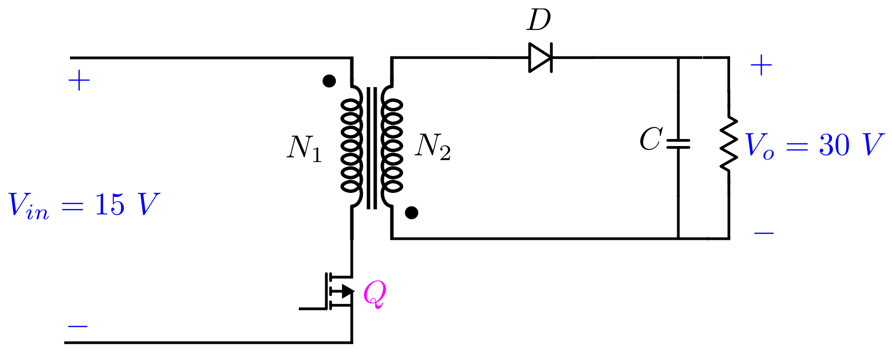
Question 1:

In a flyback converter the switching frequency is 20 kHz with a duty cycle of 50%. The input voltage is 15 V and the output voltage is 30 V. The load current is 1 A. What is the voltage withstanding capability of the primary side switch Q.

(a) 15 V
(b) 22.5 V
(c) 30 V
(d) 45 V



Solution: Correct option is (c)

To find the voltage stress across the switch Q, we need to calculate the voltage across the switch when it is off. The output voltage is assumed to be ripple free.

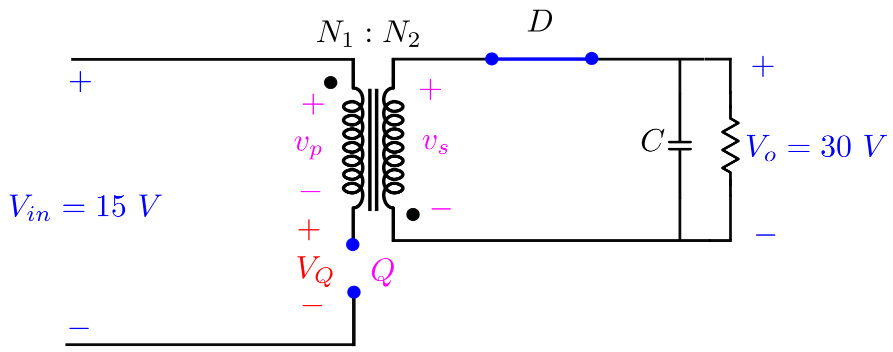
The input-output voltage relation is given as

$$V_o = \frac{N_2}{N_1}\frac{D}{1-D}V_{in}$$

Thus, we can calculate the turns ratio as

$$\frac{N_2}{N_1} = \frac{1-D}{D} \times \frac{V_o}{V_{in}} = 2$$

When the switch Q is off, the diode D is turned on. Thus, the circuit when the switch is off can becomes as shown below.



During this period,

$$v_s = 30\ V$$

Based on dot polarity we can write

$$v_p = -\frac{N_1}{N_2} \times v_s = -15\ V$$

Thus, the voltage across switch Q is

$$V_Q = V_{in} - v_p = 30\ V$$

Question 2:

Which of the following statement is/are true regarding the flux walking phenomenon?

Statement 1: It cannot be observed in Full bridge converter.

Statement 2: It can cause saturation of the converter transformer.

Statement 3: Flux walking occurs because of volt-sec unbalance across the winding.

Statement 4: Flux walking problem can be solved by connecting a series inductance with the primary winding.

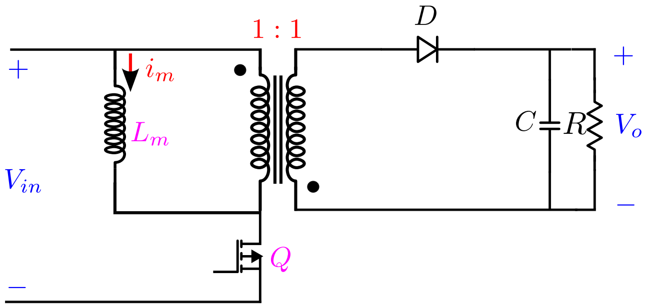
Statement 5: Correcting the duty cycle in each PWM cycle can resolve the flux walking problem.

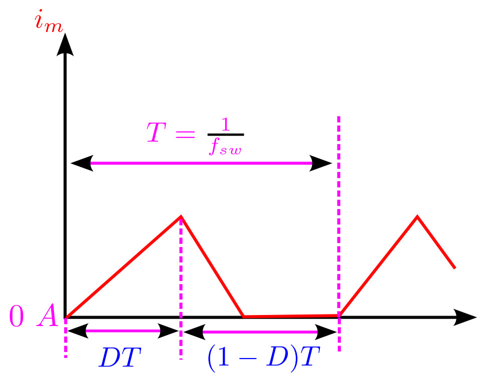
(a) Statement 2 and 5
(b) Statement 1,2 and 5
(c) Statement 2,4 and 5
(d) Statement 2, 3 and 5

Solution: Correct option is (d)

Question 3:

A flyback converter with a turns-ratio of $1{:}1$, *has a magnetizing inductance of* L_m *and is operating at a frequency of* f *and duty cycle* D *supplying a load resistance* R. *The waveform of the magnetizing current is illustrated in the figure below. What will be the expression for voltage transfer ratio* $\frac{V_o}{V_{in}}$.





(a) $\frac{V_o}{V_{in}} = \frac{D}{1-D}$

(b) $\frac{V_o}{V_{in}} = \frac{2D}{1-D}$

(c) $\frac{V_o}{V_{in}} = \sqrt{\frac{DR}{2fL_m}}$

(d) $\frac{V_o}{V_{in}} = D\sqrt{\frac{R}{2fL_m}}$

Solution: Correct option is (d)

When the switch Q is on, the voltage across the magnetizing inductance L_m is

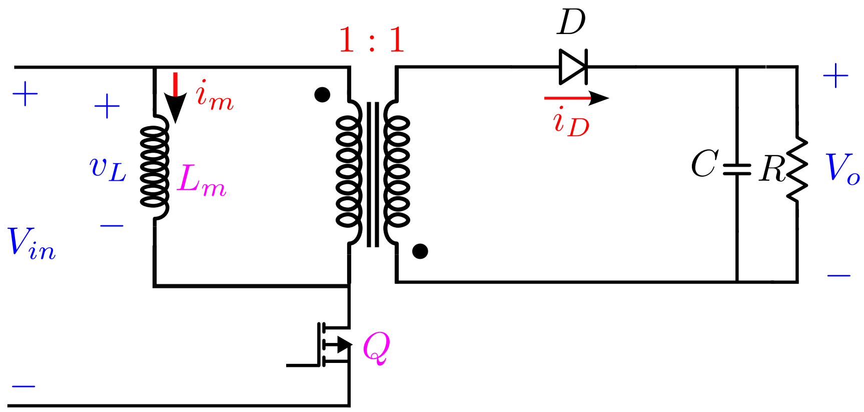
$$v_L = V_{in}$$

When the switch Q is off, and the magnetizing current i_m is non-zero, the voltage across L_m is

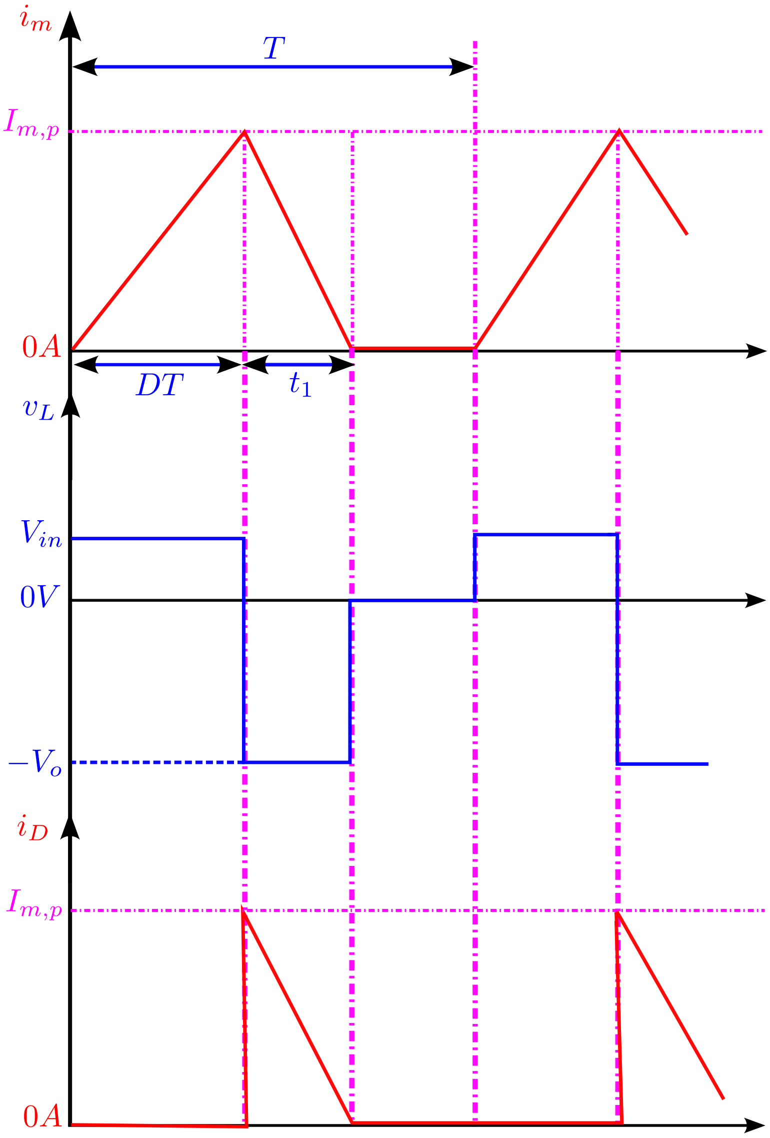
$$v_L = -V_o$$

When the switch Q is off, and the magnetizing current i_m is zero, the voltage across L_m is

$$v_L = 0$$



The waveform of the voltage v_L across the magnetizing inductance, diode current, i_D, and the magnetizing current, i_m, is illustrated in the figure below



During on period of the switch

$$v_L = V_{in} = L_m \frac{I_{m,p}}{DT}$$

Thus, we can write

$$I_{m,p} = \frac{V_{in}DT}{L_m}$$

We know that the load current flowing through R is the average value of the diode current, i_D. Thus, we can write

$$I_o = \frac{V_o}{R} = \frac{1}{2} \times t_1 \times I_{m,p} \times \frac{1}{T} = \frac{1}{2} \times t_1 \times \frac{V_{in}DT}{L} \times \frac{1}{T}$$

From the above equation we can obtain the value of t_1 as

$$t_1 = \frac{2V_o L_m}{DRV_{in}}$$

Applying volt-second balance across the magnetizing inductance L_m we can write

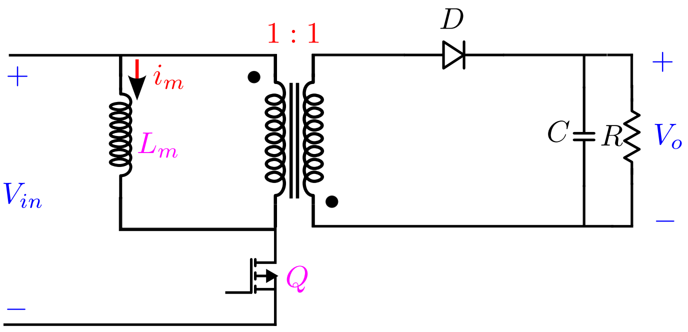
$$V_{in}DT - V_o t_1 = 0$$

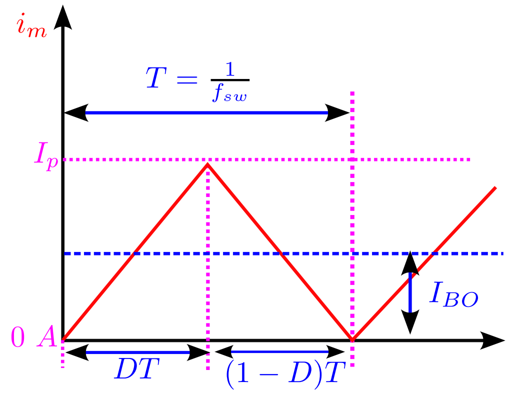
Substituting the expression for t_1 we can obtain the expression for voltage gain as

$$\frac{V_o}{V_{in}} = D\sqrt{\frac{R}{2f_{sw}L_m}}$$

Question 4:

In a regulated flyback converter with a turns ratio of $1{:}1$, $V_o = 12\ V$, V_{in} *ranging from 12 to 24 V,* P_{load} *is ranging from 6 to 60 W, and the switching frequency,* $f_{sw} = 200\ kHz$*. Calculate the maximum value of magnetizing inductance* L_m *(in* μH*) that can be used such that the average value of the magnetization current is always below* I_{BO} *under all conditions. Assume the components to be ideal.*





[Hint: Identify the condition at which i_m *will attain its maximum value and do the necessary calculations]*

Solution: Answer range (1.1-1.8)

The average value of i_m should always remain below I_{BO} essentially mean that the magnetization current will always be discontinuous and will reach the boundary condition of continuous and discontinuous mode of operation when the load current reaches its maximum value or in other words the peak value of the magnetization current reaches its maximum value.

I_p will reach its maximum value when the duty cycle, D, is maximum. The relation between duty cycle and the input output voltage of the flyback converter is given by

$$D = \frac{1}{1 + \frac{V_o}{V_{in}}}$$

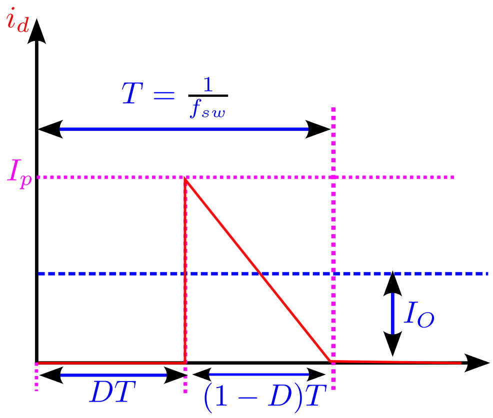
From the above expression, we can conclude that the duty cycle will be maximum if V_{in} is at its minimum value. Thus, we need to consider $V_{in} = 12$. In such a case the duty cycle is

$$D = \frac{1}{1 + \frac{12}{12}} = 0.5$$

Thus, the maximum value of the load current is

$$I_o = \frac{P_{load}}{V_o} = \frac{60}{12} = 5\ A$$

Now, I_o is the average value of the diode current. The waveform of the diode current is shown in the figure below



Thus, we can write I_o as

$$I_o = \frac{1}{2} \times (1-D) \times I_p$$

Thus, the peak value of the load current can be calculated as

$$I_p = \frac{2I_o}{(1-D)} = 20\ A$$

When the switch Q is on, the voltage across the magnetizing inductance, L_m, is

$$v_L = V_{in} = L_m \frac{I_p}{DT} = 12$$

Thus, the value of the magnetizing inductance, L_m is

$$L_m = \frac{v_L DT}{I_p} = \frac{12D}{I_p f_{sw}} = 1.5\ \mu H$$

Question 5:

A flyback converter (Converter A) shown in Fig. a is operating with a duty ratio of 0.5 such that the magnetizing current is continuous as shown in Fig. b. The magnetizing inductance of the converter is L_{m1}.

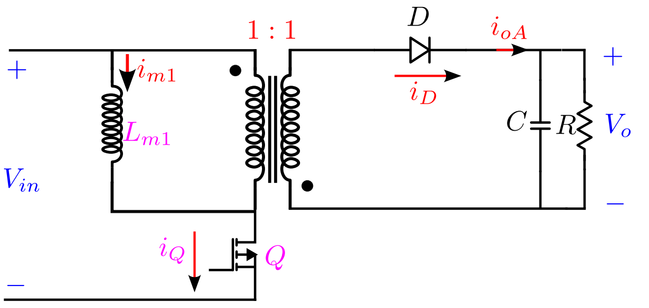


Fig. (a)

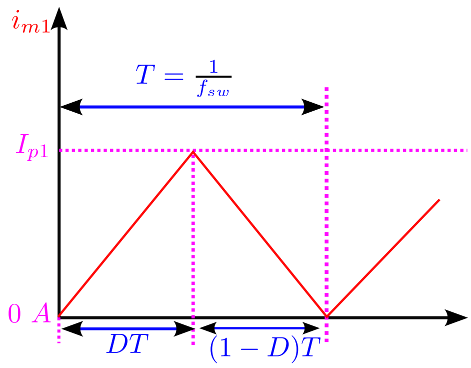


Fig. (b)

For the same application, to deliver same power to the load at same output voltage V_o another Converter B is designed by paralleling two half sized flyback converter as shown in Fig. c. Assume that both the flyback converters in Fig. c are sharing equal load. Then what would be the relationship between L_{m1} and L_{m2} such that the magnetizing current i_{m2} just reaches 0A at the end of each cycle. The switching signals of the switches Q_2 and Q_3 is illustrated in Fig. (d). All the switches Q_1, Q_2 and Q_3 are operated at same frequency and same duty ratio.

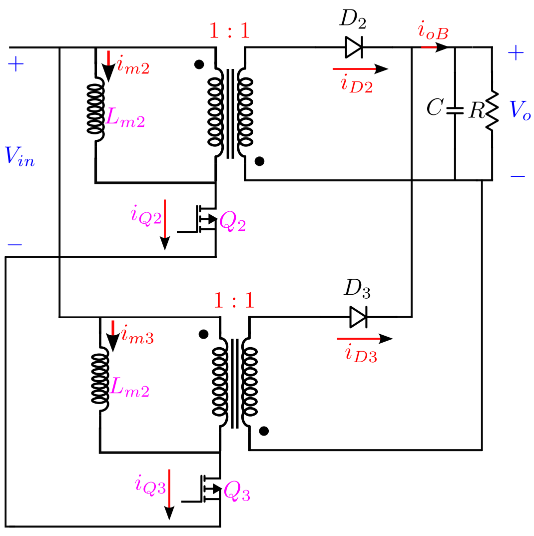


Fig. (c)

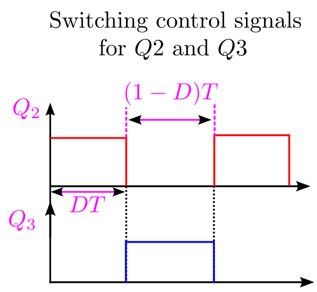
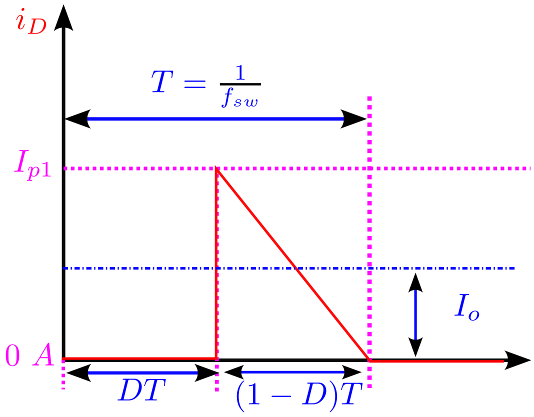


Fig. (d)

(a) $L_{m2} = 0.5 \times L_{m1}$
(b) $L_{m2} = 0.25 \times L_{m1}$
(c) $L_{m2} = 4 \times L_{m1}$
(d) $L_{m2} = 2 \times L_{m1}$

Solution: Correct option is (d)



For Converter A:

We can find the expression for I_{p1} as

$$I_{p1} = \frac{V_{in}DT}{L_{m1}}$$

We know that the average value of the diode current i_D is the load current I_o. The waveform of the diode current of Converter A is shown in the figure above. Thus, we can write

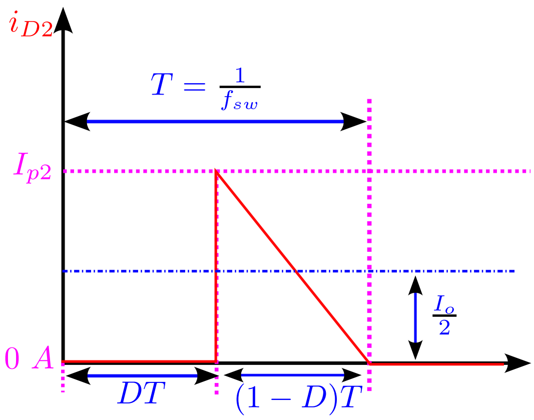
$$I_o = \frac{1}{2} \times (1-D) \times I_{p1} = \frac{D(1-D)}{2} \times \frac{V_{in}T}{L_{m1}}$$

For Converter B:

As the load is equally shared between the two parallel flyback converters, the average value of the diode current, i_{D2} must be equal to $0.5 \times\ I_o$. The expression for the peak value of magnetizing current i_{m2} can be written as

$$I_{p2} = \frac{V_{in}DT}{L_{m2}}$$

The waveform of the diode current i_{D2} is shown in the figure below



The expression for average value of i_{D2} can then be written as

$$\frac{I_o}{2} = \frac{1}{2} \times (1 - D) \times I_{p2} = \frac{D(1 - D)}{2} \times \frac{V_{in}T}{L_{m2}}$$

Thus, we have

$$\frac{D(1 - D)}{2} \times \frac{V_{in}T}{L_{m2}} = \frac{1}{2} \times \frac{D(1 - D)}{2} \times \frac{V_{in}T}{L_{m1}}$$

Thus, we can conclude that

$$L_{m2} = 2 \times L_{m1}$$

Question 6:

In continuation with Question 5, which of the following statement(s) is/are true for the output stage currents i_{oA} and i_{oB}.

Statement 1: Ripple frequency of i_{oB} is twice as that of the ripple frequency of i_{oA}

Statement 2: Ripple frequency of i_{oB} is half as that of the ripple frequency of i_{oA}

Statement 3: Peak ripple current of i_{oB} is one-third as that of the peak ripple current of i_{oA}

Statement 4: Peak ripple current of i_{oB} is half as that of the peak ripple current of i_{oA}

(a) *Only Statement 1 is correct*
(b) *Statements 1 and 3 are correct*
(c) *Statement 2 and 4 are correct*
(d) *Only Statement 4 is correct*

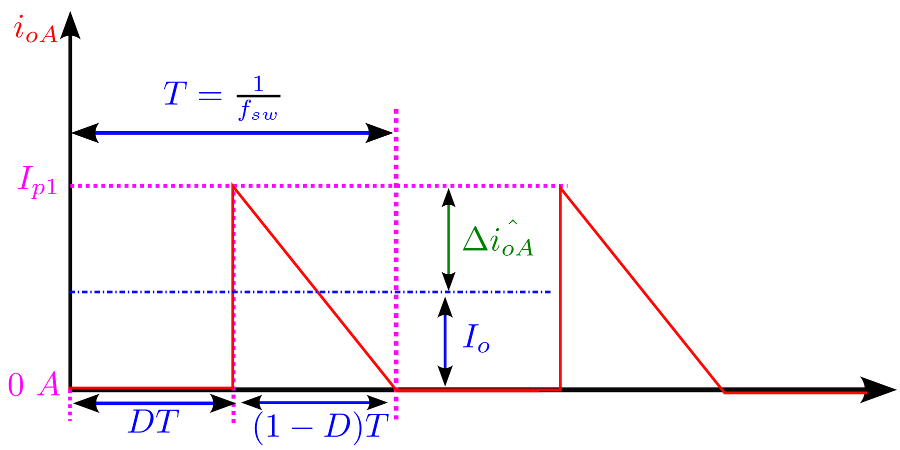
Solution: Correct option is (b)

For Converter A:

It can be concluded from the Fig. (a) of *Question 5* that

$$i_D = i_{oA}$$

Thus, the waveform of the current i_{oA} is as shown in the figure below



The peak ripple current $\Delta\widehat{i_{oA}}$ can be calculated as

$$\Delta\widehat{i_{oA}} = I_{p1} - I_o$$

The expressions for I_{p1} and I_o are already derived in the solution to *Question 5*. As mentioned in *Question 5* the duty ratio, $D = 0.5$. Substituting the value of $D = 0.5$ we can calculate $\Delta\widehat{i_{oA}}$ as

$$\Delta\widehat{i_{oA}} = I_{p1} - I_o = \frac{3}{8} \times \frac{V_{in}T}{L_{m1}}$$

As seen from the waveform of i_{oA} the frequency of the output stage current i_{oA} is

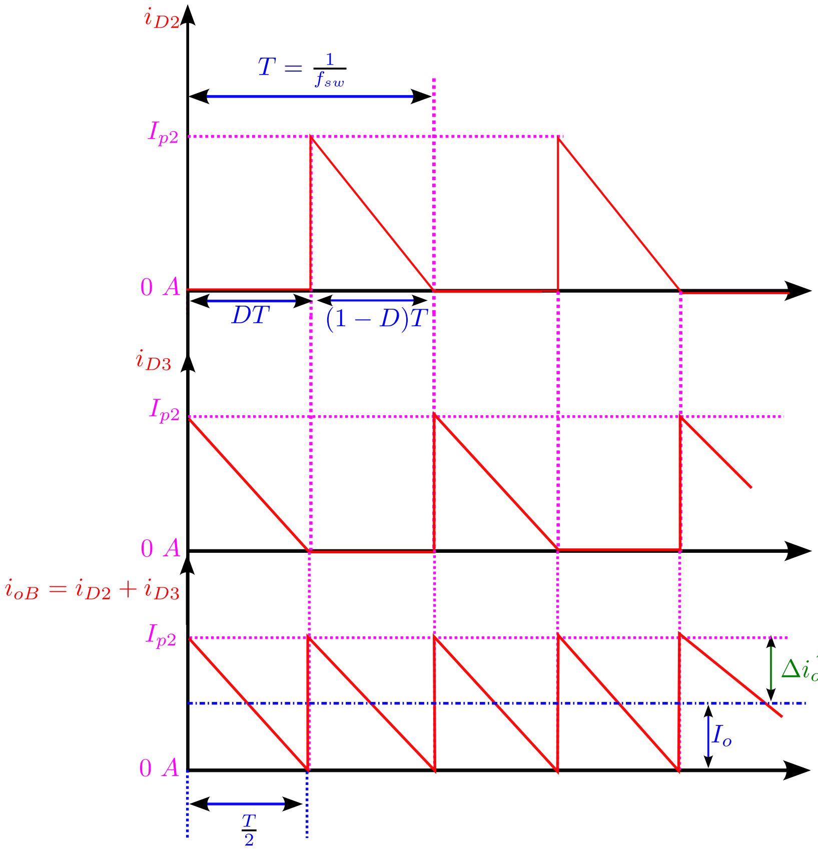
$$f_A = f_{sw} = \frac{1}{T}$$

For Converter B:

It can be concluded from the Fig. (c) of *Question 5* that

$$i_{oB} = i_{D2} + i_{D3}$$

The waveforms of i_{D2}, i_{D3}, and i_{oB} is shown in the figure below



The peak ripple current $\Delta\widehat{i_{oB}}$ can be calculated as

$$\Delta\widehat{i_{oB}} = I_{p2} - I_o$$

The expressions for I_{p2} and I_o are already derived in the solution to *Question 5*. As mentioned in *Question 5* the duty ratio, $D = 0.5$. Substituting the value of $D = 0.5$ we can calculate $\Delta\widehat{i_{oB}}$ as

$$\Delta\widehat{i_{oB}} = I_{p2} - I_o = \frac{1}{8} \times \frac{V_{in}T}{L_{m1}}$$

Thus, we have

$$\Delta\widehat{i_{oB}} = \frac{1}{3} \times \Delta\widehat{i_{oA}}$$

Again, as can be seen from the waveform of i_{oB}, the ripple frequency of i_{oB} is

$$f_B = \frac{2}{T} = 2f_{sw} = 2f_A$$

Question 7:

Consider two converters A and B. Converter A is a forward converter topology (shown in Fig. a) with demagnetizing winding. Converter B is a full bridge converter topology (shown in Fig. b). Both the converter has same values of input voltage source, turns ratio, switching frequency, output inductor and capacitor. The power switch of converter A is switched with a duty ratio twice that of converter B switches. What is the ratio of peak-to-peak inductor current ripple of converter A to that of converter B?

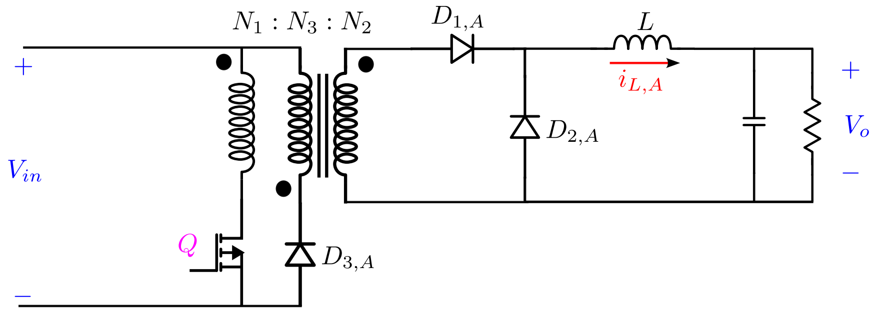


Fig. (a): Conveter A

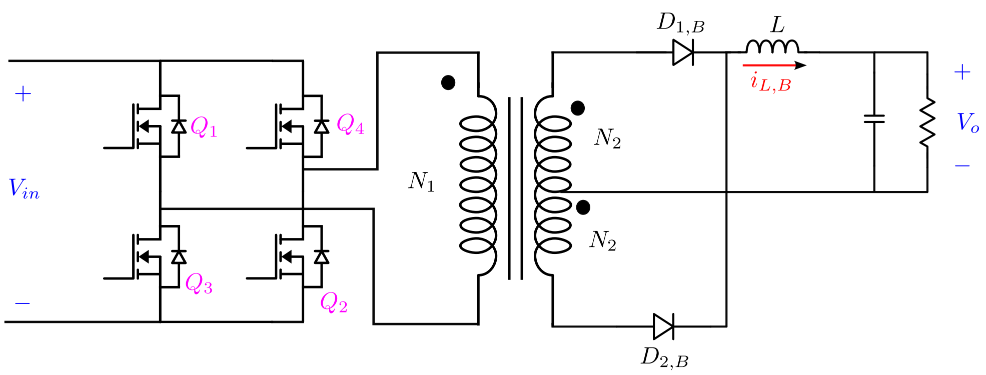


Fig. (b): Conveter B

Solution: Answer range (1.9-2)

<u>For Converter A</u>

The converter A is operating at a duty cycle given by

$$D_A = D$$

Thus, the output voltage of converter A is

$$V_o = \frac{N_2}{N_1} D_A V_{in} = \frac{N_2}{N_1} D V_{in}$$

During the period when switch Q is off, the voltage across the inductor is given by

$$v_{L,A} = -V_o = -L\frac{\Delta i_{L,A}}{(1-D)T}$$

Thus, the ripple inductor current in converter A can be expressed as

$$\Delta i_{L,A} = \frac{V_o(1-D)T}{L}$$

For Converter B

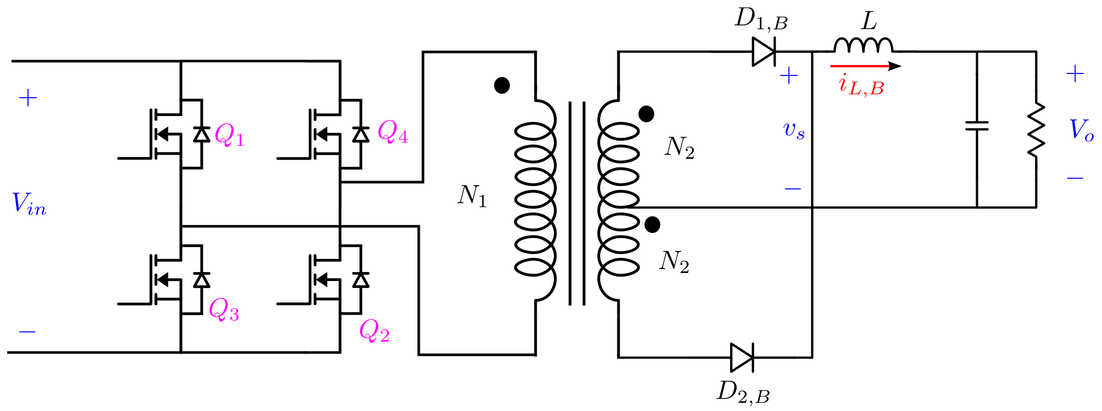
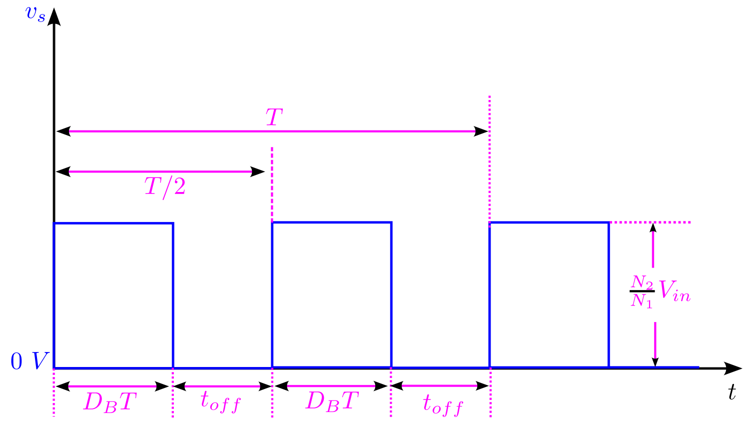


Fig. (b): Conveter B

The waveform for v_s will be as shown in the figure below



During the period t_{off} when both the diodes $D_{1,B}$ and $D_{2,B}$ are on the voltage across the inductor is

$$v_{L,B} = -V_o = -L\frac{\Delta i_{L,B}}{\left(\frac{T}{2} - D_B T\right)}$$

As has been given in the question

$$D_B = \frac{D_A}{2} = \frac{D}{2}$$

Thus, the equation becomes

$$V_o = L\frac{2\Delta i_{L,B}}{(1-D)T}$$

The expression for $\Delta i_{L,B}$ is

$$\Delta i_{L,B} = \frac{V_o(1-D)T}{2L} = \frac{\Delta i_{L,A}}{2}$$

$$\frac{\Delta i_{L,A}}{\Delta i_{L,B}} = 2$$

Question 8:

In continuation with Question 7, the Converter B is supplied from a unregulated DC voltage 100 to 150 V. A designer has switches of the voltage rating as given in the options. Which of the following voltage rating should the designer choose for safe operation of the converter.

(a) *25 V*
(b) *50 V*
(c) *100 V*
(d) *200 V*

Solution: Correct option is (d)

The voltage appearing across an OFF switch in case of a full-bridge converter shown in *Question 7* is

$$V_{block} = V_{in}$$

The maximum voltage supplied by the unregulated power supply is

$$V_{in,max} = 150\ V$$

Taking a safety factor 1.3 a designed should choose a switch having a voltage blocking capability of 200 V.

Question 9:

In continuation with Question 7 and 8, what should be the minimum voltage blocking capability of the diode $D_{1,B}$ and $D_{2,B}$ if the turns ratio of the centre-tapped transformer is 5 (2.5-0-2.5).

(a) *1000 V*
(b) *375 V*
(c) *750 V*
(d) *500 V*

Solution: Correct option is (c)

The maximum voltage supplied by the unregulated power supply is

$$V_{in,max} = 150\ V$$

The voltage appearing across the diode $D_{1,B}$ when the diode $D_{2,B}$ is off is

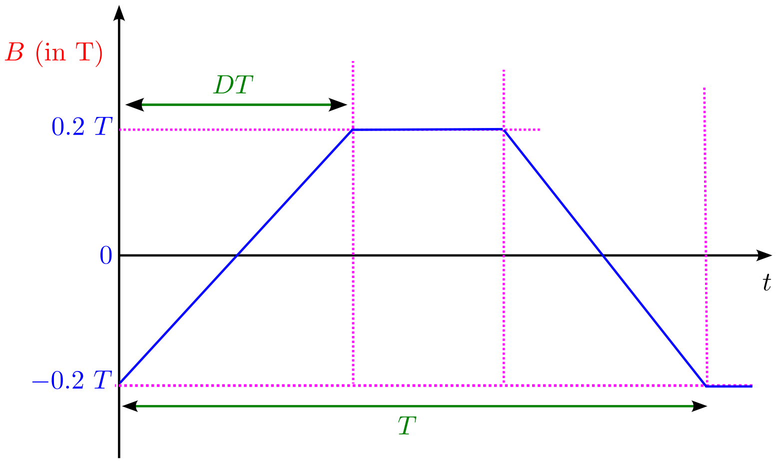
$$PIV = \frac{2N_2}{N_1} \times V_{in,max} = 5 \times 150 = 750\ V$$

Question 10

A full bridge converter has 1 turn primary and 100 turns secondary wound on a core with a 25 mm^2 cross section. The core flux density is allowed to swing up to 0.2T. The full bridge switches are switched at 100kHz and 50% duty cycle. What is the output voltage of the converter (in Volts)?

Solution: Answer range (199-200)

The flux waveform for a full bridge converter is shown in the figure below



Now, by Faraday's Law we have

$$V_{in} = N_1 \frac{d\Phi}{dt} = N_1 A_c \frac{dB}{dt} = 1 \times 25 \times 10^{-6} \times \frac{0.4}{DT} = 25 \times 10^{-6} \times \frac{0.4 f_{sw}}{D} = 2\,V$$

The output voltage of the full bridge converter is given by

$$V_o = 2 \times \frac{N_2}{N_1} D V_{in} = 2 \times 100 \times 0.5 \times 2 = 200\,V$$