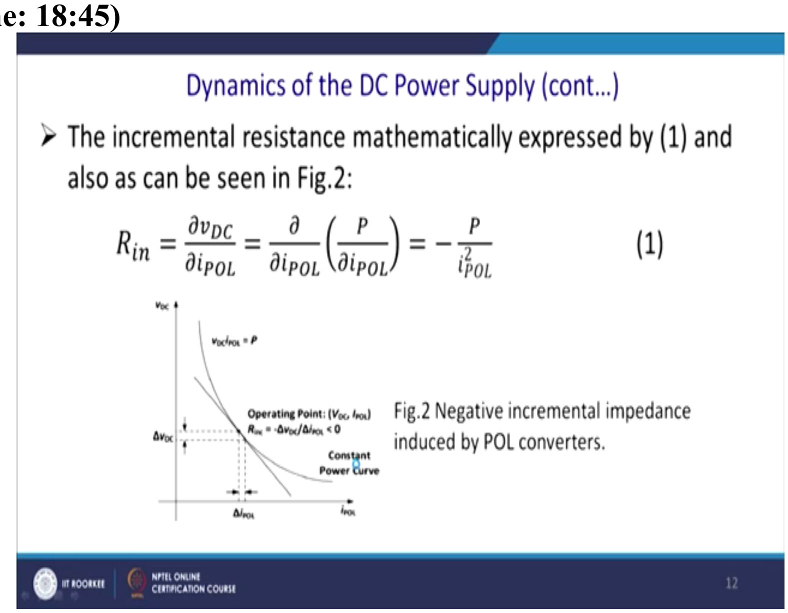
(Refer Slide Time: 17:52)



And what happened then if the voltage control loop works perfectly the voltage and therefore the power on the resistance remains constant and that there is a no problem at all. And therefore in case of V DC decrease please I of this point of loading will automatically increase in order to maintain the constant power and thus what happen? Cause increase mental resistance seen between the DC bus side and appearing with the negative incremental value.

So, voltage if decreases then current has to increase and that you have negative resistance characteristics. Positive resistance is healthy but if you have a negative resistance it has a quite predetermined value to control it.

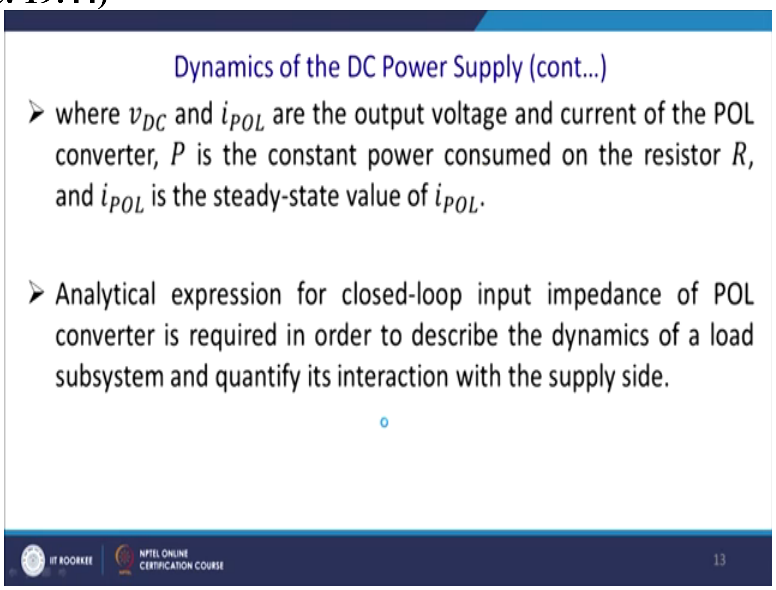
(Refer Slide Time: 18:45)



So, the incremental resistance mathematical express can be this R in is P DC by d Vdi of this POL that differentiate it you get this again the same thing - p square by i0 and negative science is basically presenting the negative resistance. So, if you have this operating point over voltage is more and thus the current is less then if you go to this operating point very close neighbourhood maybe.

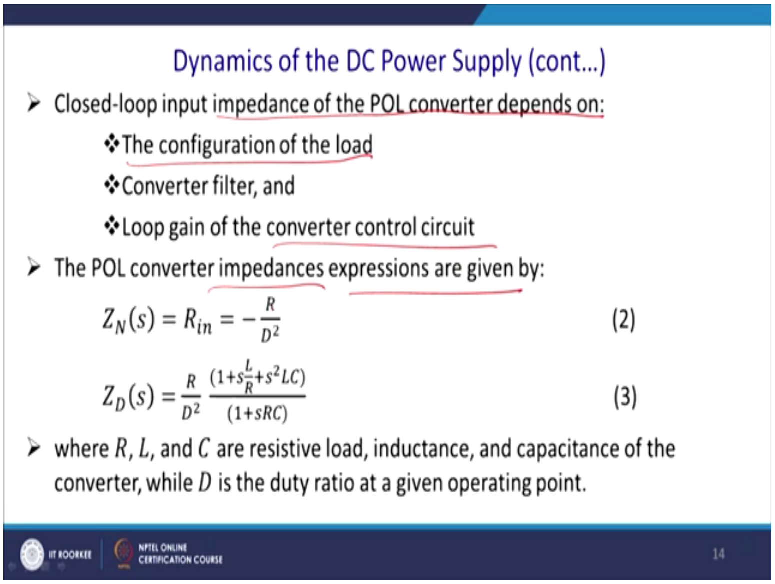
Then what happened you are you have a voltage sag and the same move into here. In operating point will change accordingly and you can see that del l V by del i is less than zero so this is the problem here to adjust so once voltage drops current decreases.

(Refer Slide Time: 19:44)



So, from this notation we clarify the notation first and we described it while V DC and i suffix POL and the output voltage and current of the POL converter and P is the constant power consumed in a resistance and i POL is the steady state value of the i POL. The analytical expressions for the closed loop point of impedance of pure i POL converter is required in order to describe the Dynamics of the load. Load subsystem and quantify the interaction of the supply side let us see that.

(Refer Slide Time: 21:12)

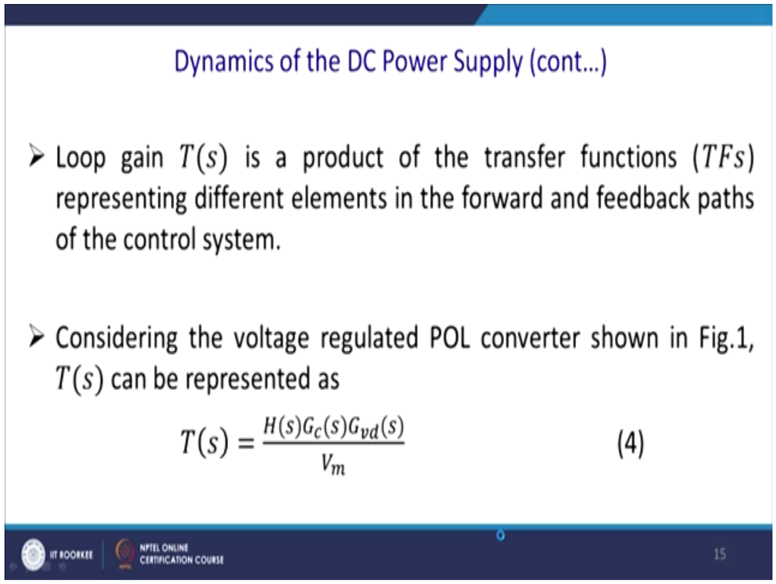


So, let us design closed loop transfer of it the closed loop input impedance of the fuel converter depends on the configuration of the load converters filters loop gain and the converter control circuit these is all the parameter will have a effect on this overall closed loop performance. The fuel converter impedance expressions is given by Z s equal to R i n equal to - R by D square where Z DS equal to R by D square 1 + this transfer function will come and where is R L and C are the resistive load inductance and capacitances of the converter and D is a duty cycle ratio.

And please understand that we have kept this thing pretty simple while discussing DC to DC converter we have kept that it is operating in a continuous conduction mode. If you try to operate this conductor in discontinuous conduction mode then things will be pretty complicated so that we are avoiding it so that can we are good research topic while designing the DC to DC in the light load and discontinuous conduction mode.

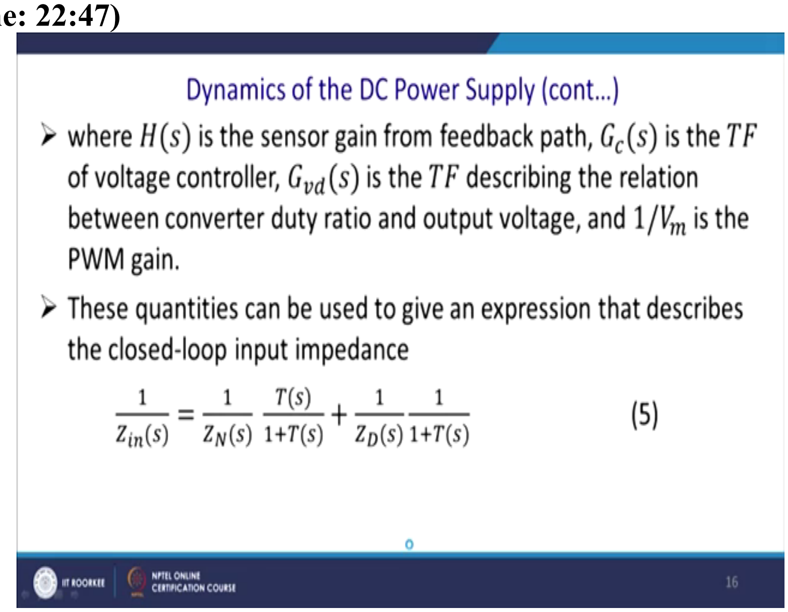
But what is your designing that why you have load is increase somewhere and that is the stability problem. So, one nasty aspect we have neglected that discontinuous operation of the DC to DC converter because of the load.

(Refer Slide Time: 22:17)



So the loop gain T s of the product of the transfer functions is represented representing in different elements in the forward and backward path of the control system. Considering the voltage regulator fuel converter shown in the figure T s can be represented by T s equal to H s CGS G vd S by V m see that this transfer function.

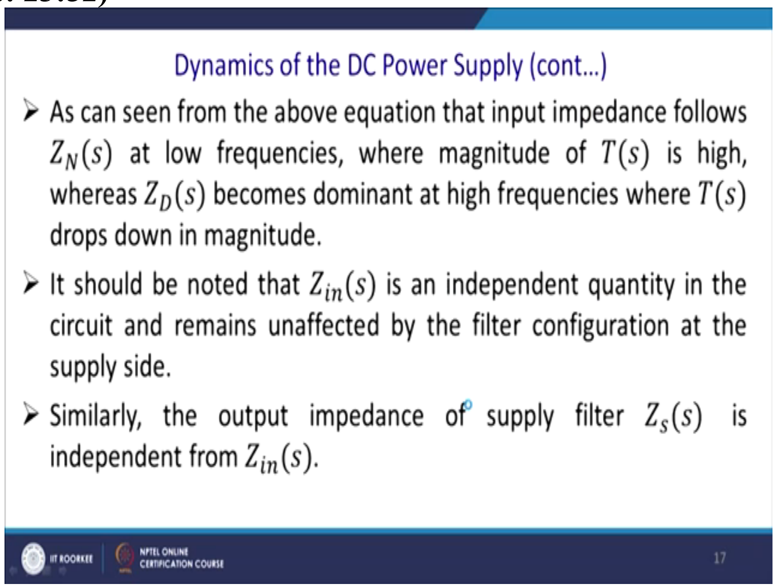
(Refer Slide Time: 22:47)



And that is what we can write here this H s this transfer function is the sensor gain from the feedback path is the resulting in the feedback path of DC of the plant is the TF AC voltage controller and G vd is the transfer function described the relation between the converter duty ratio and the output voltage and 1 by V m is the PWM voltage gain it is nothing but a modulation index. And these quantities can be expressed to given expression as described the closed loop form.

So, one by Z in that is the advertence equal to 1 by NS into the time delay system that is TS + 1 + TS there after 1 by Z D 1 by TS.

(Refer Slide Time: 23:52)



So, from this previous equation 5 so we can narrate few things and it can be seen from the above equation; previous equation that the impedance follows Z N S because these are the term and the switching frequency so, this will have a direct correlation. So, for this system we can say that we can see that the above equations follows certain relay at such a low frequency while magnitude of the TS that is the switching frequency 10 kilowatt that is 1 microsecond.

May be if it is in a switching level of megahertz really we those things apart that 10 kilowatts so that TS value is 100 microsecond. If it is 100 microsecond1 by 100 microsecond + 1 by 100 microsecond ultimately this part decimates does not have any implications. Same way a few add of this value with the 10 microsecond ultimately this value can be taken as one so that is what I am saying. So, this value does not have much implication.

So, the high power magnitude is high Z DS become the dominant and high frequency but TS drops in the magnitude. It should be noted that Z in S is an independent quantity in the circuit and remain unaffected by the filtering configuration at the supply side. So, that is something quite interesting offer. Similarly with output impedance of the supply filter Z s is independent of Z in so let us revisit this equations again and so see that; so this will have a 2 term 1 is Z in another is Z D so and where we have a different transfer function and this is a overall input transfer functions from this power electronics converter.

And while having this you know this TS you can see that TS has an entity of HS see G c S and G vd by V m and thus what happened so please recall what I am saying here that it can be seen that from the above equation that the input impedance followed that Z in S at low frequency but TS is high and where ZTs become dominant. So, this part becomes dominant and at a high frequency this part becomes dominant.

So there will be a two characteristics 1 is at a low frequency level and other is that come to the picture maybe you have a; you are interacting with the inverters or something or there is a slow oscillating some voltages mighty be your feeding from the wind turbine and speed generating will be the wind speed vs 16 hertz 17 hertz so that you convert it to the DC. There the low frequency count in the picture and if you are totally DC.

Then also then we will say that frequency is a simple as that in that case this entity, at look will be dominating otherwise this entity at the high frequency will dominate. So, this is the take away from this discussion. So, while designing the performance of the power electronics converter feeding this kind of CPLD we required to design with the proper consideration and the filter has its effects and that all has to be taken into the consideration while the closed loop transfer function. We shall continue to discuss with stability issues of the microgrid in our next also thank you for your attention.