Advance Power Electronics and Control
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Lecture - 21
Non Isolated & Isolated DC-DC Converters and Choppers

Welcome to our lecture on Advanced Power Electronics and Control. Today we are going actually it is a quite elaborated topic that is left out portion of the isolated non-isolated DC-DC converter and thereafter we will actually talk about SMPS essentially in isolated this is the DC converter. And for the high power application there we have choppers. So let use actually talk about new topology of the BUCK-BOOST converter that is called the Cuk Converter.

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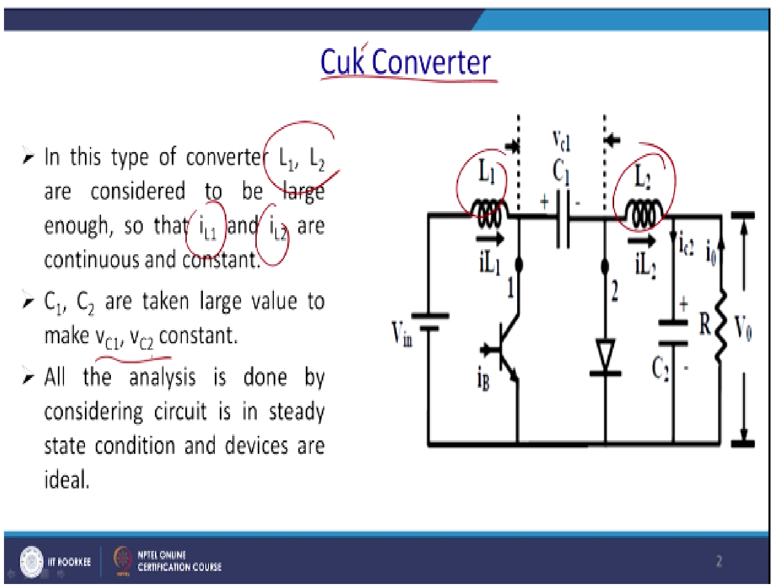

Cuk Converter essentially a BUCK-BOOST converter but there is one difference in it. The polarity of the output will be opposite to the polarity of the DC voltage supply, otherwise it is a versatile DC to DC converter you can BUCK it you can BOOST it. So we have actually two inducted here L1 and L2, it is actually because what is in the input side and constitute the part of the circuit and this part is actually constitute the BUCK part of the circuit and we had already discussed it.

And we have to choose this value of the inductor in a such a way in switching frequency so that this inducted current are in a continuous conduction mode. And C1 and C2 are chosen in such a way that capacitor voltage will have a negligible ripple. So we can assume that DC1 and DC2 is almost constant. And all the analysis done in the steady state of the circuits.

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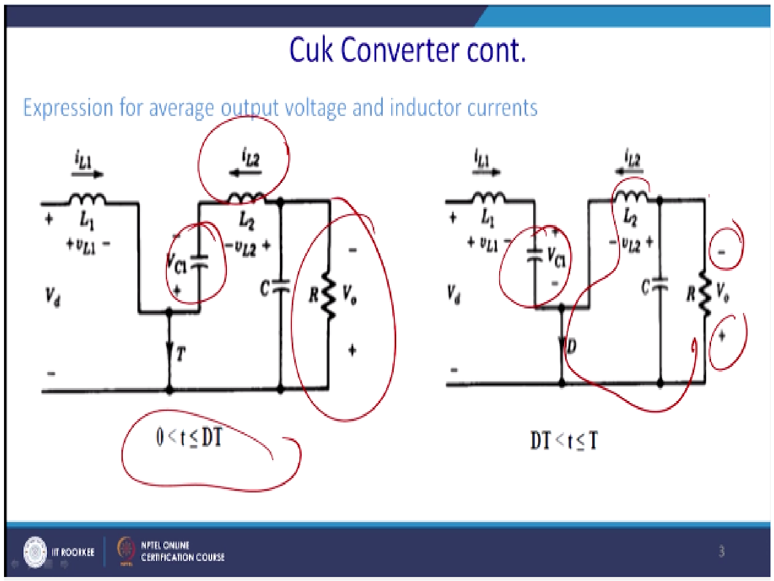

And let us go for the analysis of the circuit. So once it is ON so you have this characteristic. So this switch is sorted ultimately you will get this polarity of this capacitor will get this polarity and ultimately you know current iL2 will try to flow through this capacitor and will have a opposite polarity here. And when switch is closed then basically what happen this DC1 will come as a power of the input circuits and ultimately the iL2 will flow through this.

So ultimately iL2 will flowing through this and thus you will have a reverse polarity. So this is the characteristics of operation of the Cuk converter.

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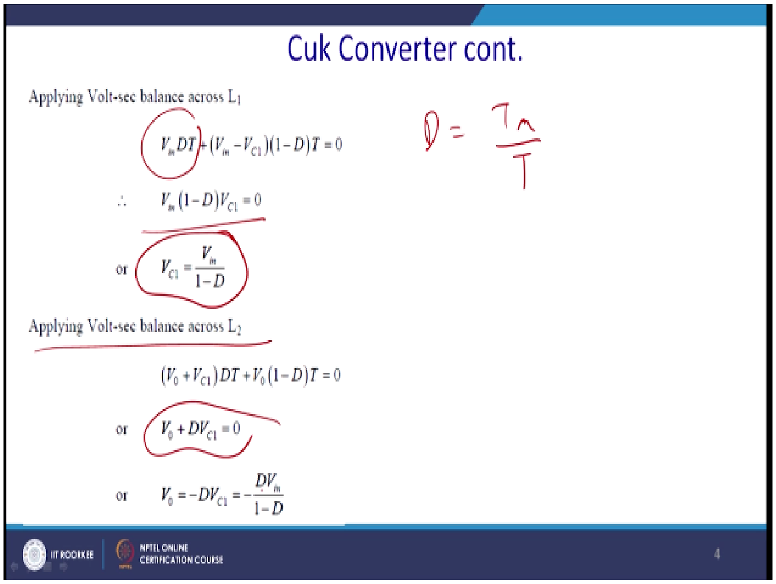

Now we can write the Volt-second balance that is actually Vin actually DT + Vin - Vc1 1-D*T, where D is the Duty cycle that is Tm/T. Now Vm called to 1-1 Vm 1-D*Vc1=0 since. So from there we can calculate the value of the Vc1, Vc1 will be actually Vm 1-D at a same expression what we will get in a boost topology. Now again for the, we apply the Volt-second balance for the second inductor that is output side that is L2 so V0+C1*DT V01-D*T0 so you can get and balance it so V0 will come 1-D*Vc1 become –D Vim-D.

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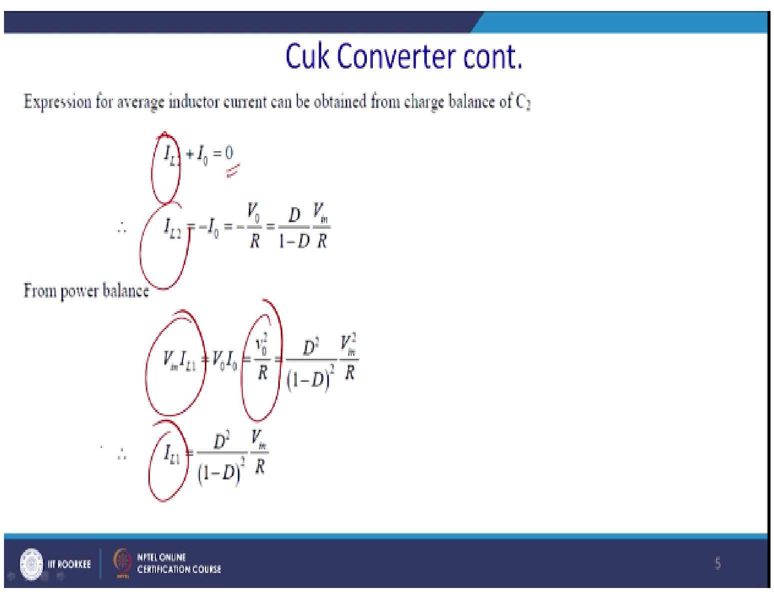

So from this expression we assume that this current L2 is negligible ripple and so iL2+i0 should be equal to 0. From there we can write iL2=-i0=V0/R that is average current so D/1-D Vm/R. So from the power balance if you consider that all devices are ideal so there is no losses, so you can write V1 Vin*L1 called to V0*i0 that should be equal to the V square/R so that will be given by D square/1-D square V square/in, so essentially you know Vm square the input current become D square/1-D square Vin by that. So this is the analysis of it.

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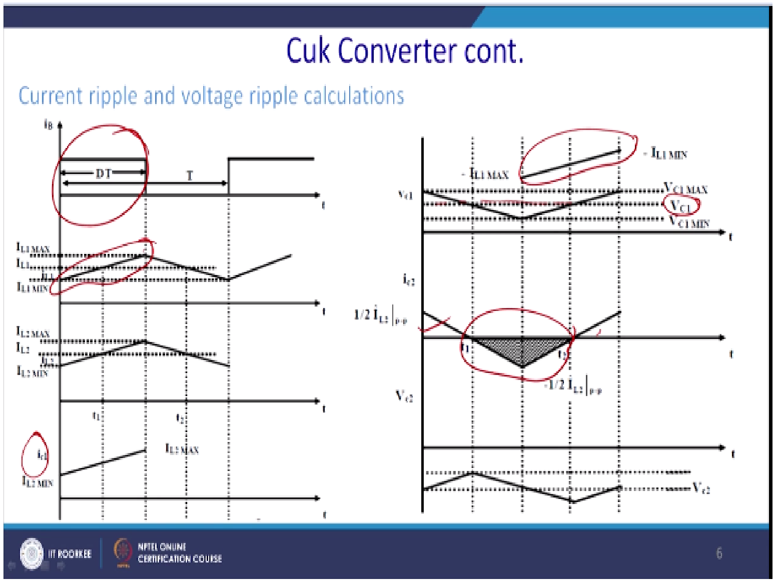

So ultimately this is duty cycle. And we assume that this ripple current of this L1 is quite small so it will restricted by this two zone and you have; it will come down like this once switches off. And similarly L2 have a this kind of pattern and thus Ic1 will have actually this kind of pattern of ramping. So similarly, why it is we charging so we will find that it will decrease to a voltage of Vc1 max and ultimately again it will actually ramp on an ultimately this value is IL1 MIN.

So what you can see here, so this portion actually, so have up this actually Vc1 MIN value of the Vc1 is this one, so inductor current is essentially will be actually storing the energy and this is the area where it will be dissipating the energy. So and this is the voltage of Vc2 and this will have a ripple and we will get this kind of voltages.

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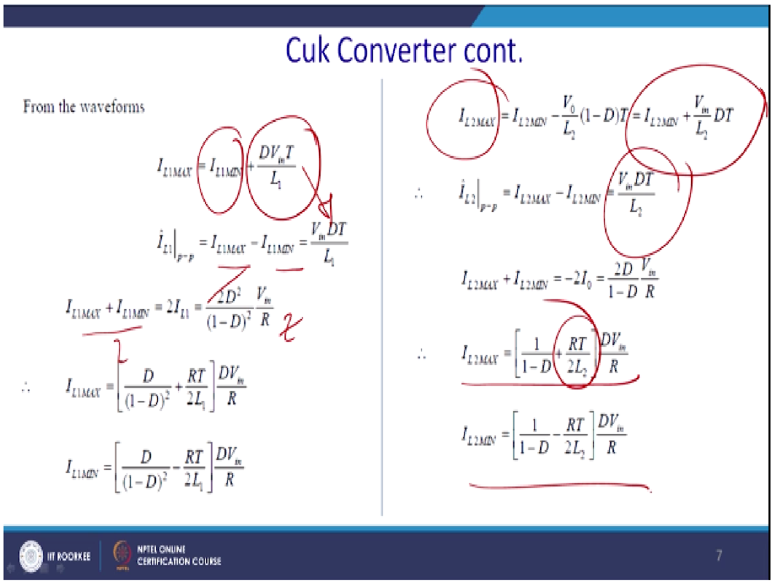

So from this IL MAX is definitely is basically IL MIN + VL DI DT that can be replaced by actually this equation DVin/L1 so IL pick to pick ripple will be actually this essentially it will be this term. So if you add up and divided it by 2 so that become the average value of the inducted current so that value is basically 2D square 1-D square V square/in if you actually divide it by 2 then this 2 will get canceled.

So IL MAX essentially is that D*1-D square + RT/2L*D*Vin/R and IL1 MIN = D/1-D square – RT/2L1 DVin/R. So we can write that actually similarly IL MAX=IL MIN – V0/L2 1- D*T so you can replace this equation by Vin/ since actually V0 will have a negative sign of this Vin so negative sign will be observed so Vin/L2*DT. So ripple in the secondary inductor will be basically or the second inductor will be L2 MAX-L2 MIN then value will be Vin DT/L2.

So average value will be basically half of the load; average value will be half of this value that is actually 2I2=2D/1- D Vin/R, so I2 MAX will be actually essentially will this value and IT MIN will be essentially this value. So this will be the factor. RT/2L2* this factor this is a common part of it. So all these analysis is being done consider that low inductor ripple and the low capacitor ripple and it is in a continuous conduction mode.

So now require to calculate the ripple voltage. And this values has to be negligibly small. Okay. So that actually you can choose in such a way that value becomes small. Essentially it has to be you know taken example you now actually what should the value of the ripple so it should be restricted 10% of the average current so you know, Vin will have some let us say 10 and T on can be you know actually 10 to the power -4 and you know this value can be of any value, so it can be 10 to the power -3.

So the average is coming out to be actually little less. Okay. In that way actually you will have a quite low ripple current and generally ripple current has been restricted around 10% of this actually or the load current for a for this analysis. And if it is further more than the analysis will change.

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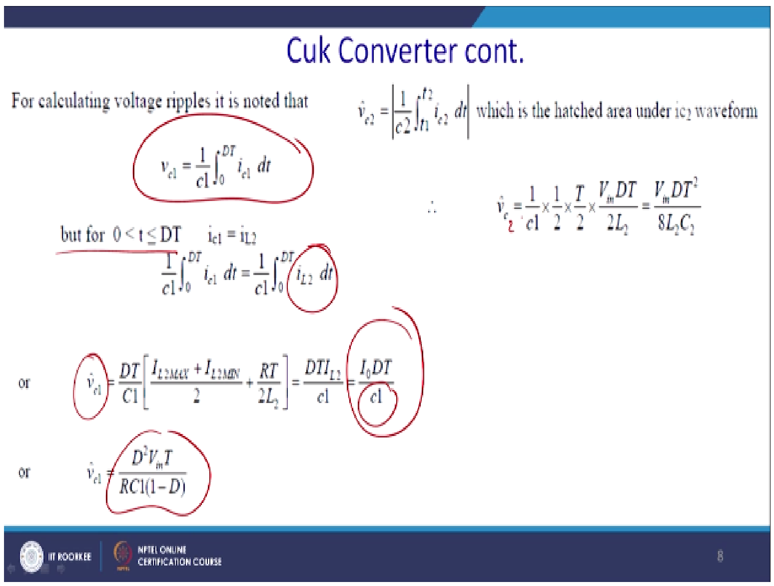

So for calculating ripple voltage same way we can integrate over the Vc1 for the T ON time of the duty cycle that is 1/c1 0 to T IC1 DT, so it will we know that actually the same issue reverse back to this actually this figure you can see that actually current which is actually flowing its ICL1 in case of switch off mode and ICL2 in case of the switch on mode. So we can integrate over it so this value will be essentially IL2*DT.

So from there we require to calculate the actually the ripple, so DT/C1 IL MAX + IL MIN + this one, so ultimately so this value will be given by; so this is quite important because while you are designing you will be asked to design that the ripple current. So ripple current should be 1% or 10% or 5% that will be prescribed by your actually requirement.

So ultimately you know you have to choose this value. So because you know it is something in your hand so because you know that what should be the input supply. So duty ratio will be in such that you know actually will you will fix that L2 in such a way within a range that you get desired ripple up to this. And same way here, so you require to have a desired ripple value may be 5% of Vc1, so I0DT/C1 so from there actually you can restrict this value of the ripple.

So you can substitute in terms of actually if you do not want to keep the any term in terms of I0 I0 is something actually depend on the load so you can change this value actually Vin/R so ultimately this equation becomes D Square Vin DT RC1 1-D square. So this will be the amount of the ripple. And so, similarly, we can calculate the value of the second capacitor and similar way and we lead to this expression basically Vin DT square 8Lc L2 C2.

So from there the second equation can be calculated. So this is the all the analysis so after this analysis hope we can design actually BUCK-BOOST converter that will be given for your design. So this is your input voltage and this is output voltage; and we want and this much of ripple into the capacitor to capacitor and inductor and please choose all those devices. So this can be a assignment and you required to find read out and design a actually Cuk converter.

Now let us come to the little high power applications. So generally this is a single switch and this works very well for below let us say kilovolt level. So when you require to run a DC motor and quite high rating then of course Thyristor is your only the choice or the J0. And you want a different kind of operations of your DC motor. Because still now interaction DC series motor still input into the applications and it has many utility and; since it is still existing and still it is going a way and till it has a life we do not want to face it out.

We rather retrofit at converter in front of it that is essentially the chopper and that will give you the more efficiency and the required performance. And for this reason we have a different kind of chopper. Chopper essentially are the essentially DC to DC regulator gives you the unregulated DC to the regulated DC but one basic difference is that its switching frequency is quite low and its power rating is quite high for this reason the Cuk converter mostly uses switches a MOSFET and here you will find and it is a unidirectional and you will find that actually.

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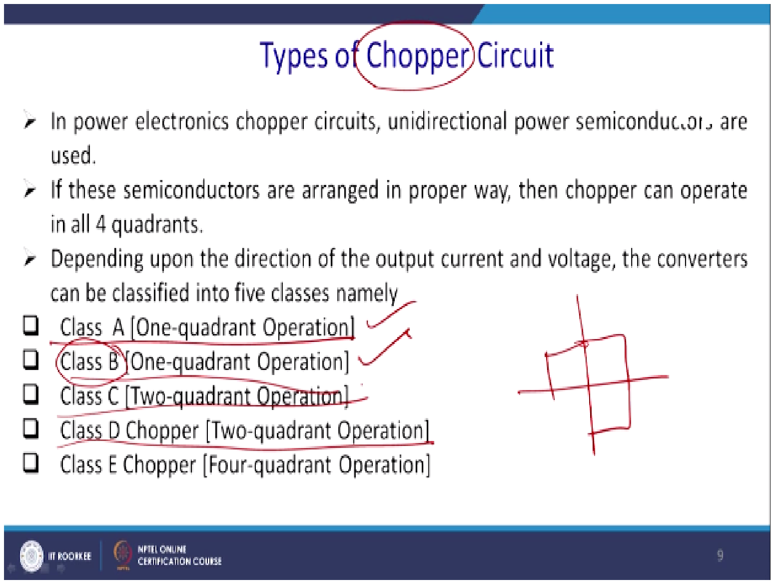

There is a different kind of mode operation on the chopper. First kind of mode is Class A chopper that is essentially a first quadrant chopper, first quadrant means actually it will be restricted in the Iv characteristics first quadrant so it is only the positive operation it means that they will take voltage and current from the source and it will be sync. So only motoring operation is possible mostly it is fitting to the DC motor.

And if you want the second quadrant operations, so this is a Two kind of second quadrant operation is possible is this or this. So we shall see that if you want that regenerative operation so we will have a actually a second quadrant operation and that is also basically Class B is also the first quadrant operation but you will have some entities of the regenerative breaking essentially it operate in a four quadrant. And thereafter you have a C chopper that will operate in both the two quadrant.

And then we will have Class D chopper which is also to quadrant but it is basically it will change the directions. And there is a Class E chopper it will operate both the directions as well as regenerative breaking is possible. First A is the motoring, B is the regenerative, if you combine A and B you can get C you get actually motoring and the regenerative actually constructive into the same circuit so essentially this becomes the Class C.

And if you incorporate basically the directional change so that you can go forward direction the reverse direction, then Class D chopper is used. And Class D chopper with the regenerative will become Class E. So this is the actually the consideration.

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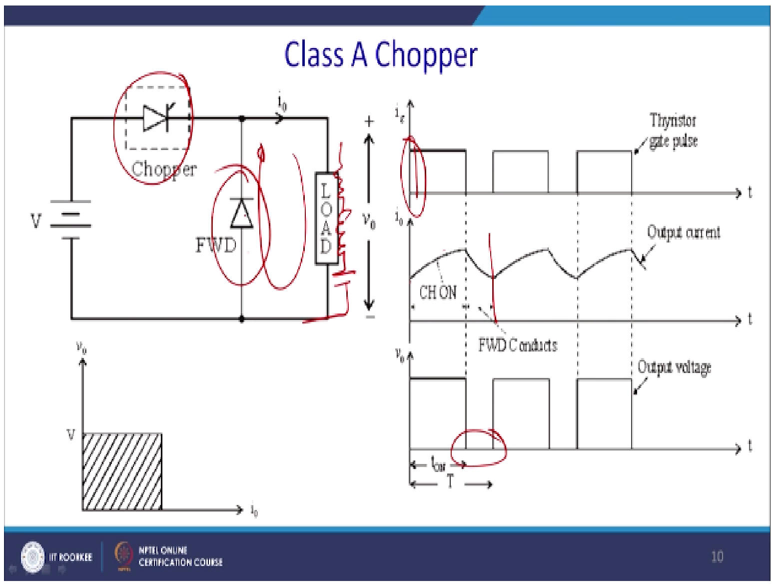

Now this is the Iv characteristics of this the chopper so you got a one Thyristor mostly and it has to be commutated by the conversation or you can use DTO. So you have a get pulses generally you have a this much of get pulse it is not followed. But if it is other kind of devices like IGBT or something because you know GTO are little constant get current to be maintained so that its forward conduction not required to be little lower.

So for this reason we have drawn this IG current, if it is Thyristor it was enough to once it is triggered so no more get current is require. So it can be GTO as well as Thyristor. So, and you have a actually a freewheeling diode to actually once it is off so current will circulate to it. And mostly it will have our LE kind of load because it is a fitting at DC motor you have a resistance that is armature resistance or the you can model in the mechanical power of the energy conversion as a resistance.

And thereafter you get an inductor because there is a huge series thereafter you have got a (()) (18:36) that can be modeled as a constant DC source. So you got a; and we assume that current inductance is quite high and due to the heavy torch a current is continuous so you will have a actually current once it is switched on so it is actually current will rise like this; once it is switched off so actually current will free wheel through the diode so current will drop and so on it will continue.

And output voltage since it is a continuous conduction mode so if diode is conducting and we assume that drop across the diode is negligible. So once it is ON actually the whole voltage comes across the load. Once it is OFF then voltage goes to the drop across the diode here will it is neglected so we will get a 0 voltage.

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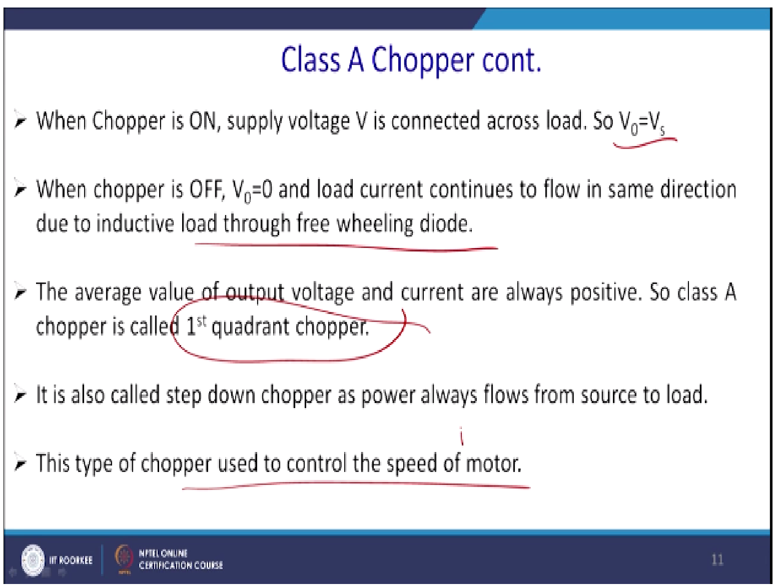

Now when chopper is ON the supply voltage phase is connected to the load so you get V0=Vs. When chopper is OFF output voltage become 0 because of the freewheeling action, so ultimately you can see that it is when; it is shorted since it is shorted so this output voltage become 0 and load current continuous to flow in the same direction due to the inductive loading and through the free wheel diode.

The average value of the output voltage and the current is always positive in Class A chopper. And for this reason it is called a 1st quadrant operation and it is called a step down chopper as power is always flow from source to load and this type of chopper is used to control the speed of the DC motor. Mostly this is series motor and defined it application in traction.

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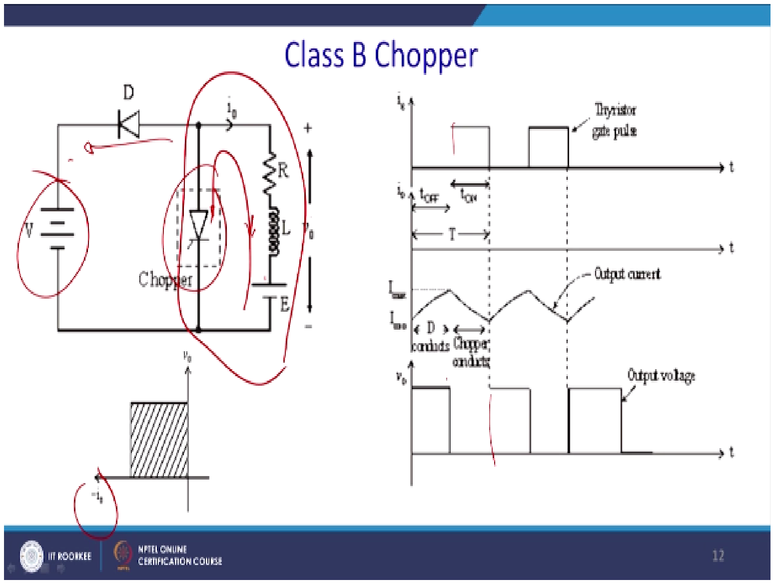

Now, this is a Class B generally it is use for please and see that actually this kind of thing is essentially are basically if you consider this part of the circuit. From this part of the circuit and just replace this thing switch and from here to here so it will see a boost topology. So this mode of operation is been done when you want actually battery to be discharged and fit the more voltage than the battery voltage or actually in a case of a regenerative braking of this DC motor.

So what happen when a switch is ON currently will ramp on and ultimately what happen when switch is off then high voltage will actually come across it. So output voltage become V+LDI DT = V0 and that voltage will be higher than V and ultimately it will fit the source, so for this reason it is called a regenerative mode of operations or since I0 is a negative direction so this will be a second quadrant operation. So we have a get trigger in pluses so it was off.

Once it is off actually you will have this actually current will go through it then after actually ones it will be actually flowing like this and output voltage actually when it is ON essentially becomes 0 and ones become OFF basically this voltage become V0 and this will fit the voltage. So this is the pulses so till that time voltage was 0, a withdraw pulses voltage become higher you are fitting in the source and ultimately this will be the chopper current I0 which has been shown here.

At this point, diode conducts and after that you know, this current become 0 and actually the switch conducts.

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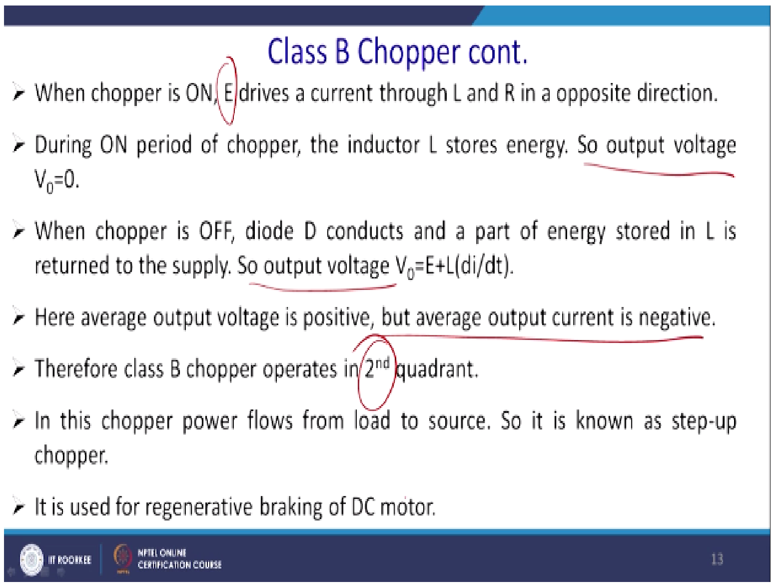

So when chopper is ON, the E the backend of the motor most of the cases will drive the current through the L and R in opposite direction. So it will fit the source. During ON period the chopper inculcator L stores energy, so output voltage V0=0. When chopper is OFF, diode D conducts and a part of energy stored in the inductor L is returned to the supply.

So the output voltage V0=E+L(di/dt). The average output voltage is positive, but average output current in this case is negative and its fit to the source. So therefore, the class B chopper operates in 2nd quadrant and this choppers power flow for the load to source so it is known as step of chopper and it is used for the regenerative braking of the DC motor.

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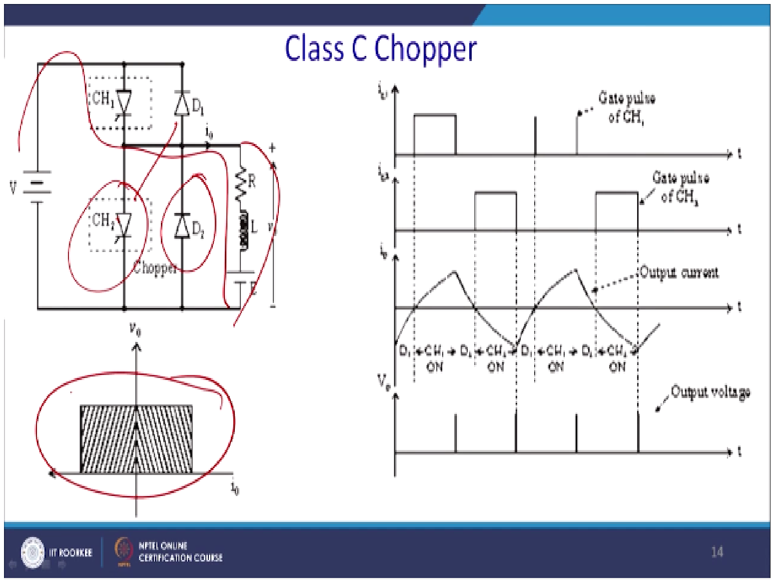

Now, Class C Chopper, essentially it will combine if you see actually this if you see this part of the chopper is a forward conduction mode for the Class A chopper. And this diode essentially makes it the CH1 if it is operated then generally D2 is operated. And if you want CH to be operated then D1 is operated, So CH1 D2 will have will make this chopper class A chopper and CH and D1 will make the chopper class B chopper.

And if you combine whole thing that becomes class C chopper that will operate in this quadrant. So, your get pulses for chopper 1 if you ON the chopper 1 then voltage current will flow through it and till this time actually this is ON. So CH1 will be ON and actually it will get the normal load current. Then, automatically the free wheel action will start ultimately you will find that this diode D2 is conduct. Similarly, thereafter CH will be ON and it will have a forward motoring mode with the system.

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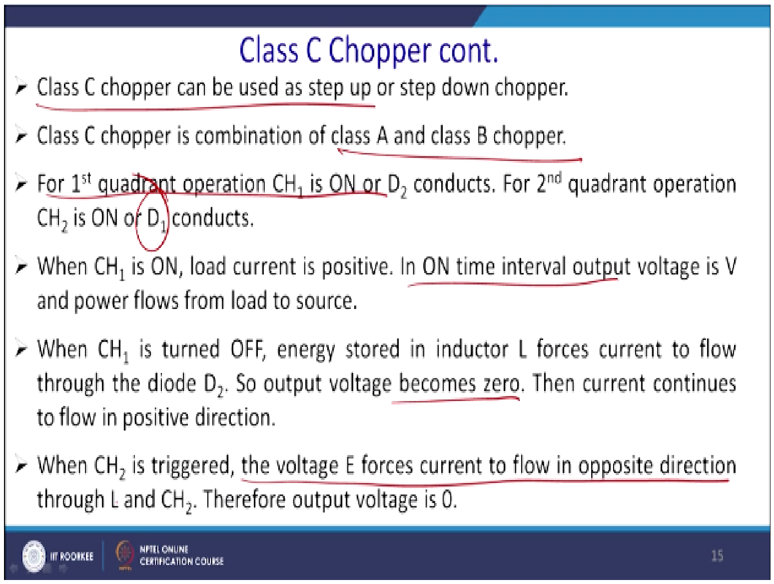

Then, so let us see does it operate. Class C chopper can be used for the step up and the step down. Class C chopper is a combination of class A and the class B chopper. 1st quadrant operation of CH1 and ON is on or D2 conducts and for the 2nd quadrant CH2 ON or D1 conducts. When CH1 is ON, load current is positive.

And ON time interval or the ON time interval of the output voltage V is a power flow from load to source. When CH1 is turned OFF the energy stored into the inductor L forces current to flow through the diode D2, so the output voltage becomes 0 when current continues to flow in the positive direction. When CH2 is triggered the voltage E forces current to flow in opposite direction through L and CH2 therefore, the voltage should be equal to 0.

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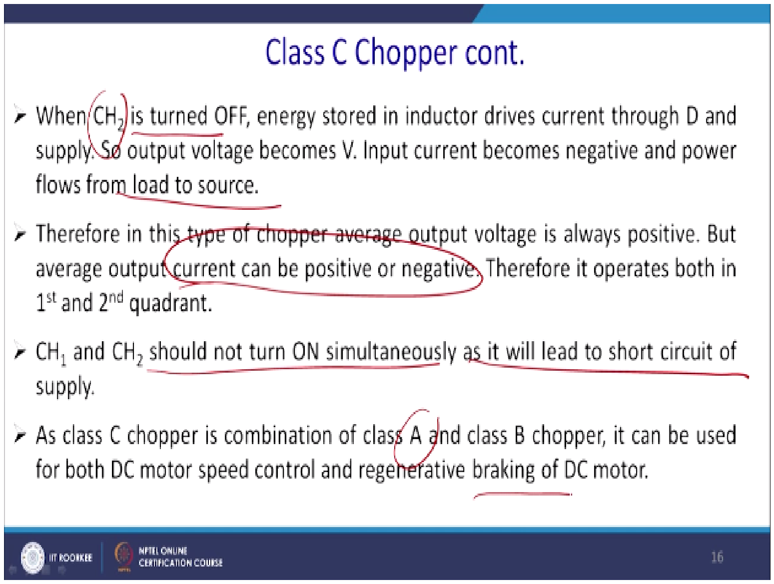

So when CH2 is turned OFF, the energy stored into the inductor drives the current through the D and supply so the voltage becomes V. The input current becomes negative and power flows from load to source. Therefore, in this type of chopper the average output voltage is always positive but average output current can be positive or negative, so that is the thing. So it can be both the polarity. So current is bidirectional.

Therefore, it operates both in 1st and 2nd quadrant. And CH1 and CH2 should not be turn ON simultaneously generally when it is when used as a complementary logic so CH1 is ON CH2 has to be OFF and vice versa. And it will lead to the short circuit of the supply. We have to ensure that actually proper time gap is given between the turn on and turn off this devices or this is actually diode comes into the picture, once CH1 is ON there will be a delay then CH2 can be ON, and in between diode will flow.

Class C chopper is a combination of the class A and the class B chopper and it can be used for DC motor speed control for motoring mode for armature voltage control and the regenerative of the DC motor when you want diode actually the source required to be searched from this actually the DC motor. So but there is issue involved, most of this actually you would have studied that if it is; power flow is unidirectional, so while using this mode this mode we require to be little cautious.

This source will have a capability to observe power. Most of the cases you know actually we generate this voltage by rectification by that diode which rectifier. And thus it is unidirectional current and flow to the AC side to the DC side. Unless you use a full control converter or the active rectifier so power is not possible to actually fit it back to the source.

So then what will happen if there is a capacitor this voltage will swell up, so this is one of the issues while actually operating in a regenerative braking if it is run through the get mode. So for this reason we may add a braking resister here if we want actually the protection of this set.

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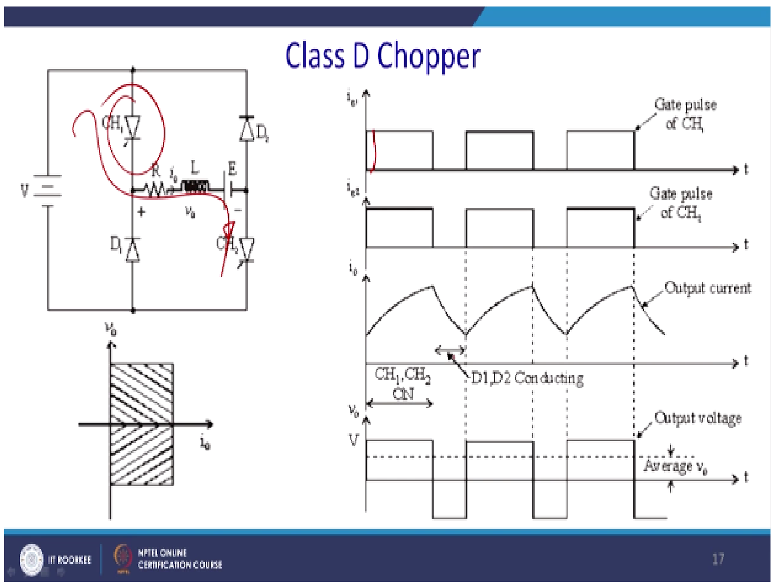

Now come to the Class D chopper. Class D chopper is essentially you know what it does do it can actually change the directions of the motor, so it is reverse rotating is possible. And so it has a forward motoring mode and the reverse motoring mode. So this IG1, if it is Thyristor it will be it will require a very small amount of current. But we require to add commutation circuit for it so either of it, so it will continue to conduct like that.

And in this mode we say that it is a forward motoring mode, so Thyristor T CH1 and the CH2 will conduct and ultimately will be rising in this direction as shown here. And then what happen when it is Thyristor is OFF then diode will come into the picture of the conduction. So diode D1 D2 will conduct here and you will get a negative voltage. Since you are getting a negative voltage while conduction of the D1 D2 for this it will operate 1st and 4th quadrant.

Please remember that class C operate this quadrant and it is a combination of the motoring forward motoring and the regeneration and it is the forward motoring and the reverse motoring. So you will get this kind of voltages and ultimately as you see that you can make the directions of the E negative it means that the direction of the; if you can make negative it means that you can lead the motor to rotate in the reverse direction. So it is also a 2-quadrant operation.

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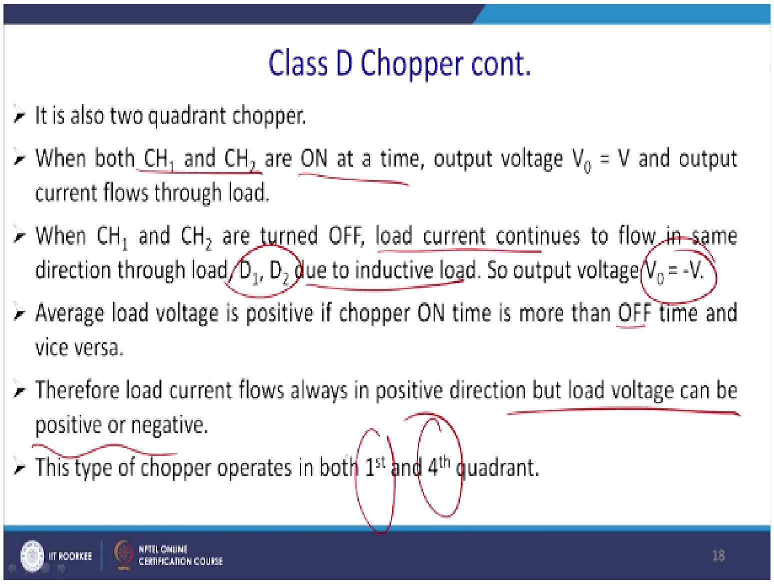

Both CH1 and CH2 are ON at a time and output voltage becomes V0 and the current will flow through the load. Please note that here the average output voltage is positive. You can actually change it like this then output average assuming that current is a continuous conduction mode, average output voltage can be made negative and thus you are applying a negative voltage and it will be actually operating the actually in the negative direction.

When CH1 and the CH2 are turned OFF, the load current actually is assumed to be continuous and so that it is actually has a high torch to deliver. And continuous to flow in the same direction through diode D1 D2 due to the inductive load and this output voltage become –V. The average load voltage is positive if chopper is ON is more than the time of T OFF and vice versa. So if is T ON it is more than T OFF then it is the forward motoring mode.

If it is T OFF in more than T ON it is a reverse motoring mode. And therefore, load current flows always in a positive direction but the voltage changes positive where the load voltage changes to the positive and the negative voltage polarity. This type of chopper operates in 1st and the 4th quadrant that is actually the for the motoring purpose we say that forward motoring and the reverse motoring mode.

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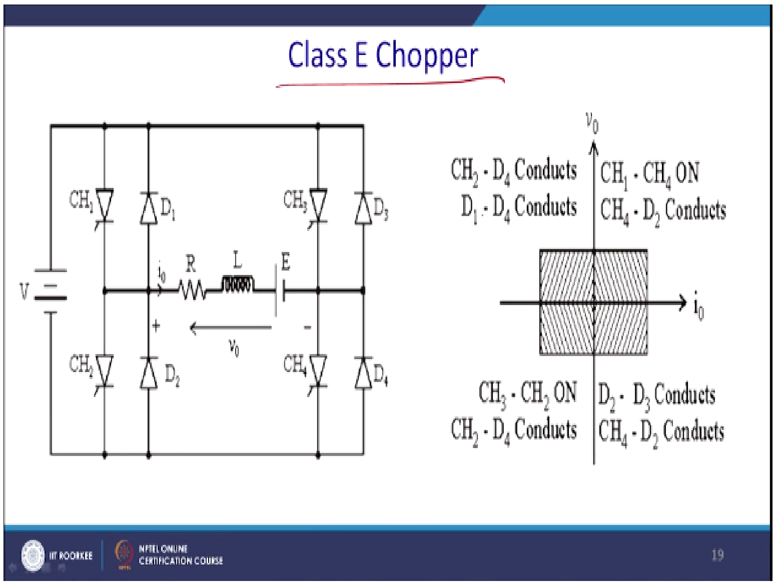

So another thing is that Class E chopper there is a combination of all forwarding motoring, regenerative braking, forward regenerative braking, reverse motoring and the reverse regenerative braking. We shall continue to our discussion with the Class C chopper in our next class. Thank you for your attention.