Power Electronics

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Lecture - 29

In the last class we found that in buck, boost buck - boost and chuck converters, there is no isolation between the input and the output. In other words, the ground or the reference point for the input as well as to the output is the same. Also, the magnitudes of the input and output cannot be greatly different. So, we can use a transformer and solve both these problems. The principle is that we should not allow the transformer to saturate.

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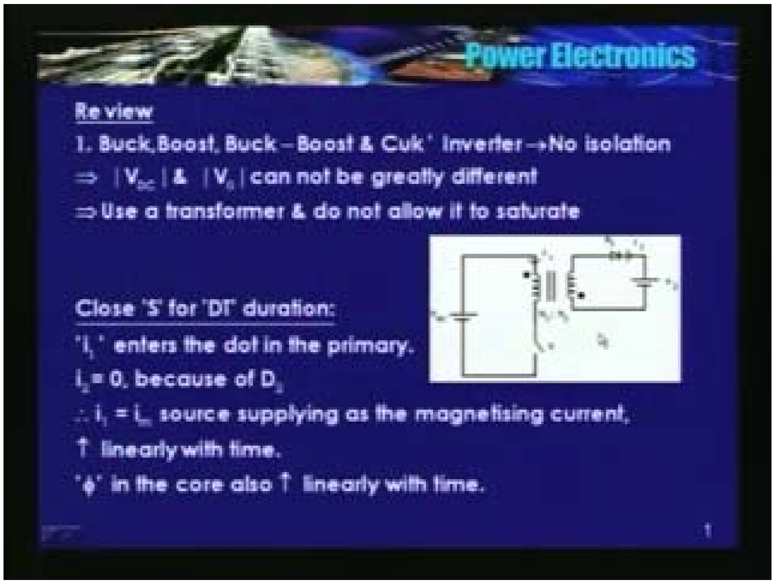

Power Electronics

Review

1. Buck,Boost, Buck – Boost & Cuk ' Inverter → No isolation

⇒ $|V_{DC}|$ & $|V_0|$ can not be greatly different

⇒ Use a transformer & do not allow it to saturate

Close 'S' for 'DT' duration:

'i_1 ' enters the dot in the primary.

$i_2 = 0$, because of D_2

∴ $i_1 = i_m$ source supplying as the magnetising current,

↑ linearly with time.

'ϕ' in the core also ↑ linearly with time.

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So, we discuss the operation of this circuit, we use a transformer between the input and the output. We use the output, also, separate voltage source and we connected a diode in the secondary in such a way that only 1 winding is carrying current at a time. So, when we close the switch, current enters the dot. Current cannot leave the dot in the secondary because of this diode. Therefore, i_2 is 0, primary is energized. So, we know that if the secondary current is 0, primary current is only the magnetizing current. A DC voltage is being applied to the magnetizing inductance. Therefore, the primary current which is same as the magnetizing current increases linearly.

If the magnetizing current increases linearly, flux in the core also increases linearly. Only 1 winding is carrying current, there is no current in the secondary. After some time, we are opening the switch, what is the condition? Condition is that flux in the core should be

continuous. If that is the case, the direction of flux produced by the secondary should be the same as that of the direction of flux produced by the primary.
In other words, direction of flux produced by primary is same as the direction of flux produced by the secondary. That can happen only when, if current enters the dot in the primary, current will enter the dot in the secondary.

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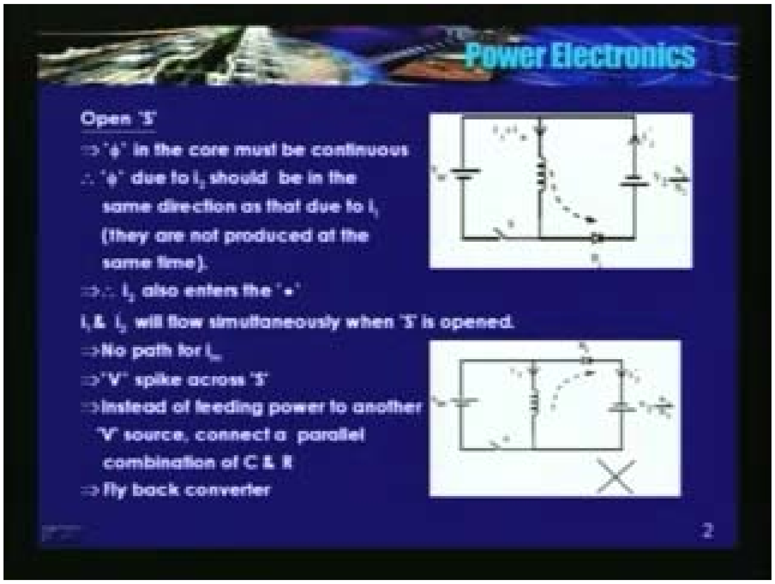

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Open 'S'

⇒ 'ϕ' in the core must be continuous

∴ 'ϕ' due to i_2 should be in the same direction as that due to i_1 (they are not produced at the same time).

⇒ ∴ i_2 also enters the '•'

i_1 & i_2 will flow simultaneously when 'S' is opened.

⇒ No path for i_m

⇒ 'V' spike across 'S'

⇒ Instead of feeding power to another 'V' source, connect a parallel combination of C & R

⇒ Fly back converter

So, in this circuit, you find; when I close the switch, current I_m was increasing linearly, we opened the switch, current starts flowing in this direction. The so called stored energy in the inductor is transferred to to the, this source, secondary, voltage source connected to the secondary winding.

What happens if I were to make a small mistake in the diode connections? In other words, both the windings were to current carry, simultaneously? This is the equivalent circuit; close the switch, current flows in this direction, so current can also flow in the secondary. Magnetizing current was in this direction, remember. I am opening the switch, current has to be continuous, magnetizing current has to be continuous. So, it starts flowing, it has to flow in this direction but then there is no path there is no path. So, diode connections are very important. If you make a mistake in the diode connections, the circuit will fail because there is no path for the magnetizing current to flow when I open the switch.

So, we found that so energy from the voltage source which is connected in the primary can be transferred to another source which is connected in the secondary. Now, instead of having a voltage source, you connect a capacitor and some load across it. So, I have another power supply using using a transformer. So, this power supply is known as fly back converter.

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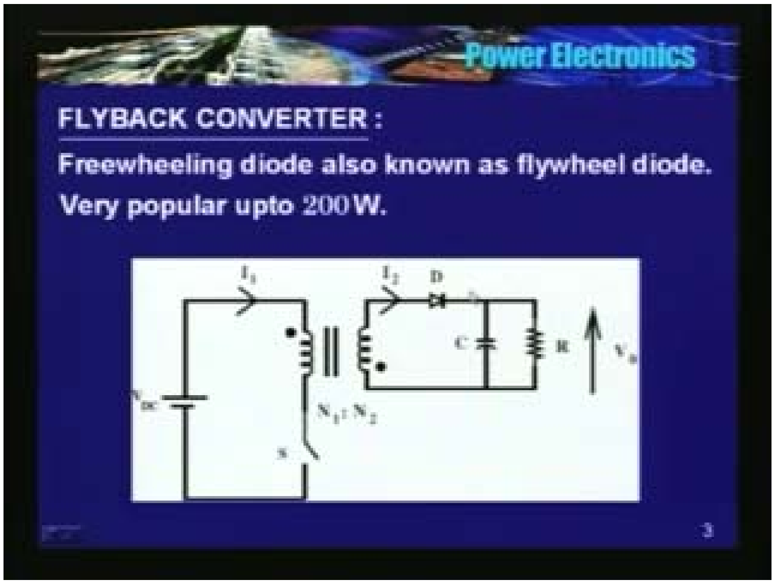

FLYBACK CONVERTER :

Freewheeling diode also known as flywheel diode.

Very popular upto 200 W.

Circuit topology is same as the previous one. Only thing is I have replaced the voltage source or V_2 by the parallel combination of C and R. C is equivalent to output capacitor, output which maintains a constant voltage at the output and a load is connected, a variable R. It is very popular in power supply when the power rating is less than around 200 watts or so. So, if the power supply voltage of the power supply is of the order of 200 watts, invariably, you can think that it is a fly back converter, very popular in low power range.

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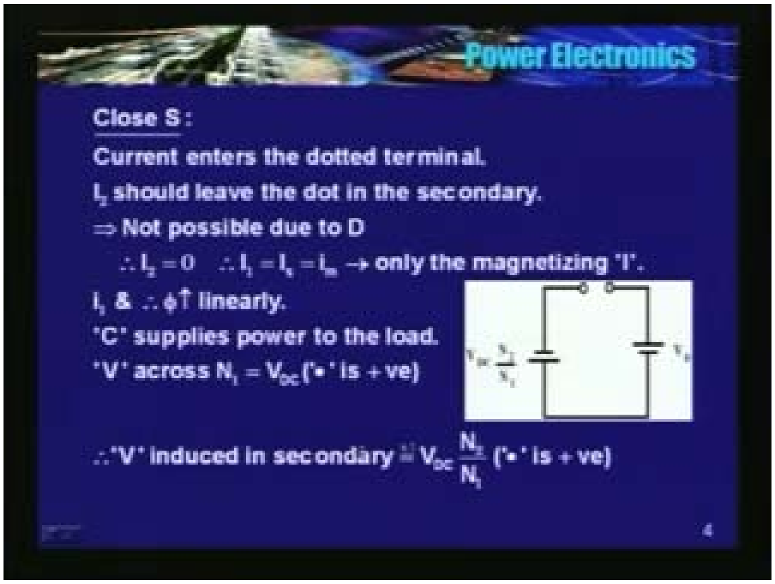

Close S :

Current enters the dotted terminal.

I_2 should leave the dot in the secondary.

$\Rightarrow$ Not possible due to D

$\therefore I_2 = 0 \quad \therefore I_1 = I_s = I_m$ → only the magnetizing 'I'.

I_1 & $\therefore \phi \uparrow$ linearly.

'C' supplies power to the load.

'V' across $N_1 = V_{DC}$ ('•' is +ve)

$\therefore$ 'V' induced in secondary $\cong V_{DC}\dfrac{N_2}{N_1}$ ('•' is +ve)

Principle of operation is same as the previous one. Current enters the dot when I close the switch current enters the dot when I close the switch, current cannot leave the dot because of this diode. So, primary current is only the magnetizing current, increases linearly. Voltage induced or voltage applied to the primary is V_{DC}. The reflected voltage or voltage induced in the secondary is V_{DC} divided by N_1 multiplied by N_2. See, here is the equivalent circuit with with dot as positive with the dot as positive. So, what is the voltage that is appearing across the diode? V_{DC} into N_2 divided by N_1 with positive this terminal, anode is negative. The when, when the diode is on, current is flowing in this direction. So definitely, this terminal should be positive.

So, cathode potential with respect to this bus is V_0. So, the equivalent circuit when the diode is off is something like this, V_0, anode is or or the positive of the output voltage source is connected to the cathode and this is the voltage induced in the secondary of the transformer. So, voltage appearing across the diode is sum of these 2.

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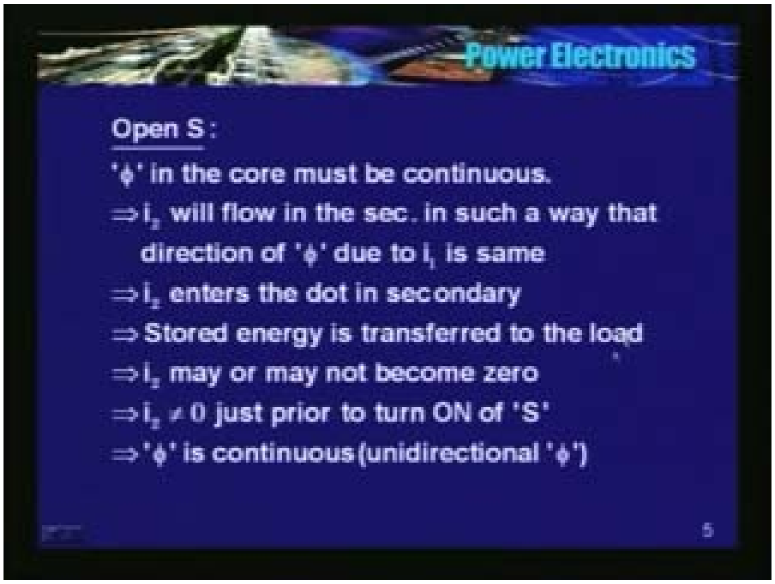

Open S :

'φ' in the core must be continuous.

⇒ i_2 will flow in the sec. in such a way that direction of 'φ' due to i_1 is same

⇒ i_2 enters the dot in secondary

⇒ Stored energy is transferred to the load

⇒ i_2 may or may not become zero

⇒ $i_2 \neq 0$ just prior to turn ON of 'S'

⇒ 'φ' is continuous (unidirectional 'φ')

After some time open the switch, stored energy is transferred to the secondary, direction of flux should be the same. In other words, direction of flux produced by the primary should be the same as the direction of flux produce by the secondary. So, if current enters the dot in the primary, current will enter the dot in the secondary. Now, what happens after some time when you want to close the switch? The i_2 may not become 0. I will repeat; the i_2 may not become 0.

So, when I close the switch for the second time, whatever that the current that was flowing in the secondary gets transferred to to the primary because at a time only 1 winding can carry the current. So, in the primary, I have closed the switch, circuit is complete, current can flow. So, if current can flow in the primary, current cannot flow in the secondary. So, whatever the current that was flowing in the secondary, the equivalent current starts flowing in the primary.

So, in other words, if there is some current flowing in the secondary, as soon as I close the switch, source has to supply a finite amount of current. Similar to something in a buck converter or or a buck - boost converter. It does not happen in in boost converter. Boost converter source current is almost continuous, increases and decreases, whereas, in buck converter when I close the switch, whatever that current was through the inductor, now this battery has to supply. Instantaneously, battery has to supply a finite amount of current.

Same thing happened in buck boost. It does not happen in chuck. So, if the current becomes 0 in the secondary prior to closing the switch in the primary, the source current starts from 0. So, what is the significance? If the source current starts from 0, it implies that the magnetizing current is also starts from 0. So, if the magnetizing current starts from 0, flux in the core also starts from 0. If there was a finite current flowing in the secondary, just prior to opening the switch when I close the switch, source has to supply the equivalent current. So, the magnetizing current when I close the switch, starts from a finite value.

In other words, there was some flux in the core prior to closing the switch. In other words, we did not make the flux in the core 0 or we did not reset the flux. Mind you, either I am increasing the flux by increasing the magnetizing current, so when I open the switch thus current starts flowing in the secondary, flux starts decreasing, operation is always in the first quadrant. Operation is always in the first quadrant, the BH loop.

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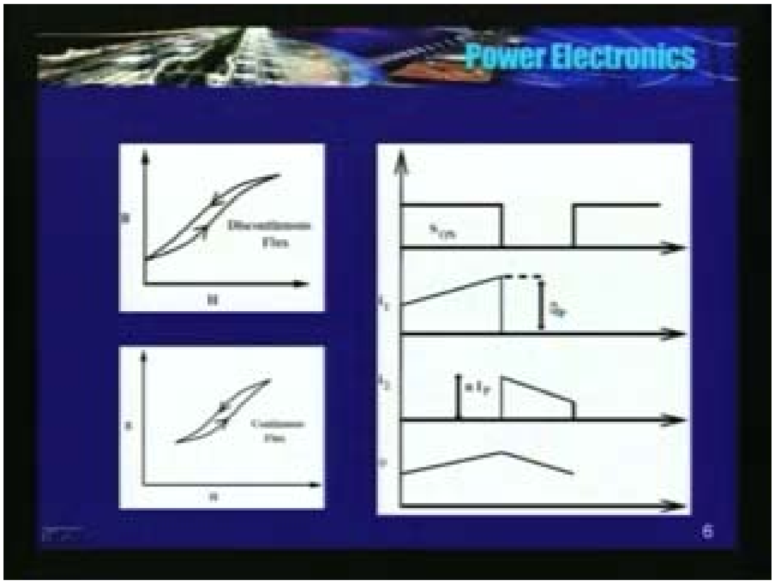

So, if you see, current starts from 0 when I close the switch, starts increasing and it has become 0 prior to closing the switch for the second time. So, this value of flux, residual flux may be is equal to the residual flux, magnitude should be very small, may be, nearer to the origin, this point. Instead of this, I can have some sort of this situation, wherein, secondary current is finite prior to closing the switch. So, when I close the switch, equivalent current starts flowing from the primary and starts increasing. I will open the switch, current starts decreasing and reaches the same point. It does not cut the Y axis. Mind you, this is the residual flux point. In other words, some DC flux is there in the core. So, this is the variation of flux. Flux increases, it starts from finite value. Mind you, this is at steady state this at steady state and decreases.

See the secondary current, it does not become 0 not become 0, prior to closing the switch. So, when I close the switch here, this current force to become 0 and immediately, the equivalent primary current starts flowing from here, equivalent starts current flowing from here so, which is the generally preferred condition.

Invariably, in DC to DC converter, we operate fly back converter in discontinuous mode. Now, what is discontinuous? In AC to DC line competitive converters, discontinuous conduction implies load current is discontinuous. In buck, boost, buck - boost and chuck discontinuous current implies the inductor current is discontinues. Load current is assumed to be continuous because it is a voltage source, output is a voltage source. I am connecting a resistor across it or, so voltage source implies terminal voltage is independent of the magnitude of current that is supplying. So, load current is invariably is supposed to remain constant. But then the inductor current that is connected in the circuit may become 0. So, that mode of operation is known as discontinuous mode of operation.

Now, in fly back converter or in converters, wherein, I use a transformer, discontinuous conduction implies flux in the core has become 0. I will repeat; in power supplies wherein, there is a transformer, discontinuous conduction implies that flux in the core has become 0. Continuous conduction implies flux in the core is non 0. It starts from a finite value increases and decreases. So, why am I saying that discontinuous mode of conduction is preferred? It is because we are applying a DC voltage to the transformer and operation is always in the first quadrant. We are not applying negative ampere turns to the core. H is always positive. So, there is some flux present in the core.

Now you see here, accidentally D has increased accidentally D has increased. It implies that most of the times switch is switch is closed. Current increases linearly. It had a finite value, current increases linearly and most of the time, accidently D has increased. So, switch is closed for most of the time. It may so happen that flux core may saturate. It may so happen that core may saturate. So, if core and if core saturates, either switch or the inductor or source will fail or all 3 of them may fail. So, we should not allow the transformer to saturate or you know should allow the core to saturate. So, one of the way to avoid this situation is operate it always in the discontinuous mode. So, how do I do that or how do I stop the core getting into saturation?

Best way is to introduce an air gap in between the core. This is we provide an air gap in the core. So, if there is an air gap, you cannot saturate it. It is always linear, reluctance is always constant. So, you can avoid this situation. But then if I provide an air gap, it implies that the coils are not tightly coupled. The moment I provide an air gap, you can have a leakage flux. So, if there is an leakage flux, what happens if I when I close the or when I open the switch?

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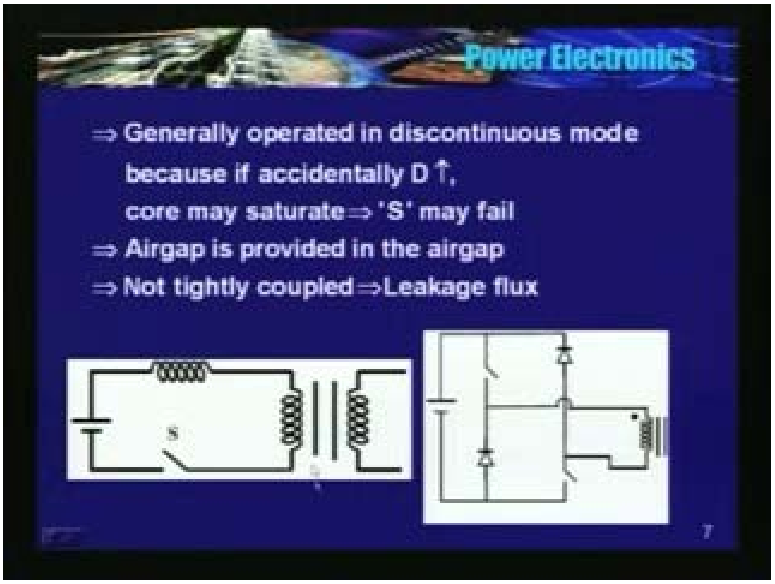

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- ⇒ Generally operated in discontinuous mode because if accidentally D ↑, core may saturate ⇒ 'S' may fail
- ⇒ Airgap is provided in the airgap
- ⇒ Not tightly coupled ⇒ Leakage flux

See, in this equivalent circuit; I have provided an air gap, coils are loosely coupled, there is a leakage flux now, it always comes in series, leakage flux and this is a magnetizing or this could be considered as an ideal transformer with the magnetizing branch. Now, when I open the switch, there is a power for the magnetizing current there is a path of the magnetizing current. What happens to this inductor? What happens to the energy that is stored in this leakage inductance?

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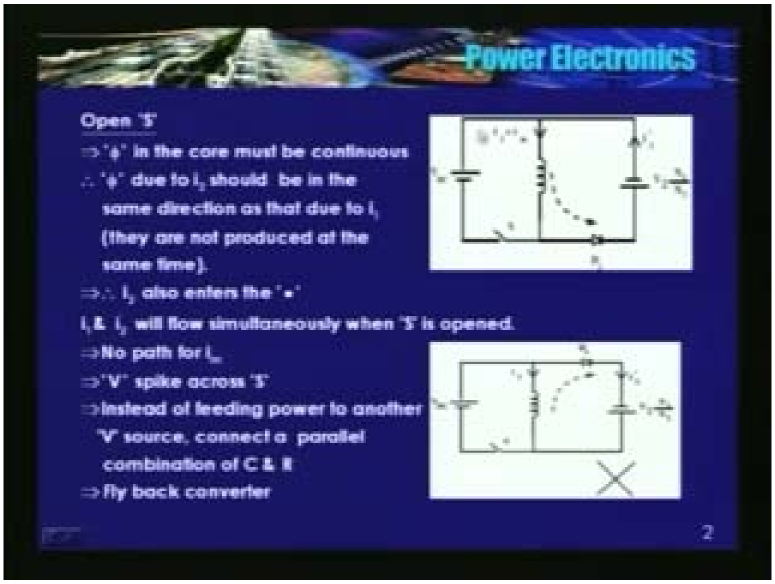

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Open 'S'

- ⇒ 'ϕ' in the core must be continuous
- ∴ 'ϕ' due to i_2 should be in the same direction as that due to i_1 (they are not produced at the same time).
- ⇒ ∴ i_2 also enters the '•'
- i_1 & i_2 will flow simultaneously when 'S' is opened.
- ⇒ No path for i_L
- ⇒ 'V' spike across 'S'
- ⇒ Instead of feeding power to another 'V' source, connect a parallel combination of C & R
- ⇒ Fly back converter

See in this equivalent circuit, I will go back, see here; there is a leakage there is a small inductance in this path here, leakage. This is the magnetizing. So, when I open the switch, where can it go? This current was flowing in this direction. It has to come this way, it cannot nor it can go this way. So, you may experience or you may observe a spike because of this. Is there a solution? Yes, there is a solution. So, use this set up of branch circuit.

See, I have not connected or I have not shown the secondary connections which is still there. I have not connected or I have not shown the dotted polarities also. That is okay. So, you have a circuit, primary circuit is something like this; 2 switches, one of the ways, 2 switches and 2 diodes. Operation is same; I close these 2 switches, current starts flowing in this direction. Mind you, current was flowing in this direction. Open the switch, magnetizing that it current was flowing in this direction, open the switch, now current can flow in this way current can flow in this way.

So, there is no problem about the voltage spike generated due to the leakage flux. But then there are 2 switches and 2 diodes, device losses, voltage drop across the device, all those issues should be taken into account while designing the converter. Which is the, what is the transfer function now? We have not derived the transfer function for the fly back converter.

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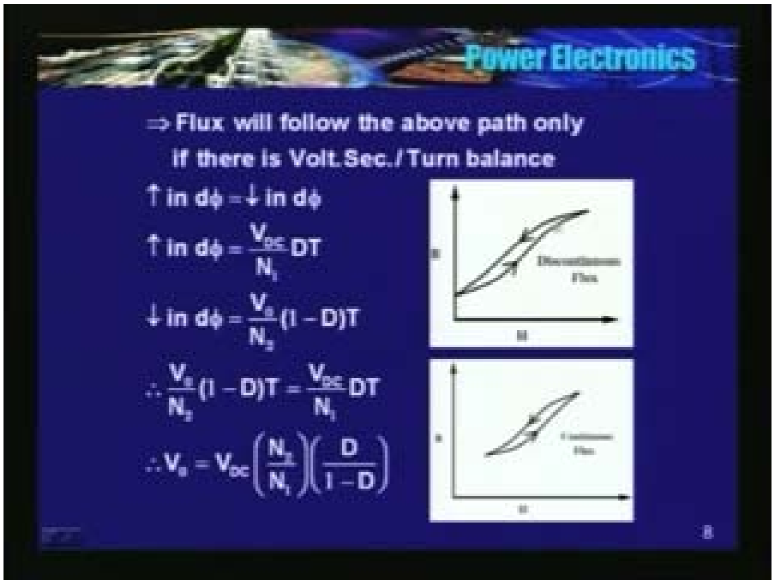
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⇒ Flux will follow the above path only if there is Volt.Sec./Turn balance

$$\uparrow \text{in } d\phi = \downarrow \text{in } d\phi$$

$$\uparrow \text{in } d\phi = \frac{V_{DC}}{N_1} DT$$

$$\downarrow \text{in } d\phi = \frac{V_0}{N_2}(1-D)T$$

$$\therefore \frac{V_0}{N_2}(1-D)T = \frac{V_{DC}}{N_1} DT$$

$$\therefore V_0 = V_{DC}\left(\frac{N_2}{N_1}\right)\left(\frac{D}{1-D}\right)$$

What is the input output relationship? I had shown these 2 flux plots or variation of flux in the core. This starts from 0, comes back to 0 to the same point. Here also it comes with the starts with the finite value, comes back to same finite value. In other words, there is a steady state. It can happen only if there is a volts second per turn balance.

I will repeat; you can have a steady state or the fluxes, they follow the plot which I have shown you, only if there is a volt second per turn balance. In other words, increase in flux when the switch is on should be equal to the decrease in flux when the switch is off. Positive d phi by dt or positive d phi should be equal to negative d phi. Volts second per turn, what is that?

See here, volt V_{DC} into DT is time, volt second per turn, per turn. It is nothing but increase in flux increase in flux. So, increase in flux is volt this is the source voltage is the one which forcing the flux in the core, V_{DC} divided by N_1 into time for which the switch is closed. DT should be equal to the decrease in flux. The decrease in flux is V_0 is the voltage applied to the secondary, V_0 to number of turns in the secondary is N_2 and this is the time for which the secondary is carrying current, assuming it is in continuous conduction or at the boundary, remember, 1 minus D. So I will equate it. Increase in flux should be equal to decrease in flux. I will find that V_0 is equal to V_{DC} multiplied by N_2 divided by N_1 the turns ratio, divided by D into 1 minus D.

So, D divided by 1 minus D, this is nothing but a buck - boost converter. Transfer function for buck – boost, D divided by 1 minus D. But in addition to this term, there is N_2 divided by N_1 - the turns ratio. So, hence the name isolated buck – boost. It is also isolated buck – boost, there is an isolation. The transformer function is same as the buck - boost converter.

Now, in this transformer function you can see that V_0 and V_{DC} can be greatly different. V_0 and V_{DC} can be greatly different because I will fix or I will choose this ratio, suitable ratio. By, suitably selecting this ratio, magnitudes of V_0 and V_{DC} can be anything now. They can be greatly different. So invariably, D is maximum value D to be approximately chosen to be 0.5. We do not choose or designer does not take the worst condition to be 0.5. It takes this to be 0.5 and choose this N_2 by N_1 suitably.

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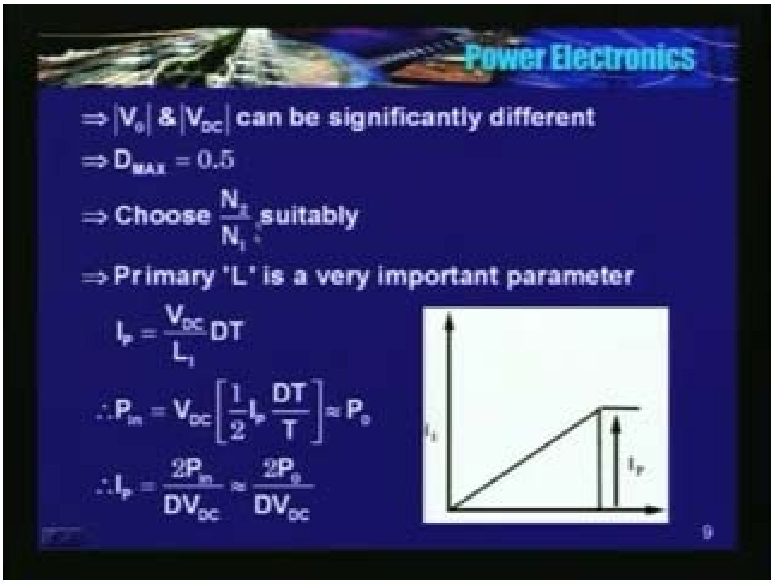

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$\Rightarrow |V_0|$ & $|V_{DC}|$ can be significantly different

$\Rightarrow D_{MAX} = 0.5$

$\Rightarrow$ Choose $\frac{N_2}{N_1}$ suitably

$\Rightarrow$ Primary 'L' is a very important parameter

$$I_p = \frac{V_{DC}}{L_1} DT$$

$$\therefore P_{in} = V_{DC}\left[\frac{1}{2} I_p \frac{DT}{T}\right] \approx P_0$$

$$\therefore I_p = \frac{2P_{in}}{DV_{DC}} \approx \frac{2P_0}{DV_{DC}}$$

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Which is another important parameter in fly back transformer design? Mind you, though it may be a transformer, only 1 winding is carrying current only 1 winding is carrying. Another important parameter is the primary inductance, L_1 L_1. Why? We will see. See here, what is the peak value of the current when the switch is closed? It is I_P is equal to V_{DC} divided by L_1 into D into T. The slope of this line is V_{DC} divided by L_1 and time for which the switch is closed. So, what is the input power? Input power is input voltage V_{DC} into the average value of the primary current.

What is the average value of i_1? It is nothing but half of I_P, the peak value into DT divided by T. It is area of this triangle divided by the time period divided by the time period. Area of this triangle is half IP, this is DT divided by the time period. So, this is the average power input. Now, if I neglect the losses, this is equal to the output power. So, if I know the output power and if I know the input voltage, I can calculate the peak value of current I_P.

Now, if I know I_P, I can choose a suitable value of L_1. So, primary inductance is a very important parameter in the transformer transformer design.

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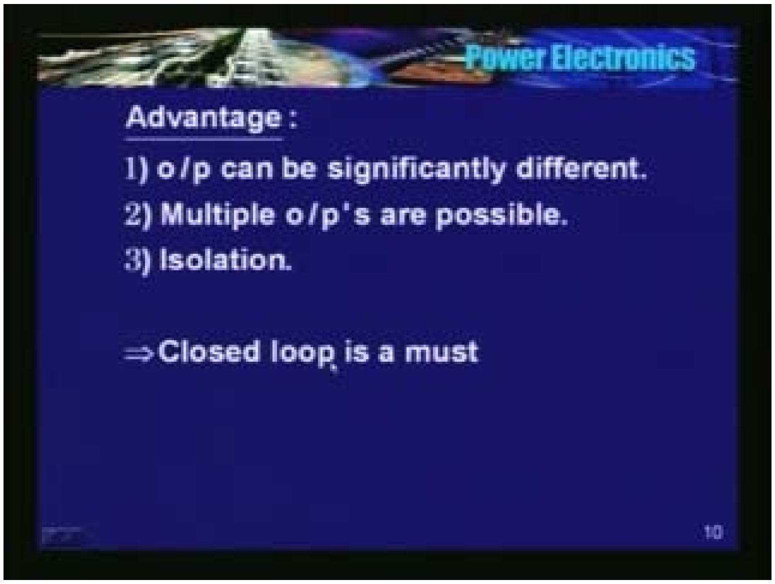

Advantage :

1) o/p can be significantly different.
2) Multiple o/p's are possible.
3) Isolation.

⇒Closed loop is a must

What are the other advantages of fly back converter? Why it is so popular? It is nothing but an isolated buck – boost. Apart from the isolation between the input and output, I told that the magnitudes of V_{DC} and V_O can be greatly different. Another important advantage is that you can have multiple outputs.

See, in buck, buck – boost, boost or chuck; there is 1 input and 1 output, whereas here, you can have a large number of outputs. 1 input, 1 input and large number of secondaries.

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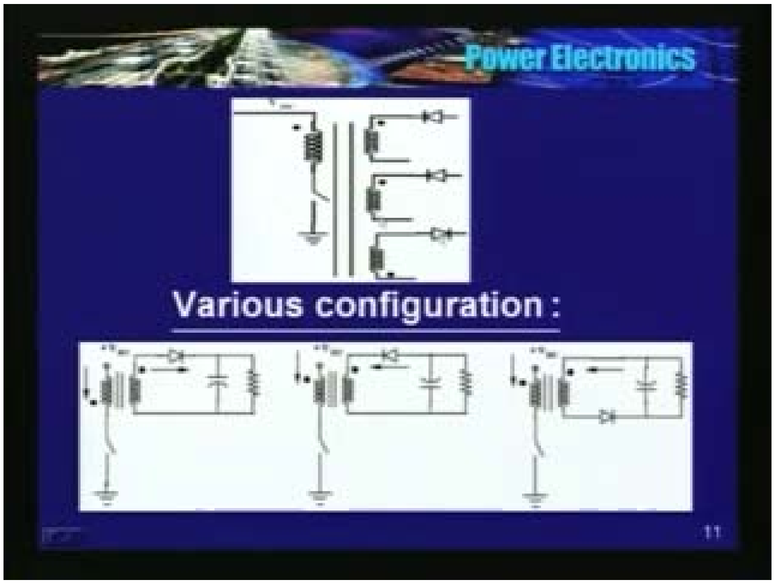

Various configuration :

So, when I close the switch; energy is stored in the primary, no current is flowing in the secondary because of this diodes. Open the switch; energy is transferred to to these secondaries. So, I can have a large number of secondaries now. Now, I can have positive voltage and I can have a negative voltage, I can have any number of voltages. Say, plus 5, minus 12, plus minus 5 so on, anything.

See, here are the various configurations. Current leaves the dot, current leaves the dot. See, current enters the dot, current enters the dot, current enters the dot and current leaves the dot. So, this is positive. Now, see here, current is entering the dot here, here also current should enter the dot. See the circuit connections here. So, this is positive, this terminal is positive this terminal is positive. So here, this is positive, this is positive.

So, similarly here, current enters the dot, current enters the dot. See the diode connections now. I have interchanged. I have connected a diode here. Now, this is positive this is positive, this is negative or this can be a reference point reference point. So, we can have multiple outputs multiple outputs.

So, point to be remembered in fly back is that diode connections are very important. You should connect diode in the secondary in such a way that only 1 winding is carrying current at a time. I told you that fly back converter is very popular in low power range. Why? What is the principle of operation? We use a transformer, but then we used we operated like an inductor. In the sense, only 1 winding is carrying current at a time. Suppose, someone says I have used the transformer, I expect that both the windings carry current simultaneously. Transformer, it transfers the energy from primary to secondary. But then we did use the transformer in a fly back converter. But then we connected a diode in the secondary such a way that only 1 winding is carrying current.

We have seen in AC circuit operation; secondary current may be 0, primary just supplying the magnetizing current. But we never had a situation wherein, primary is open and secondary is carrying a current. At least, I never encountered that sort of a situation in AC circuit analysis. But here, secondary is carrying current when there is no current in the primary. So, in other words, I am storing the energy in the magnetizing inductor and transferring it to the output. The primary current is only the magnetizing current, remember, primary current is only the magnetizing current. i_2 is 0 when i_1 is finite. When there is a current in the primary, there is no current in the secondary. So therefore, i_1 is always equal to I_m. It is the magnetizing current that I am storing and I am transferring to the secondary.

So, let us see what happens or what happens when I increase the power rating? Or if I want a higher output, what sort of a topology do I need to use?

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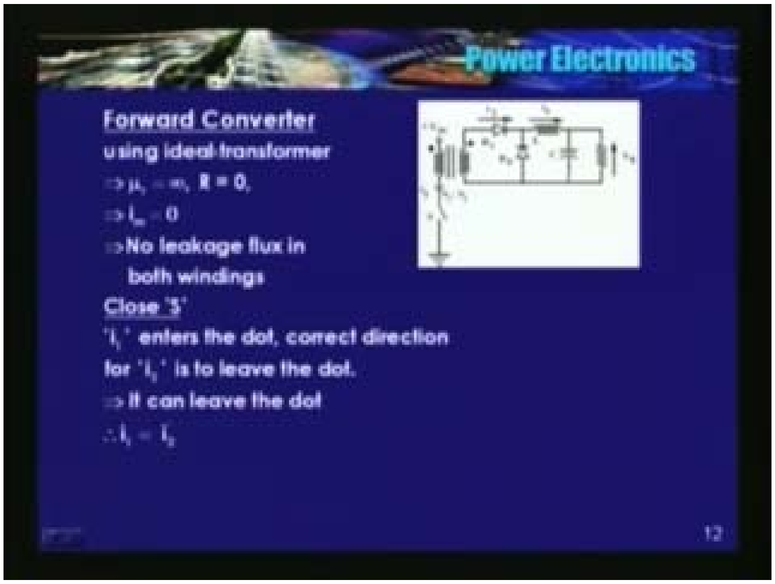

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Forward Converter

using ideal transformer

⇒ $\mu_r = \infty$, $\mathcal{R} = 0$,

⇒ $i_m = 0$

⇒ No leakage flux in both windings

Close 'S'

'i_1' enters the dot, correct direction for 'i_2' is to leave the dot.

⇒ It can leave the dot

$\therefore i_1 = i_2$

So, there is a one more converter what is known as forward converter forward converter. See the circuit connections, again I have used the transformer, 2 winding transformer. Again, let me make few assumptions. I am assuming that transformer is ideal, transformer is ideal. In other words, mu r is infinity. Therefore, reluctance of the core is 0. So, ampere turns required to establish the flux in the core is 0. In other words, magnetizing current is 0, remember. I will repeat; mu r is infinity, therefore magnetizing current is 0.

See the circuit topology. Close the switch, current enters the dot current enters the dot. Correct direction for the secondary current is to leave the dot. When primary is primary is carrying current, the current direction in the secondary is to to leave the dot. Current can leave the dot. See the diode here, current can leave the dot.

So, path is something like this; diode, inductor, output, capacitor and load, back to the secondary. So therefore, what is the primary current? It is the equivalent secondary current, i_1 is equal to i_2

prime because I_m is 0, no magnetizing current no magnetizing current. What is the voltage that is applied to the primary winding? It is V_{DC}? What is the voltage induced in the secondary? It is V_{DC} divided by N_1 multiplied by N_2. So, dot is positive, connected to the positive of the battery. So, this is also positive.

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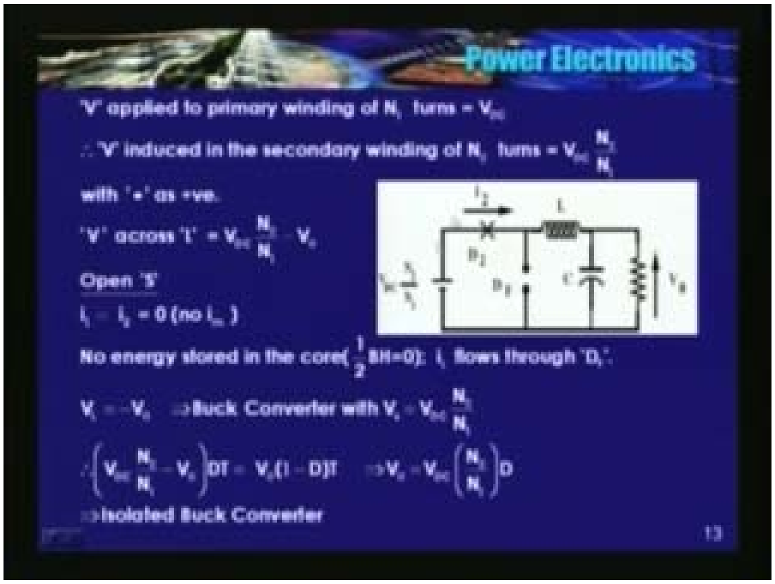

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'V' applied to primary winding of N_1 turns = V_{DC}

$\therefore$ 'V' induced in the secondary winding of N_2 turns = $V_{DC}\frac{N_2}{N_1}$

with '•' as +ve.

'V' across 'L' = $V_{DC}\frac{N_2}{N_1} - V_0$

Open 'S'

$i_1 = i_2 = 0$ (no i_m)

No energy stored in the core($\frac{1}{2}BH=0$): i_L flows through 'D_F'.

$V_L = -V_0 \Rightarrow$ Buck Converter with $V_s = V_{DC}\frac{N_2}{N_1}$

$\therefore \left(V_{DC}\frac{N_2}{N_1} - V_0\right)DT = V_0(1-D)T \Rightarrow V_0 = V_{DC}\left(\frac{N_2}{N_1}\right)D$

$\Rightarrow$ Isolated Buck Converter

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So, the equivalent circuit is you see here; positive, diode is conducting, inductor, output stage, back here. DF is off. See in this circuit. Diode DF is off because this is positive, this is also positive, this is negative, a reverse voltage appeared across the diode. So, diode DF is off. So, when the switch is on, the equivalent circuit in the secondary is looks something like this. Don't you think is very familiar circuit. This is nothing but a buck converter with the input voltage V_{DC} is replaced by V_{DC} into N_2 divided by N_1.

Here the forcing function is voltage induced in the secondary, whereas, in a buck converter, voltage forcing function is the input voltage source itself, VDC itself. Here the forcing function is V_{DC} into N_2 divided by N_1. What happens when I open the switch? What is the current just prior to closing the opening the switch in the in the primary. There is no magnetizing current because we have assumed a core to be ideal or mu r is infinity, reluctance is 0, magnetizing current is 0. So, primary current is equal to the secondary current, i_1 is equal to i_2 prime.

So, when I open the switch, i_1 becomes 0. There is no magnetizing current, the question of providing a path for the magnetizing current does not exist. So, what happens in the current in the secondary? Now, the moment I open the switch in the primary, there is no current in the primary. Therefore, i_2 is also becomes 0, this current becomes 0. This current or the output filter current should be continuous because flowing in this direction, it starts flowing this way, DF.

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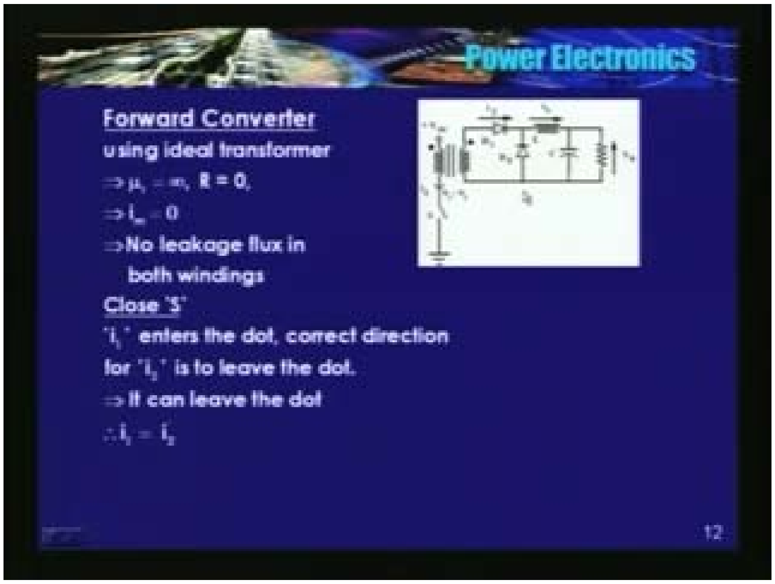

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Forward Converter

using ideal transformer

$\Rightarrow \mu_r = \infty, R = 0,$

$\Rightarrow i_m = 0$

⇒ No leakage flux in both windings

Close 'S'

'i_1' enters the dot, correct direction for 'i_2' is to leave the dot.

⇒ It can leave the dot

$\therefore i_1 = i_2$

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See in this circuit; when this current becomes 0, this also will 0 become 0. If this becomes 0, this may not be 0. Let me tell you one thing; this is the inductor current, output is a current source type similar to buck or chuck converter. I can represent it as a current source. This current may remain approximately constant. So, when I close the switch, i_2 that is equal to i_L increases. Why it is increases?

See here, a voltage a DC voltage is being applied here. So, i_2 increases slightly depending upon L and DT. Voltage appearing across the inductor is V_{DC} into N_2 divided by N_1 minus V_0. So, when I open the switch; DF starts conducting, DF starts conducting, voltage appears appearing across the inductor L is nothing but V_0 itself V_0 itself. So, the transfer function is V_0 is equal to V_{DC} N_2 divided by N_1 into D. When the switch is opened, voltage across the inductor is V_0 for this duration - 1 minus D into T duration. So, this is nothing but isolated buck converter. Isolation because, there is a turns ratio. If this is 1, this is nothing but V_0 is equal to V_{DC} into D. So, forward converter is also known an isolated buck converter.

What happens if I consider a non ideal transformer? Let me tell you 1 thing, you cannot have an ideal transformer. Mu R is finite, not equal to infinity. R is finite. If R is finite, ampere turns required to establish the flux in the core is again finite. It is not 0. Source has to supply some ampere turns to establish the flux in the core. So, when I close the switch, if there is a finite current flowing in the secondary, so what is the primary current? It is equivalent to secondary current plus the magnetizing current plus the magnetizing current.

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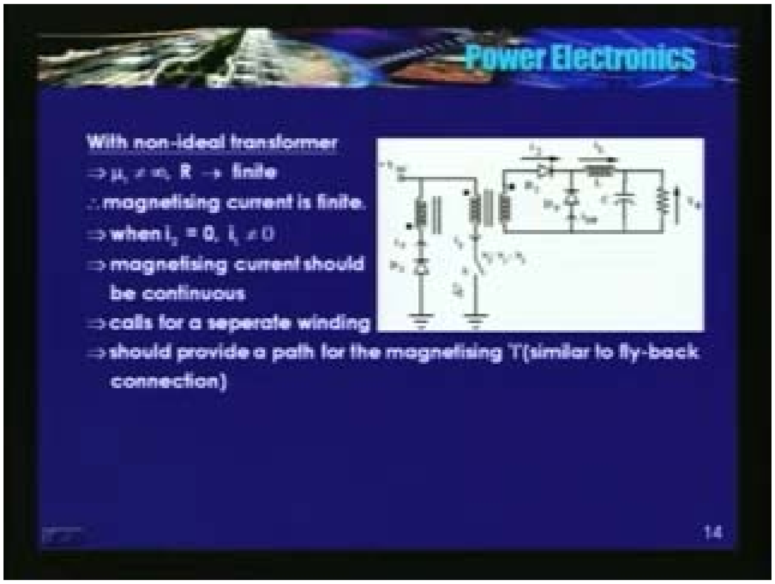

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With non-ideal transformer

- ⇒ $\mu_r \neq \infty$, R → finite
- ∴ magnetising current is finite.
- ⇒ when $i_2 = 0$, $i_1 \neq 0$
- ⇒ magnetising current should be continuous
- ⇒ calls for a seperate winding
- ⇒ should provide a path for the magnetising I(similar to fly-back connection)

See, a non ideal of a forward converter using a non ideal transformer or this is a practical forward converter, mind you. Let me tell you, the previous forward converter cannot exist. You cannot have a forward converter with 2 winding transformer. This cannot exist this cannot exist because you have to source has to supply some ampere turns to establish the flux in the core and that current has to be continuous. See, this inductor current is is continuous because DF provides a path. It was flowing when I close the switch, i_2 starts flowing that is nothing but i_L, DF was off.

So, this is the path when I open the switch. D_2 turns off. So, this current can flow through this diode. There is a path for the load current or inductor current. Since, there is more leakage inductance here, there is no magnetizing current here. Circuit works satisfactorily or circuit can work. But there is always a finite magnetizing inductance. Ampere turns required to establish the flux in the core is finite. That has to be continuous. So, when I open the switch, there is no path for the current to flow. So, this is a practical forward converter. There is 3 windings, this is nothing but the previous circuit. So, I have used a yet another winding; a tertiary winding with the diode and see the dotted terminals. And, the third branch is connected to the same supply, as of now. Let us see what we can do with this sometime later.

How does this works? I told you, you have to provide a separate path for the magnetizing current. So, how does this circuit work? Close S, magnetizing current or flux in the core increases linearly, similar to the fly back similar to fly back. But then there is no secondary current. But in forward current in forward converter, when I close the switch, there is an equivalent current flowing in the secondary. Secondary current can flow because of the diode connection. i_2 is finite, so there is i_2 prime, the prime.

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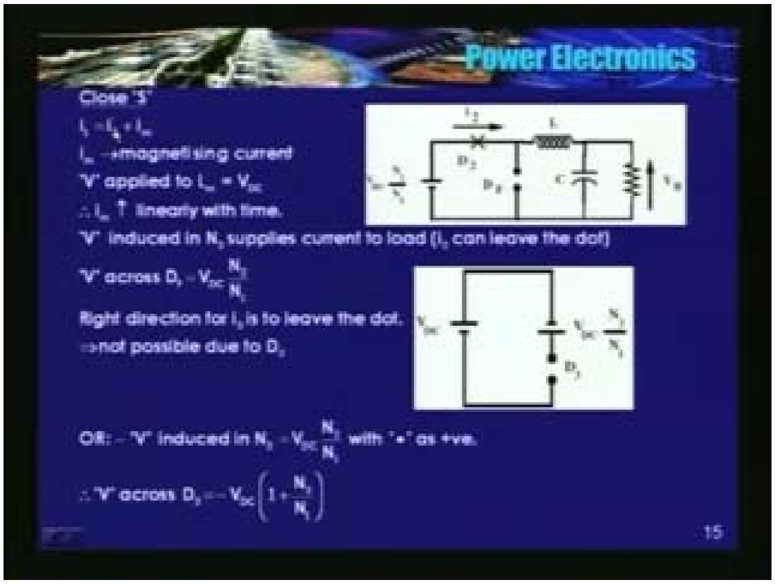

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Close 'S'

$i_1 = i_2' + i_m$

i_m → magnetising current

'V' applied to L_m = V_{DC}

∴ i_m ↑ linearly with time.

'V' induced in N_2 supplies current to load (i_2 can leave the dot)

'V' across $D_3 = V_{DC}\frac{N_3}{N_1}$

Right direction for i_3 is to leave the dot.

⇒ not possible due to D_3

Off: – 'V' induced in $N_3 = -V_{DC}\frac{N_3}{N_1}$ with '•' as +ve.

∴ 'V' across $D_3 = -V_{DC}\left(1+\frac{N_3}{N_1}\right)$

So, voltage applied to the magnetizing inductance is V_{DC}. So, I_m increases linearly with time. What is the voltage induced in N_2 turns? It is V_{DC} multiplied by N_2 divided by N_1. What happens in the tertiary or what will happen in this circuit? This is the one which producing the flux. Current enters the dot, so right direction here is to leave the dot leave the dot. You cannot have that situation because of D_3. Current cannot leave the dot; current can only enter the dot. Dot is positive, dot is positive, dot is positive, dot is connected to the positive of the battery. Positive to cathode, anode is grounded anode is grounded.

D_3 is reverse biased D_3 is reverse biased. No current can flow in this direction or in other words no current can leave the dot in the tertiary winding. Similar to a fly back connection fly back connection. Only difference is fly back, we have connected a capacitor and a resistor, whereas, here I am connecting it to the same source.

So, what is the voltage induced in this winding? Voltage applied to the primary is V_{DC}. So, voltage induced in the tertiary winding with N_3 is V_{DC} into N_3 divided by N_1. V_{DC} divided by N_1 multiplied by N_3 is a voltage induced in the tertiary winding. Let me … So, this is a circuit connection, see, with dot has the positive, V_{DC} into N_3 divided by N_1. Other other end of the transformer winding is connected to positive of the battery V_{DC}. This is the circuit connection.

What is a voltage appearing across D_3? See, this connection of these 2 voltage sources. So, voltage appearing across D_3 is is given by this equation. What is the voltage appearing across the freewheeling diode in the secondary? It is the secondary induced voltage, V_{DC} into N_2 divided by N_1. You open the switch after sometime, what will happen? Go back to the previous circuit, open the switch; i_1 becomes 0, so i_2 also will become 0. But then magnetizing current has to be continuous. i_L load current here, is continuous. There is a path, there is a path here. Now, D_3 starts carrying the current.

See, this D_3 and N_1 or or this is nothing but fly back converter connections fly back converter connections fly back converter connection. Now, how do I explain? See, when I open the switch, I said, flux try to decrease, D phi D_2 is going to be negative. In other words, all dotted - this terminals going to be negative. If this is negative, this is positive. This is negative, anode is connected to ground, so D_3 can conduct D_3 can conduct. Current can flow through this path, back to source back to source. D_3 starts conducting but current that is flowing through D_3 or a current that is flowing through that N_3 winding is is only the equivalent magnetizing current. Let me tell you one thing, it is just equivalent magnetizing current.

So, what is the peak value of the magnetizing current just prior to opening the switch? It is V_{DC}, the voltage applied to the primary turns or N_1 turns divided by LM is a magnetizing inductance multiplied by the time for which the switch is on, DT. Now that current gets reflected to the tertiary winding, a winding which is having N_3 turns.

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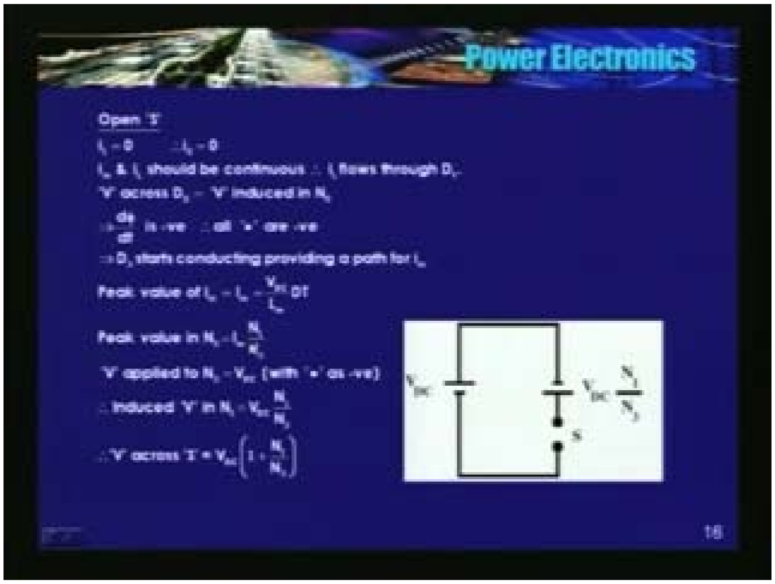

Open 'S'

$i_s = 0$ ∴ $i_1 = 0$

i_m & i_L should be continuous ∴ i_L flows through D_2

'V' across D_3 = 'V' induced in N_3

⇒ $\frac{d\phi}{dt}$ is -ve ∴ all '•' are -ve

⇒ D_3 starts conducting providing a path for i_m

Peak value of $i_m = I_m = \frac{V_{DC}}{L_m} DT$

Peak value in $N_3 = I_m \frac{N_1}{N_3}$

'V' applied to $N_3 = V_{DC}$ (with '•' as -ve)

∴ induced 'V' in $N_1 = V_{DC} \frac{N_1}{N_3}$

∴ 'V' across 'S' = $V_{DC}\left(1 + \frac{N_1}{N_3}\right)$

So, the peak value of current that is flowing in N_3 is given by I_m into N_1, Im is the peak current that was flowing in the primary winding, just peak value of the magnetizing current peak value of the magnetizing current, just prior to opening the switch that was flowing in N_1 number of turns. Now, this current gets reflector in the tertiary which is having N_3 turns. What is the voltage applied to N_3? It is V_{DC} with the dot as negative because the other end of the winding is connected to the positive. So, this is connected to positive. So, this has to be negative. In other words, this is negative, this is negative, this is negative. Dot is to …

So, some of the operation is close switch S; current enters the dot, current can leave the dot, an equivalent voltage is applied here, i_L increases linearly and the tertiary winding current is 0 because current cannot leave the dot. Open the switch; magnetizing current has to be continuous that it starts flowing in tertiary winding, all dots are negative now. So, i_2 is 0, i_1 is 0, i_3 is finite. It provides a path for the magnetizing current. So, that is about the forward converter operation. More about it, we will see in the next class.

Thank you.