Fundamentals of Power Electronics
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Lecture – 52
Buck-Boost converter

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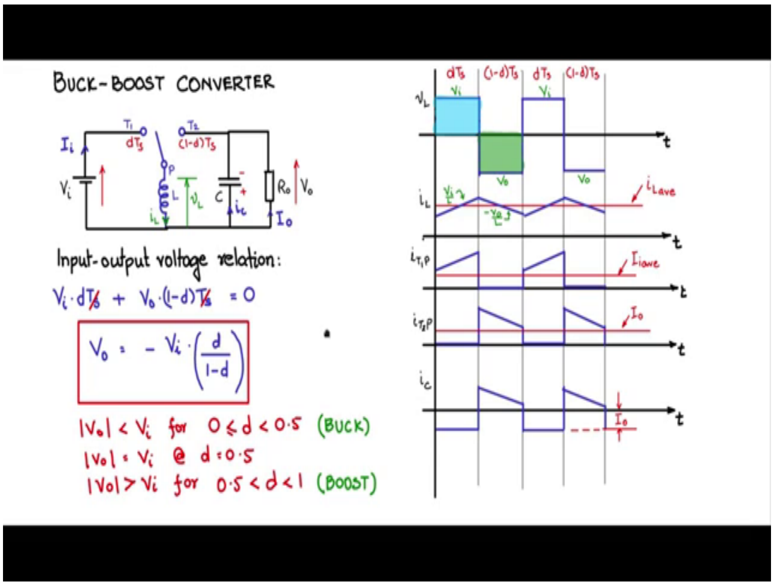

The third of the primary converter is the Buck Boost Converter it can do both operations, it can do buck operation and also boost operation depending upon the value of the duty cycle or the duty ratio. Now let us draw the circuit, you have the input voltage source single pole double throw switch connected like this, in the case the buck converter the inductor was on the output side, in the case the boost converter the inductor was in input side, the case the buck boost converter the inductor is in the middle connected down to ground. Then you have a capacitor connected across the output in this fashion and R naught.

So, this is V i this is R naught this is V naught measured in this fashion and V i measured in this fashion you have the pole throw 1, throw 2 C and L. Now, during dT S period let us say the pole is connected to T 1, so let us say we connected like that. So, which means the current will flow in this path, current flows in this path and charges of the inductor. Now during the 1 minus dT S period the pole is connected to T 2 in this fashion. The inductor current should continue to flow, but it cannot flow in the input path because T 1 throw is open now.

So, it has to continue to flow in this path, take this direction and come back and join and free wheel in this fashion. So, the inductor current continues to flow, but when it is flowing to the capacitor look at the direction the charge on the capacitor will be plus minus in this fashion which means you will have a negative voltage V naught will be negative and I naught will be flowing in this path in this direction. So, that is one difference that you would find in the buck boost converter with respect to the buck and the boost topology.

So, this freewheeling action which causes the output voltage to develop is called the fly back action and in the isolated version we call the buck boost converter; isolated buck boost converter as the fly back converter. So, anyway let us now try to understand this buck boost converter with waveforms and try to design find out what are the values of the L and C and also the type of switches that you will use for the single pole double throw switch.

Let us now try to understand the operation of the buck boost converter with the help of waveforms, typical and important wave forms. We have here the single pole double throw switch P is connected to T 1 for a period of time dT S p is connected to T 2 for a period of time 1 minus dT S, we will measure the voltage across the inductor v L in this fashion, common point here measuring pro point here. I naught is as indicated here in this direction i C is in this direction as we explain, i L current waveform and now we shall plot the important parameters and try to understand the operation of the buck boost converter.

Like before I will divide the time axis into four segments dT S, 1 minus d T S dT S and 1 minus d T S together they makeup T s that is one switching period, likewise I have two switching periods here for the waveform and let us plot first the voltage across the inductor. So, we will plot V L and during dT S time what is the voltage across? During dT S the pole is connected to throw 1 and the entire vi is coming across the inductance pole is having the same voltage as v i, so this will be V i. And during the time 1 minus dT S, the pole is connected to T 2 and therefore, T 2 potential which is actually minus V naught here minus V naught comes directly across L.

So, therefore, you will see V naught coming directly across L and we have seen that the charge on the capacitor is reverse plus minus in this direction because the current is flowing like that to complete the inductor freewheeling current path and therefore, V naught measured in this fashion with the common here and the measuring probe here we will show a negative voltage value, so that is V naught which is minus.

And then again next cycle V i here, V naught here and so on and so forth it continuous. So, this is the inductor voltage waveform remember to use this for the old second balance equation to obtain the input output voltage relationship. Next let us look at the current through the inductor i L, so that is another next important wave form that we need to look and understand.

So, the inductor current will have an average value, so this is the average value which I am indicating and for now I will call this as i L average because it is neither connected to the input nor to the output infect it is connected to both, for parts of the time and therefore, we will see what it is later or now call it as i L average, this is the study dc portion, on top of it there will be the ripple portion.

Now, the ripple portion as before I am trying a straight line because the voltage across the inductor is fixed constant V i during the dT S period. So, there is going to be at delta i L change with fixed slow, fixed rate and that is V i by L. And then, during the 1 minus dT S period it is going to fall because the inductor is going to discharge into the load at a constant voltage being applied across the inductor which is minus V naught. We see that there is a minus V naught applied here, so there is a minus V naught by L and that is that falling slope.

And so on it continues again for the next positive and the next negative discharge portion of the inductor current. Next let us have a look at current through T 1 P; T 1 P current, the current through T 1 P; the current through T 1 p should be that part of the inductor current that flows through the input source when P is connected to T 1 during dT S period and that will be the dT S portion of the inductor current. So, we can draw the dT S portion inductor current 1 minus dT S portion will not flow through the inputs source because T 1 is open.

So, there is no current flow during 1 minus dT S period again the next dT S period you will have the inductor current flowing through the input source, so T 1 P will have a current like the inductor current, but only the dT S period part. Now this has an average, this is the current this i T 1 P is the current that is flowing here and we will call that one as I i and I i, the average I i current will be will be the average of this wave shape, so this average is I i average can call it as that.

Next let us look at current T 2 P, the direction of the current through inductor cannot change, so, what was T 1 P now becomes T 2 P the inductor freewheeling in this fashion and T 2 is connected to P during 1 minus the T S period. So, the that portion of the inductor current that occurs during 1 minus d T S period will flow through T 2 P. So, during dT S period T 2 P will show 0 current, then it will show the inductor portion of the current passing through T to P during 1 minus dT S period again dT S period 0 and so on.

So, this will have an average. Now this current the same current flowing here also splits in two parts i C and I naught i C is the 0 average part and the average part flows through the load. So, the average part is nothing, but I naught looking at the figure you can see that the average part has to be I naught and the non average part flows through i c. So, in effect if I remove this average part bring down this wave form to 0 average I will get the current through C that is i C.

So, if I do that exercise I will see that I will be bringing down removing the average part bringing out the wave form by I naught. So, this amount which it has come down is equal to I naught, now this current wave shape wave from will have 0 average because the current through the capacitance has to be 0 average under steady state conditions.

So, these are the various wave forms, various voltages and currents that you will see in the buck boost converter. Let us now find the input output voltage relationship and the input output current relationship for the buck boost converter. So, a first the input output voltage relation let us use the voltage across the inductor wave shape, the voltage across the inductor and apply the old second balance for the voltage waveform.

So, this is the portion of the waveform inductor voltage waveform above the 0 line and this is the portion of the inductor wave form below the 0 line, the area under this portion of the curve and area under that this portion of the curve should cancel out and balance each other out in the steady state. So, that is what we will be doing, applying the old second balance, so let us consider this area the old is V i second is dT S plus take this portion of the area during minus dT S period is V naught into 1 minus dT S should be 0.

So this is the old second balance equation. I will remove this variable and rearranging you have V naught is equal to minus V i d by 1 minus d, so this is the input output voltage relationship. Observe the negative sign because of the direction of the measurement here and because the capacitor charges and reverse here you will see the negative sign appearing. If you choose chose the direction of measurement in the opposite direction this will become a positive one, any way we are bothered about the magnitude of the conversion, so V naught which is equal to V I d by 1 minus d.

So, if you look here the absolute value the only magnitude V naught I am considering is less than V i it is the buck operation for the value of d 0 to 0.5. So, between 0 and 0.5 and the value of d is less than 0.5 you will see that this is less than 1 and therefore, it is attenuation or buck operation. V naught is equal to V i for d is equal to 0.5 0; 0.5 you will see the attenuation factor here is 1 and therefore, V naught is V i by magnitude.

And V naught is greater than V i for d between 0.5 and 1, during which time this ratio becomes greater than 1 and therefore, it is boost operation. Therefore, you see that this converter operates in buck mode for d less than 0.5 and in boost mode for d greater than 0.5 and therefore, it is called the buck boost converter.

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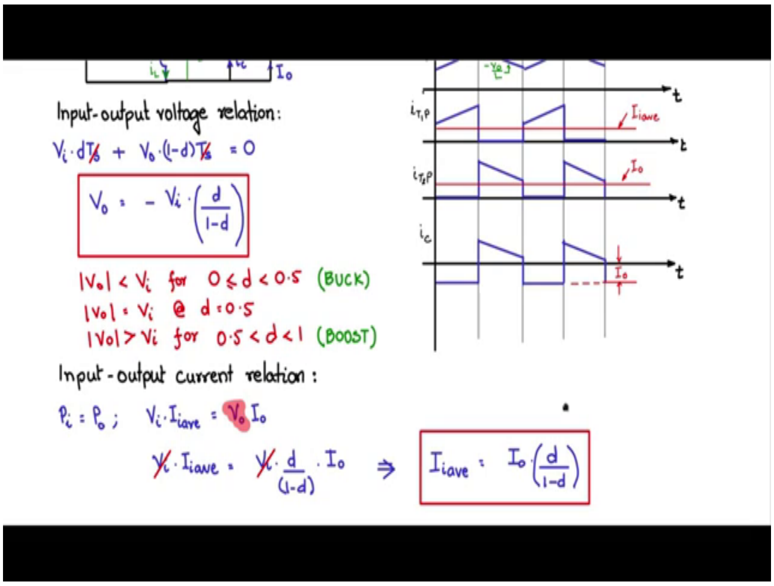

Let us now find out the input output current relationship, so let me move this up a bit. So, the input output current relationship you can use amp second balance, but much simpler to use the power balance P i is equal to P naught, V i I i average is equal to V naught I naught. I naught is the average on the output side therefore, I am taking the average on input side because the input current is switched. Therefore, I am taking to take the relationship of I i average with I naught; I naught is also an average.

And now this portion let me replace it with this equation I will use that equation from the old second balance relation V i into I i average is equal to I will only bother about the magnitude, so V i d by 1 minus d into I naught. So, let me remove these two these two parts V i and V i and simplifying you get I i average is equal to I naught into d by 1 minus d and this is the input output current relationship for the boost converter.

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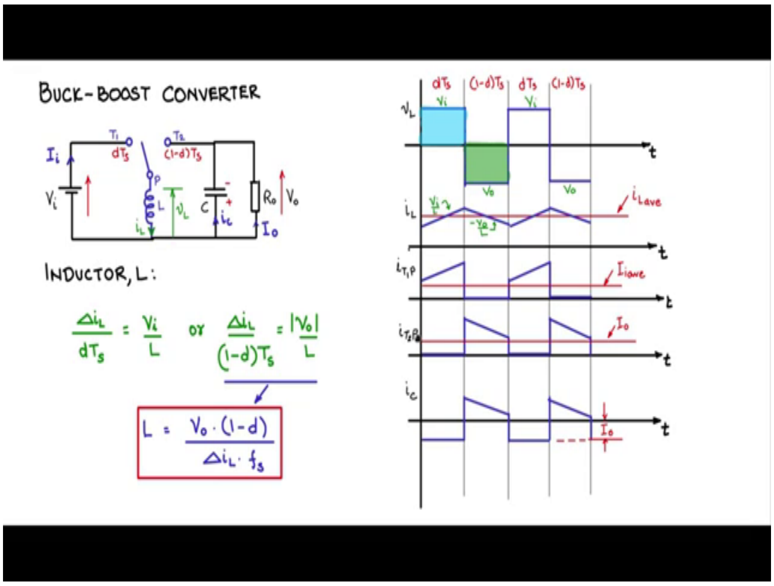

Let us now try to find the values of the components inductor first, then capacitor and then we will try to identify the switches and the ratings. So, first the inductor L, so let us look at the inductor current waveform we see that the inductor has a change delta i L I will call the delta i L like before in time dT S and another delta i L change during the 1 minus dT S period.

So, we can use the faradays law where V is equal to L d i by dT or d i by d T is equal to V by l. So, delta i L change during dT S time period and the slope is V i by L or I can use delta v L change during 1 minus d T S period with a slope V naught by, so I am only taking the magnitude because we want to find 1 which is always first. So, using this equation I will use this equation because it has just only V naught and V naught is a regulated voltage rather than V i. And therefore, from this you have V naught retired retain L I will push it on this side delta a will come in the bottom 1 minus d will come here and T S which was here 1 by T S is f s I will put f s in the denominator.

So, this way you simplify you get the relationship for the inductor value L, so this is the basis for the inductor value design. All values are known V naught is coming from the output specification, d is coming from the input output voltage relationship because input is specified output V naught specified d can be found out, f s is the designer parameter designer will choose what is the frequency of operation of the switches of the switches buck boost converter and delta i L as before you take a 10 percent of whatever this i L average is, but just look at the other two waveforms i T 1 P and i 2 P i L average is nothing, but I i average plus I naught which is the average of i T 2 P.

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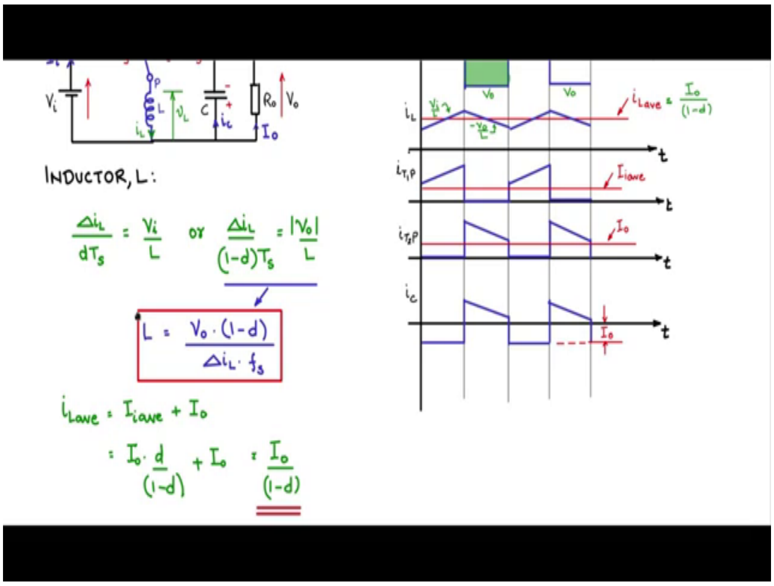

The i L average is equal to i T 1 P current waveform average which is I i average plus i T 2 p average which is I naught because these two sum up to give you i L. I i average from the input output current relationship we know is I naught into d by 1 minus d plus I naught which workouts to I naught by 1 minus d.

So, this is i L average and therefore, is i L average is I naught by 1 minus d, so this also you can estimate from the specified parameters, I naught you know from the max power that needs to be delivered that is a specification, output specification d is obtained from the input output voltage specifications and therefore, i L average is known and therefore, 10 percent of i L average is known and you can find out the value of inductor.

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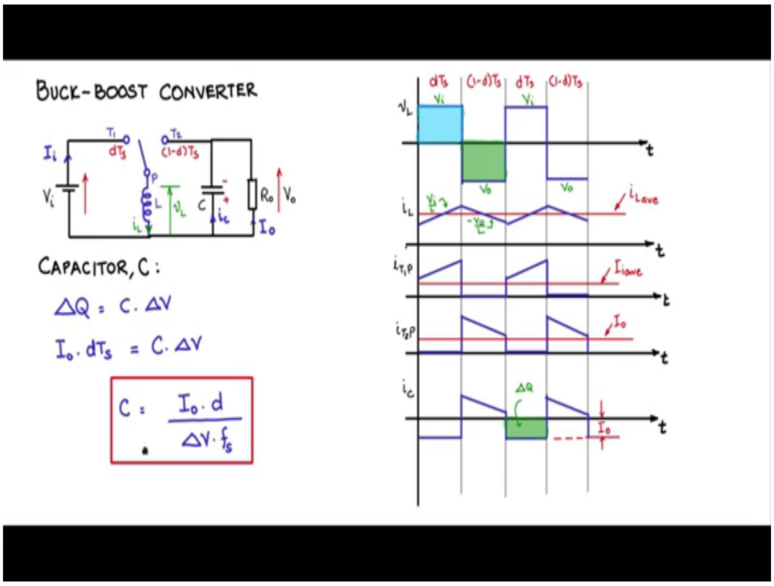

Next let us find out the capacitor value, we go again by the change in the charge in the capacitor with in a cycle, we know that the area under the i C curve is the change in the charge, the area under the i C curve during 1 minus dT S period and the area under i C curve during the dT S period should match balance out, so let us use that idea. And it is easier to get the change in charge during dT S period because this is a rectangle of height I naught and width dT S.

So, let us use delta Q is equal to C delta V and this is the delta Q and this height is I naught into dT S will give you the area delta Q which is C into delta V and from here see you can find out I naught dT S I will take it to the denominator f s and delta V comes down f S and this becomes the relation to obtain the value of C.

I naught is known from the output spec, d is calculatable from the input output voltage relationship spec, delta V is a spec of the output voltage ripple, f s is the designer parameter which is chosen by the designer depending upon the frequency at which a single pole double throw switch is being operated. So, using this equation you can arrive at the value of C.

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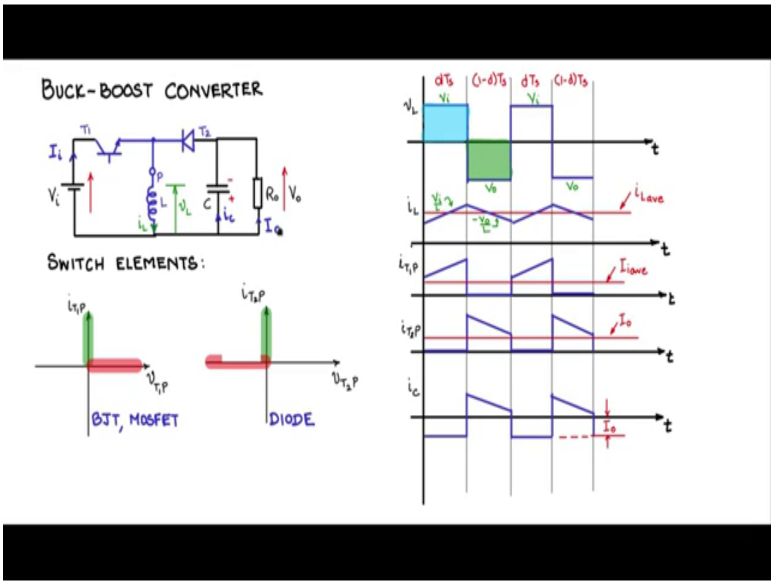

Let us now select the switch elements for the single pole, double throw switch. Considering the switch elements now, let us find out what is the static switch requirements? Static characteristics of the switch; now we will take T 1 P and T 2 P one after the other and see how the static characteristics for the switch looks like v T 1 P on the x axis, i T L p on the y axis.

Now if we take this switch during the time dT S when pole is connected to T 1 there is a current flow, the current flow is from T 1 to P; T 1 to P being positive and you see that i T 1 P is always positive above 0 and there is no current flow from P to T 1. So, therefore, we can say that all the positive axis of the current or possible operating points, then when P T 1 is open P T 2 is connected, the pole voltage is at minus V naught and T 1 throw voltage is at plus V i.

So, throw T 1 is at higher positive potential as compared to P and therefore, T 1 P should support positive voltage during off condition. So, therefore, all these are potential operating points. Now this if you look at the characteristic and characteristic of typical devices you will see that they map to BJT and MOSFETs and even IGBTs. So, T 1 P can be replaced with a BJT, now when you come to T 2 P V T 2 P and i T 2 P or the important variables here.

So, during the time when T 2 and P are connected there is a current flow from T 2 to P because inductor current should not change direction. So, all the positive axis of current becomes potential operating points and during the time and P T 2 is off P is connected to T 1, so P is a positive potential T 2 is connected to the output, so it is a minus V naught, T 2 is minus V naught P is positive potential, so T 2 P is a negative voltage.

So, the switch T 2 P should support negative voltage. So, all these negative axis of the voltage become possible operating points and this has a typical nature of a diode switch characteristic. So, now we know that for this we need to use a diode. let us now use the BJT for T 1 P and diode for T 2 P replace it in place of this single pole double throw switch and see how the topology valves.

So, let us erase some portion making space we will put a BJT here like this, observe the direction of the current flow is from T 1 to P direction and then we will make some space here and then put the diode here again the direction of current flow is from T 2 to P keeping that in mind, so this is T 1 and this is T 2. So, now, you have the BJT and the diode interposed inside the circuit and this gives you the entire buck boost converter topology with semiconductor switches.

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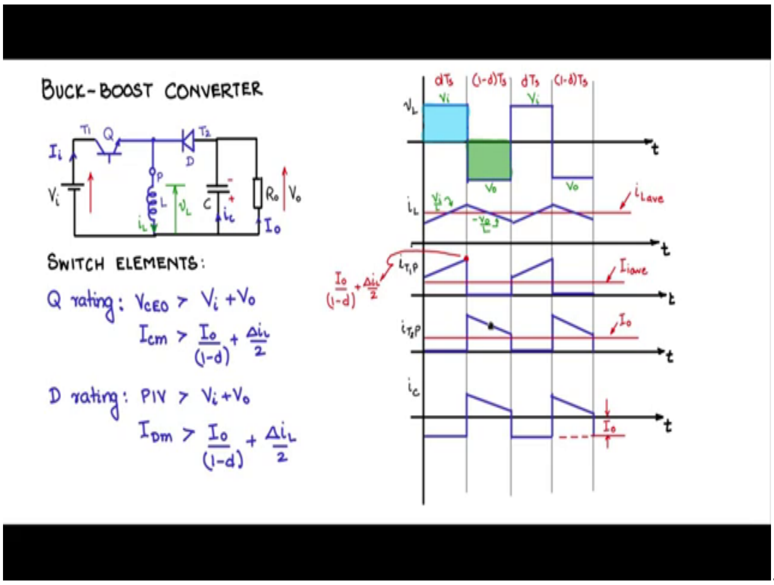

So, now this is Q and this is d let us write down the ratings for Q and ratings for D, the V CEO rating of this when the switch is off. Collector is at V i potential and the emitter the diode is free, the diode is conducting freewheeling during that time the emitter will be connected to minus V naught.

So, V i and on this i minus V naught, so the Q V CEO should be greater than V i minus of minus V naught V i plus V naught. I Cm the current through that V C i T 1 P this is the peak current and we know this is i L average, the peak value is plus delta i L by 2, i L average we know is I naught by 1 minus d and plus delta l by 2.

So, therefore, I C m is I naught by 1 minus d plus delta i L by 2. The d rating similarly we can find out peak inverse voltage across this when diode is off T 2 is at minus V naught pole because Q is conducting pole is at V i. So, the peak inverse voltage is V i plus V naught should be greater than that and I D m the peak voltage is same peak current is same as this I naught by 1 minus d plus delta l by 2 and you can find out from the wave shapes current wave shapes here, the average and the rms values also if needed.