# Fundamentals of Power Electronics


**Prof. L. Umanand**
**Department of Electronics Systems Engineering**
**Indian Institute of Science, Bengaluru**


## Lecture - 54
## Forward Converter

Today we will begin the discussion on Isolated Converters. Till now we have been discussing on non-isolated converters mainly the buck converter, the boost converter and the buck boost converter which are called other three primary converters. We will use the buck converter and the buck boost converter and derive the isolated versions of these isolation has many many benefits.

Firstly, there is no physical connection between the primary side and the secondary side of the galvanic isolation, the primary side which is the input source side. And, the secondary side which is the load side if it was isolated there will not be any surges passing on to the load side and damaging components on the load side. There will be reduced conducted emission both ways from the source side to the load side and from the load side to the source side.

Not only that the galvanic isolation gives us one more degree of freedom by means of the trans ratio. By using trans ratio I can use the buck derived forward converter or the other versions of the converters to also provide you boost the output voltage can be higher than the input voltage because, of the trans ratio freedom and you can have multiple outputs that is the you can have the same converter 5 volts plus minus 15 volts and so on.

So, these are the advantages that you gain by putting in a transformer and most of the pack practical power supplies will use the transformer as isolated version of the converter for most of the practical power electronic equipments.

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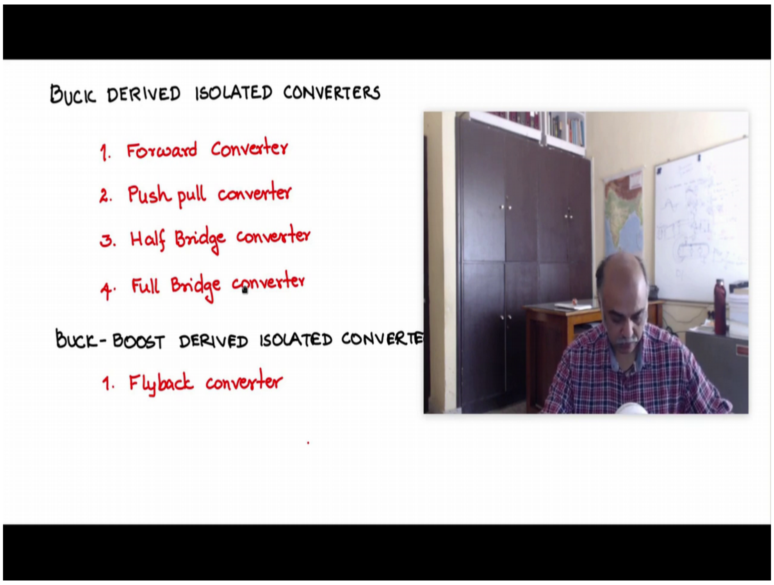


We shall now try to look at and study some of the isolated converters. Firstly, we will begin with buck derived. There are many buck derived isolated converters. We will be studying the following. One is the forward converter issues involved with that and then we have the push pull version or the push pull converter.

Then the half bridge converter followed by the full bridge converter. These 4 are the important converters which are very very popular and most power electronic equipments and we will discuss these. Then on the buck boost derived isolated converters there is one very important converter which is one of the most popular converters in use and that is the fly back converter. So, we will discuss the fly back converter also.

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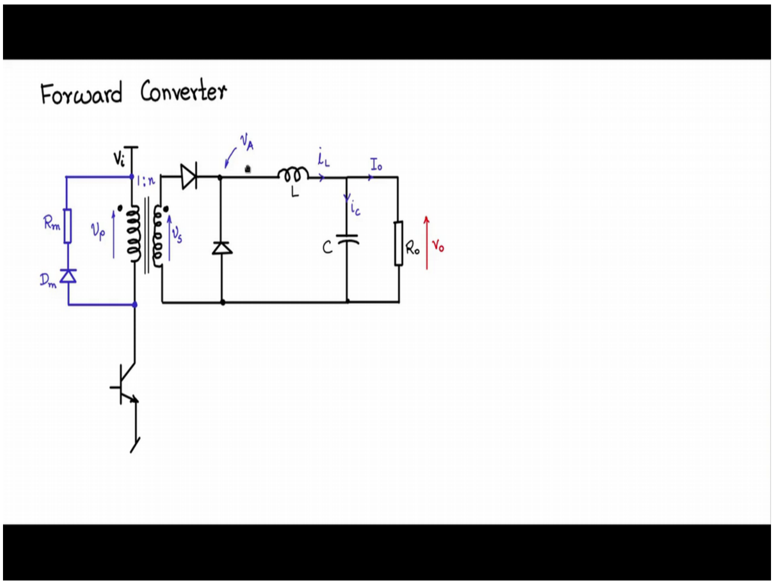


Let us now see how the forward converter circuit apology is. This forward converter is a buck derived isolated converter. So, we shall start from the buck converter topology. So, let us have this unregulated source V i and we know the buck topology another BJT you have this diode the inductor capacitance and the load. So, this is the buck converter circuit, you have V i R naught V naught i and c. Now let me do one thin. First let me shift this transistor which is on the top rail to the ground rail because then we need to drive this transistor with respect to the emitter. I lifted up floating emitter is much more difficult to drive than a grounded emitter. So, let me make some space here and let me place the BJT here. Now the emitter is on the ground side same direction of the current flow to see the current flows in the same direction.

So, only way it is on the return rail now this emitter is grounded. If I take this is ground and driving this BJT or MOSFET with respect to the ground is much easier. So, normally we will do that. So, we will put the BJT or the transistor that is the control switch on the return rail rather than on the top right. Now we can remove this transistor. So, we will remove that and close that. Another modification that we will do in the representation is let us put label symbols for the ground. This is the ground, I will put a label symbol for the V cc or V i. The positive of the source now, I can remove this without loss of generality, so that it does not clutter up the circuit.

Now that we have removed this, this still represents the same, but converter circuit I will allow put this switch down vertical like this in this fashion. So, this is still the same, but converter circuit and I will shorten this. Let me put the label here and remove this portion. So, this becomes the buck converter circuits, still the same buck converter circuit only with some repositioned switch positions. Next I would like to insert the isolation.

So, at that point let me put in the primary winding, then I will put the secondary winding and join them up. This still naught complete I cannot just join them up here because let us say when the inductor is freewheeling, when the indicator is freewheeling, this diode is conducting and it is effectively shortening the secondary. When it shorts the secondary, the primary will draw a huge current and blow up this transistor.

Therefore, we cannot allow shortening of the secondary when the inductor is freewheeling through this diode. So, we will put a diode here, so that you do not have a reverse current flow. I will make some space and put the diode. So, at least now it is safe. Even if this is prevailing the voltage, this diode will not allow short circuit to happen across secondary and thereby reflected on to the primary. Next let me mark this V p V s and this is trans ratio 1 is to 1.

This voltage here let me call it as V A, this is inductor current i L, this is output I naught current and this is I c, this portion from V A onwards is nothing, but pure buck converter. So, observe here that the circuit is still incomplete. Let us see what happened now. Let us say this transistor is on. The moment the transistor is on, there is going to be a magnetizing current that is going to flow here and the reflected load current also will flow through here.

When you switch it off, when you switch it off inductor freewheel there is a reversal of polarity. The dot will become negative, non dot end will be positive, dot will be negative, non dot end will be positive, this diode will be reverse biased because this diode is conducting what will come across that will be a negative voltage. This diode will be reverse biased and off. So, there is no path for the flux, internal flux of this core to reset meaning when there is a current flow here, you have switched it off. There is a id L by dt, the voltage across this di by dt has been cut off.

There will be a huge voltage because of the negative di by dt and huge voltage will appear across this and blow up this transistor. Therefore, you have to provide a flux a path for the flux in the core to reset. So, we will see that there is a path for the inductor current to flow in this direction here. So, we will make a path in this fashion. We will put a resistance and the diode like this. So, we will call this as Rm and Dm diode corresponding to the magnetizing flux reset path. Rm is corresponding to the magnetizing current reset path.

So, now when you switch this on, there is a current flow through this magnetizing current and the load reflected current flowing through this and when you switch off, there is no load reflected component. Only the magnetizing power portion of the current will freewheel like this. It will freewheel and Dk with Lm by Rm time constant Lm is the mutual inductions and Rm is this resistance. So, Ly r time constant It will start decaying and go to 0 and when the magnetizing current goes to 0, the flux in the core is reset and brought back to its original state, so that you may next you can start the next cycle by switching this on. Now this is the complete forward converter circuit or working forward converter circuit.

Let us now try to understand this forward converter circuit. Let us try to understand its operation and the waveforms at various points. Now if you see this portion of the circuit the one that I am indicating with the cursor, this portion of the circuit on the secondary side is exactly like a typical buck converter. So, you have two switches here, two diodes if you consider this as throw 1 and throw 2 and this is the pole, this is the pole voltage VA would be the pole voltage have the inductor current capacitor current I naught. All this portion of the circuit, the waveforms will be very typical like the buck converter circuits that we discussed.

On the primary side is nothing, but a chopper or a switcher and we will discuss the waveforms of the chopper and the switcher and also this portion of the circuit where you are doing core resetting, these are the extra portions that will come apart from the regular buck converter waveforms. Now, let us relate the regular buck converter waveforms to the forward converter. Let us look at the buck converter waveforms for now.

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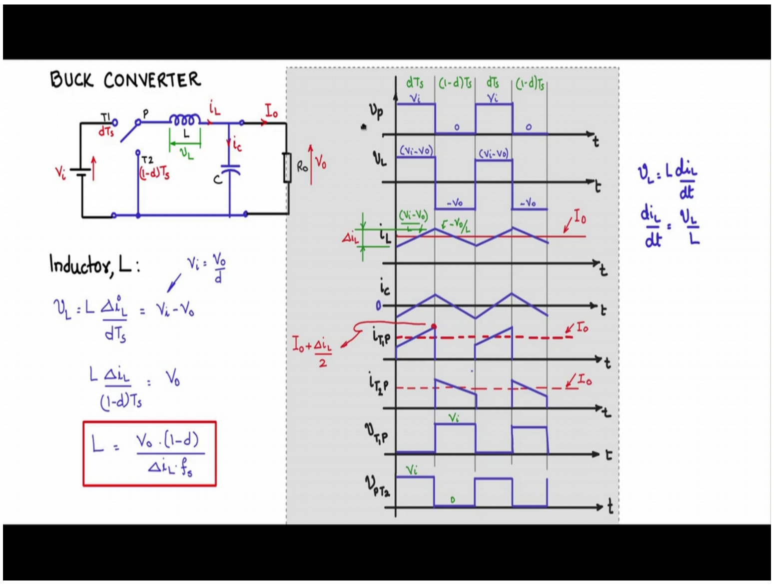


And revisit these buck converter along with the waveforms here, so that we again remember these waveforms. This portion the buck converter portion is very much similar to the secondary portion of the forward converter. All these waveforms are valid. Only we will allow to look at the notations and change the notations to the forward converter notations. So, now what I will do is copy these waveforms which we had drawn for the buck converter and place it along with the forward converter and in comparison change the values on the notations.

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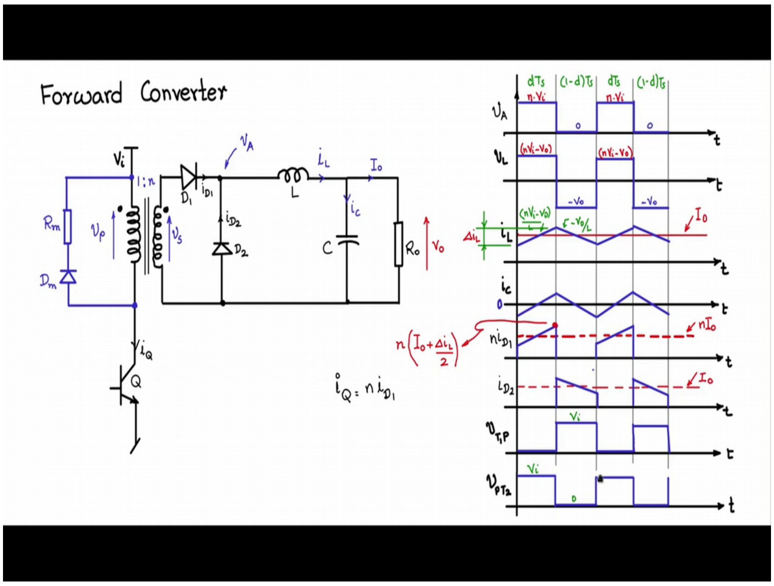

So, let us place the waveforms move it. So, here you see that these are the same buck converter waveforms during dts time we have the switch on 1 minus dts times switch is off two cycles; so, again dTs and 1 minus dTs. Now V p the pole voltage will map To VA. So, let us change that. So, I will remove that and put it as VA. So, VA here and when during dTs the voltage here what will happen when the switch is on? What will appear is V i and this V i look at the dots will translate to the secondary voltage as n times V i the n times V i will appear across at VA. So, therefore this V i will change to n times V i. So, let us make the change n times V i and then during the time when this is off, the inductor will freewheel through this diode and the potential of VA with respect to hear the output ground could be 0 and 0.

So, this will be the VA wave form and from the VA wave form all these waveforms are typical, but converter waveforms for example, the voltage across the inductor V L will remain unchanged except that here V i minus V naught will become n V i minus V naught. So, let us make that small change. So, this will become n V i minus V naught n V i minus V naught. This will remain V naught. When the indicator is freewheeling this potential is 0, V A potential is 0 and the other side of the inductor is at minus V naught. So, that is what we have indicated here remains unchanged.

Now let us take the inductor current i L. The inductor current i L also will be similar we will see the inductor current rises. Now it rises for a change of delta i L in dTs time, it will be n V i minus V naught by L. So, instead of V i minus V naught by L, it will become the n V i minus V naught by L. Let us make that change. So, we have n V i minus V naught by L.

On the falling side during the freewheeling time the voltage across the inductor is minus V naught. So, this will remain minus V naught by L. Look at the ic current waveform i c there is no change. It will be this ripple component of the inductor current only that will flow through i c zero average current because second balance has to be maintained. The average value of the inductor current is I naught, that still remains I naught.

Now, let us mark some symbols here. Q for this BJT and the current that flows through Q is i Q and let me mark this as d 1 diode this is d 2 this is i d 1 and this is i d 2. So, these are the currents that I have marked. So, now let us look at some of these waveforms. Now, look at the waveform here i t one p it one p for the buck converter was the bgt the controlled switch current. So, when during dts time when the control switch was on this was the current that was this part of the inductor current was flowing through that switch. So, you still have the inductor current flowing here. So, what will flow through i d 1 will be equal and to i T 1 p. So let us change this it 1 p to i D 1.

So, it will be that current that is flowing. So, i D 1 this diode will be on whenever Q 1 is on and only that part of the inductor current will flow through it during dTs time period. Now if you look at this wave form, I T 2 p it should be same as i D 2. So, I can just change it i D 2. Nothing else will change in these two waveforms. So, now what is the current i Q through this primary side switch.

So, when the switch is on the current flow through the primary side switch i Q and i primary are same and i primary is the reflected current whatever i d 1 n times i d 1 gets reflector on the primary and i Q is the same as that. So, i Q is equal to n times i d 1 we can say that. So, therefore if I change this to n times i d 1 it becomes i Q current. So, if I say n times i d 1 all the values here will be multiplied by scaling factor n. So, let us say this becomes n and the average value will be n times i naught. So, this wave shape is the wave shape that you can expect to see through the BJT Q or i Q.

With respect to the primary side switches with respect to V t 1 p, the voltage or the V t 1 p, I will discuss that separately. V p 2 t V p t 2 is the voltage across the diode d 2. There is no change except that V i becomes n V i. So, I will remove the voltage portions of the wave form now and I will get back to that in the meantime. Before that I would like to give the input-output relationship.

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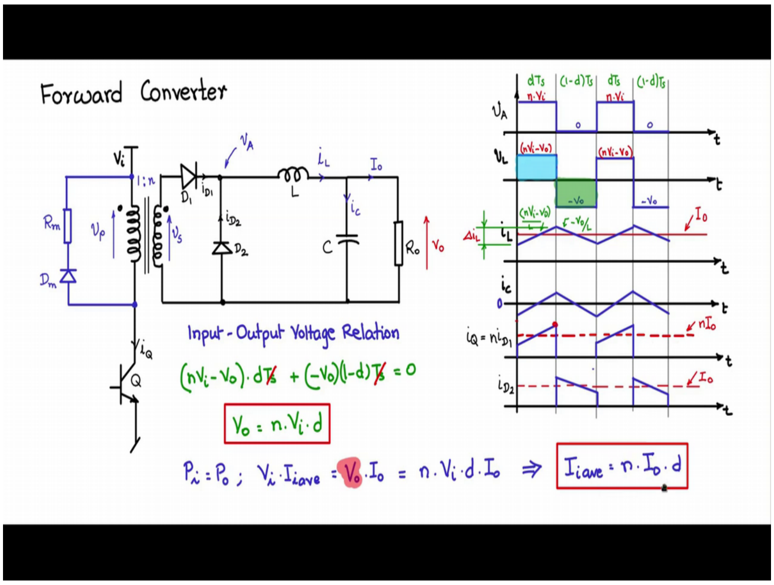


So, let us write down the input output relationship and for that we need to look at the inductance voltage wave form that is the voltage waveform across the inductor. We know that we have to look at the old second balance. So, what is the voltage during d T s period multiplied by the time period will give the area of this triangle and during the 1 minus d T s period we have minus V naught and multiplied by 1 minus d T s will give the area of this rectangle.

These two should be equal for volt second balance and that will give us the input output voltage relationship. So, let us now write down the input output voltage relationship and see what is the change. So, here we are having n V i minus V naught n V i minus V naught into d T s plus minus V naught into 1 minus d T s is equal to 0. So, let me cancel out this and the remaining variables if I rearrange them V naught is equal to n V i into d. So, this is the input output relationship for the forward converter. Look that look here that there is a new term here n; n is the trans ratio of the transformer that comes in and gives in an additional degree of freedom.

So, you the designer has the flexibility in the choice of n and therefore, the output can even be higher than the input. So, in a typical buck converter, the output is always V naught is always less than V i, but here even though d varies from 0 to 1 0 is less than 1. In this case the duty cycle cannot go more than 50 percent because if the transistor is on for 50 percent, there needs to be an equal and amount of time needed to give for the core to reset.

So, therefore normally the duty cycle we keep it at 50 percent and use the freedom of n to scale it to any level. So, if you have n is equal to 10, you can have V naught much greater than V i. So therefore, buck and boost everything is possible because of the isolation because of the scaling provided by the isolation, however this n is fixed variable which cannot be changed dynamically, d is available which can be changed dynamically. So, this can be taken care at the end at the design time once and d can be used as a control input to take care of changes in a dynamic fashion. So, d becomes a control input.

So, this is the input output relationship for the voltage. In a similar manner the same manner we can also get the input output current relationship. We can use the power balance thing P i is equal to P naught which means V i i i average because the input current is chopped switched and therefore, the average of that will be V i into ii average will be equal to P naught which is V naught into I naught.

So, now we can replace this V naught with the input output relationship that we have just derived and that means, that we can say equal to n V i into d into I naught, this will be the P naught output power. So, this implies that i average will be equal to n i naught into d. So, this will be the input output current relationship. So, this value is the average of this i Q average of this i Q wave form will be this in terms of n i naught and d.