Switched Mode Power Conversion
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Lecture - 13
Non-Isolated converter – 11

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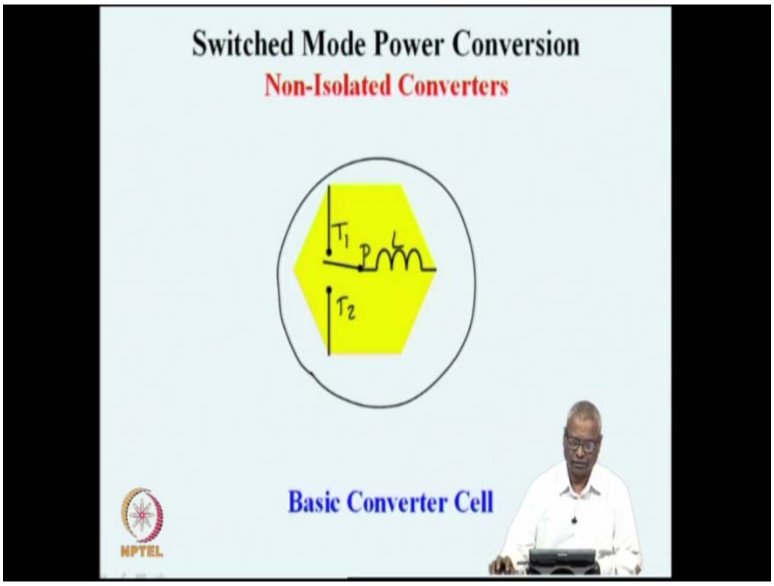

Good day to all of you. In today's session, we will look at another one of these basic power converters belonging to the family of non isolated converters. We had seen in the last session that such a cell, a converter cell consisting of a single pole double throw switch and an inductor with 2 throws T 1, T 2. And a pole formed the basic power converters cell and with this, we were able to make several ways of converting power DC power from one will voltage to another or from one current to another.

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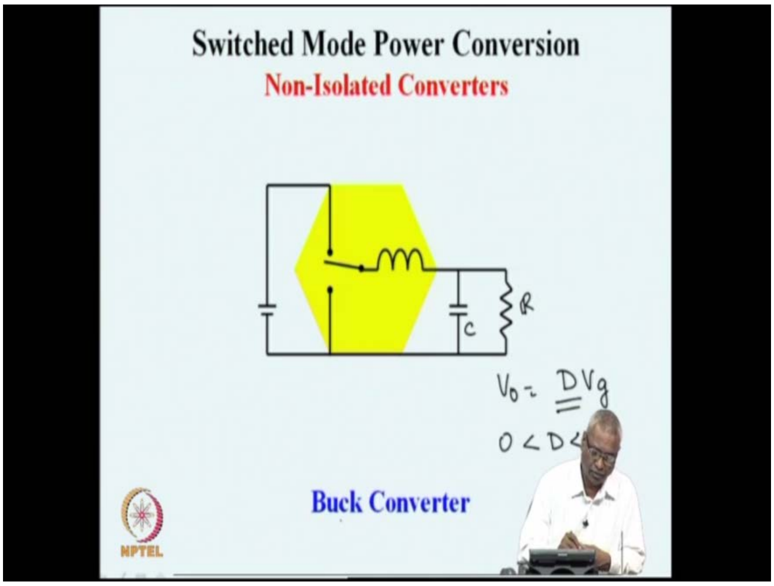

We had seen that the first type of power converter circuit that we saw consisted of connecting a voltage, input voltage source to this basic converter cell. And a load resistance R supported by a capacitive filter at the output of this power converter cell and we saw that this was classified with the name of Buck power converter where the output voltage V naught was D times the input voltage V G an output voltage was always less than then the input voltage the D varies from 0 to 1. And because of this reason this non-isolate, non-isolated converter was called Buck converter. It was bucking the input voltage and providing an output voltage which was less than the input voltage.

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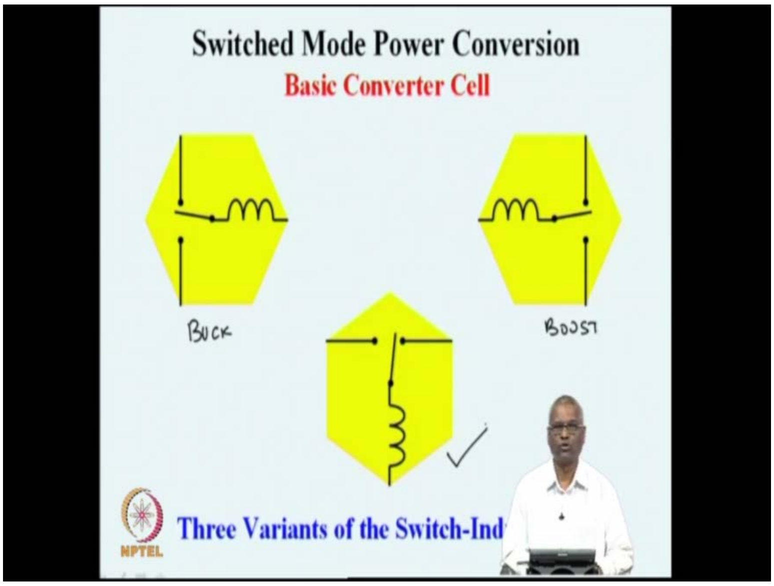

We had also seen that this basics cell could be used in 3 different variants to form different basic power converter cells. The first one and the second one we had already seen all the Buck power converter, the Boost power converter and what we will be seeing today will be the third converter, which goes by the name of Buck boost or fly back power converter.

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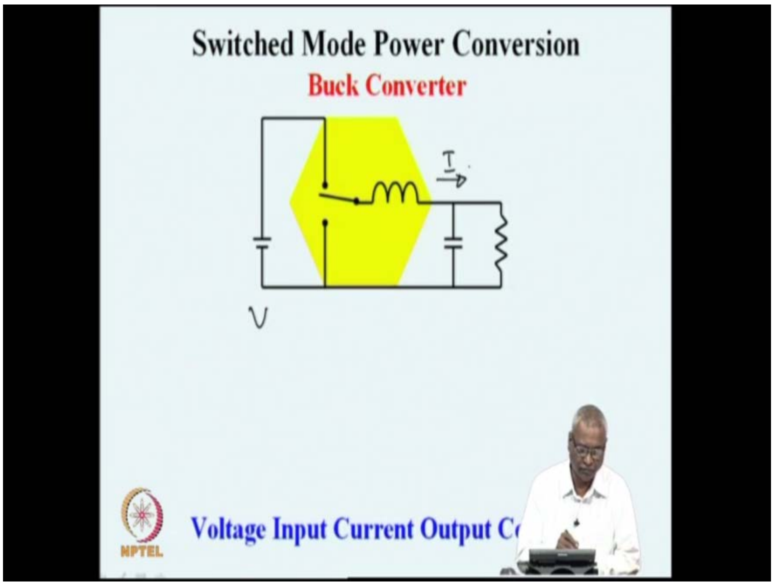

In the first type of power converter the input was a voltage and output was a current, we could say that this is the voltage input current, output power converter.

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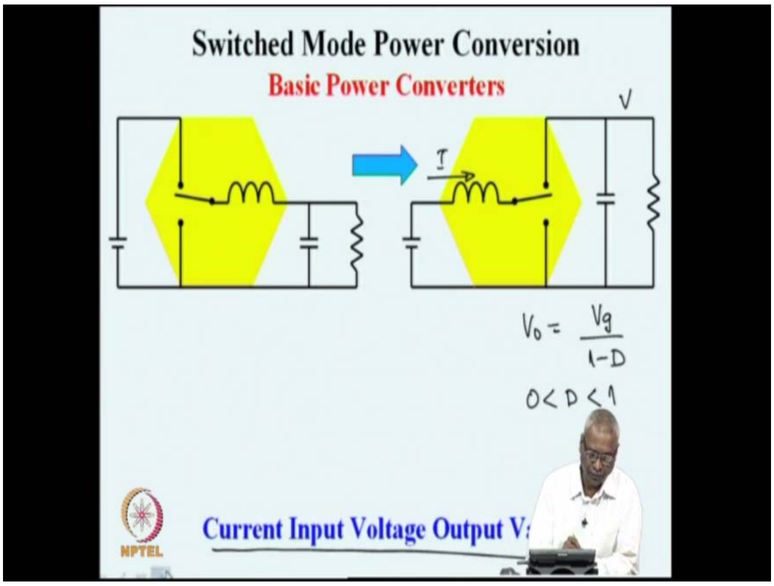

And the second converter had current as the input and voltage as the output. And we could say that as a current input, that voltage output power converter, which boosts the output voltage in this converter V naught is V G divided by 1 minus D where D is varying in the ratio of 00 to 1. And this converter was boosting the input voltage. The input current is stiff and output voltage is stiff and we could call this as a current input and voltage output variant.

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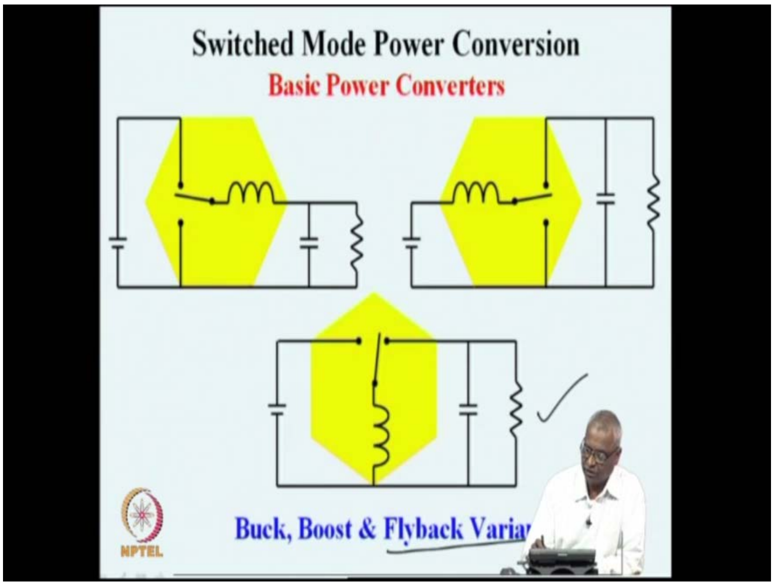

The third variant that we are going to see today is the current input and current output variant where the input current and the output current or both stiff on account of the inductor which is getting charged from the source and discharging into the load. And this converter is called the fly back power converter. And in this lecture today, we will see several of the features of the fly back power converter. So, we will limit our analysis during today's lecture to the fly back variation which is a third variation of the power converter.

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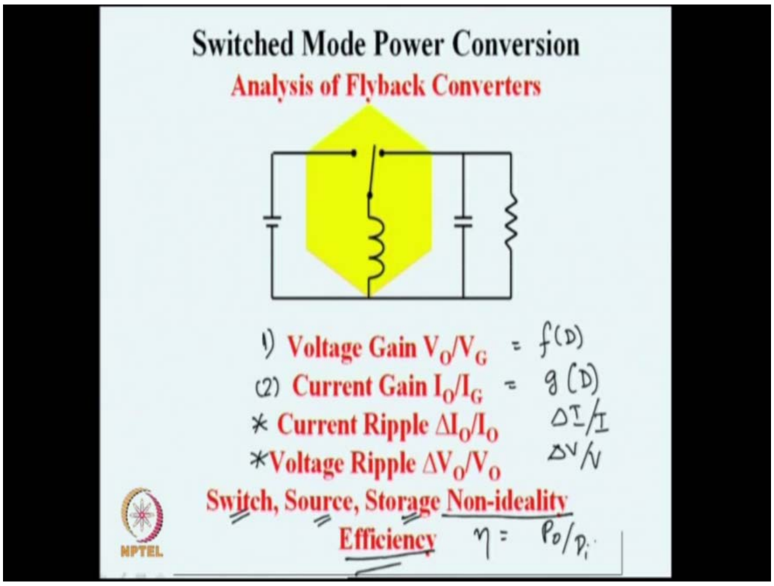

This converter is having the name fly back power converter or Buck boost power converters because this is capable of providing an output voltage, which is both less than as well as more than the input voltage. So, we will see the analysis process during this 1 hour of lecture. And we had seen that the steady state analysis of all these converters consists of the voltage gain V naught by V G as a function of the duty ratio D. This is one of the first things that we would like to find out. And similarly, the current gain are the output current to input current ratio, again has a function of gain. These are the desirable characteristics of the power converter, but the converter has a number of undesirable characteristics.

For example, the inductor currents are, are not perfectly constant and there is a ripple in the inductor currents. And these ripples can be quantified by the ratio of delta I by I, how much is a variation in current in relation to the steady current that is y. And similarly, delta V by V on the capacitor tells us how much is a variation in the voltage as a fraction of the DC voltage. So, all these quantities are undesirable quantities, these are a the current ripple and the voltage ripple and then the analysis also takes into account .The non idealities of several of the components that are present here the non idealities of the switch, the non ideality of the source and the non ideality of the storage elements, which are the inductors and the capacitors. And eventually, we also like to find out what is the efficiency of power conversion, which is the ratio of the output power divided by the input power. This is what we would like to find out through the process of our analysis. In this analysis is done based on several simplifications on the operating performance.

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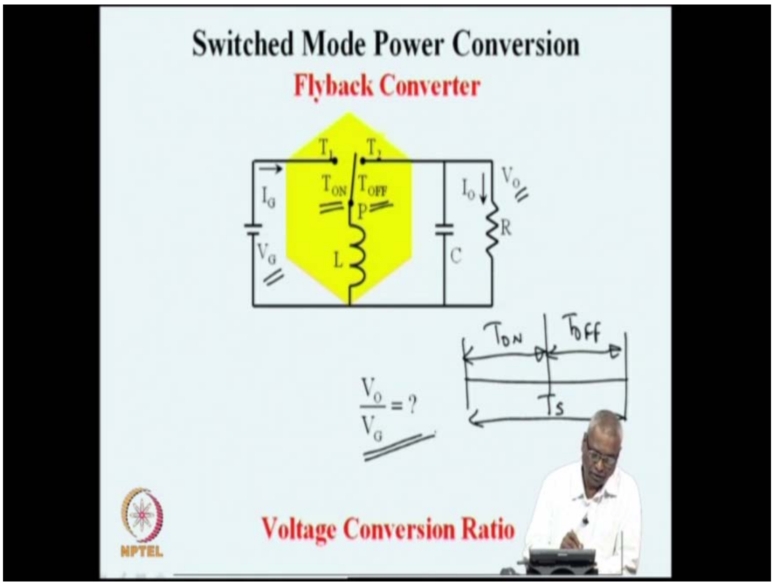

So, the first question is what is the ratio of output voltage V naught to V input voltage V G voltage conversion ratio? And the converters operating at a constant switching, frequency during the, on time of the switching frequency. If you call a switching frequency as consisting of a total duration of T S, out of that, there is a duration called T ON and there is a duration called T OFF. And during T ON, the switch is connected to P T 1 and during T OFF; the switch is connected to P T 2. So, under that condition if ever thing is ideal inductor does not have any resistance, the switches do not have conduction drop, the switches operate instantly with all these simplifying assumptions we like to know what is the ratio of V naught by V g?

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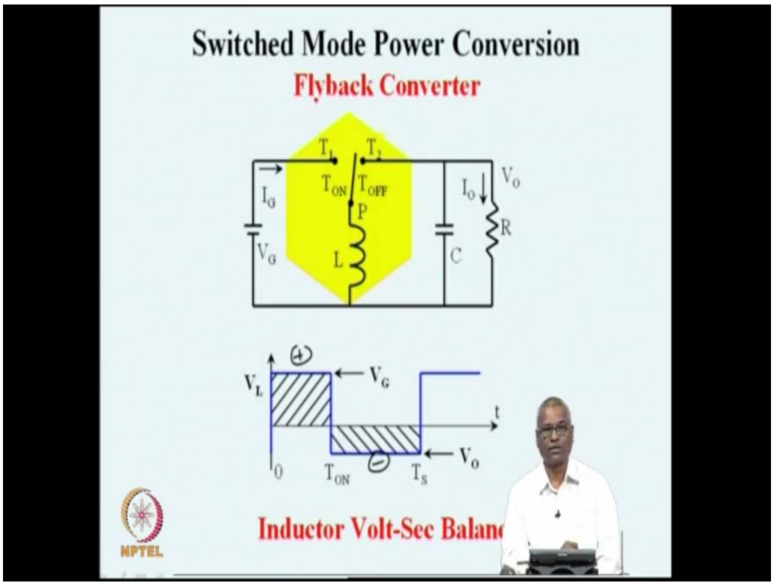

And this is obtained by applying the inductor volts second balance. We have done this twice before once for the Buck converter and once for the Boost converter. The method is very simple, find out under steady state, what is the voltage across the inductor? What is the periodic voltage across the inductor? So, in one period which is 0 to T S the voltage across the inductor is V G during the on time, because the switch is connected to P T 1. And during the off time the switch is connected to P T 2 and the voltage across the inductor is V naught V naught is applied across the inductor.

And we see that the inductor is applied a positive voltage during a portion of the switching period, and a negative voltage during the next part of the switching period. And the principle that is used in order to find out the relationship between V naught and V G is that the inductor on an average does not support any DC voltage or the periodic DC voltage of the inductor is 0. Or this we see here the positive volts second across the inductor is a same as a negative volts second across the inductor during the off period.

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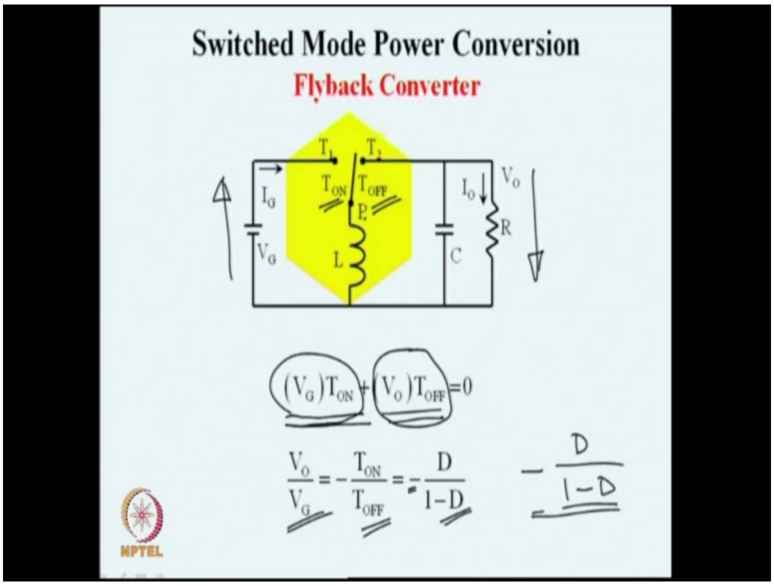

So, if we apply this volts second balance on the inductor, we can write the equation that during the on time the inductor is applied voltage of V G, because the switch is connected to P and T 1 and during the off time the switch is connected to P T 2. And at that time, the voltage applied is V naught. So, the volts second on the inductor is during the on time V G T ON and during the off time V naught T OFF. And if we equated to 0, which is the voltage across the inductor on an average over one switching period.

We find out the ratio of V naught by V G is minus T ON by T OFF, which is the ratio of on time divided by off time or D duty ratio divided by 1 minus D, the compliment of the duty ratio. The important point is there, is a minus sign here this is minus D by 1 minus D, what it signifies is that the far a positive voltage V G, the output voltage will be in the negative direction, which is V naught is negative that is what this minus sign signifies. So, we apply this volt second balance and we find out that the inductor has are the output voltage is minus D times D divided by 1 minus D times input voltage.

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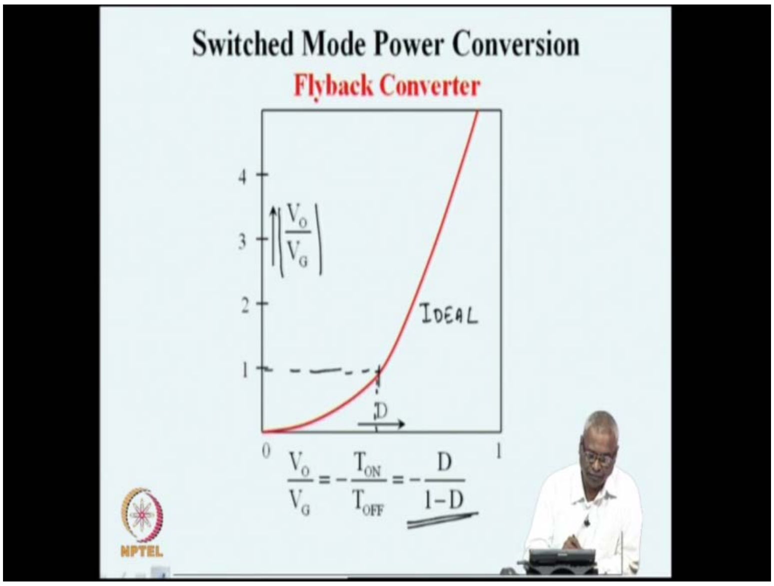

This can be plotted this ratio; this function of D of this V naught by V G can be plotted as a function of D. And you see that it starts from 0 when D is 0 and it goes to infinity when D is 1 and this would be the ideal gain characteristics of the fly back converter. So, as D varies from 0 to 1, the gain varies from 0 to infinity, when D is equal to 0.5 the gain will be 1, when D is 0.5 again is 0.5 divided by 0.5 which is 1 input and output voltages will be equal.

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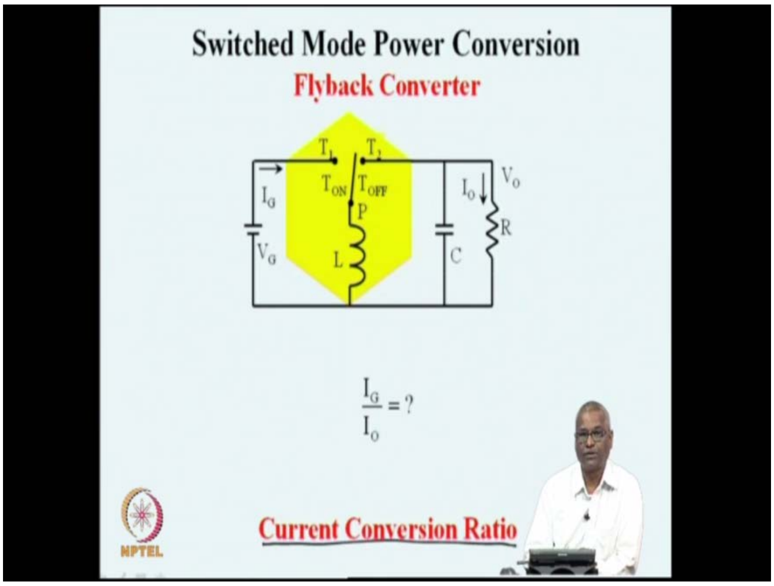

The ratio of I G by I naught is found simply by current conversion or this is defined as a current conversion ratio and this can be found out by averaging the output current.

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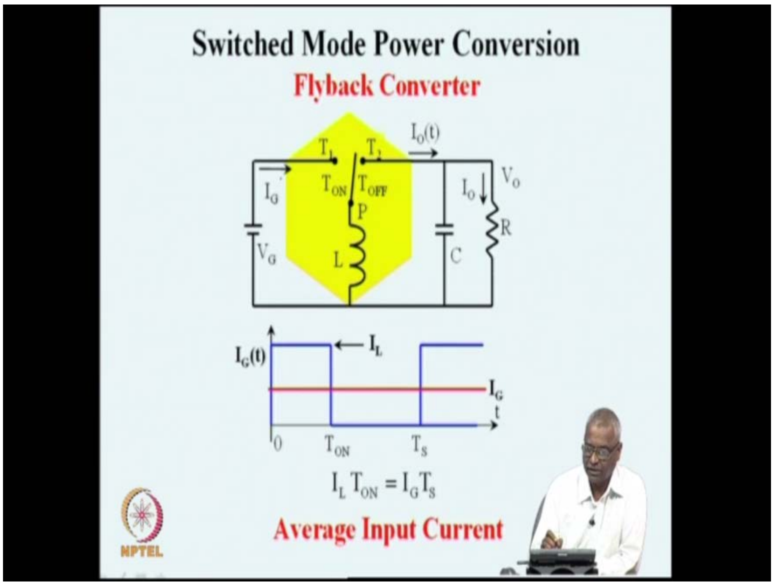

We see that this I naught t the, is the same as the inductor current during the off time, and inductor current is I l it does not have any ripple. So, this current during the off time is flowing through the load. And so the average of that is I l into T OFF which is equal to I naught into T S and we can say that I l is I naught into T S by T OFF, this is the average input current. In the similar way, average input current can be seen as during T ON I l is same as I G, rest of the time I G is 0. So, it is possible to find the relationship between the average input current and the inductor current. So, this also has the relationship as shown here.

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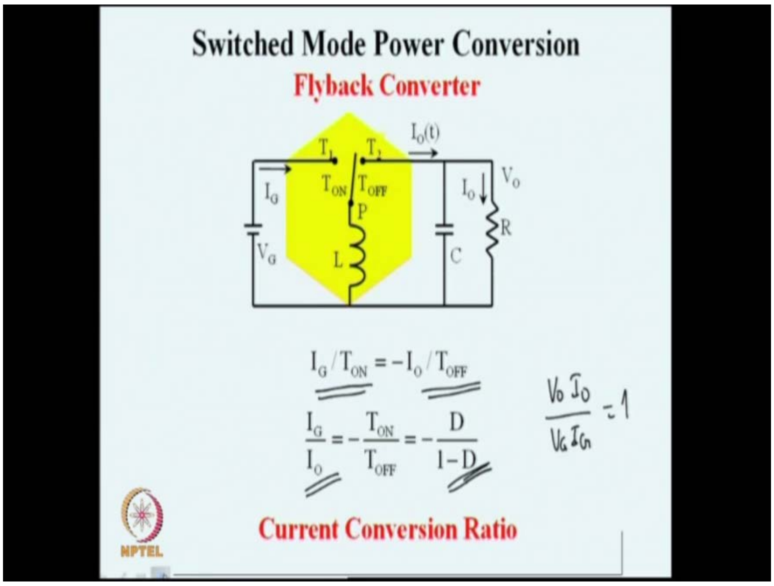

So, if we combine these 2 quantities, which is the inductor current, we find that the input current average divided by T ON is the same as output current average divided by T OFF or the ratio of the input current output current is minus D by 1 minus D. We had also seen in the other converters, that this ratio V naught by V G in the ideal case will be the same as I G by I naught. So that the efficiency of the power converter which is V naught I naught by V G I G equal to 1 .So, on account of conservation of energy and because there are losses in the ideal converter V naught by V G will be the same as I G by I naught and which is this ratio D by 1 minus D this results.

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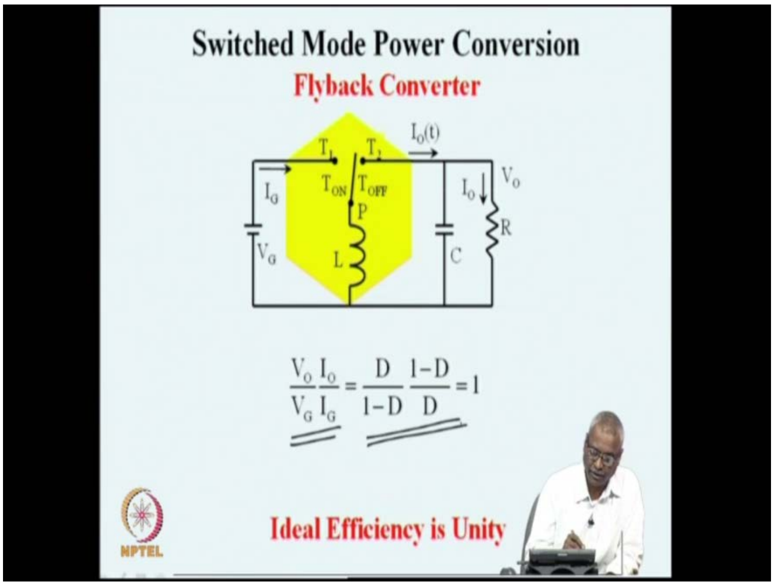

Similar results, we have seen for the buck converter and the boost converter and we are seeing the same thing following similar lines of analysis and the efficiency is given by the ratio of voltage conversion and current conversion, which is 1 and this is what we expect in the ideal case.

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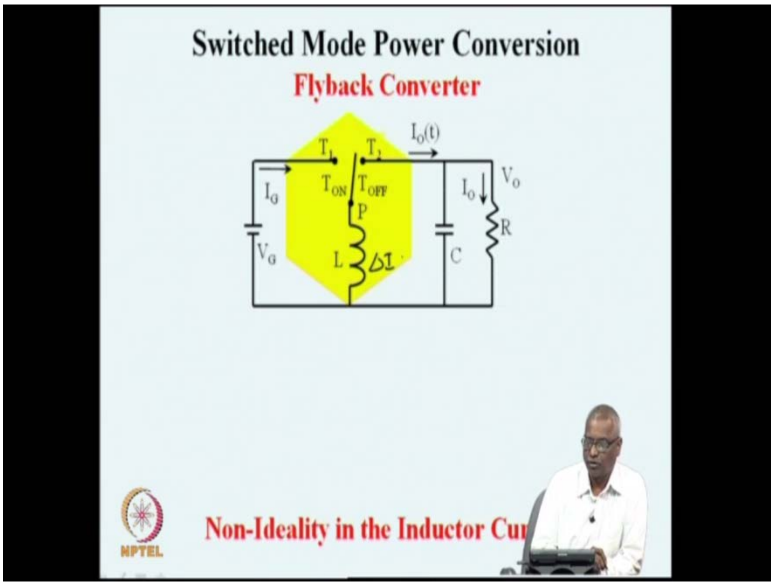

The non idealities are the inductor current ripple and the capacitor voltage ripple and this is found out the current ripple or delta I in the inductor is found out by integrating.

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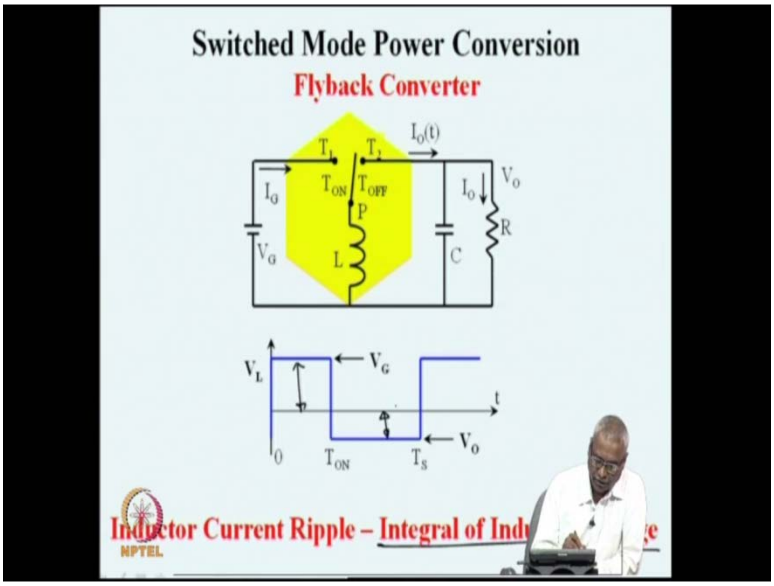

The voltage across the integral of inductor voltage will give us what is the current ripple the inductor is applied voltage of V G during on time and V naught during off time.

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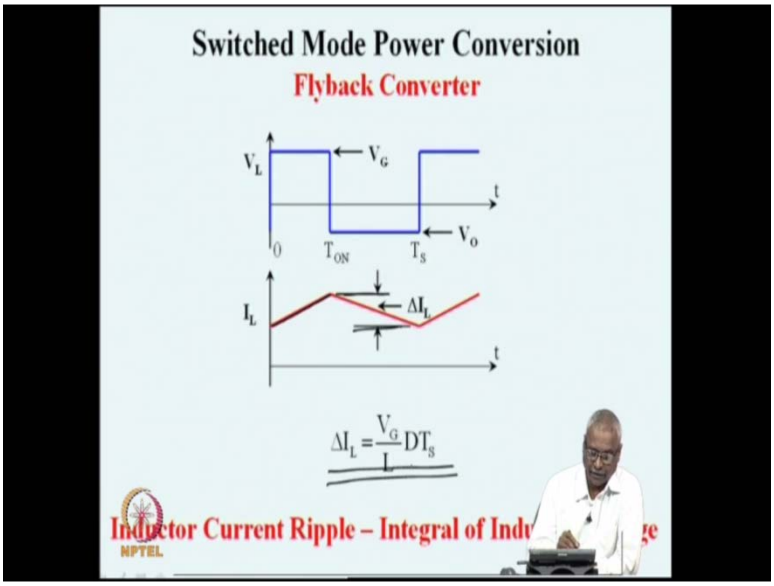

And if we integrate this voltage, we will see that during the on time this positive voltage V G results in an increase in the inductor current during the off time the negative voltage, that is applied across the inductor results in a drop in current. Understudy state the rise in current during on time is a same as drop in current during off time and we can write this delta I l or the ripple current as the slope V G by l and multiplied by on time which is D times T S .So, the inductor current ripple is related to the input voltage and inductor through the on time.

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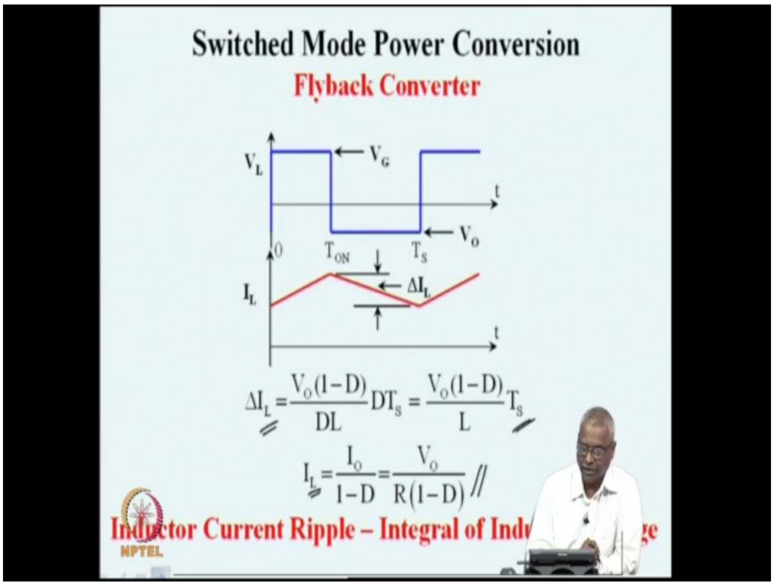

It will always good to represent the voltage, the voltage ripple as a fraction of the current through the inductor. The current ripple as a fraction of the current through the ripple and when we do that this I l is a related through the output current V naught by R divided by 1 minus D delta I l. We had just now found out V naught by l into 1 minus D T S.

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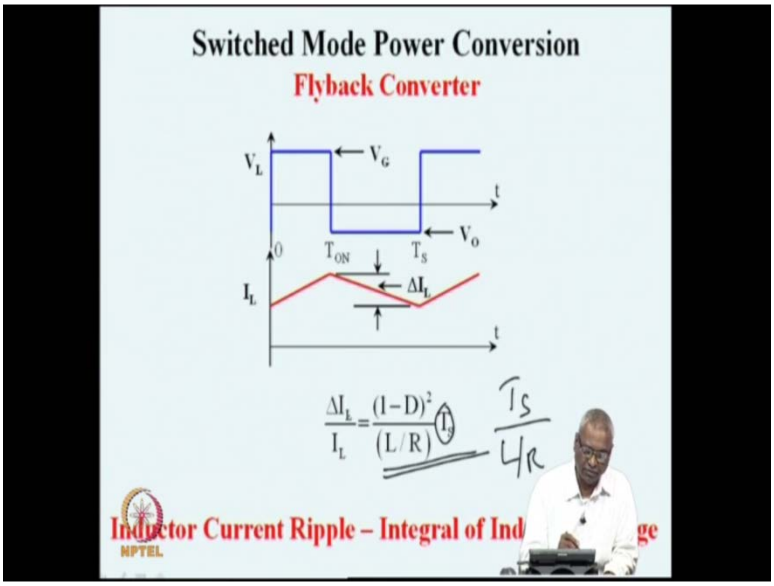

And if we combine these 2 quantities, we get the ratio of the ripple current to the average current in the inductor, which is 1 minus D whole square T S by l by R T S is the switching period and l by R is the time constant of the load and the inductor. And if this ratio switching time is very much small compare to the time constant of the converter then this ripple will be small.

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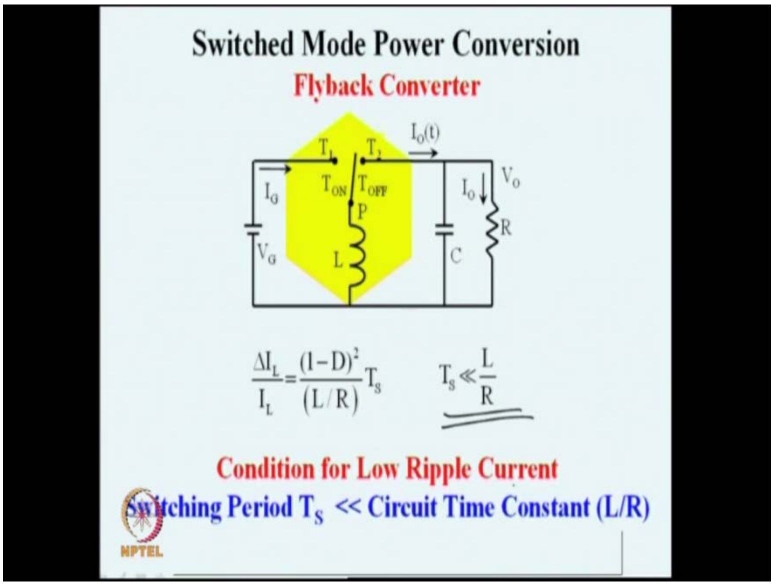

And that could be one of our conditions for design of the converters. So, we can say that for low ripple current as the performance of the inverter of for the inductor current to reach the ideal condition, it is necessary that this inequality is met better T S. If it is becoming a smaller and smaller fraction of l by R then our inductor ripple current will go towards 0. So, the design criterion is that the switching period T S must be very small compare to the circuit time constant l by R.

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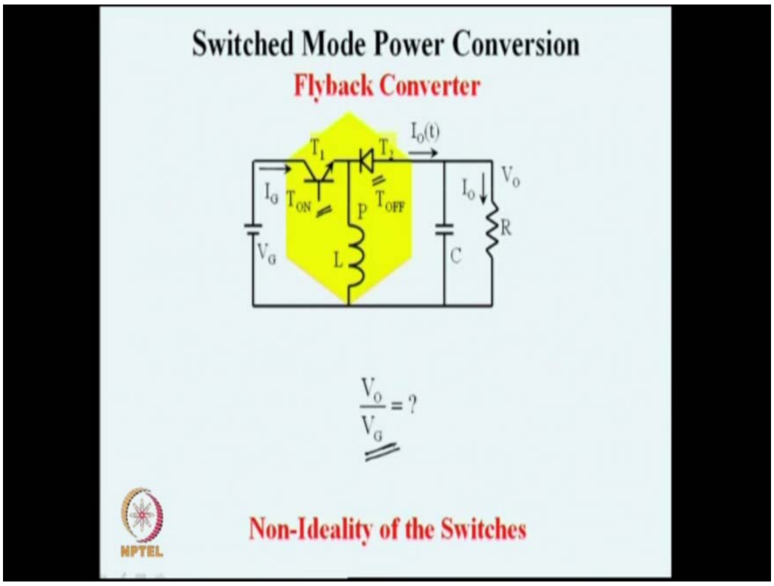

The non ideality in the converter, on account of the switches having non zero drops can be found out by finding out, what is the voltage drop in the switch? When it is on and what is the voltage drop in the diode? When the diode is conducting. If we apply these non idealities, we will come across a different ratio of V naught by V G that we apply gain the same principle, which is the volts second balance.

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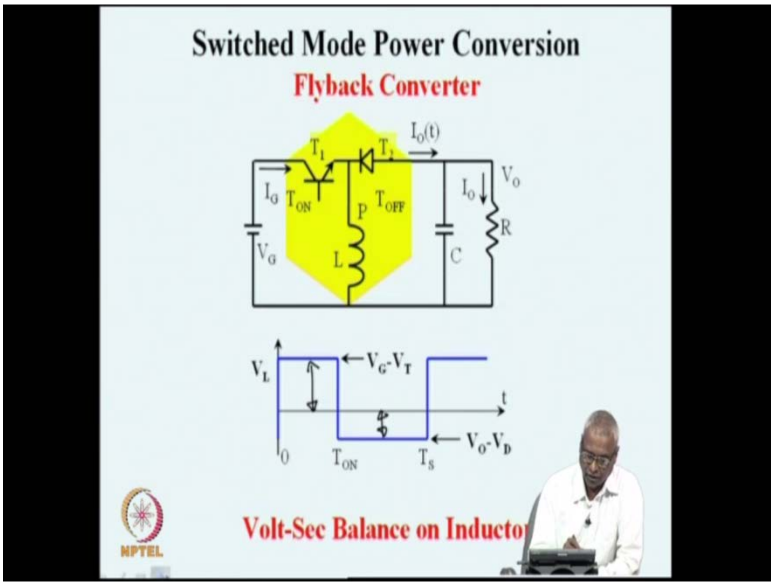

We keep account of the voltage drop volts second balance. And the inductor is now V G supply voltage minus the device drop the transistor drop during on time. And similarly, the output voltage plus the diode drop during the off time.

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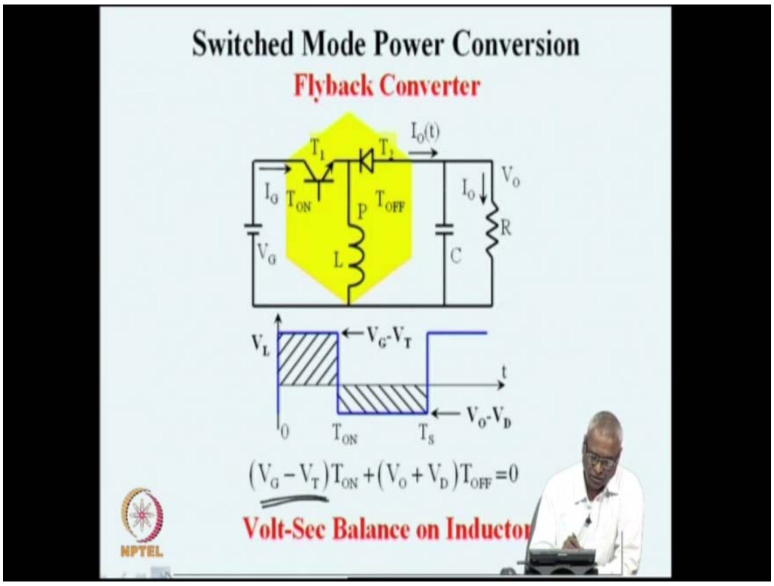

And if we now take the volts second balance, we find that if we see that V naught plus V D that is because the polarity of V naught is negative. On account of that, this ratio the on time voltage is algebraically V G minus V T into T ON off time voltage is algebraically V naught plus V D into T OFF.

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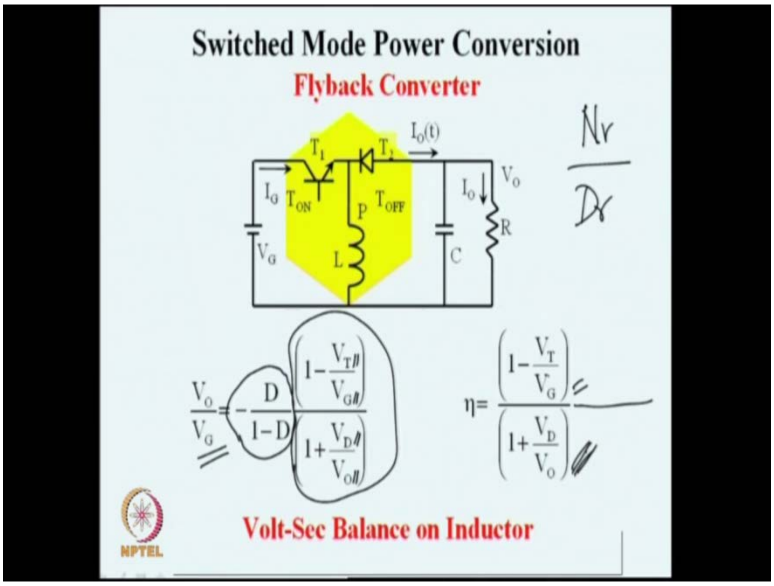

And from this volts second balance, we get the ratio of the output voltage to input voltage is the same as the ideal gain D by 1 minus D multiplied by a correction factor .You can see that this correction factor consists of 2 parts; numerator which is 1 minus V T by V G, and a denominator which is 1 plus the V D by V naught. If the correction factor has to approach 1, then the device drop V T has to be small compare to the source voltage V G. And similarly, if the denominator has to approach one the diode drop V D has to be small compared to the output voltage V naught. And from this, we can also say that the efficiency is the factor by which the voltage ratio is different from the ideal voltage ratio, which is 1 minus V T by V G by 1 plus the V D by V naught. So, if we look at the circuit, this term also can be this efficiency can also be seen as 2 terms; one consisting of a numerator and another consisting of denominator.

The numerator is effectively 1 minus V T by V G, you can say that it is the efficiency off charging from V G, we lose the voltage drop and rest of it goes into the inductor. So, you can say that the numerator represents the efficiency of charging. And the denominator 1 plus V D by V naught represents the efficiency of discharging, because during discharging of the inductor. The current passing through the diode drop is loss and current passing through V naught is the output low, output power. And so this nicely can be decomposed into 2 parts, numerator as the efficiency of charging and the denominator as the efficiency of discharging. And it nicely fits in and this with number will always be less than 1 and if it has to approach 1 V T has to be very much less than V G and V D has to be very much less than V naught.

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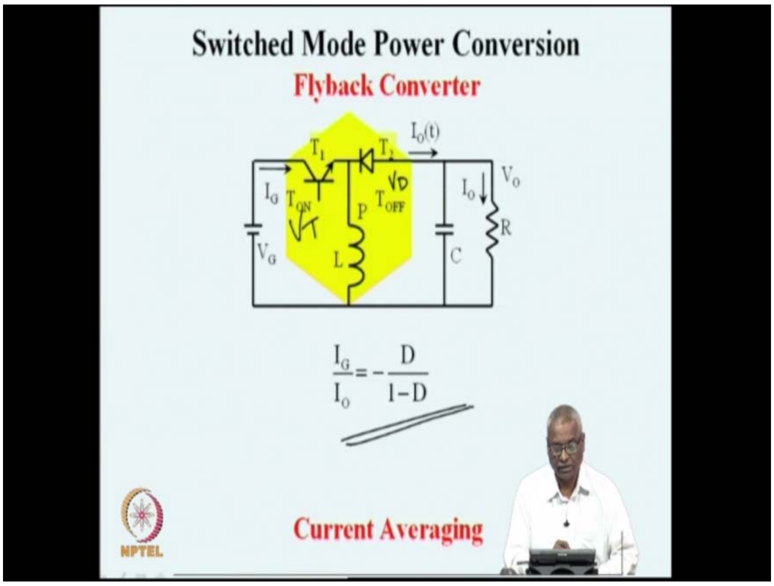

We had also seen that none of these serial non idealities V T of the switch or V D of the diode, they are all series non idealities it does not affect the current conversion ratio And they remind the current conversion ratio I G by I naught remains the same as the ideal number which is minus D by 1 minus d.

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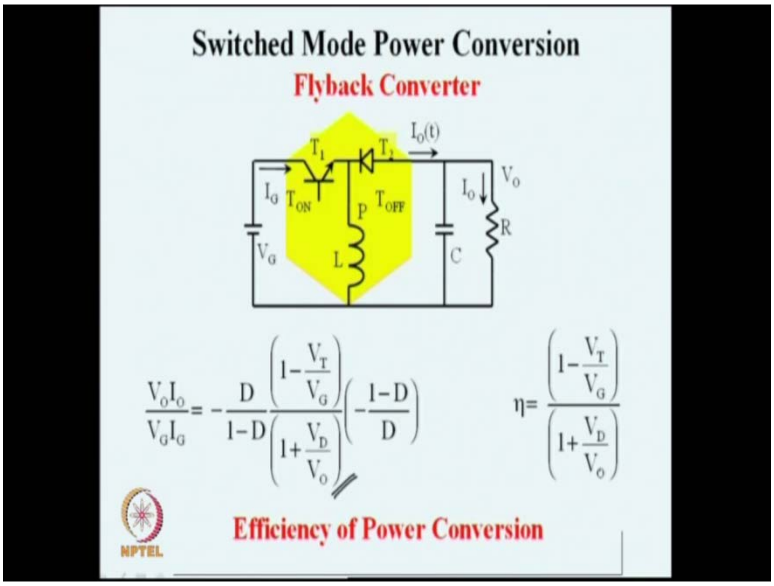

And when we multiply these 2 terms we get our efficiency which is 1 minus V T by V G divided by 1 plus V D by V naught. The method of evaluating the voltage gain, current gain, and the current ripple in the inductor the efficiency on account of the switch drops they follow the same method; volts second balance on the inductor, integrating the inductor voltage to get the inductor current and so on.\

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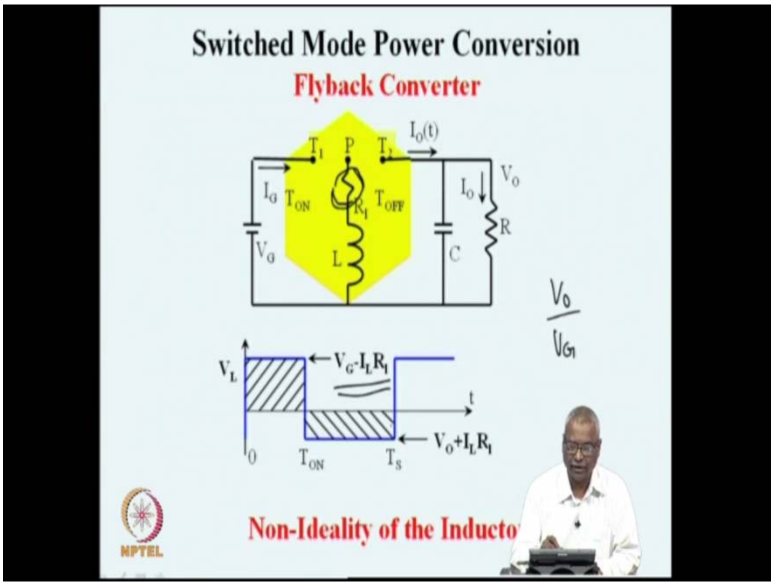

The inductor has another non ideality, which is a resistor. So, no inductor can be with 0 resistances as we are using a conducting wire to wind the inductor it has a resistance which is R l. On account of that, the output voltage V naught by V G will be different from what we calculated in the ideal case and that also can be found out from the gain, the ideal the volts second balance on the inductor. During the on time the inductor is applied voltage of V G minus I L R I and during the off time, the voltage across the inductor is output voltage plus I L R l.

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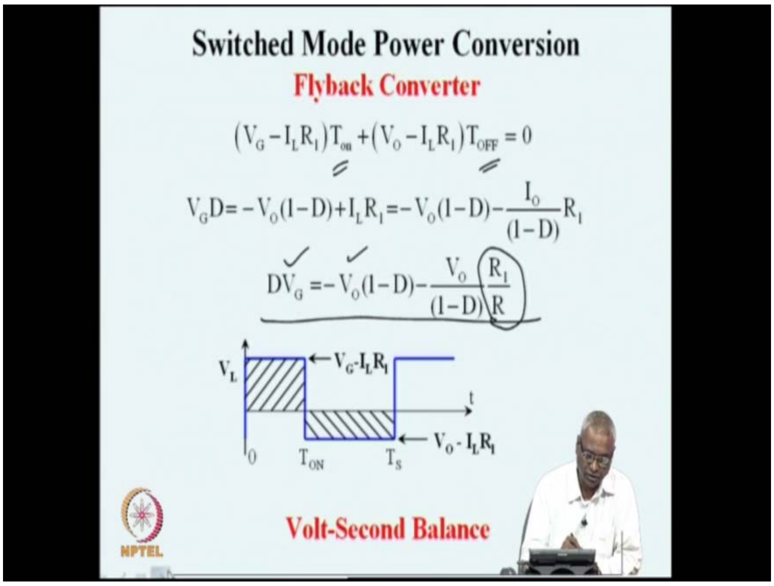

And if you find out the ratio of these areas and equated to 0 V G minus I L R l T ON first term and V naught minus I L R l T OFF, the second term if both of them are made equal to 0. Then on simplification, we find that we have an expression which relates V G and V naught through the non ideality of the resistor R l by R and the duty ratio D.

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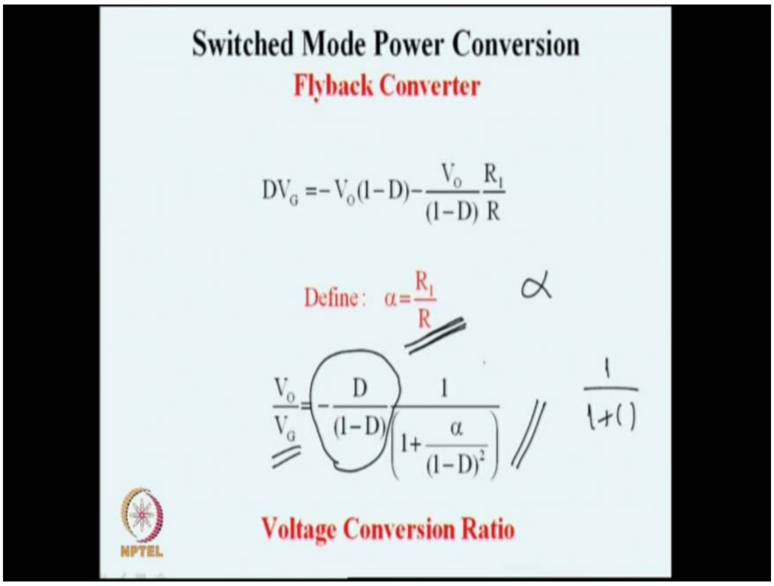

And on simplification, if we apply this term alpha equal to R l by R, the parasitic resistance of the inductor can be normalized by the load resistance R, and that ratio is defined as alpha. So, if we defined like that then V naught by V G can be written as the ideal ratio V naught by V G multiplied by a correction factor 1 by 1 plus alpha by 1 minus D whole square, this alpha is the ratio of R l by R. So, we have seen that now by an amount which is 1 by 1 plus alpha by 1 minus D whole square, the voltage gain is reduced from the ideal. And this number will always be less than 1, because it is 1 by 1 plus some positive quantity and this correction factor being less than 1.

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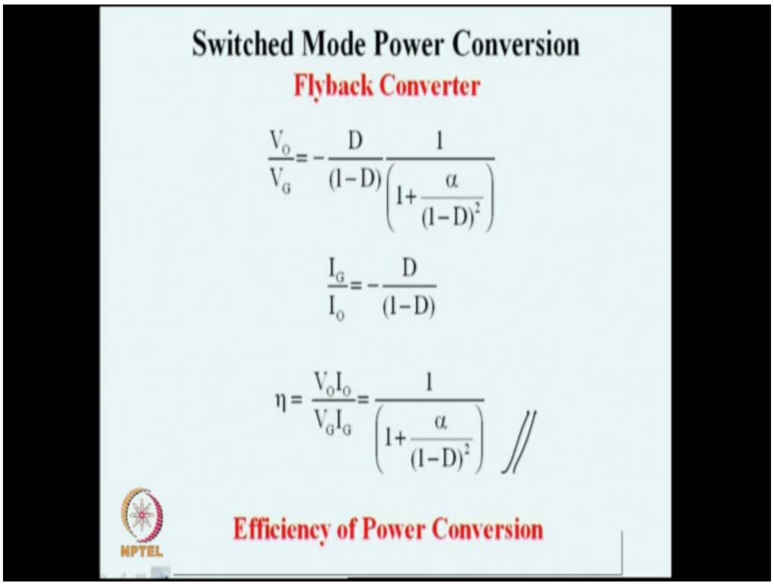

We can also say that, this correction factor is the same as efficiency; the efficiency of power conversion is the same as this correction factor 1 by 1 plus alpha by 1 minus D whole square. Interestingly this correction factor is identical for the boost converter as well as the fly back converter.

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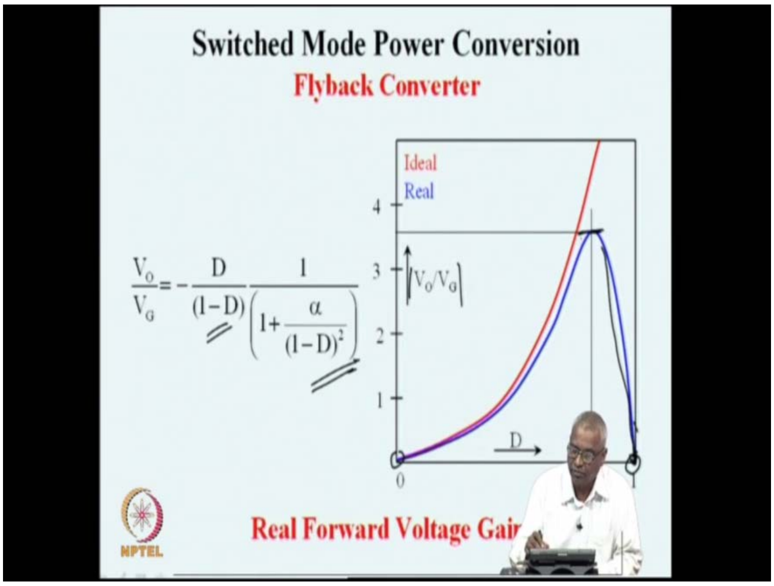

So, on account of this correction factor, V naught by V G now is not just D by 1 minus D, which is shown by the red color line here it is getting modified by a Correction factor. And once the correction factor is included, the gain of the converter drops to 0 has you go to duty ratio 1. It reaches a peak at some point and then instead of going all the way it infinity it changes direction and falls all the way back to 0 back to 0. So, as duty ratio is 0, the gain of the converter is 0 and as the duty ratio goes to 1 also a gain of the converter is 0. And in between there is some value for which the gain is maximum and it is possible to find out what is that value off duty ratio at which this gain is maximum, and also what is that maximum gain all this can be found out by simply analyzing this factor.

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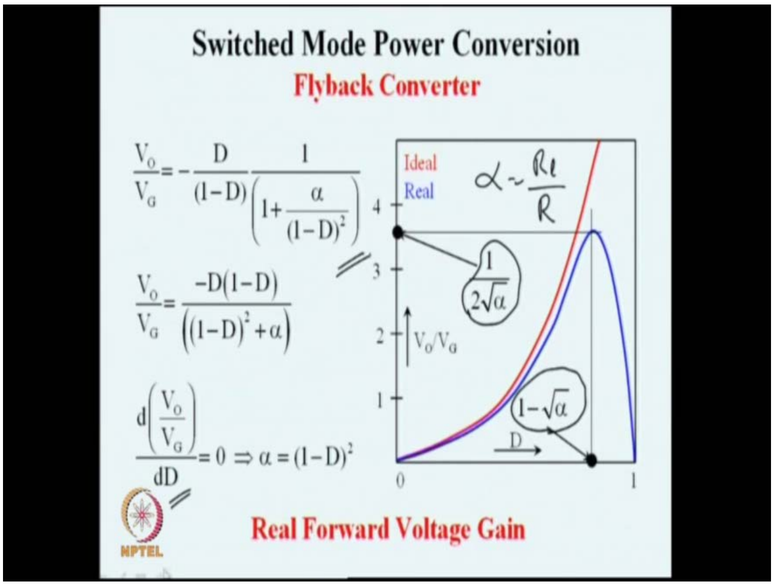

And this function has a maxima and minima, and if we differentiate it with respect to duty ratio and equated to 0. We can find out that this maximum occurs at a duty ratio which is 1 minus route alpha and the maximum value itself is 1 by 2 route alpha, where alpha is the ratio of the parasitic resistance to the load résistance is alpha is the inductor resistance normalized to the load resistance. And this is a real forward gain what you see is the blue line here it is modified from the ideal on account of the correction factor that we see here.

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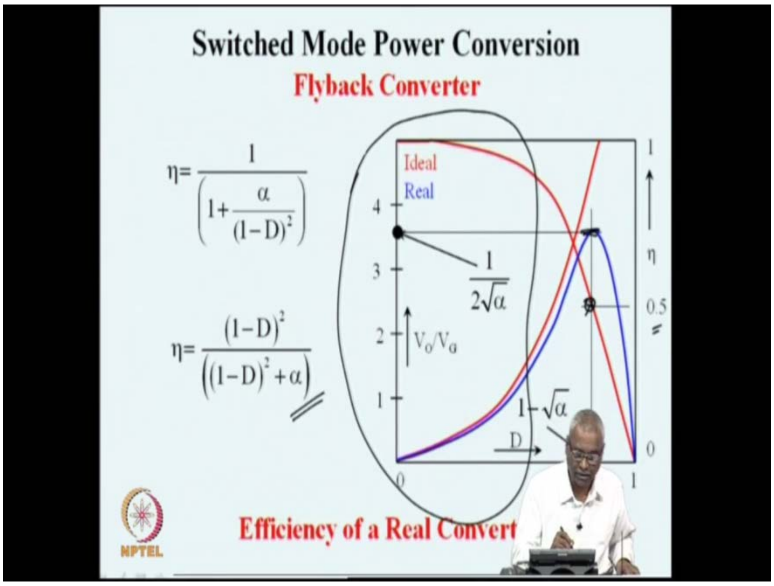

Now, we can also find out the efficiency of the power conversion and plot it on the same graph. So, that we get certain other insights into the operating characteristics of the converter. The efficiency is also a function of alpha and D. And on this same figure for D if we plot efficiency in the vertical axis for duty ratio exactly at the point where maximum output voltage is obtained at that time, the efficiency turns out to be 0.5. Or at that operating point only half of the power is delivered to the load, the remaining half is lost in the converter that is not a very satisfactory state of things.

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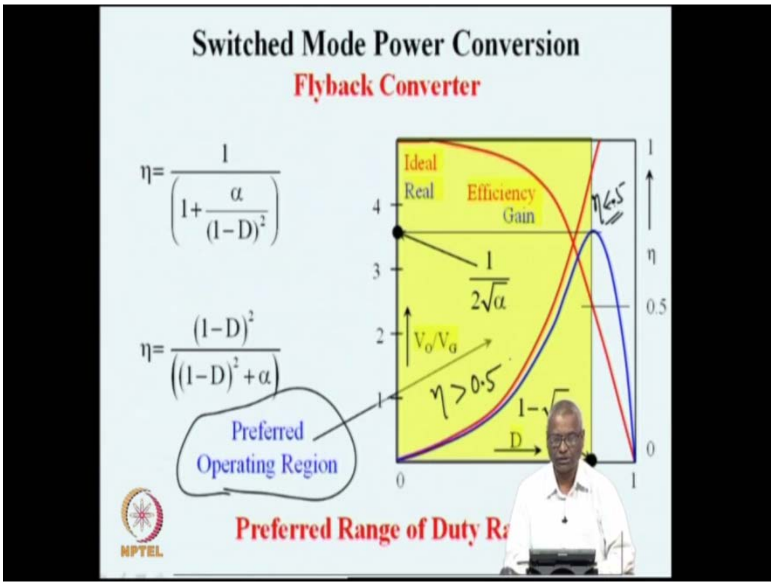

And so we would like to operate at the lower end of duty ratio where the efficiency is more than 0.5 what you see here and the yellow region here is the region where the gain is in the increasing range where it has not reach the maximum. So, in that region gain is more than 0.5 and on the other region in the next region, the efficiency is less than 0.5 and that is not our preferred region, our preferred operating region is the region where efficiency is greater than 0.5. So, what is shown here?

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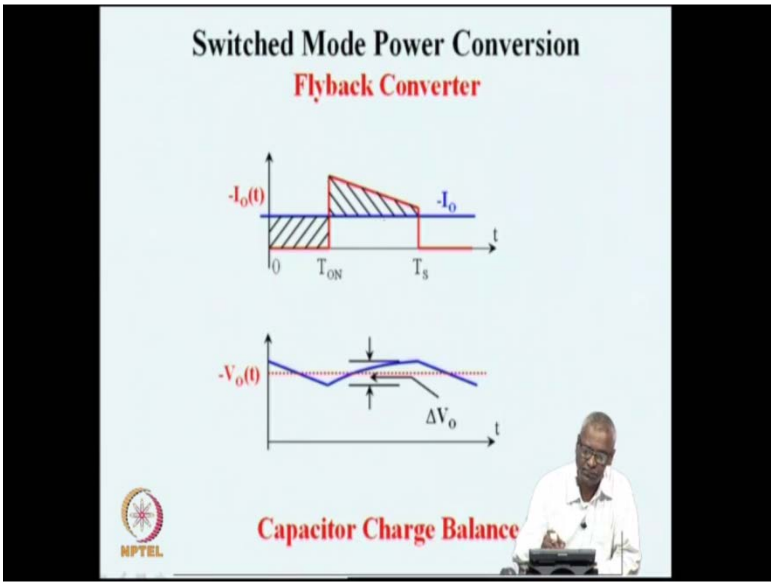

The next non ideal performance of the converter is on the output voltage, output voltage has V naught plus delta V naught. And this delta V naught can be found out by finding out what kind of current is coming out of this, out of that all the D C current will go to the load and the A C current will go in to the capacitor. And by integrating this current in the capacitor it is possible to find out the output voltage ripple is the same strategy, which we have followed in the other converters as well, I have plotted the current I naught of t, which comes out of the converter what you see here is a function of t. And then the current load, current going into the load is a flat current I naught.

So, the difference between I naught of t and I naught what is shown in hatched region is what is going into the capacitor current .So, the hatched region here is capacitor current it has negative value in the on period and the positive value in the off period. During the on time, the capacitance discharging its energy into the load on period of the switch, during off period of the switch, the capacitor is getting energy from the source and the load is also being supplied. So, by integrating this capacitor charge, we will be able to get what is the voltage ripple on the capacitor. And that integrally gives you here delta V naught, delta V naught can be found out by finding the hatched region on the site during the off period or the hatched region during the on period, on period current being constant it is easier to do the integration.

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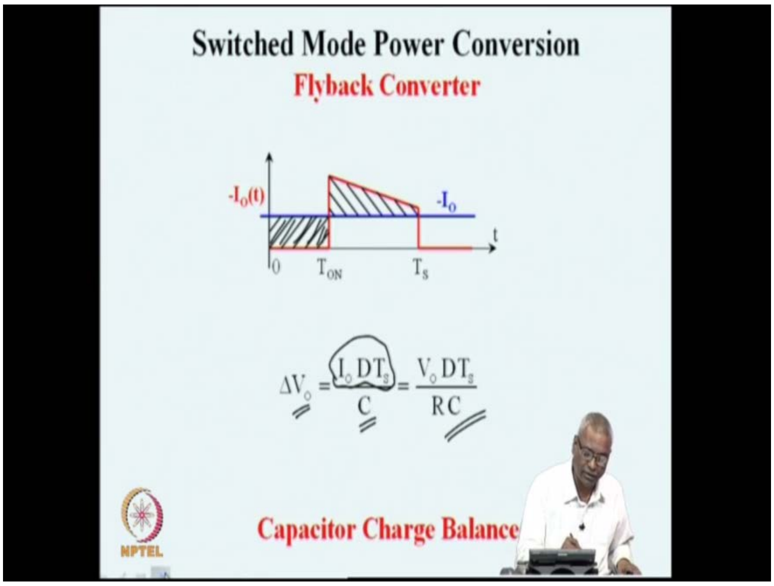

So, we find that I naught into D T S is the area here and this area multiplied or this I naught multiplied by D T S is the current taken from charge taken from the capacitor divided by the value of C will give us delta V naught. And that is output voltage multiplied by on time divided by RC time constant of that.

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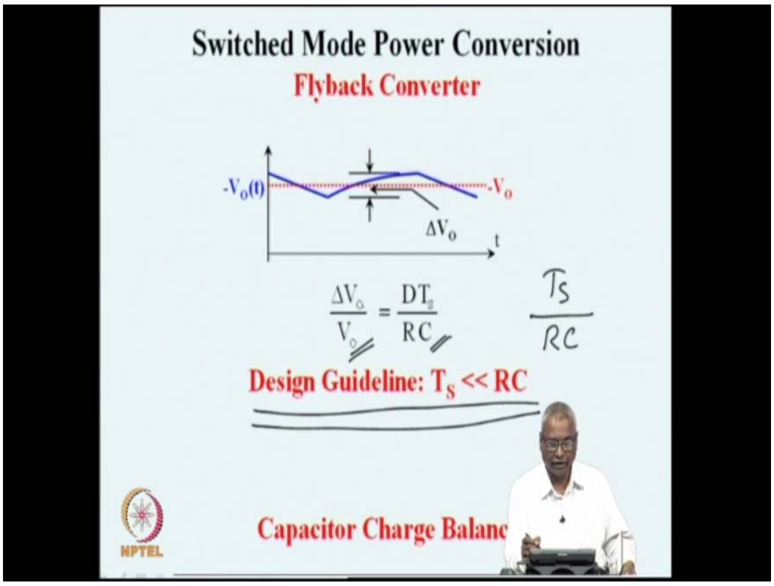

Again it is good to represent it as a ratio normalized it on the output voltage. So, this is duty ratio times switching period divided by the load time constant, and the design guideline to keep the unwanted ripple on the output, because clear from this, that if the switching period T S is very much less than the load time constant RC . Then we will have low ripple and that could be our design guide line and this is obtained by the capacitor charge balance.

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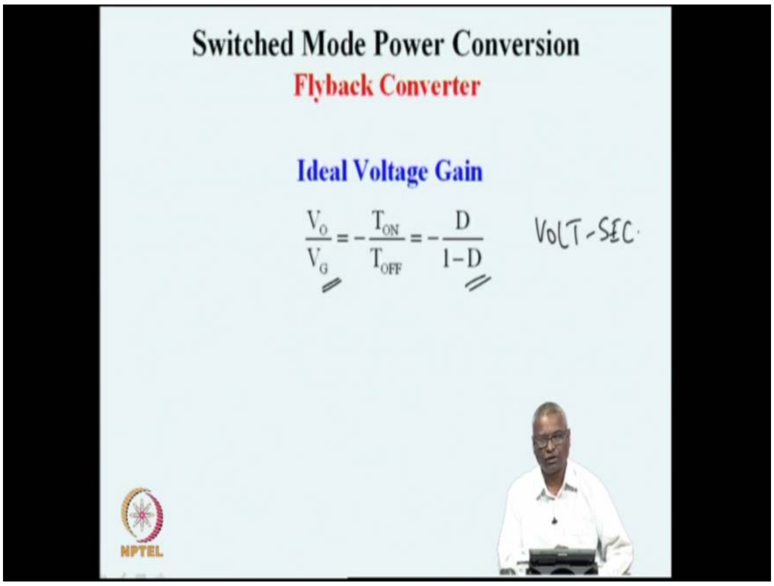

So, practically now, we have done the ideal as well as the non ideal steady state analysis of this converter. And we see that the ideal voltage gain of this converter is V naught by V G which is minus D by 1 minus D. This was obtained by applying the volts second balance on the inductor; this was our method of evaluating the ideal voltage gain.

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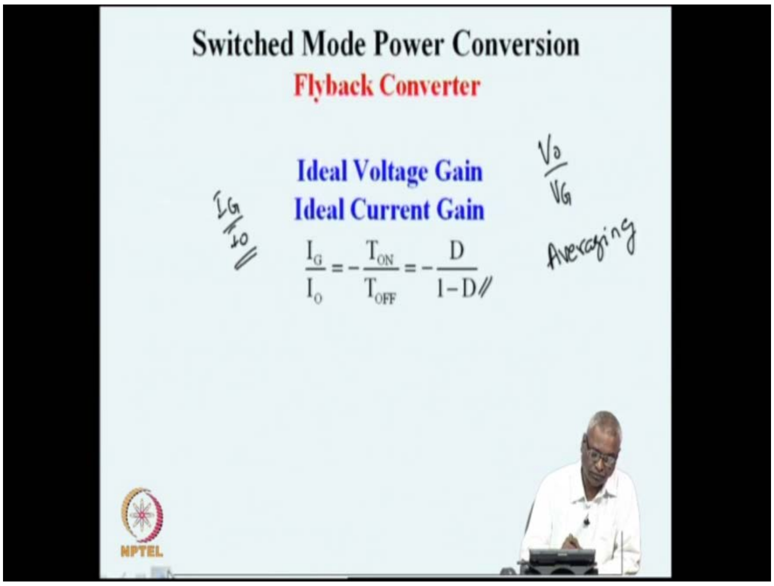

The ideal current gain is obtained by averaging the current through the input as well as the output and relating it to the inductor current, which is in between. And this also turned out to be a function of D, and we have seen that, this ideal voltage gain and ideal current gain, ideal forward voltage gain V naught by V G and ideal reverse current gain I G by I naught both will be same. So that the product of them will be 1 to keep the efficiency 1 or 2 to keep that the losses are 0 in the converter V naught by V G will be the same as I G by I naught. So that the efficiency in the power converter is 1, this was the second ideal performance characteristic that we found, this was obtained by averaging the current. The ideal voltage gain was obtained by finding out volts second balance on the inductor and equating it to 0.

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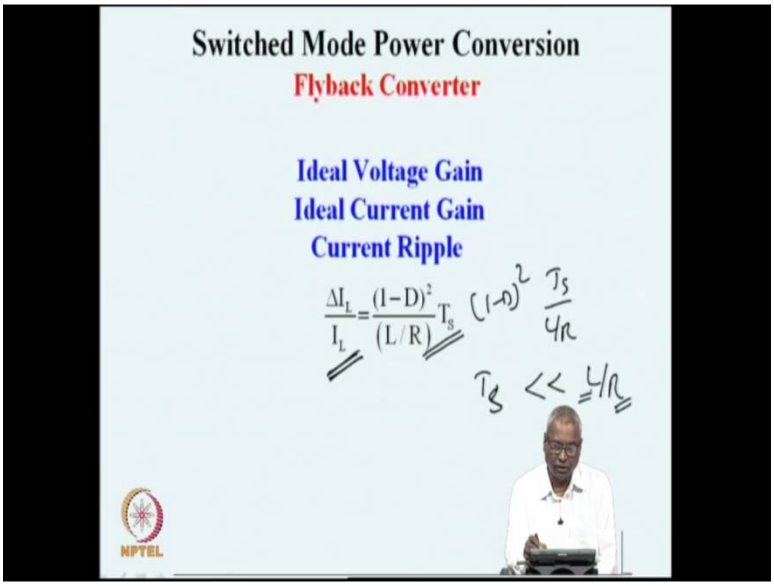

The current ripple is an undesirable performance in the converter and we try to normalize it as a ratio of ripple current divided by the inductor average current. And that also was found out by evaluating by integrating the inductor current and finding out the ripple current in the inductor and normalizing it to the average current in the inductor. This turned out to be the ratio of T S by L by R with a multiplier 1 minus D whole square, and this gave as the design criterion for the current ripple to the very small, that T S has to be very much less than L by R .So, many times R being the load current is not under our control, but the inductor in the power converter is what we have to provide and that inductor value can be selected appropriate to the switching period. So, that the current ripple is small or negligible.

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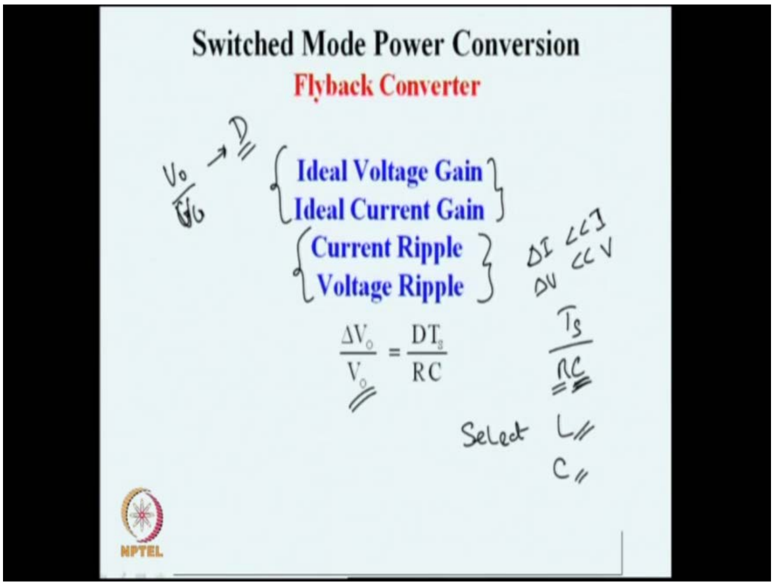

In the next step is the voltage ripple on the converter, the voltage ripple on the output voltage again this also has been normalized. So, that it is represented as a ratio of the switching period divided by the RC time constant. And this could be used profitably, the load resistance in the converter is not under our control, it is decided by the user, but the capacitor that is used in the converter can be selected. So that the voltage ripple will be small and negligible. So these undesirable quantities of delta I and delta V has to be very much less than I and very much less than V, that criterion can be used in order to select L and C.

The first one if this is used, if you know what is V naught and V G, this can tell us at what operating duty ratio one should operate. So, that the converter does the power conversion with the voltage ratios that we desire. And the current ripple and voltage ripple are made as small as possible by selecting the value of L and C. These are the desirable performance characteristics of the converter which will tell us, what should be the operating point these are the undesirable performance characteristics of the converter. This will give us a boundary on the value of L and C to be used. So, that the undesirable performance features are negligible compared to the desirable performance features.

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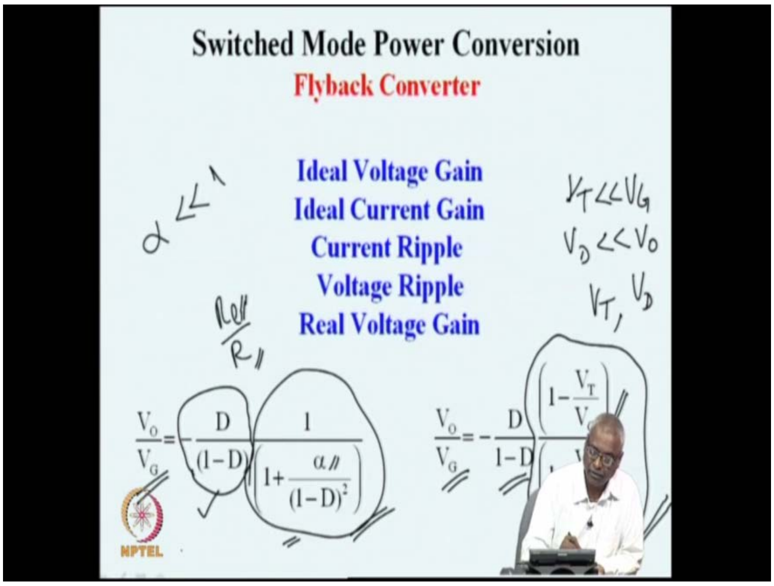

The real voltage gain whenever there is a presence of non idealities of switches like the transistor switch drop or the freewheeling diode drop, and similarly, the non ideality of the inductor the parasitic inductor R l by R, which is represented by this quantity alpha. Now, these non idealities in the switches, conduction drops of the switches non idealities in the inductor, which is the parasitic resistance of the inductor they all affect the ratio, the conversion ratio V naught by V G. The way we have done the analysis, we write it in a such a way that the ideal conversion gain is now modified by a correction factor, which is a function of the non idealities. For example, when the inductor non ideality of R l is considered the parameter which quantifies these non ideality is R l by R. The ratio of parasitic resistance of the inductor represented as in relation to the load resistance is alpha and operating duty ratio D and alpha decide how much this correction factor is.

So, from the ideal gain, we have now a modifier or a correction factor, which is a function of the non ideality in the converter. And similarly, whenever the switch has a conduction drop, we do the analysis based on volts second balance. And we represent the results as the ideal gain in multiplication with a correction factor and this connection factor will be close to 1, if the converter is a good converter, that the parasitic elements are the conduction drops do not affect the performance so much.

So that the correction factor on account of the inductor or the correction factor on account of the switch drops will be negligible or will be the correction factors will be close to 1. For that to happen the switch drop V T has to be very much small compare to V G, and the diode drop has to be very much small compare to V naught. And similarly, on this side, this alpha has to be very much less compared to 1, R l has to be very small in comparison with R. So, these are the parasitic effects and there their affect on the effect on the ideal performance figures.

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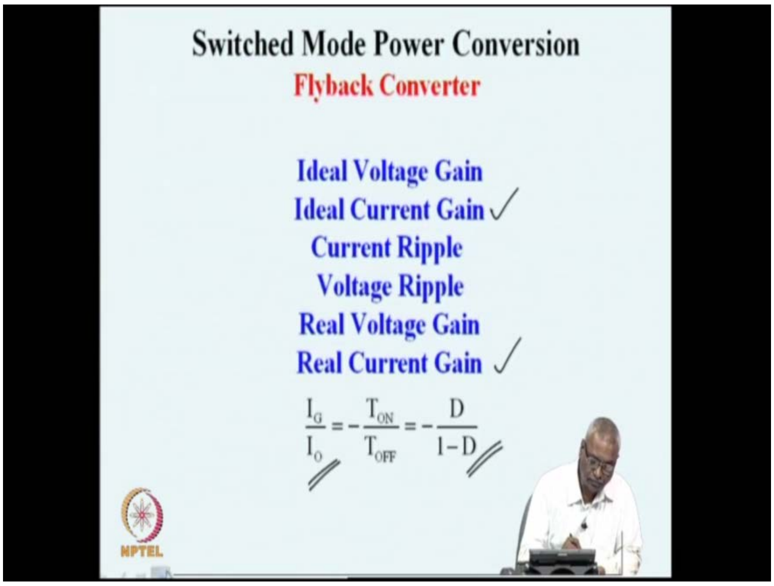

The real current gain is not affected by any of these parasitic effects, this is an interesting result, because we know that all the parasitic effects that we have been considering conduction drop of the switch, conduction drop of the diode, then the series resistance drop of the inductor and so on. They are all series non idealities; they drop in voltage when certain current is flowing and because they are in series non idealities. They have no effect on the current ratios in the converter ratios of input current to inductor current, input current, output current, output current to inductor current and so on. And we had seen in the analysis, that it is simply the averaging of this current do not or not affected averaging of the current is not affected by the series non idealities. And so the real current gain and the ideal current gain, these two are perfectly the same minus D by 1 minus D.

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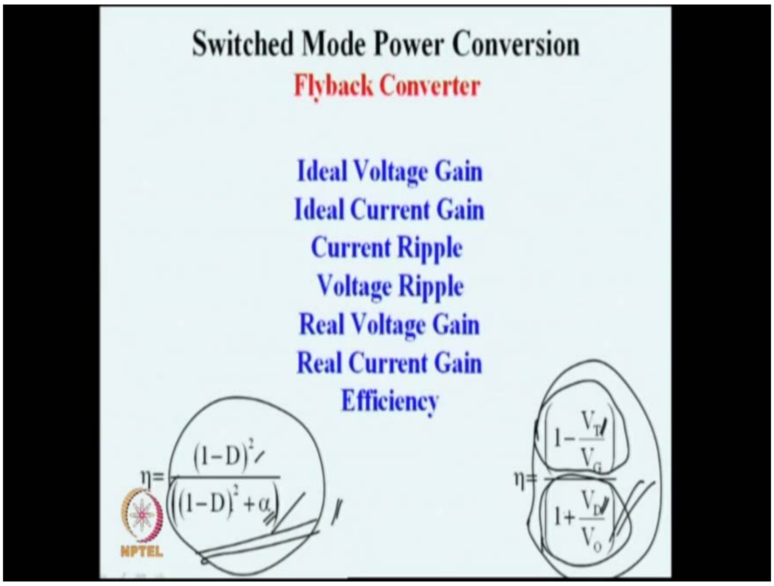

And on account of these non idealities, series non idealities, we have seen that the efficiency of the power converter has been affected. And this efficiency, because of the inductor is an account of the loss in the inductor I square are loss in the parasitic resistance of the inductor. And similarly, the conduction loss in the active switch and the conduction loss in the freewheeling diode, all these quantities give rise to losses in the converter and it also reflects on the efficiency of the converter. So, the efficiency on account of the parasitic resistance is this quantity, efficiency on account of the switch is this quantity. And overall efficiency will be the product of this correction factor 1 multiplied by the correction factor 2.

So, we can say that there is loss in gain, loss in voltage gain on account of the parasitic loss in the inductor. And similarly, there is a loss in voltage gain on account of the conduction drop in the switch. And over all the efficiency is affected by 2 factors; one is the I square r loss in the inductor which is the factor given by 1 minus D whole square divided by 1 minus D whole square plus alpha. And the other one is the loss in the switches conduction loss in the active switch controlled switch. As well as the uncontrolled switch and this has efficiency of charging and efficiency of discharge. So, effectively the overall efficiency is the product of these two correction factors.

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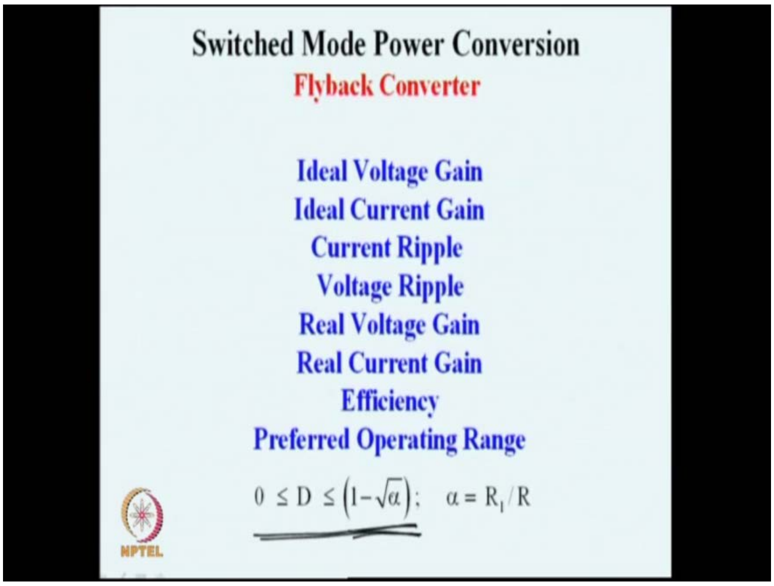

And we had seen that in all this in the ways in the boost converter as well as the a fly back converter, when the duty ratio goes beyond this number 1 minus route alpha. The converter operates with an efficiency which is less than 0.5, which is not a very good operating point losses are higher than what is being delivered to the load. So, the preferred operating range is the region where duty ratio is less than 1 minus route alpha normally, we would keep it even considerably less than 1 minus route alpha. So, that the efficiency is closer to 80 percent or 90 percent.

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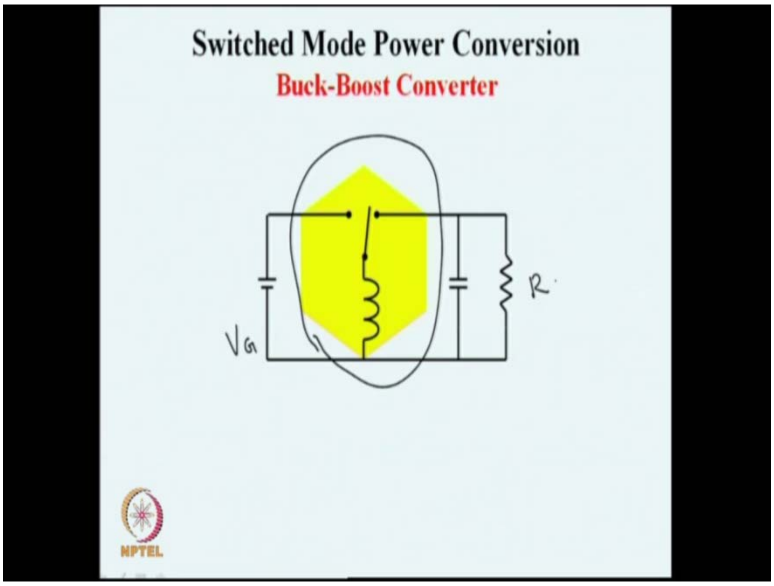

To, what we had seen in the past, in the past 1 hour is to look at this buck boost converter of fly back converter has made up of a converters cell connected to a voltage source and connected to a load.

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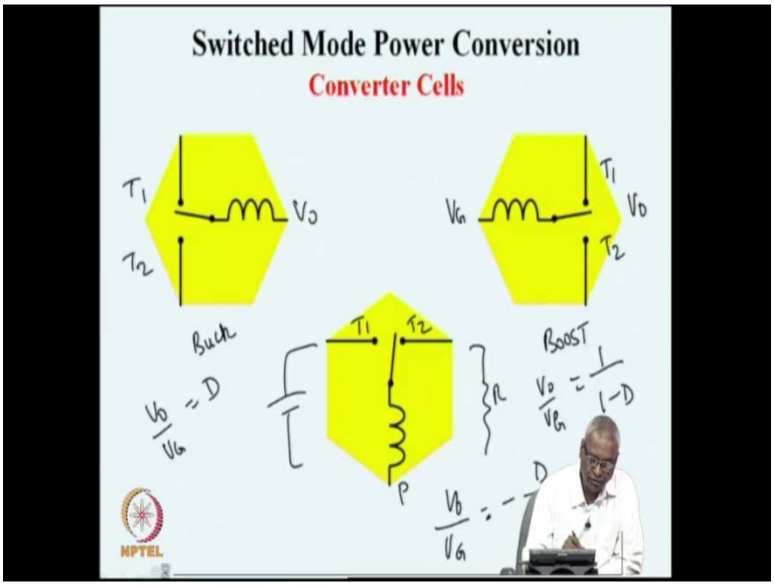

Earlier we had seen that this cell can be used in 3 different variations, where the throws are on the input side and the inductor is on the output side. And this we called as the buck converter where V naught by V G was D duty ratio, Then we had also seen that if the V G is connected to the inductor end and V naught is connected to the throws, then this works as a boost converter is called a boost converter where V naught by V G is 1 by 1 minus D duty ratio in the ideal case. And now, what we have seen is that the same cell can be connected in a third way, these are the different ways in which the cell can be converted connected, where the source is connected to one side and the load is connected to the other side. And the common point is the pole or the inductor of the switch and T 1 and T 2. And we had seen that in this case the ratio is minus D by 1 minus D. The output has a polarity which is negative of the input polarity and the ratio is minus D by 1 minus D in the ideal case.

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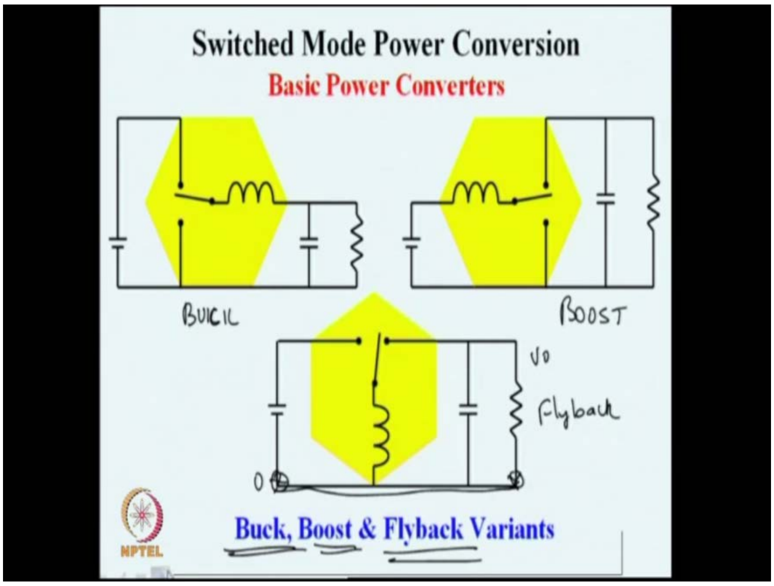

So, these are the 3 different power converter topologies, basic power converter topologies. This is the buck converter, the second one is the boost converter what you see here and the third one is the fly back converter, which is this .These converters are all non isolated converters, that is the electrically the input and output have a common potential on one side of the, of the voltage, V G is with respect to 0 and V naught is also with respect to that same 0. And these converters are all called non isolated converters. So, just before we go into that.

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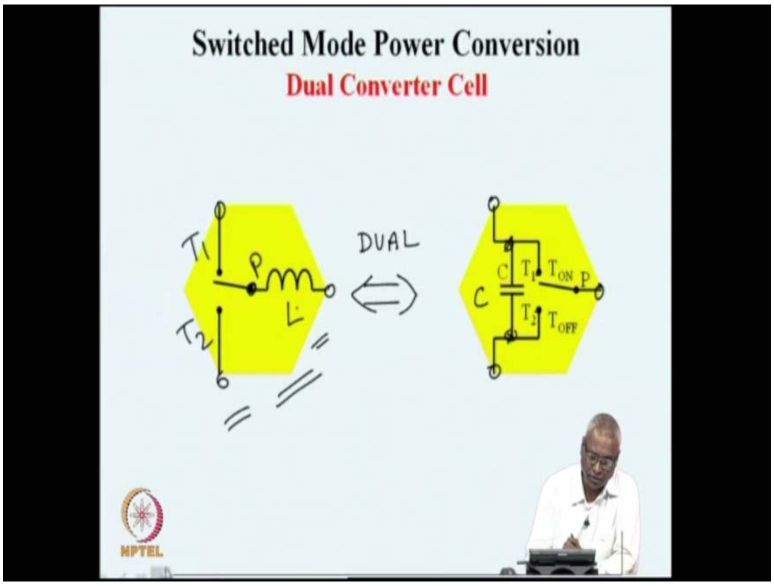

We will look at another slight variant of the same converter cell, this converter sell what you see on the right hand side is a dual of the converter cell that we have seen before. The first cell that we had seen is consisting of a single pole, double throw switch, where an inductor is connected in series with the pole and the 3 terminals are brought out. And we had seen that it can be converter it can be connected a source and a load in different ways the buck converter, the boost converter and the buck boost converter. The dual of this circuit where the switch is connected as before a single pole, double throw switch, but instead of using an inductor, we use a capacitor there is only one storage element which is capacitor.

And we have seen that in the case of a single pole double throw switch, the capacitor can be connected across the throws between T 1 and T 2, because there is the circuit conditions that the capacitor voltage can never be short circuited. Just as the circuit condition, that the inductor current can never be short-circuited and so the inductor was connected to the pole. In the same way the capacitors has to be connected across the throws. So, whether the switch is connected to P T 1 or it is connected to P T 2, the capacitor is never short circuited. This also has 3 terminals and this is a dual configuration of the one that we have seen.

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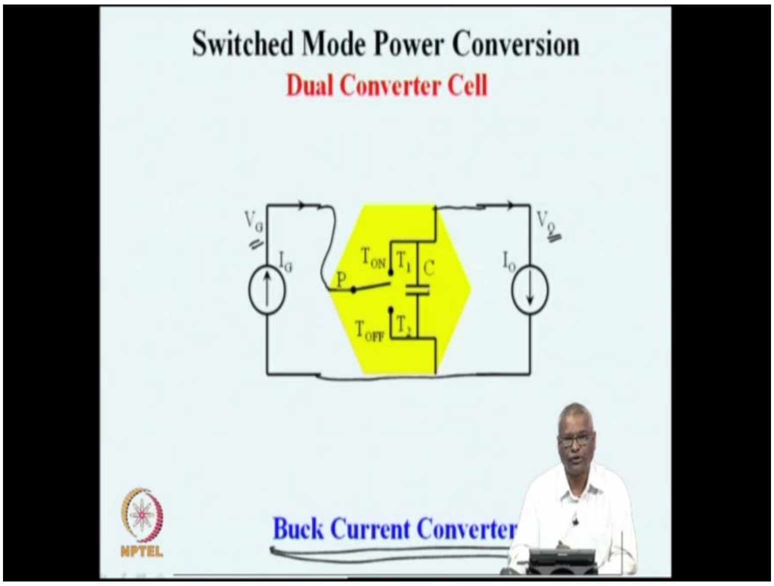

And it is possible to connect this as a buck current converter. And if we had seen the previous cell as a converter, the buck voltage converter where it converts V G to V G to

V naught in the previous a configuration. Now, we can have a source of I G and a load of I naught and this cell, this converter cell can be connected in several ways between the source and the load and the way I have shown here is a buck current converter. In such a configuration this is connected to P, these points are connected together and this is connected here. So, such a Configuration it is a buck current converter, we will see that it can be also here also we can apply similar to volts second balance. We can apply amp second balance on the capacitor.

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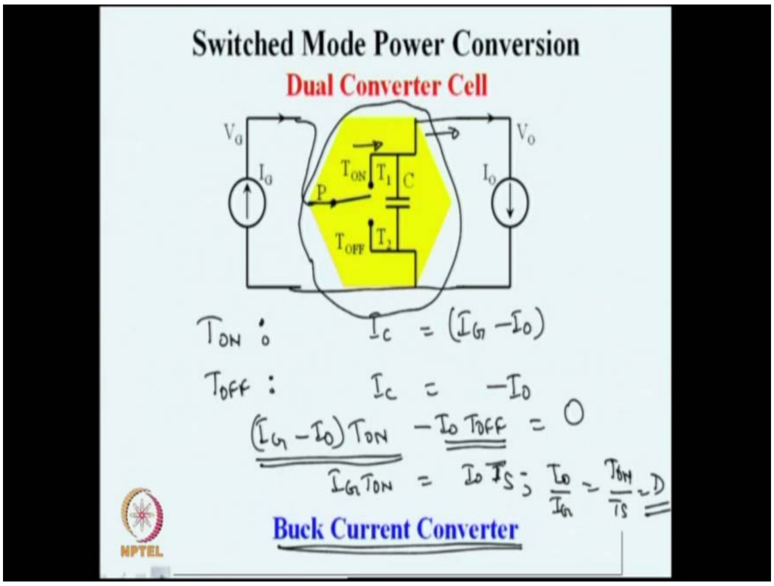

The dual property of what we had seen before the dual converter cell, what you will have seen is during the, or the connection is made like this. So, during the T ON, during the time the switch is in T ON, the inductor current I C capacitor current I C is I G coming from here, because of switch is connected to T ON I G coming from here and I naught going out of here. This is the on state current into the capacitor, if you see the off state when the switch is connected to this end I G is just short circuited through the switch And I naught only is flowing through the capacitor with the minus sign because it is coming out of that. This is a Capacitor current during the off time. So, if we find out, what is the total charge into the capacitor between the I G minus I naught into T ON minus I naught into T OFF.

So, under steady state the net charge over one cycle in a capacitor has to be 0. This is similar to volts second in an inductor, because the net volts second apply to an inductor over one cycle represents the flux change and under steady state flux change from cycle to cycle is 0. In the same way the charge that is supplied to the capacitor during the on time, and the charge that is depleted from the capacitor during the off time. They have to be equal to each other if under steady state, the capacitor does not gain any voltage from cycle to cycle. If we simplify this, you will find I G into T ON is equal to I naught into T S or I naught by I G I naught by I G is T ON by T S which is D.

So, this is a buck current converter, the output current is duty ratio times the input current. And this is the perfect dual of what we had seen before that from a current source of I G, you can supply power to a current sink of I naught using a single pole double throw switch and a capacitor c. The connection between the throws poles and the capacitor are shown in this way and what we have seen here. In this external box is our switch cell, this switch cell consists of one single pole double throw switch and one capacitor connected as per the circuit loss, this is a buck current converter.

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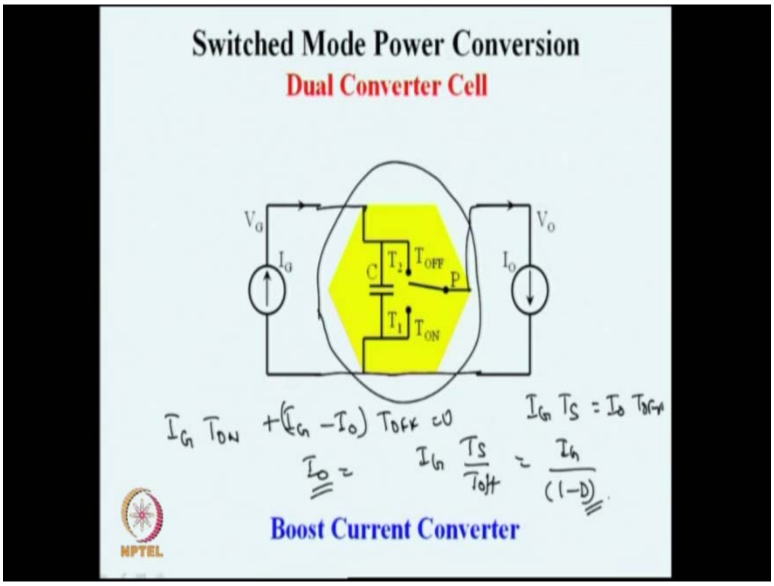

And if you just a see a very interesting thing just like a boost voltage converter, we can have a boost current converter with the same cell connected by flipping the cell, where P was earlier on this side is connected to the output. And the P the throws which were on the output side, where connected to the input side. And now this connection is done over like this and then P gets connected here, this will become a boost current converter. Here also it is possible to find out during the on time, during the on time P T 1 is connected here I naught is completely shuttered in that time I G flows through c, you will find that, I G into T ON is the charge on the capacitor, when the switch is connected here.

And when the switch is connected in the off state, the current through the capacitor is now what was coming in here I G into T ON. Now, it is I G minus I naught into T OFF equal to 0 and this can be written as I G into T S equal to I naught into T OFF or I naught is equal to I G into T S by T OFF, these is I G divided by 1 minus D. This is what we call as the boost current converter, the output current is input current divided by 1 minus D or the output current will be more than the input current. This is a dual of the boost voltage converter and this is a boost current converter.

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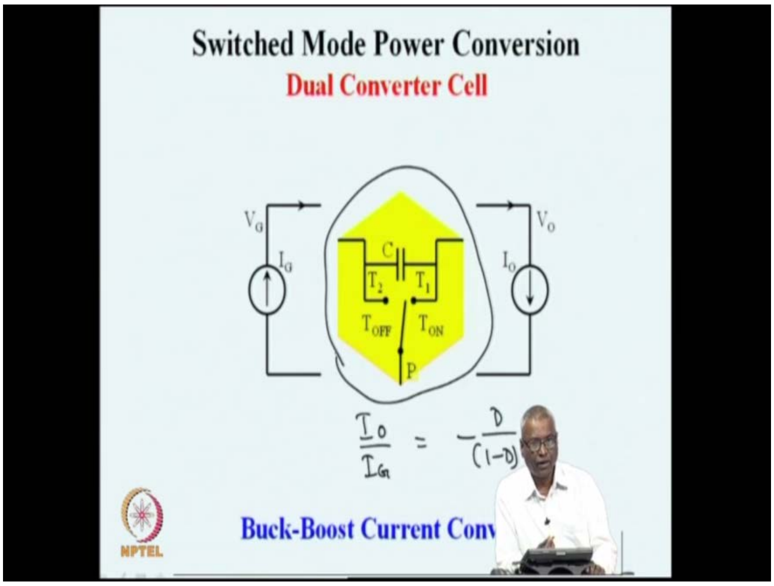

And in the same way, the third way of connecting the same cell is with the pole at the common point and T 1 and T 2 connected to the source and the load. And if the calculations are done on the amp second balance here, you should be able to find out that I naught by I G was must be minus D by 1 minus D which is the same as the buck boost current converter. So, we have seen that, this cell which is a dual off the inductor plus s V D T cell also has identical 3 variants off buck current converter, boost current converter and buck boost current converter. So, effectively single, switch and single energy storage element can be connected in these many ways 3 variants each of them as a current converter or voltage converter.

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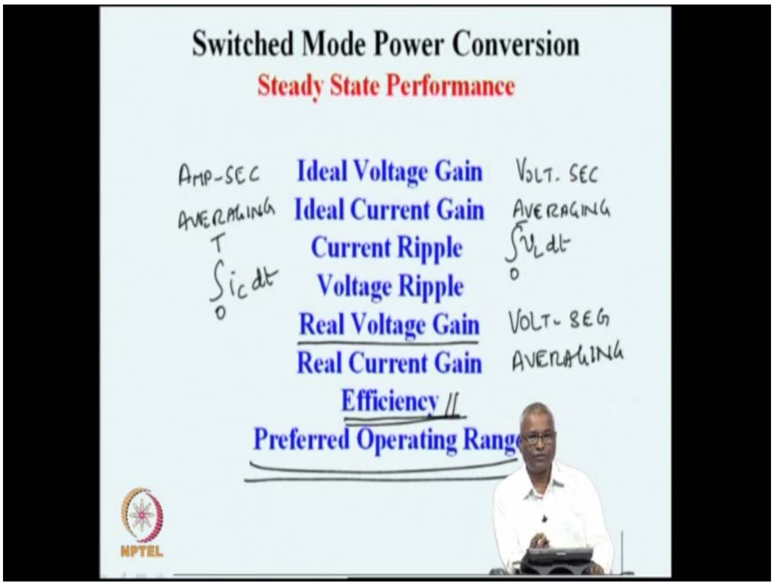

And we see that in all these converters, it is possible to find out the voltage gain, current gain, current ripple, voltage ripple, real voltage gain, real current gain, efficiency and then the preferred operating range all of them through the different steps that we had seen. The ideal voltage gain will be done by volts second balance on the inductor or ampere second balance on the capacitor. So, in the capacitive energy storage element to find out this gain current gain or voltage gain really, we will use the ampere second balance or volt second balance.

In order to get the ideal current gain, we will find out the averaging process. Similarly, here also averaging process and the current ripple is found out by integrating v L and voltage ripple is found out by integrating i c dual properties integrating i c d t over one period 0 to T, will give us the voltage ripple measure, and similarly integrating v L d t for one cycle 0 to T, will give us a current ripple. In the real voltage gain is also obtained by volts second balance by volts second balance, but keeping account of the drops that are taking place on account of the parasitic resistances is parasitic voltage drops and so on.

Real current gain is again found out by similar averaging process and then the efficiency can be easily found out as the correction factor, which appears on the voltage gain. The real voltage gain, and the ideal voltage gain will differ by a correction factor and that correction factor will be our efficiency. The preferred operating range is normally found out where the efficiency is closer to 1. In most converters, the closer to unity efficiency is the preferred operating point, because losses in the converter will be small.

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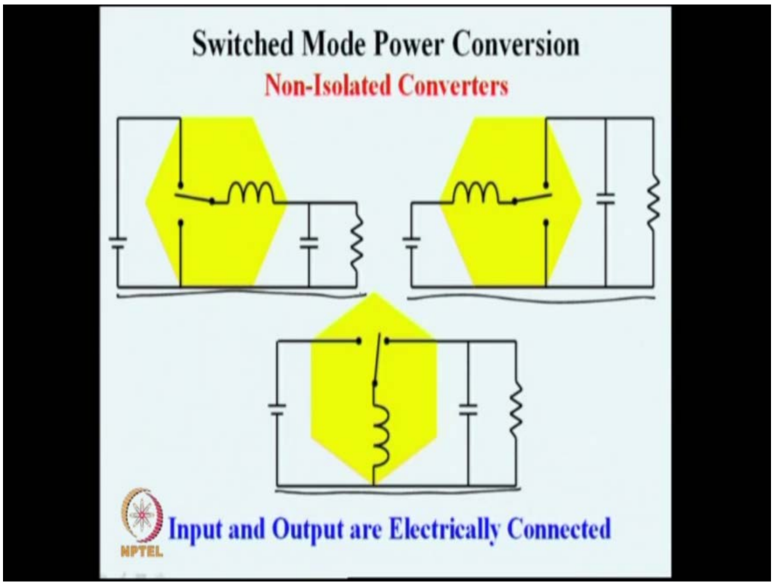

All these converters that we have seen up to now, the current converters or voltage converters they all have one of the lines common and they are all called non-isolated converters. Even though, practically all the converters can be reduced to an equivalent circuit of such a non isolated converter for the purpose of simple analysis.

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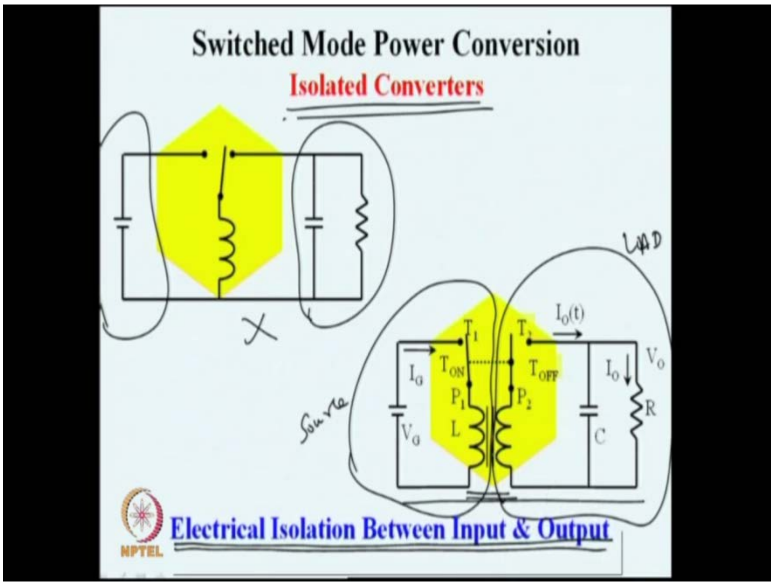

In real life, we require in many applications, the load to be supplied power from a source, which do not share a Common electrical connection. So, such power converters are called isolated power converters. In such power converters, the source side and the load side are not to be connected electrically as you see here, see this has a source portion and the load portion are perfectly isolated from each other. Electrically, there is no connection between the source side and the load side. So, that the potential, the potential on the load and the potential on the source can be arbitrary they can be floating at different levels. And so this electrical isolation between input and output is very essential in many, many applications.

So, what we will see in the in the next set of lectures will be several power converter topologies which help us to achieve the electrical isolation. Performance wise they are identical to the non isolated versions they also operate with pulse width modulation, with a constant switching period and certain on time and certain off time. All those fundamental basic characteristic features are same between the isolated power converters and non isolated power converters. But the non isolated, the isolated power converters provide load power which is electrically isolated from the source potentials and that is very essential in many, many applications from the point of view of safety of personal as well as safety of equipment. So, what we will see will be several power conversion topologies which are suitable for isolated power supplied to the load from a source with total electrical isolation.

These circuit topologies invariably will use electromagnetic isolation, what you see here is an electromagnetic element with a primary inductance or a primary winding and a secondary winding. The magnetic element can be charged by drawing a current in the primary and the magnetic element can be discharged by discharging the current into the load. In such a way, that the power first get's converted to electromagnetic, electrical power is converted to magnetic current energy, magnetic energy is reconverted electrical and supplied to the load. So, that way we keep the total electrical isolation between the input and output.

So, in the coming lectures, we will see several circuit topologies which provide electrical isolation with different number of switchers, energy storage elements, transformers and so on. And after that is over, we will be able to see a few more operating modes on these converters. The next lecture will be on isolated power converter topologies. So, we will see forward converter, fly back converter again and bridge converters and several of them.

Thank you very much.