Fundamentals of Power Electronics
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Lecture - 58
Flyback converter

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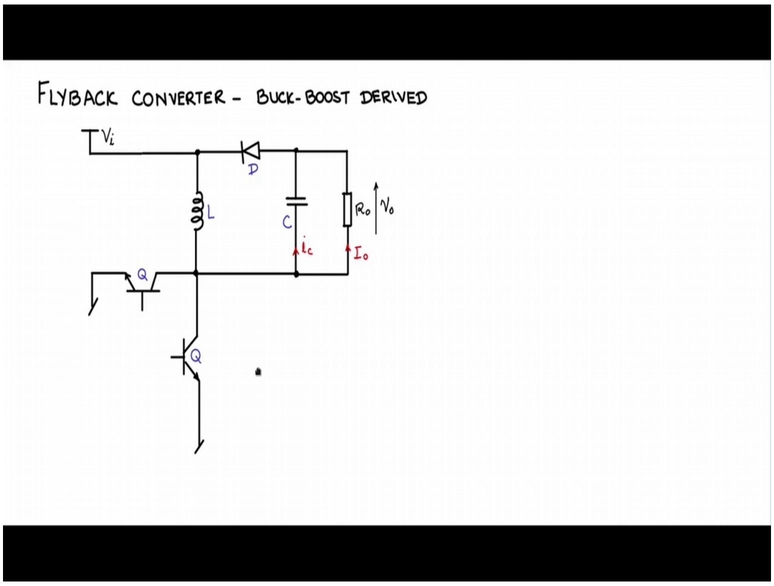

Let us now discuss another converter, very popular converter; one of the most popular converters that you will find in most power electronic equipment that is the Flyback converter. It is a buck-boost derived converter. The forward converter was a buck derived converter, the flyback converter is the buck-boost derived converter and let us see how the isolated buck-boost derived converter looks like.

So, let us begin by drawing the circuit of the buck-boost converter and let us derive the isolation from that. So, we have the source, you have the switch, controlled switch, inductor, uncontrolled switch, diode there, the capacitance and the load. So, this is the buck-boost converter which we know and which we have discussed and we know its operation function.

Let us now name the parts; you have V I measured in this fashion, R naught, V naught, L, C, Q, control switch D diode. Observe that when the switch Q is on the inductor current flows in this direction when the switch Q is off the inductor current will flow in this fashion charging of the capacitor in reverse so, this is i c, I naught.

Now I will make one modification just like we did in the forward converter. This controlled switch is on the rail side. Now, this switch has to be driven to saturation on and off by controlling the voltage across its base and emitter. The emitter is lifted up, floating it is much better to have the switch ground based and the ground based drive is much easier to make. So, without loss of generality we can move this switch from the top rail to the return rail, maintaining the flow of the current path in the same manner.

So, we can place that Q here, you see the current flow is in this path when the switch is on and the return path for the current is in this path, in this direction. So, we are still maintaining the same direction of the current flow and we can remove that switch. So, we have shifted the controlled switch to the ground rail, we can mark the ground this as the circuit ground and we can label the positive of the input source V i like this, and in order not to clutter up the circuit you can remove that.

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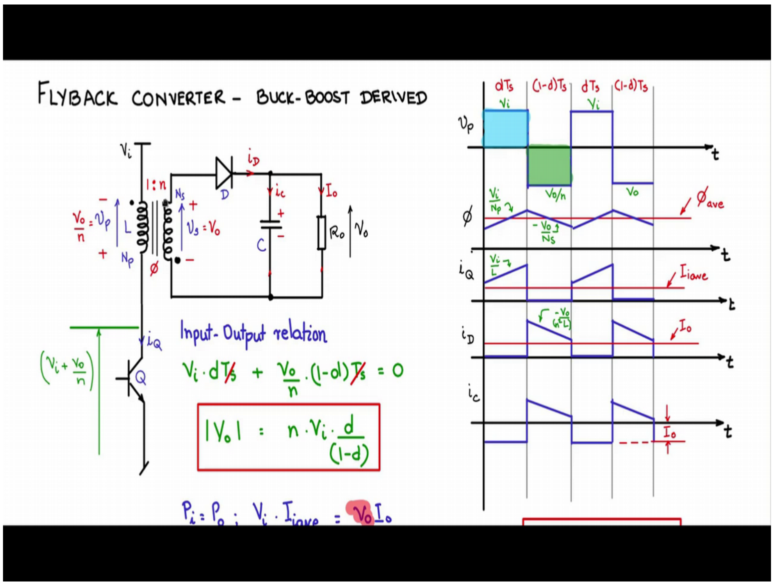

We can do next step of the modification make this portion vertical. Let me, let me draw the controls switch vertical ground and that becomes Q erase this portion. And you can shorten this, in this fashion and, so this becomes the non-isolated buck-boost converter. Now let us introduce the isolation this portion of the circuit we will push it out and introduce isolation here. Observe that this is an inductor and we are winding one more winding on the inductor so, that it provides the isolation, but the behavior of this magnetic will still be inductor energy storage.

So, let us put in one more coil there, let me make some space arrangements. Put in the core and put in the secondary coil and then connect it in this fashion. This is still behaving as an inductor L, it is the behavior is in like an inductor not like a transformer. Let me put the dot polarity here, this is dot polarity. So, operation is as before, so we have the Q here, when the Q is on during d t s time you will have current flow like this and the voltage across this is V i, the voltage across this is V i here, n times V i and reverse biases the diode.

Because here it is plus minus reverse so, this the V naught and the secondary voltage will reverse bias the diode. And then when the switches off, there is a reversal of polarity the non dot end becomes positive, non dot end becomes positive and that will drive free wheel through this diode and charge of the capacitor. So, the buck derive buck of buck-boost operation is still maintained.

We can do some more modification in the circuit to make it a bit more attractive. So, what we can do is remove, first remove these markings this diode and the dot polarity. Let us reverse the diode, if you reverse the diode I can reverse the I should reverse dot polarity. So, that when the dot end; non dot end is positive the diode should be on and if you reverse the diode the capacitor will get charged in this direction plus and minus and we will have as measured in this fashion a positive voltage.

So, just to make it more pleasing in that fashion we have reverse the position of the diodes and the dot polarities without loss of generality. The operation still remains the same. So, this is i c and this is I naught, you have i Q here, this is the primary voltage V P across the inductor measured in this fashion. And the secondary voltage V S, this is D and this is i D ok. We will push it out and then let us say that there is a turns ratio between the primary to the secondary as 1 is to n.

Now, in order to understand this circuit, now this is the complete isolated buck-boost converter also called as the flyback converter; very popularly called as the flyback converter. And look at the simplicity of it, you have one switch, you have one magnetic core operating like an inductor and you have one diode and one capacitor simplest least number of component count and that is why it is so popular. Now we know how the buck-boost converter operates, this is entirely similar to the operations of the buck-boost converter not withstanding that we should draw the waveforms and try to understand its operation, but let us revisit, relook at the buck boost converter.

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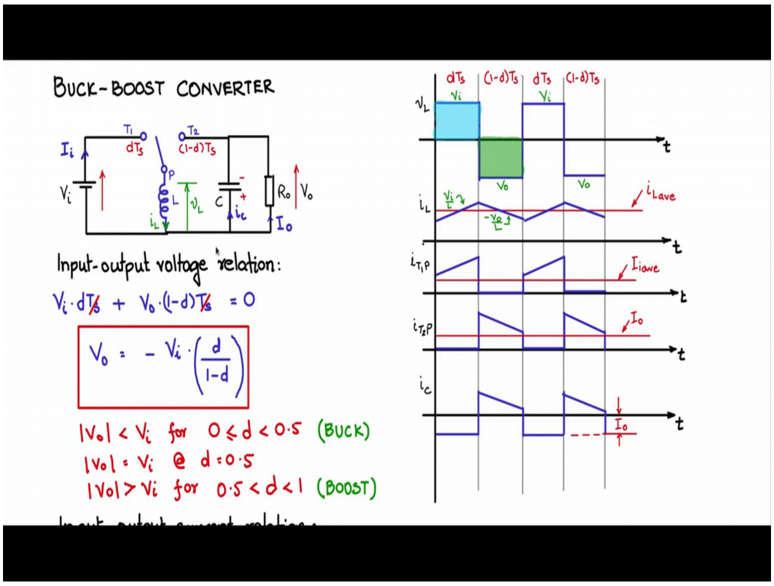

So, this is a buck-boost converter that we had discussed some time before and the waveforms here. So, V L this is the voltage across the inductor remember this the current through the inductor i L. Now the current through the inductor will be split into two parts; current through the primary of the inductor and current through the secondary of the inductor, I will explain and the currents through the switches here. So, let us copy this portion of the waveforms and paste it alongside the flyback converter and try to understand the operation of the flyback converter with these waveforms and try to modify this waveforms to fit the variables in the flyback converter.

So, let us now paste the waveform here move it around make some space and this is the waveform that we will try to map here. So, v L here will be v P primary of the inductor of the flyback converter will be the V L waveform d Ts is the period of time and Q is on, 1 minus d Ts is the period of time and Q is off. Again d Ts when Q is on, 1 minus d Ts when Q is off. i L is the inductor current we will split that into the primary indicator current and the secondary inductor current this portion flows through the primary and this portion the falling slow portion will flow through the secondary and let us rename some of these variables to map into this circuit.

V L here the voltage across the inductor is indicated as V P here voltage across the primary inductor and V S voltage across the secondary inductor. So, let us replace this V L with V P voltage across the primary inductor. Now. the voltage across the primary inductor during the time d Ts when the Q transistor Q is on the entire V i comes across the primary inductor. So, let us indicate that with the plus, dot end is plus, non dot end is minus.

On the secondary side you have the dot end plus, non dot end minus. Observe that the voltage across V S is n times V i and that is that plus V naught is coming across this diode and reverse biasing it and switching it off. So, what is that voltage which is coming across the diode reverse biasing it, n times V i plus v naught comes across that and this will reverse biases switch it out. Therefore, during the time n Q is on, during d Ts time only the primary current is flowing the secondary is off. Of course, the capacitance is discharging to the load.

Observe also that during d Ts the current that is flowing through the primary i Q is only for the part d Ts and during 1 minus d Ts there is no current flowing through that. The only link between the primary and the secondary side of the inductor is the flux. So, let us indicate that flux here and i L we will replace it with flux. So, this is the flux waveform or we have to change these values. So, let us say here flux is phi average, this is the average phi and the slope is not V i by L, V i by L is for the current waveform and here it is V i by. Now if I say this is the N P and the secondary is N S number of turns. So, it is V i by N P the slope the rate at which flux changes.

Now, what is the waveform of the current that is flowing through the primary or the current that is flowing through Q, i Q. i Q is nothing but the current that was flowing through 1 to pole current that is i T 1 P. So, i T 1 P it becomes the i Q. So, see that during the d T s period of time i Q there is a current which is raising linearly like this and the slope where is V i divided by L and that is the slope of this.

So, observe that i Q you will have a finite current only when Q is on and during the period 1 minus d Ts Q is off and there is no i Q i Q current is 0. Now what is the current through the diode D, i D? Let us change this T to P it is from throw 2 to P of the buck-boost topology that becomes i D and as you can see from this operation when Q is on dot is plus, dot is plus, diode is reverse biased, diode is off there cannot be any i D current.

However, the capacitance is charging into the load. So, you have a negative i naught flowing through at that time, discharging into the load.

Now let us take the time period 1 minus d T s. During 1 minus d T s Q is off. So, the Q is switched off i Q will become 0 and what will happen to the polarities of the primary and the secondary of this inductor? So, you will see that the non dot end will become plus, dot end will become minus, non dot end is plus, dot end is minus and you will see that V S the secondary voltage will rise up to that level just greater than V naught so, that diode D is forward bias and diode D will conduct and charge up the output capacitance.

So, V S will be v naught because the diode is conducting, V naught will come across V S and what will be V P? V P will be V naught by N because there is a 1 is to N turns ratio so, V P will be v naught by N. And how does it reflect on to the waveforms? We will see that V P waveform during 1 minus d Ts will go negative, but we know; but the amplitude of that voltage across V P will be V naught by N.

So, let us mark that V naught by n and in the flux waveform it will be V naught by N S because V naught is coming directly across N S, V naught by N S will be the downward slope of the flux waveform downward rate, i Q is 0, Q is off i Q is 0 at the time and i D; i D is the current through the diode. Now the current through the diode observe the flux minus V naught by N S because the non dot end is positive it is going to be a downswing current flow and also the flux. So, the current will have rate of minus V naught by N square L. L is on the primary side on the secondary side will be N square L and that will be the slope of the current there.

The average of i D will be I naught like before in the case of the buck-boost converter. The current wave shape of the capacitance will remain unchanged and it will be of the same shape and amplitude was output portion we are not changed anything. Now, let us try to find the input-output voltage relationship. So, input-output relationship first a voltage we apply volt second balance for the voltage waveform across the inductor you can choose either primary or secondary. So, let us say we take the primary voltage across the inductor.

So, during d Ts we have V I, during 1 minus d Ts we have V naught by N. We use that so, we have V i into d Ts plus V naught by N into 1 minus d Ts should be equal to 0 volt second balance. You can remove this variable and then on simplification and if we take only d magnitude of V naught because you do not need to worry about the sign because you can take anything as ground because is isolated it will be the n times V i d by 1 minus d. So, this becomes the input output voltage relationship.

Note that the output voltage is having n as 1 degree of freedom and d as the other. So, is the variable it can continuously vary on the fly during operation so, you can use that as a control input, n is again a variable which you can change only once at design time. So, this can be a designer variable. So, by design choice you can fix the value of n. So, you have more flexibility in choosing the output.

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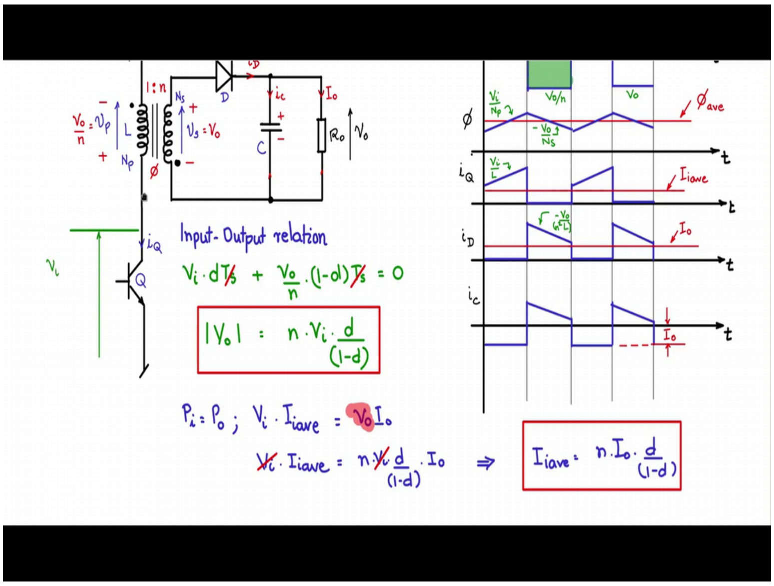

Now likewise for the current also you can get the input output current relationship, can use the power balance relation V i into P i is equal to P naught; V i I i average is equal to V naught I naught and V naught you can replace using the input-output voltage relationship. So, we have V i into I i average equals n V i d by 1 minus d into i naught. So, if you remove; cancel out V i you will have I i is equal to n I naught d by 1 minus d; so, this would be the input-output current relationship. You see that i Q, i Q is having an average current which is the I i average and that value will boil down to n I naught d by 1 minus d. We know d, you know n and you know I naught you can evaluate that.

When the transistor Q is off, we saw that when the diode D was off it the peak inverse voltage that it need to support was N times V i plus V naught and for the case of the transistor when it is off it has to support a voltage of V i. So, you have supply voltage V i coming across that plus also the reflected voltage from the secondary at the time when this is off diode is on there is V naught coming across this one and on the primary side it is V naught by n with plus minus in this fashion plus minus this one, plus this V i. So, you have V naught by n together coming across the collector emitter of Q.

So, you will have to rate the vco rating of Q to be greater than V i plus V naught by n. So, in this fashion we have this flyback converter which is this is the functional schematic of that and you can use that and very very popular and you can also have multiple outputs you can have multiple secondary windings across the; wound across the inductor and you can take out isolated multiple outputs from this flyback type converter.