Power Electronics

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Lecture - 27

In our last class we discussed the operation of buck-boost converter and cuk converter. The transfer function of buck-boost converter is D divided by 1 minus D. The ratio of output voltage, magnitude of output voltage to the input DC voltage is D divided by 1 minus D. Another feature of buck-boost converter is that the output voltage is negative with respect to the negative bus of the DC input. It is negative, output voltage is negative.

So therefore, ideal buck-boost converter, the output voltage tends to infinity as D tends to 1, whereas, a non ideal buck-boost converter, output voltage tends to 0, similar to a boost converter because the assumptions that we made are not valid for high values of D. For D less than or equal to 0.5, the magnitude of output voltage is less than or equal to the source voltage and for D greater than 0.5, the magnitude of output voltage is higher than the input.

So, what is the relationship between the average source current and the average value of the load current? I have derived this for buck as well as boost converters. The same procedure, you equate the input power to output power assuming the converter is loss less. So, average value of the input voltage is V_{DC}. So, average value of the output voltage is D divided by 1 minus D. So therefore, the average value of the output current is the inverse of inverse of the ratio of the voltages. It is 1 minus D divided by D.

So, input power is equal to output power. You just equate it. So, if voltages are related by D divided by 1 minus D, currents are related by 1 minus D divided by D. What about the cuk converter? Why why cuk converter is so popular? Though the transfer function of cuk converter is same as that of a buck-boost converter, D divided by 1 minus D, current and voltage relationship is the same. But then, why it is so popular? Why it became instantly popular?

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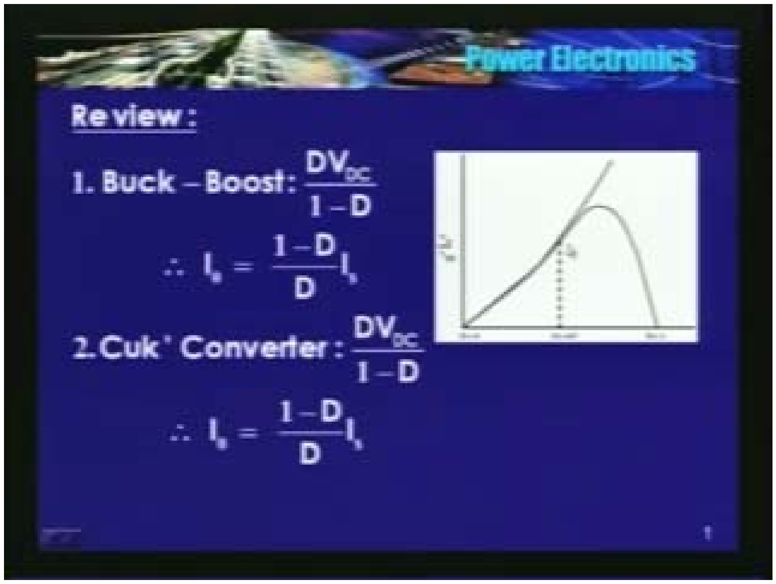

So, you see the slide here, this all we have discussed in the last class. Ratio is 1 at D is equal to 0.5 tends to infinity, whereas, non ideal buck-boost reaches a peak, is again, at depends it depends on the function of the internal resistance of the inductor and the load resistance. Remember, D_{max} for buck-boost is not the same as that of the boost and it becomes 0 at D is equal to 1.

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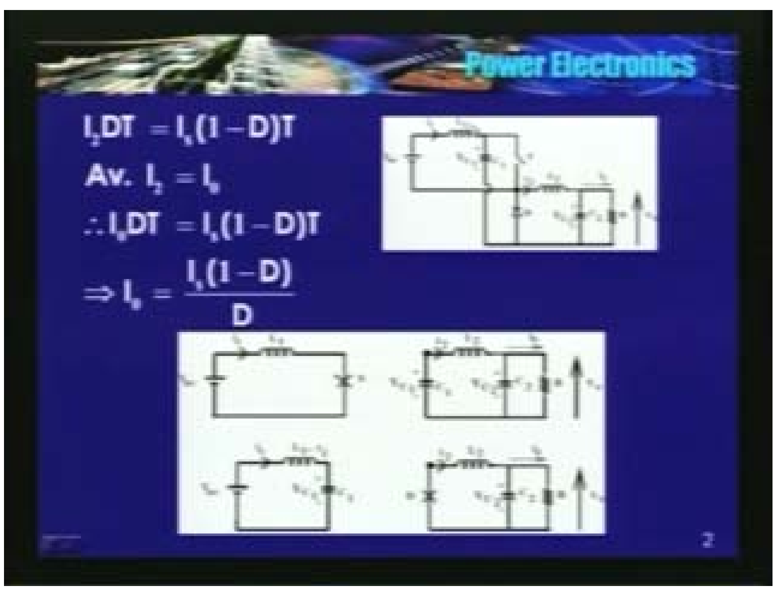

Now, coming to cuk converter, there is a capacitor connected in between this inductor and the output stage or this is some sort of an intermediatory voltage source, an intermediatory voltage source. So, when I close S, current is or energy stored in the inductor V_{C1} is applied to the load because this point gets connected here. So, V_{C1} is applied to the load.

I said, there is an inductor here and a voltage source. So, I can represent this combination by a current source. So, current varies smoothly unlike in buck and buck-boost. There are no sudden changes in the source current. Source current jumps to a value which was flowing through the diode just prior to closing the switch and becomes instantaneously 0 when I open the switch, both in buck as well as buck-boost. So, that sort of a thing is absent in in the cuk converter. Open S, stored energy in the inductor is transferred to the capacitor.

So, we had represented this case, this combination in a buck converter by current source. I told you, there is an inductor is always present is always present across, always present in the circuit. So, we can represent it by a current source. So, I can say that capacitor C_1 discharges discharges at a constant rate. Here, i_2 does change over a very small band ...

So, I can assume that capacitor C_1 discharges at a constant rate. Now, when I open S, stored energy in the inductor is transferred to the capacitor V_{C1} and I told you that I can represent this combination by a current source. So, capacitor charges here at a constant rate. Just the opposite; when I close the switch, the intermediatory capacitor discharges and when I open the switch, intermediatory capacitor charges. Both are at constant rate but then the values of these 2 values, the load current and the source current are different.

So, if you see the equivalent circuits, so this is nothing but a boost converter where V_{C1} can be represented by the load here. So, the relationship between V_D and V_{C1} is is given by 1 divided by 1 minus D or V_{C1} is equal to V_{DC} divided by 1 minus D, whereas, this is nothing but a buck converter with the input voltage or forcing function of V_{C1}. The relationship between V_{C1} and V_0 is is proportional to D or V_{C2} or V_0 is proportional to D into V_{C1}. Now, how about the current relationship?

Boost converter, voltages are related by 1 divided by 1 minus D. So therefore, currents are proportional to 1 minus D, inverse of that. So therefore, average value of the source current i_S and the capacitor current, assume that capacitor current I_0 is given by 1 minus D. But then the same capacitor current is is is flowing through the load or the average value of the capacitor current is nothing but average value of i_2 itself. So, that is we have a relationship between average value of the source current and average value of the load current for a buck converter.

What is that? Average value of the source current is D times, D times the average value of the load current. So, I will equate it here. You will get i_S divided by 1 minus D into D. So, this is nothing but a boost. You write a relationship between the currents, capacitor current and i_S. This is nothing but a buck converter. There is a relationship between the source current and the load current, average values.

Now, substitute and you will get the relationship between i_S and I_0. So, this directly, so we have a current source at the input and we have a current source at the output. Both are the current source. So, how does the current, how does the various wave forms look like? We will draw it for the continuous current because both, I said, input as well as output is a current source. So, we can safely assume that assume that current is continuous. How do they look like?

Close S, source current increases linearly. Same, even $i_{2,}$ the current that is flowing through the inductor L_2 also increases linearly because now capacitor V_{C1} is supplying power. When I open the when I close the switch, input stage or input inductor is being charged by the source voltage, whereas, at the load side, the power is being supplied by the intermediatory capacitor $V_{C1.}$ So, there also i_2 increase linearly. So, they look like, something like this.

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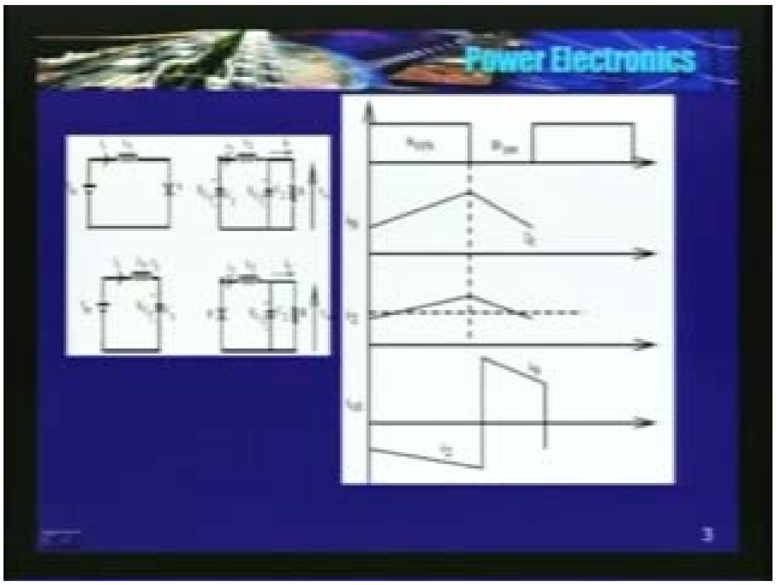

When I close S, current increases: when I open S, current decreases linearly. Similarly, similarly at the at the load side, when I close this; this is the equivalent circuit, V_{C1} supplies power, current increases linearly and when I open S, current freewheels through D. So, current decreases linearly. By the way, the diode has to carry i_2 as well as i_S, i_2 as well as i_S. If you see in this circuit, see, diode as to carry the current i_2 as well as i_S, i_S. The circuit as i_S, when the switch is opened flows like this and i_2 flows like this.

So, how does I_{C1} look like? I_{C1} is or capacitor 1 is supplying power or i_2 to the load. So, if this is $i_{2,}$ i_C is this. Same, the opposite direction, capacitor is discharging at a constant rate or at a rate determined by $i_{2.}$ This is $i_{2,}$ capacitor current I_{C1}. When I open S, what happens to I_{C1}? It is same as the source current now, it is charging. So, this is the current that is that will flow through the capacitor C_1 and I am assuming that the capacitor current or the source current is continuous. So, when I open when I close the switch again, I_{C1} instantaneously jumps to $i_{2.}$ It starts supplying $i_{2.}$ So, this is I_{C1}, how does I_{C2} look like?

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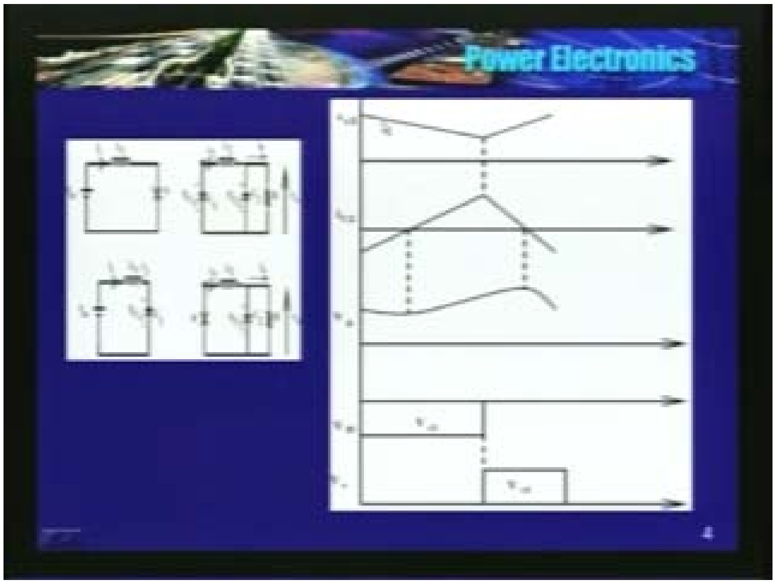

So, capacitor V_{C1} is discharging and it is charging here. How does I_{C2} look like? Now, I need to apply KCL at this point, at this node. As long as i_2 is higher than $i_{0,}$ the difference in i_2 minus i_0 will flow through the capacitor. If i_2 is greater than $I_{0,}$ V_{C2} will charge and when I_{C2} is less than $I_{0,}$ capacitor will discharge.

So see, this is the variation of $i_{2.}$ This is the average load current. So, in this duration, capacitor will discharge. Mind you, capacitor current linearly changes and here also, beyond this point, capacitor is discharging in this region. When i_2 is higher than the average load current, capacitor is charging. So, this is constantly increasing, this is constant. So therefore, the capacitor current I_{C2} is also linearly changes. So, this sort of a variation in voltage wave form, we have seen in the buck converter, buck converter.

So therefore, in a boost and a buck-boost converter, the output capacitor current changes drastically, in the sense, the entire load current is being supplied by the output capacitor when the switch is closed, both in boost as well as buck-boost converter, whereas here, the capacitor current, even at the, which is connected at the load side gradually changes, gradually changes.

Now, what is the voltage that is coming across the diode as well as the switch? So, when I close switch S, V_{C1} appears across the diode. If you see in this circuit, see, when I close S, this point gets connected here or entire V_{C1} appears across D or in other words, D should block V_{C1}. Again, V_{C1} is a function of the duty cycle, is related to V_{DC} by 1 divided by 1 minus D. So, maximum value of V_{C1} that the diode should block and what is the voltage that is coming across S?

What happens when I open S? When I open S, diode starts conducting, diode starts conducting. It carries both, the load current or i_2 as well as i_S. So this point gets connected here. So, voltage across the switch is also the capacitor voltage V_{C1} because this point and this point is the same.

When the switch is opened, diode starts conducting. So, this point gets connected here. So, voltage that is coming across S is V_{C1} itself. So, this is the voltage across the diode V_{C1} and this is voltage across the switch. That is about the cuk converter.

So, we have studied 4 DC to DC converters; buck, boost, buck-boost and cuk converters. Now, let us solve few problems in these DC to DC converters.

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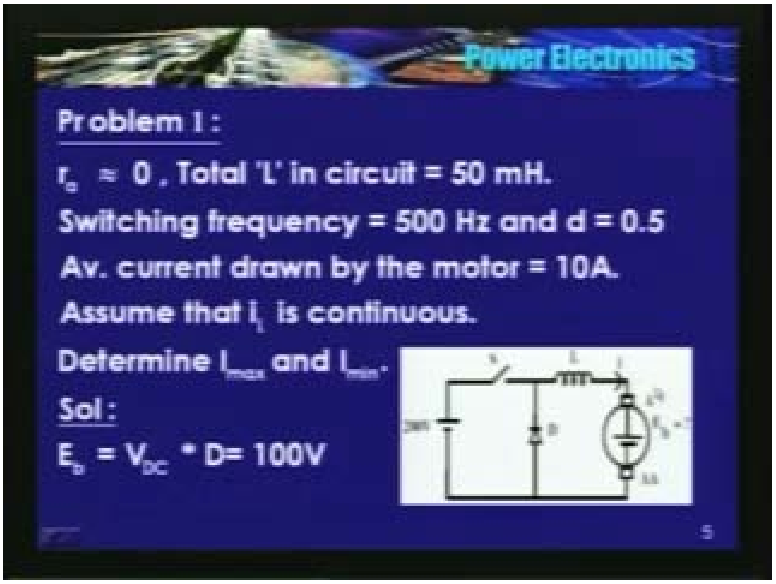

The first problem is a buck converter feeding a DC machine. The problems says that R is 0, total inductance is 50 millihenries, switching frequency is 500 hertz, D is 0.5, average current drawn by the motor is 10 amperes, $I_{average.}$ Assume that i_L is continuous or assume that load current is continuous, assume that load current is continuous. Determine the peak to peak ripple in the load current. We know that when I close S, load current increases and when I open S, load current decreases. So, what is the peak to peak voltage ripple?

It is said that current is continuous. So, input voltage is given which is 200 volts, D is given, R_A is 0. So therefore, output voltage, average value of the output voltage that is coming across the armature terminals is D into $V_{DC.}$ So, D is 0.5, V_{DC} is 200 volts. Therefore, applied voltage to the armature is 100 volts. It is said that R_A is 0, armature resistance is 0. Therefore, applied voltage to the armature is same as the induced emf E, E_b or the back emf. Otherwise, it is E_b plus I_a R_a. So therefore, E_b also equal to 100 volts. Now, how do I determine the peak to peak ripple in the load current? So, what happens when I close S?

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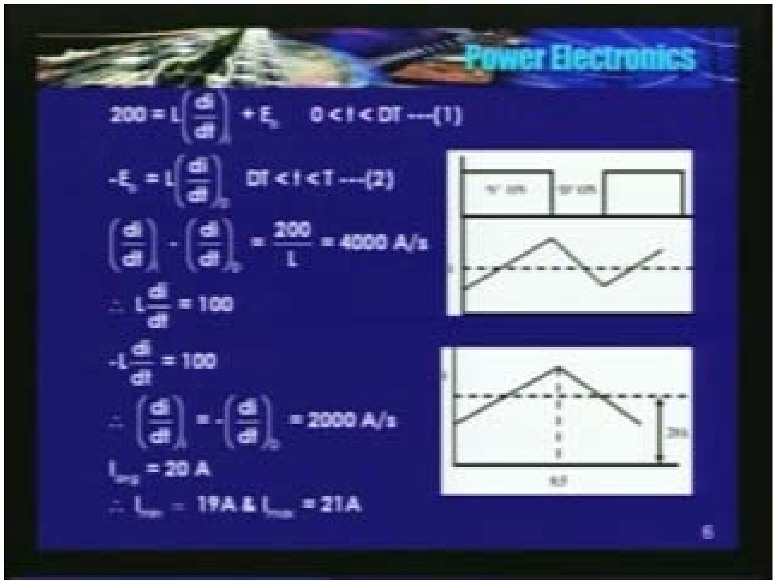

Current starts from I_{min}, increases linearly and it attains a maximum value I_{max}. So, what is the voltage equation? V_{DC} is equal to L di by dt plus E_b. Resistance is 0 and when I open S, current flowing through the load, it freewheels through the diode. So, KVL says that L di by dt is minus E_b from DT to T. So, it looks like this; S_{on}, D_{on}, this is the armature current, increases linearly, reaches the peak, comes down. So, this is the average value of the armature current, 20 amperes. So, these are the 2 equations that we wrote.

So, I di by dt, put a suffix here, that is increased and I put a decrease. Now, using this equation subtract. What do you get? di by dt I minus L di by dt decrease is equal to 200 divided by L, 200 divided by L. From these 2 equations, I will get this. So therefore, L di by dt is 100, L di by dt is 100. How? See, it is very obvious here, 200 - average value, Eb also is 100, so remaining L di by dt is 100 and minus L di by dt is also 100. So, you substitute these values in this equation. You will get L di by dt is 100, minus L di by dt is also 100. So, this is what we get here, if I substitute. So, di by dt is 2000 amperes per second. Value of L is known, value of L is known, it is how much? It is 50 millihenries, L is 50 millihenries, it is given.

So, I know this slope, I know the average value, I know the time for which this switch is closed. So, this point is DT by 2. This is linear, this is 20 amperes, I know the slope, so I can calculate this as well as this. So, it is all you will get. I_{min} is equal to 19 amperes and I_{max} is equal to 21 amperes. So, if I know the slope, if I know the average value, I can always determine I_{min} and I_{max} because I know all these values. So, they found to be 19 amperes and 21 amperes.

So, armature current is varies between 19 and 21, 19 and 21. So, if the armature current varies from 19 and 21, therefore, torque also will pulsate, torque also will pulsate in this. So, in order to reduce the torque pulsation, I need to reduce this ripple - I $_{min}$ difference between I_{min} and I_{max}. So, that will call for a higher switching frequency or the different value of L. So, we we did derive the expression for the current in the the the ripple in the inductor current. So, use that expression and if you want to minimize the ripple, find out the new value of L for the same input and output conditions.

A Second, very interesting problem, so what it says? Nothing but a boost convertor nothing but a boost convertor, 100 volts, inductor of 100 micro henries, there is a switch connecting to ground and through a diode it is connected to a 300 volts source.

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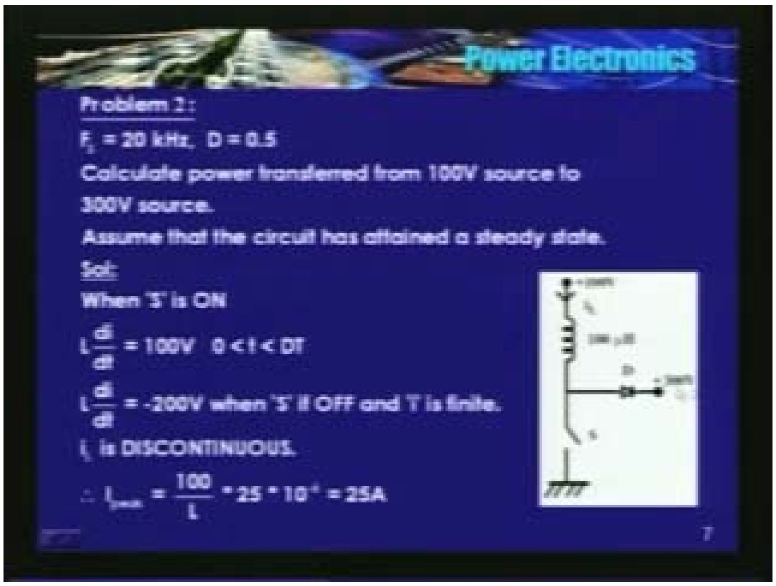

So, how does this work? When I close S, diode is reverse biased because this point gets connected here to ground. Cathode is connected to 300 volts. So, inductor charges at the constant rate, L di by dt is 100 volts. Open S, the stored energy is being transferred to the source. The essential condition for the boost convertor to work is output voltage or V_0 should be higher than V_{DC}. So here, V_0 is 300 volts, V_{DC} is 100 volts.

Problem says, switching frequency is 20 kilo hertz, D is equal to 0.5. Calculate the power transferred from 100 volts source to 300 volts source. Frequency is 20 kilo hertz, D is 0.5, power transferred from 100 volts to 300 volts. Assume that circuit has attained a steady state. Let us solve. It is not mentioned that whether the current is continuous or not. Now, you need to tell me whether the current will be continuous or not, giving the circuit equation.

Input is 100, output is 300, duty cycle is 0.5. In other words, time for which energy stored is same as time for which energy is allowed to transfer to to the load. So, when I close S, the forcing function is 100 volts. 100 volts is being applied to the inductor for some time, current increases linearly and switch is opened for the same duration, D is equal to 0.5. But then now, the voltage that is coming across the inductor is 200 volts. 100 at the input or source voltage, load voltage is 300 volts.

So, when I close the switch, voltage that is coming across the inductor is 100 volts. When I open the switch, voltage that is coming across it is 200 volts. Duration for which the switch is opened is same as the duration for which the switch is closed. Therefore, inductor current has to be discontinuous.

See, for steady state, voltage across the inductor, average value should be 0. I can have a positive voltage appearing across the inductor. That means current is building up but then definitely, I cannot have a situation wherein, average value across the inductor being negative. In this case, 100 volts is being applied for D into T across the across the inductor. When the switch is closed, plus 100, when the switch is opened, voltage across the inductor is difference of 2 voltages, 300 minus 100 that is 200 volts for 1 minus D duration. So, D is 0.5, so 200 into 0.5 cannot be equal to 100 into 0.5.

What is the peak value of the inductor current? Peak value of inductor current is 100, the voltage that is applied divided by L into time for which the switch is closed or 100 divided by L into D into T, D into T. So, D is 0.5. So, you will get 25 amperes.

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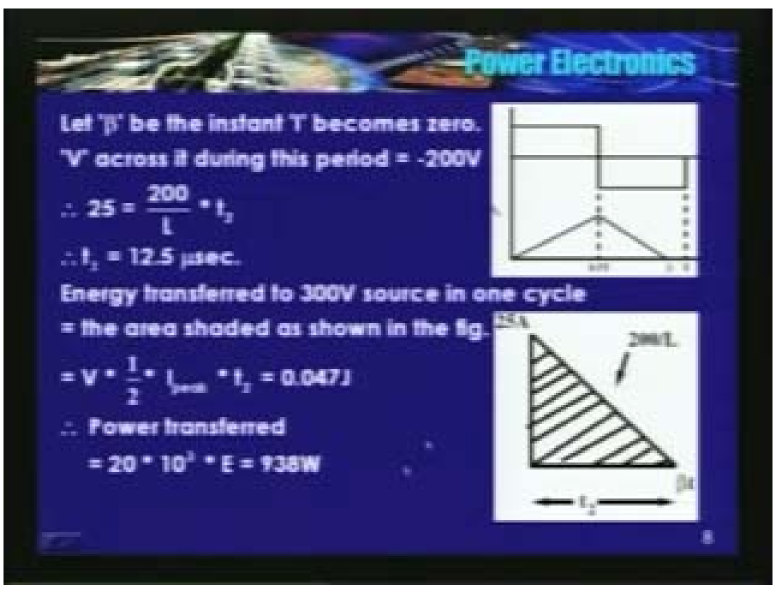

So, at at 0.5 T, current is maximum. So, current, when I open S, current starts flowing through the 300 volts source and current falls linearly. Voltage that is appearing across the inductor is 200 volts, it follows linearly. So, slope of this line is 200 divided by L and let beta be the instant where the current becomes 0. I know the slope, I know the peak current, I know the peak current, I know the slope of this line. So, I can calculate this point or T_2.

So definitely, if this is 25, forcing function is 100. If this is 200, forcing function is 200. This should be half of this, 12.5 micro seconds 12.5 micro seconds. Previous one was 25 micro seconds, whereas, this is 12.5 micro seconds.

Now, what is the energy that is transferred to the 300 volts source? It is the area or is proportional to the area under this curve, this. The average value of the output voltage that is 300 volts into average value of the, this current or will give you will give the output power. So, what is the average value that is or energy transferred? 300 into this, half of i_{peak} into T, it is the area of this triangle divided by the whole time period will give the average value of this current or the cycle. Is that okay? The area of this triangle divided by the total time period T is the average value of the current that is flowing into the source flowing into the source.

So, that is what I did, 300 half into i_{peak} into T_2 divided by the total time period or multiplied by the frequency 1 and the same, 20 kilo hertz or divided by the time period 1 over T. So, power that is received is 938 watts.

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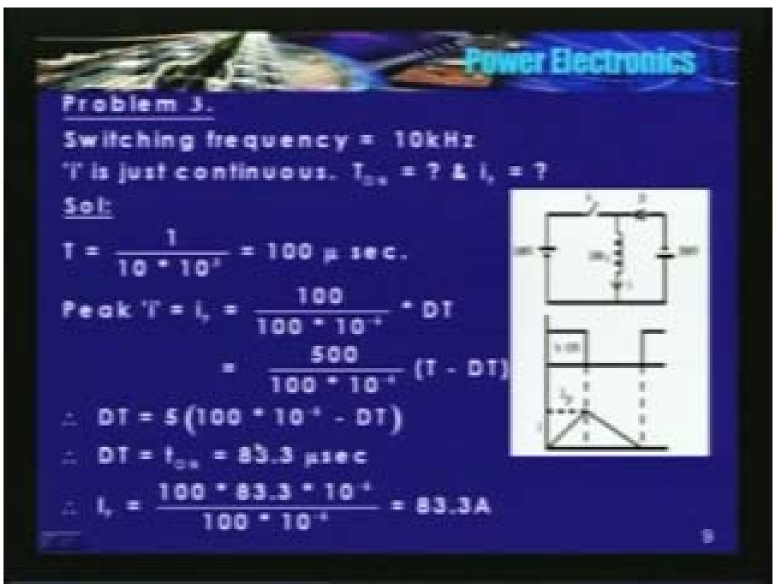

We will solve another problem, a problem on buck-boost. The input source voltage is 100 volts, output voltage is 500 volts, value of L is 100 micro henries, switching frequency is 100 kilo hertz, the current is just continuous, current is just continuous. So, what is T_{on} and the peak value of the inductor current? How do I solve?

Current is just continuous, so it starts from 0, reaches a peak just prior to opening the switch. What is the voltage that is appearing across that inductor when the switch is closed? It is the source voltage itself. So, in this case, source voltage is 100 volts, current is just continuous, current is just continuous. So, it becomes 0 just prior to closing the switch in the next cycle. But then the voltage that is appearing across the inductor when the switch is open is the output voltage, is the output voltage.

So, in this circuit if you see, close S, diode cannot conduct, 100 volts appears across this inductor. Open S, stored energy is transferred to this 500 volts source. So, voltage that is appearing across this is 500 volts. Current is just continuous, so it starts from 0, reaches a peak, touches 0 just prior to closing the switch again. So, I know the slope of this line. What is the slope of this line? V divided by L. V is 100 volts, L is 100 micro henries. So, peak value is D into T. So, this value is D into T. I know the slope of this line, I know this peak value. So, equation for this line is same, 500 is the forcing function, 500 divided by L into T minus DT is the equation for this line. The slope of this is proportional to output voltage 500 volts, whereas, this slope is the input voltage V_{DC}, 100 volts. So, peak value is 500 divided by 10, the value of inductor into T minus DT.

Now, both are the same both are the same. So, I will equate it, I will equate it and you find that DT or T_{on} is 83.3 micro seconds. So therefore, the value of peak current, you substitute here. You get as 83.3 amperes, 83.3 amperes, a very simple problem.

Again a buck convertor; input is 60 volts, output is 12 volts, inductor that is connected is 20 micro henries, millihenries. 20 millihenries is the inductor that is connected in series. Average current that is flowing is 5 amperes. The question is what is the peak to peak ripple flowing through the load? Switching frequency is 1 kilo hertz, duty cycle is 0.2.

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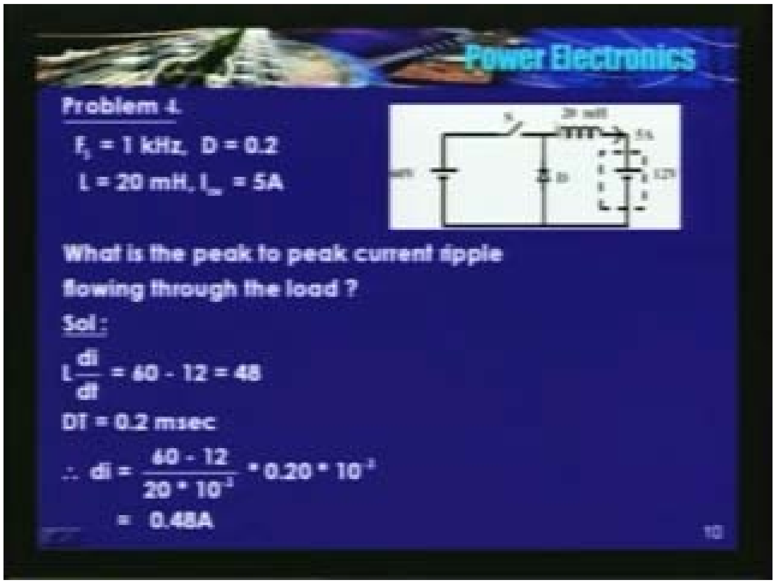

So, the problem, simple circuit buck convertor; 60 volts, battery is 12 volts, 20 millihenries - the inductor that is connected, 5 amperes is the current that is flowing, switch is controlled at or switched at 1 kilo hertz with D is equal to 0.2. What is the peak to peak ripple? It is a straight 1 line problem. I know the input, I know the output, I know the value of inductor, I know the time for which the switch is closed.

1 simple equation; L di by dt is equal to V_{in} minus V_{out}. So, whether the current is starts from 0 or starts from any finite value, does not matter, it has to starts from I_{min} and just prior to opening the switch, it has reached a peak in a buck convertor. When i starts from the minimum value, it could be 0, does not matter. It reaches a peak just prior to opening the switch. So, the difference between I_{min} to I_{max} is is peak to peak ripple and this depends only on the voltage that is appearing across the inductor. Value of the inductor and time for which it is closed, everything is known. L is known, time for which it is closed, DT is also known. So, di is straight forward, 60 minus 12 is a voltage appearing across inductor. This is this, L is 20 millihenries and D into T. D is 0.2 and this is T, is 0.48 amperes, this is the peak to peak ripple.

So, we have solved quite a few problems. Last and a very interesting problem in cuk convertor, very interesting problem in Cuk convertor, input voltage in a Cuk converter is 50 volts, output voltage V_0 is 150 volts, peak to peak ripple in a current flowing through L_1 and L_2 is 1 ampere. See, peak to peak ripple in both the inductors is 1 ampere. So, I can assume it as if like, they are current sources and peak to peak ripple in the intermediatory capacitor voltage is 10 volts or V_{C1}, peak to peak ripple in V_{C1} is 10 volts and peak to peak ripple in output voltage that is V_{C2} is 1 volt.

See, that is the reason I always said that output voltage in any converter can be assumed to be constant and ripple free. It is always desirable or or it is expected that power supply maintains a constant voltage across the load. So, V_{C2} is peak to peak ripple in V_{C2} or V_0 is 1 volt, intermediatory stage V_{C1}, the ripple in V_{C1} is 10 volts.

The switch is switched at 25 kilo hertz, switching frequency is 25 kilo hertz and we have been asked to neglect the internal resistance of L_1 and L_2. So, we will solve this problem.

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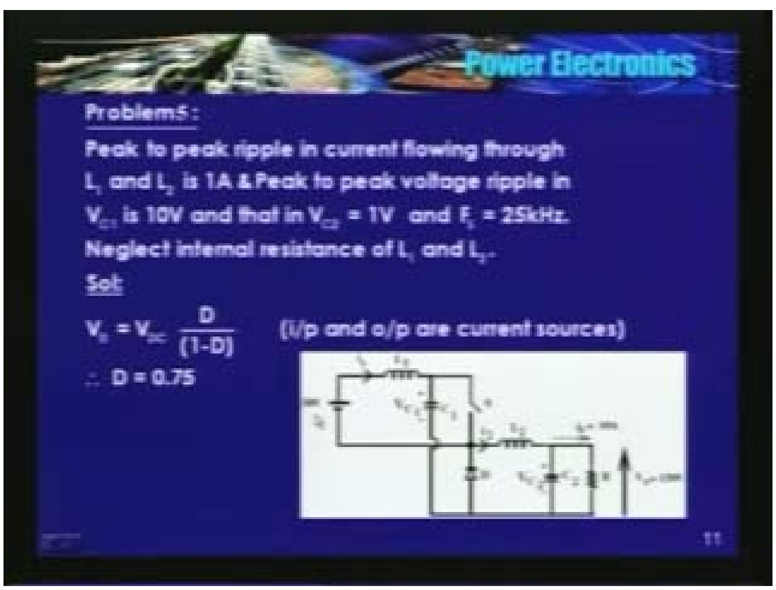

The relationship between V_0 and V_{DC} is given by D divided by 1 minus D or V_0 is equal to V_{DC} into D divided by 1 minus D. So, we know the source voltage 50 volts, output voltage 150 volts. So therefore, D is equal to 0.75. So, switching frequency is 25 kilo hertz, D is 0.75. So, we know the time for which S is closed and opened.

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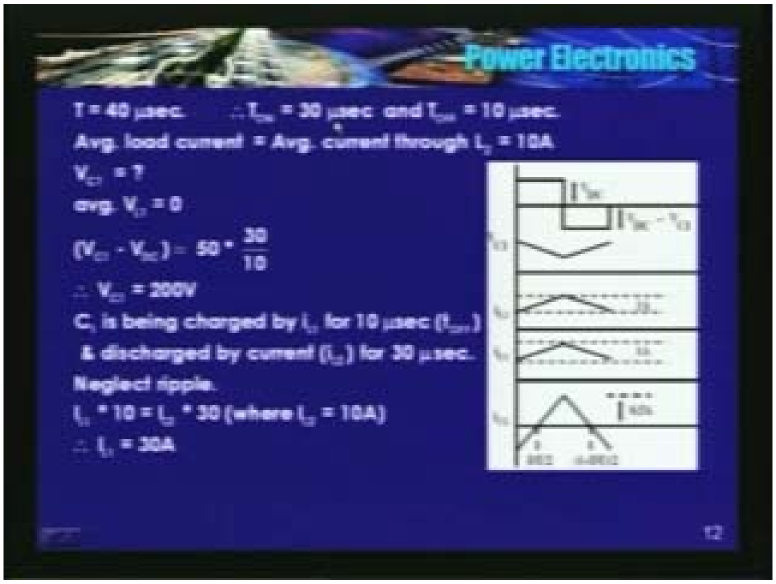

So, what are they? The total time period is total time period is 40 micro seconds, T_{on} is 30 micro seconds because D is 0.75 and T_{off} is 10 micro seconds. Now, how do I calculate V_{C1} and the ripples in the inductor currents and the output voltage?

We know that average voltage across the inductor is 0 at steady state. So, what is the voltage appearing across the inductor L_1? I have to calculate V_{C1}. I can calculate V_{C1} only from the input and the time for which the switch is closed. For that I need to equate, I need to equate the average voltage across the inductor to 0 or in other words, I can straight away apply because I know the input voltage, I know D, I can calculate V_{C1}, V_{C1}.

So, voltage across the inductor when the switch is closed is V_{DC} and when it is open, it is V_{DC} minus V_{C1}. So, I will equate it, we find it to be 200 volts. This also should be equal to, this also should be equal to V_{DC} divided by 1 minus D. V_{C1} is nothing but V_{DC} divided by 1 minus D. This is the nothing but a boost converter. So, V_C, supply voltage is 50 volts, D is 0.75, so, 1 minus 0.75, 0.25. So, 50 divided by 0.25 is 200 volts.

How do I find out the average value of current that is flowing through the inductors? What do I need to assume or what is the principle? Average current flowing through the capacitor at steady state should be 0. V_{C1} or the capacitor C_1 discharges at a constant rate. Current that is flowing out of the capacitor C_1 when the switch is off is the average load current itself and capacitor charges at a constant rate and this current is proportional to the source current. So, capacitor discharges at a constant rate and that current is average value of this current is same as the load current and capacitor charges at a constant rate and this current is proportional to the source current.

So, capacitor is being charged for 10 micro seconds, duration for which the switch is opened and capacitor C_1 is being discharged for 30 microseconds or the duration for which the switch is closed. So, I will neglect the ripple in i_{L1} as well as i_{L2}, I will neglect the ripple in i_{L1} as well as i_{L2}. It is said that ripple in current is 1 ampere, so I will neglect it. So, i_{L2} is the current that is flowing in the inductor 2, L_2. So, iL_2 into 30 micro seconds for which the device is closed or this is the period the capacitor is discharging and 10 micro second is the period for which the capacitor is charging at i_{L1}.

It is mentioned that average load current is 10 amperes. We know that average value of the capacitor current is 0. So, average value of the load current should be equal to average value of this inductor current I_2. So, i_{L1} comes out to be 30 amperes, i_{L1} comes out to be 30 amperes.

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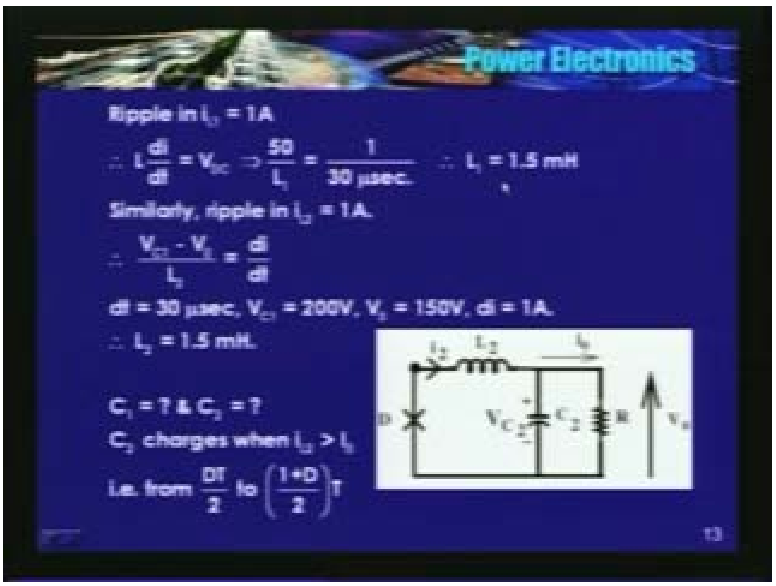

What is next? How do I determine L_1? How do I determine L_1? Ripple is given, ripple is given, ripple is 1 ampere, time for which switch is closed is also given. So, what is the circuit equation? Circuit equation is Ldi by dt is equal to V_{DC}, Ldi by dt is equal to V_{DC}. So, 50 volts is the input voltage L_1, ripple in the L_1 is 1 ampere or di is 1 ampere in 30 micro seconds in 30 micro seconds. 50 is the input voltage, L_1 is the inductor value, 1 is the ripple in the current, 30 micro second is the time for which the device is closed. So, you will get L_1 to be 1.5 micro or 1.5 millihenries. I do not know, may be, micro, milli. Find out, it is this. Looks like, 1.5 millihenries.

Similarly, ripple in the inductor 2, it is 1 ampere and what is this ripple proportional to? See, when I when I see when I close this switch, voltage that is appearing across L_2 is V_{C1} minus V_{C2}. So, that is the voltage that is coming across the L_2. I know V_{C1} which is 200 volts, I know V_0

150 volts, time for which this circuit is known or is same as the time for which the switch is closed.

So, I can calculate the value of L_2. V_{C1} minus V_0 divided by L_2 is the rate of change of current. Rate of increase in current, di by dt. Switch is closed for 30 micro seconds. This is 1 ampere, 1 ampere. V_{C1} is 200 volts, V_0 is 150. So, you can calculate $L_{2.}$ Now, what is the value of C_1 and C_2? How do I calculate C_1 and C_2?

Now, to determine C_2, I need to know the time for which C_2 is charging and C_2 is discharging. Similar to buck converter, C_2 charges when the inductor current I_2 is less than the load current sorry the capacitor C_2 charges when the inductor current is higher than the load current, higher than the load current, higher than the load current.

So, that can happen that happens from DT by 2 to 1 plus D divided by 2 into T. We are assuming the current increases. See here, current increases and decreases. i_{C2} is charging in this period and during this period i_{L2} is higher than higher than the load current. So, this is DT by 2, this is 1 plus DT by 2, 1 plus DT by 2.

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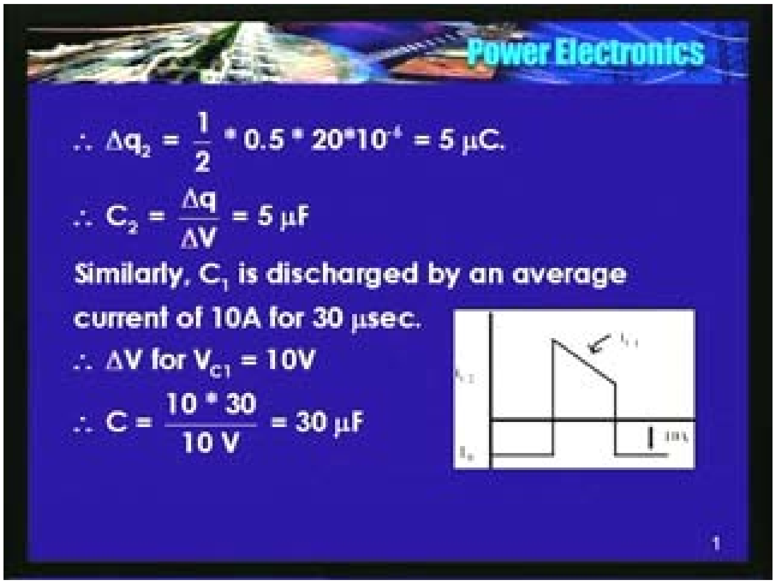

So, the charge that is lost is given by this 0.5 is the, see, this is peak to peak ripple is peak to peak ripple is 1 ampere. So, this is definitely 0.5 amperes. Peak to peak ripple in both of them is 1 ampere, so this is 0.5. So, this is known, I need to find out the area. So, it is this, this is the charge, this is the charge micro coulomb, micro coulomb.

So, C_2 is given by 5 microfarad. So, delta V is known is 1 volt, 1 volt, 1 volt, 1 volt. Ripple in delta V_0 is 1 volt. So, capacitor C_2 is 5 microfarads, delta q is Similarly, C_1 is discharged by an average current of 10 amperes. This is the average of load current, average value of i_2 is same as average value of current that is flowing through C_1 that is capacitor is being, this current is supplied by a capacitor, entire i_0 and this is the charging.

So, this is the discharge period, I know the current, I know the time for which this occurs. So, I can calculate I can calculate the value of C. So, this is the charge, 10 ampere into 30, charge that is lost divided by the voltage. Ripple in the voltage is 10 volts, ripple in the voltage is 10 volts this is 30 micro farads.

So, that is about it. A very interesting and very educative problem, we solved almost all the aspects in DC to DC conversion. First you find out the maximum and minimum ripple in the load current. Then, a very good problem in cuk converter, then a good problem in boost converter. It was a very educative problem, in the sense, D was it was just mentioned D is equal to 0.5, it was not mentioned that whether the current is continuous or not. We had to deduce. So, more about it we will see in the next class.

Thank you.