Fundamentals of Power Electronics
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Lecture – 51
Boost converter

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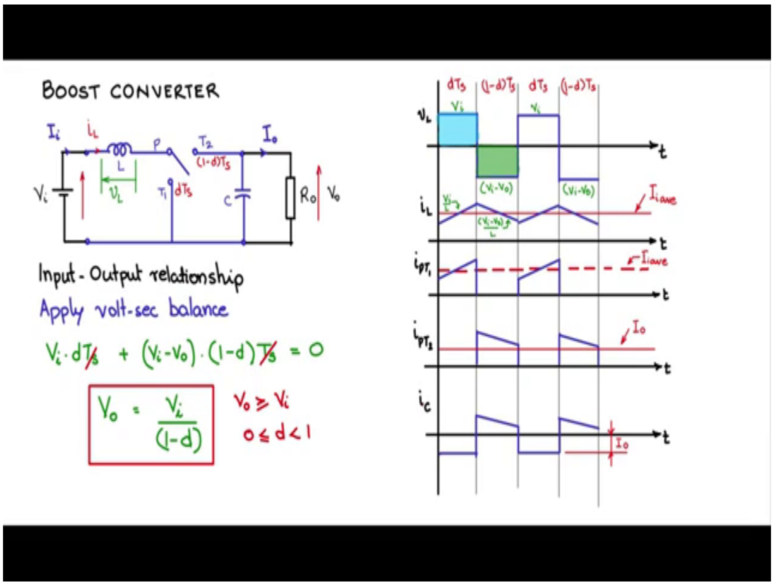

Consider the boost converter circuit. We have this inductor, single pole double throw switch and the capacitor. Let us see how it operates and the various waveforms. Let me mark this I naught current flowing through the output load resistor, I in current flowing through the input source V i. Let me mark the voltage across inductor is the voltage across the inductor V L with the common point the probe placed here and the measuring point the probe placed here.

Now, let us discuss its operation and wave forms visually and get some insight into this converter topology. Now I am going to display the wave forms here and I have split the time axis into four parts has before. Now let us say that P T 1 is going be on during d T s period and P T 2 is going to be connected during 1 minus d T s period. So, let me mark this time periods here on the graph d T s and 1 minus d T s; d T s and 1 minus d T s together form a switching period T s.

So, let us plot first the voltage V L across the inductor and during d T s, the pole P is connected to T 1 pole P is at 0 voltage and the other side of the inductor is at V i voltage. So, a voltage V i measured positive like this.

Now, during the period 1 minus d T s 1 minus d T s t is connected to t two. So, the potential here is V naught V P or the pole potential is V naught and this side the inductor is till V i. So, voltage across the inductor is V i minus V naught. Now is V i minus V naught positive or negative? We know that the inductor cannot support an average voltage. Therefore, the average voltage has to be 0. In steady state which means in steady state during the one minus d T s portion, there should be a negative voltage so that there is volt second balance.

So, that can happen because the voltage across the inductor during that period is V i minus V naught that can happen only V not a greater than V i. So, it is automatic that V naught will be greater than V i in order to have the volt second balance happening. So, this will become negative like this and so on to the next cycle. V i and V naught V i minus V naught. So, this is the voltage waveform across the inductance.

So, now, let us now see the current waveform through the inductance. I am drawing this average current here; this average current flowing through the input flowing through the same inductor and the inductor has two parts the average part and the ripple part.

So, let me call this I in average and let me draw the ripple. I have drawing the ripple as a straight line and it has a slope V is equal to L d i by d t. So, d i by d T slope have placed it as a straight line linear fixed slope. The voltage across the inductor is V i during that time constant L is a constant; V i by L is the slope which is the constant. And during this time V i minus V naught is negative. So, it is a following slope V i minus V naught by L is the slope. So, it repeats for the next cycle and so on. So, this is the inductor current waveform.

Next let us see the waveform of the switch P T 1. So, let me draw this I average level position I average and i PT 1 P T 1 current flowing from the inductor into this and when this open the inductor current cannot be distil discontinuous its start flowing into P T 2. So, the inductor current inductor current flows through P T 1 during the time d T s when P T 1 is on. And only during d T s time you will see the inductor current flowing through P T 1, otherwise P T 1 is 0.

Next let us see what is the current through P T 2. So, during P T 1 the inductor current flows through like that and during P T 2 during 1 minus d T s the current flows through P T 2 and that is same as the inductor current portion during that time. So, this is the current through this P T 2.

Now, what is the average of the P T 2? Average of the current through P T 2 flows through capacitance and through the output load resistance. We know that the average the current through the capacitor has to be 0. Therefore, the average has to be I naught. So, average is I naught. What is the current through the capacitance? The current through the capacitance is this waveform P T 2 waveform shifted down by the average because the average cannot be any finite value here, it has to be 0. So, we have a 0 average current flowing here in this fashion where this amount, but the amount by which it has shifted down is I naught.

So, these are the various waveforms that we see for the boost converter and using this waveforms, let us find the input output relationship and the values of the inductor capacitance and what goes on to form the single pole double throw switch. Let us now try to find the input output voltage relationship for the boost converter. So, for that we have to use the volt second balance equation. So, let us apply this volt second balance to what voltage you will be applying a to the inductor voltage. So, look for the inductor; look for the voltage across the inductor which is this waveform and later apply the volt second balance.

Now, during d T s this is the volt second area, we can use, we can use a simple relationship of a rectangular area because this is a constant voltage would. So, let us apply that. So, this is V i into d T s V i is the amplitude d T i d T i is the width and this is the area the rectangle during the d T s period. Now during the 1 minus d T s period the voltage across the inductance is V i minus V naught. So, this area we will calculate V i minus V naught into 1 minus d into T s.

Now this area positive area negative area should balance out. So, therefore, that should be equal to 0. I will remove these 2 variables or the picture. Now the remaining variables if you simplify you have a V i into d and you have V i and V minus V i into d. So, this V i into d and this V i into d will cancel out, you have a V naught into 1 minus d push it to the other side. So, you will end up with V naught equals V i by 1 minus d. Now this is the input output voltage relationship for the boost converter, observe 1 minus d comes to the denominator here; d takes on values from 0 to 1. If d is 0, V naught will be V i if d is one V naught will tend to infinity, but it will not actually tend to infinity d cannot take value 1 because then this will be permanently on and there would not be switching.

So, it should be less than d should be less than 1. So, V naught greater than or equal to V i and d takes on values between 0 and 1 on this fashion. So, this would be the input output relationship the boost converter and because V naught is always greater than V i we call this as the boost converter. Let us also obtain the current relationship.

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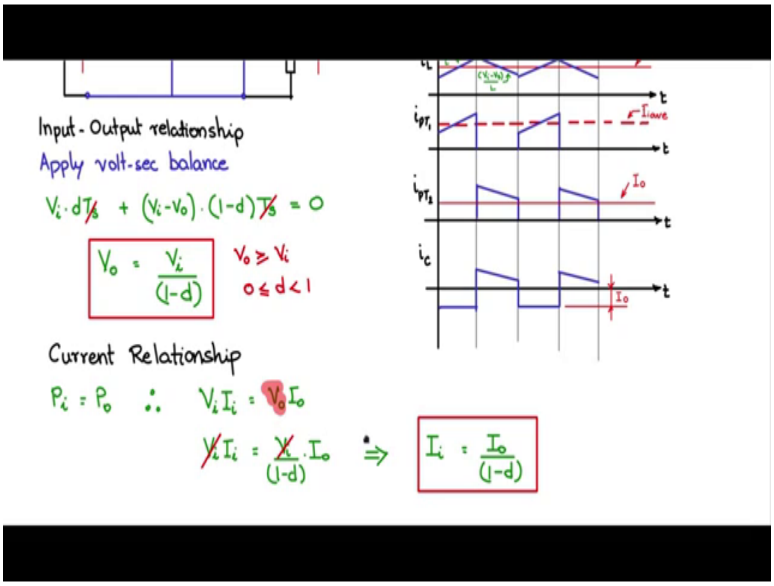

We could use the amps second balance across the capacitance or like we did last time we could use the power balance P i is equal to P naught and therefore, V i I i is equal to V naught I naught. Now this V naught I know from the volt second balance relationship is this much. Let me substitute that V i I i is equal to V i by I minus d into I naught. I will remove these two variables and therefore, you have I naught I i is equal to I naught by 1 minus d and this is the input output current relationship. You could also get the same relationship if you take the amp second balance or the charge balance find out the area of i C here and find out the area of i C here, equate them and get the relationship.

But it is not a straight forward because a trapezium and find the trapezium area, we need to know this heights finding this area is easy because we this is a rectangle with height I naught, but may be difficult to find this in a straight forward manner. So, we use this current relationship we obtain a current relationship using the power balance which is much easier.

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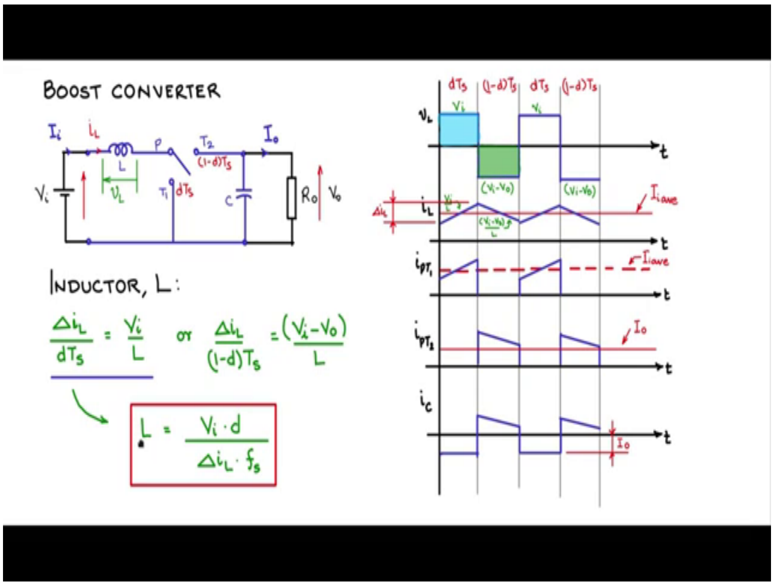

Now, let us find the values of the components L C and then identify the switch elements this of this single pole double throw switch. So, first the L consider the inductor L, what is its value? Take the inductor current wave form and we know that the height of this current ripple; let us set it as delta i L. Now this is the change in the inductor current. So, we will use a Faraday's equation V is equal to L d i by d T and we know the slope of this V i by L we have written here V i minus V naught by L for this part of the slope.

So, consider that during this d T s period; during this d T s period, there is a change of delta i L. So, d i by d T will be delta i L by d T s. So, delta i L by d T s is equal to what slope rate which is V a by V by V i by L here in this period. So, we will write that down V i by L or I could take 1 minus d into T s period. So, during that the current is falling. So, there is still a change of the same delta i L though negative slope 1 minus d T s equals V i minus V naught by L V i minus V naught by L. So, this is a negative slope; the change in delta L is negative in the sense that it is a falling value.

So, you can take absolute values for finding the value of L because the L has to be positive, you can take instead of V i minus V naught V naught minus V i. Anyway if you substitute for V naught all will boiled down to the same equation here. Let us take that equation and find out L. So L, I will push it there delta i L, I will push it down here. So, V i d I will push it up there delta i L T s. If I push it up and say T s is equal to 1 by f s, then I can put f s in the bottom here denominator. So, this is the relationship for finding the value of L for the boost converter.

Here you know V i; V i is a input spec of the un regulated dc source; d how do you find d? We know we know V naught; V naught is again output spec. So, knowing V naught V i, we can use input output relationship and find d, f s is the designer parameter at what switching frequency are you switching these switches could be 20 kilohertz, 50 kilo hertz or 100 kilo hertz.

So, whatever the designer fixes specifies. So, that will be the switching frequency here and delta i L. Now here i L unlike in the case of the bug converter, the average value the inductor current was I naught in the case of the boost converter the average value the inductor current is the input current average. So, 10 percent of this input current average will be delta iL. How do you know the input current we know V i we know P naught P naught and P i are same and therefore, P i by V i will give you I i; so, you 10 percent of that will give you delta i L. So, all these parameters are determinable from the specs and you can find out the value of L.

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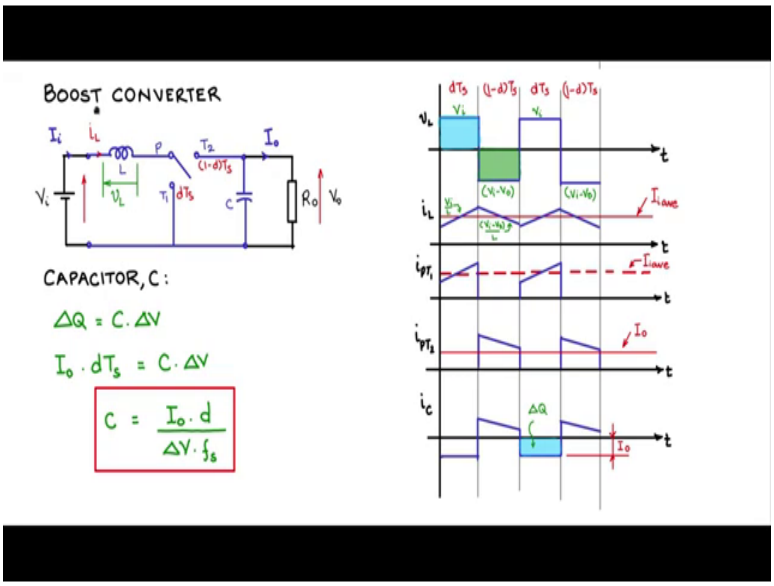

Next let us find out the value of the capacitor C, for that we have to look at the capacitor current waveform and we know from amp second balance that this area the top portion of it above the 0 line and the bottom portion of the area below the 0 line, they should match.

Now the area under this i C curve will be the charge Q. So, in every cycle this amount of area will be delta Q. So, let us use like in the both bug converter case, we will try to find what is delta W and delta Q we know from physics is C into delta V. So, what is delta Q? It is the area covered under the i C curve i C envelope. In this case between one minus d in T s period and d T s period, it is much easier to find the delta Q of this because this is a rectangle of height I naught and width time with d T s.

So, therefore, delta Q i will replace it by I naught, I naught is a height of this rectangle and the width of that the time in the time scale is d T s. So, that is equal to C into delta V. Now C we can write it down as I naught into d T s. I will take it to the denominator as f s; f s is 1 by T s and delta will come down delta V will come down into f s. So, this is the relationship for the capacitor value. Do you know I naught? I naught is obtained from the output spec. Whenever a power supply is designed P naught is given P naught P naught and V naught are given the voltage of the output and the power that needs to be delivered to the output, d can be found in the input output voltage relationship, f s is a designer parameter, delta V is again an output spec what should be the output voltage ripple and using that find out the value of C. So, this is the basis for the design e the basis for the design of the C for the boost converter.

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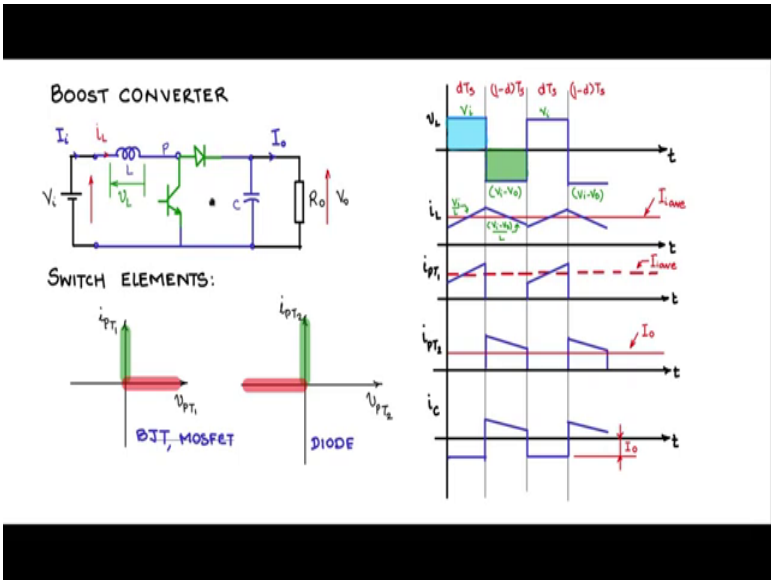

Now, let us select the switches for the single pole double throw switch and find out the ratings. So, the switch elements like we did for the bug convertor, we will use the static characteristic for the switches, the i V characteristic. So, consider first P T 1; let us consider this switch P T 1 and then after words P T 2. So, let us say we draw the i V characteristic of v P T 1 and i P T 1. And then let us match the requirement with a practical switch characteristic and then select the component.

So, now, if you take i P T 1 current flowing from P 2 T 1 is i P T 1 positive and if you if you look at the operation of the circuit when P and T 1 are closed, the current i L flows in this direction from P to T 1. You can also observe i P T 1 wave shape here; all are positive there is no negative component of i P T 1 which means there is no current flow from through 1 to P all current flows are P to through 1. So, only the positive current access or potential operating points. So, let us mark that.

So, these are potential operating points meaning that P T 1 should allow positive direction of current flow from P to T 1. Now for the voltage, when the switch is off when the switch is off what should it support what is the voltage of P pole P? So, when T 1 is off, P and T 2 are connected. So, T and P and T 2 are connected the output voltage will come at this pole point. So, the pole voltage will become V naught; V naught is positive T 1 is at ground potential.

So, P T 1 is a positive voltage and the switch P T 1 during off condition should support or withstand a positive voltage which means all the positive voltage points on this axis become possible operating potential operating points. So, we expect a switch to have this kind of a characteristic and we saw while we were discussing the bug converter that it is similar to a BJT or MOSFET characteristic or even an IGBT. So, I can use a BJT or a MOSFET here in place of P T 1. And for P T 2, let us draw the i v characteristic v P T 2 and i P T 2.

So, looking at the inductor current we know that the current flows current used to flow from P to T 1 and then when you switch off P T 1 and connect to P T 2, the current has to flow from P to T 2 in this direction. And you can also look at P T 2 current wave form all are positive there is no negative, meaning there is no current flow from through 2 to P. So, therefore, we can say that all the positive current access can be potential operating points.

Now, when the switch P T 2 is off meaning when P is connected to T 1 during that time P T 2 is off, what is the voltage it will with stand? T 2 is at V naught potential, P is at ground potential when P is connected to T 1. So, P T 2 is negative and therefore, you will see that it has to withstand all negative possible negative potential. So, this character is provided by a diode. So, therefore, P T 2 should be a diode. Now let us replace the single pole double throw switch with the selected types of the switches; let us say BJT or MOSFET and the diode at the respective places.

So, let us erase some portion of this P T 1 and then introduce a BJT wherever I have introduced BJT, you can as well introduce a MOSFET or also an IGBT all are valid switches in those places; they are controlled switches. So, I have put this BJT in here to match for this characteristic requirement, then this P T 2 we said matches a diode. So, we will make some space there and introduce this diode here.

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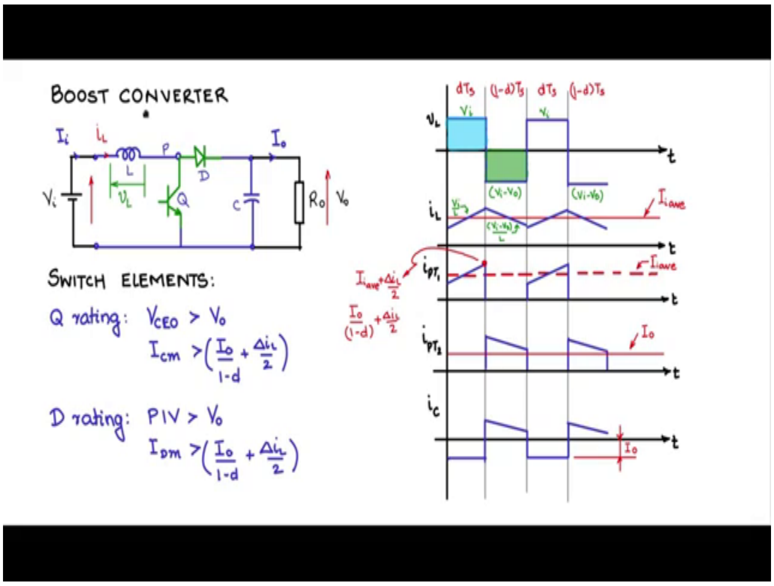

So, let us clear up this is called Q and this is D. So, this becomes the complete topology of a boost converter with the semiconductor switches in place. What are the ratings of Q and D?

So, let us say Q the ratings of that so, first the voltage rating V CEO rating. So, during the off condition, what is the voltage that Q has to with stand? During the off condition, the inductor current is passing through the diode to the output. So, the diode is conducting. So, V naught comes as the pole voltage here. So, Q should with stand at least the V naught amount of voltage. So, V CEO should be greater than V naught definitely, then what should be the max current rating I c m rating collector current max rating should be greater than. Here you see in i P T 1 this point here is the max current that occurs and that is i in average plus delta i L by 2.

So, this is I in average plus delta i L by 2 and I in average can be related to the I naught current we know, we develop the input output current relationship where I i is equal I naught by 1 by 1 by I naught by 1 minus d. So, therefore, I will say I naught by 1 minus d is this I in average plus delta i L by 2. So, in terms of known items d is known I naught from specs delta i L by 2 is known you can say what should be the current max spec for Q, I naught by 1 minus d plus delta i L by 2.

So, for the diode rating, you have the peak inverse voltage. Peak inverse voltage should be greater than what? So, when Q is conducting the diode D is off and it is seeing the peak the inverse voltage. So, during the time when Q is on, the pole point is connected to the ground. So, pole voltage is 0 and the diode cathode is connected to V naught. So, therefore, at least V naught amount of reverse voltage the diode has to withstand. So, it should be greater than V naught and I d maximum is like here you have i P T 2 the max point is same I naught by 1 minus d plus delta i L by 2.

So, all other currents like average and rms currents can be calculated from the wave shapes. So, this would be the way you choose the ratings for the semiconductors switches of the boost converter.