Question 1:

*The **boundary between Continuous Conduction Mode (CCM) and Discontinuous Conduction Mode (DCM)** in a DC-DC converter is the operating condition where the **inductor current just touches zero** at the end of the switching cycle but doesn't stay at zero for any significant duration.*

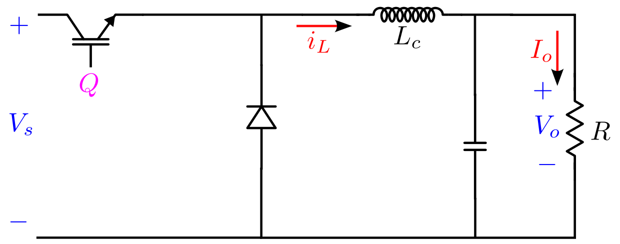
In the chopper circuit shown in the figure below, the input dc voltage has a constant value, V_S. The output voltage, V_O, is assumed to be ripple free. The switch, Q, is operated with a switching time-period, T, and a duty ratio, D. What is the value of critical inductance, L_C, at the boundary of continuous and discontinuous conduction of the inductor current, i_L.

(a) $L_C = \frac{V_S D(1-D)T}{2I_O}$

(b) $L_C = \frac{2V_O}{(1-D)TI_O}$

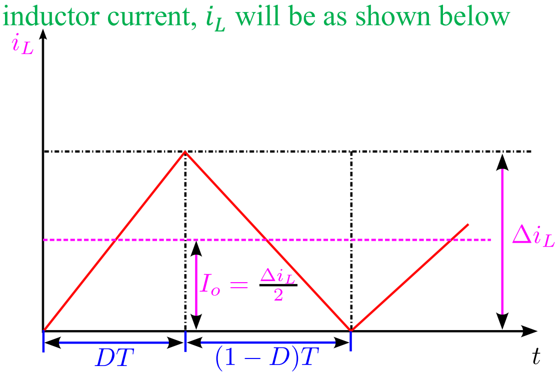
(c) $L_C = \frac{V_S(1-D^2)T}{2I_O}$

(d) $L_C = \frac{V_O(T-1)}{2DTI_O}$



Solution: Correct option is (a)

The waveform of the inductor current, i_L will be as shown below



When the switch Q is off, the voltage across the inductor is given as

$$v_L = -L_C \frac{\Delta i_L}{(1-D)T} = -V_O$$

Thus, we can write

$$L_C = V_O \frac{(1-D)T}{\Delta i_L}$$

At the boundary of continuous and discontinuous conduction mode

$$I_O = \frac{\Delta i_L}{2}$$

The relationship between output and input voltage of a buck converter is given by

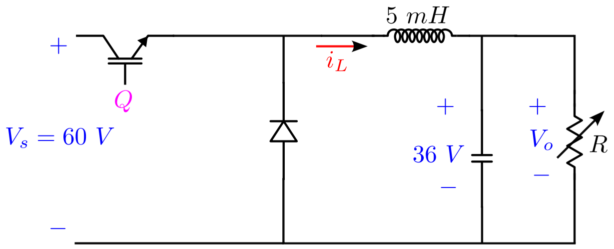
$$V_O = DV_S$$

Thus, the expression for L_C is given as

$$L_C = V_O \frac{(1-D)T}{\Delta i_L} = V_S \frac{D(1-D)T}{2I_O}$$

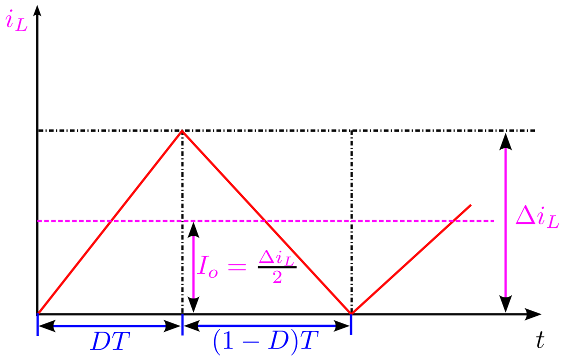
Question 2: Numerical type

A buck converter feeding a variable resistive load is shown in the figure below. The switching frequency of the switch, Q, is 100 kHz and the duty ratio of 0.6. The output voltage, V_o, is 36 V. Assume that all the components are ideal, and the output voltage is ripple free. The value of R (in Ω) that will make the inductor current, i_L, just continuous is __________________.



Solution: Answer range (2500-2500)

The waveform of the inductor current, i_L will be as shown below



When the switch Q is off, the voltage across the inductor is given as

$$v_L = -L\frac{\Delta i_L}{(1-D)T} = -V_o$$

Thus, the inductor current ripple is given as

$$\Delta i_L = V_o\frac{(1-D)T}{L} = 2I_O$$

Thus, the load current is given by

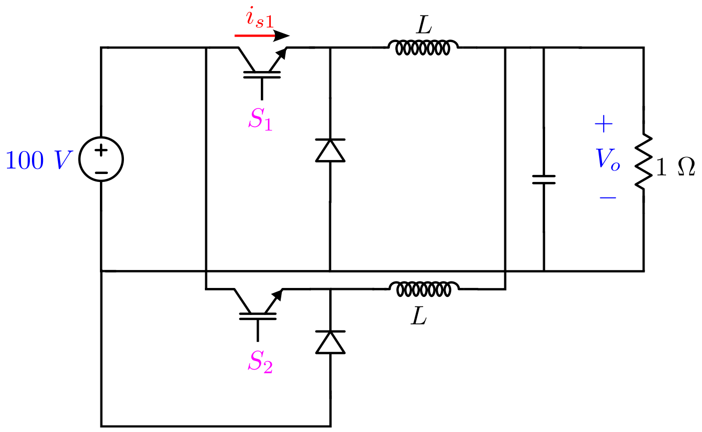
$$\frac{V_o}{R} = V_o\frac{(1-D)T}{2L}$$

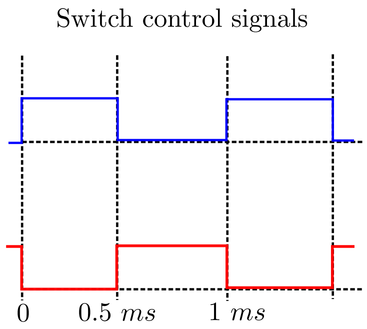
Thus, the value of the load resistance is given as

$$R = \frac{2L}{(1-D)T} = \frac{2Lf}{(1-D)} = 2500\ \Omega$$

Question 3: Numerical type

The figure shows two buck converters connected in parallel. The common input dc voltage for the converters has a value of 100 V. The converters have inductors of identical value. The load resistance is 1 Ω. The capacitor voltage has negligible ripple. Both converters operate in continuous conduction mode. The switching frequency is 1 kHz and the switch control signals are as shown. The circuit operates in steady state. Assuming that the converters share the load equally, the average value of the current of switch S_1, i_{s1}, (in Ampere) up to two decimal places _______________.





Solution: Answer range (12-13)

Two buck converters are connected in parallel. Thus, the output voltage, V_O, is given by

$$V_o = DV_{in} = 0.5 \times 100 = 50\ V$$

Thus, the load current can be calculated as

$$I_o = \frac{50}{1} = 50\ A$$

Now, power balance equation is given by

$$100 \times i_{s1} + 100 \times i_{s2} = V_o I_o$$

Where, i_{s2} is the average value of current flowing through switch S_2.

As the load is shared equally, we must have

$$i_{s1} = i_{s2}$$

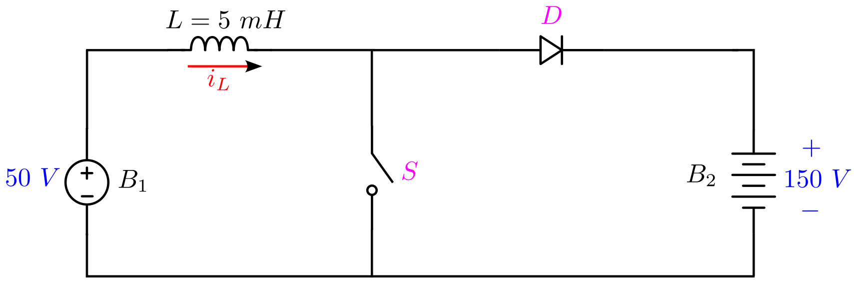
Thus, i_{s1} can be calculated as

$$2 \times 100 \times i_{s1} = V_o I_o$$

$$i_{s1} = \frac{V_o I_o}{2 \times 100} = \frac{50 \times 50}{2 \times 100} = 12.5\ A$$

Question 4: Numerical type

A dc-to-dc converter shown in the figure is charging a battery bank, B_2, whose voltage is constant at $150\,V$. B_1 is another battery bank whose voltage is constant at $50\,V$. The value of the inductor L is 5mH and the ideal switch S is operated with a switching frequency of 5 kHz with a duty ratio of 0.4. Once the circuit has reached steady state and assuming the diode D to be ideal, the power transferred from B_1 to B_2 (in Watt) is _______________ (up to 2 decimal places).



Solution: Answer range (11-13)

When the switch, S, is on, the voltage across the inductor is given as

$$v_L = 50 = L\frac{\Delta i_L}{DT}$$

During this period, the inductor current rises from its minimum value I_{min} to its maximum value I_{max}

Thus, the ripple inductor current can be calculated as

$$\Delta i_L = \frac{50}{L}DT = \frac{50}{5\times 10^{-3}} \times 0.4 \times \frac{1}{5\times 10^{3}} = 0.8\ A$$

Let us calculate the time, $t_{f,}$ for the inductor current to fall from I_{max} to I_{min}. The inductor current starts falling when the switch S is off. During this period, the voltage across the inductor is given as

$$v_L = 50 - 150 = -100 = -L\frac{\Delta i_L}{t_f}$$

Thus, t_f can be calculated as

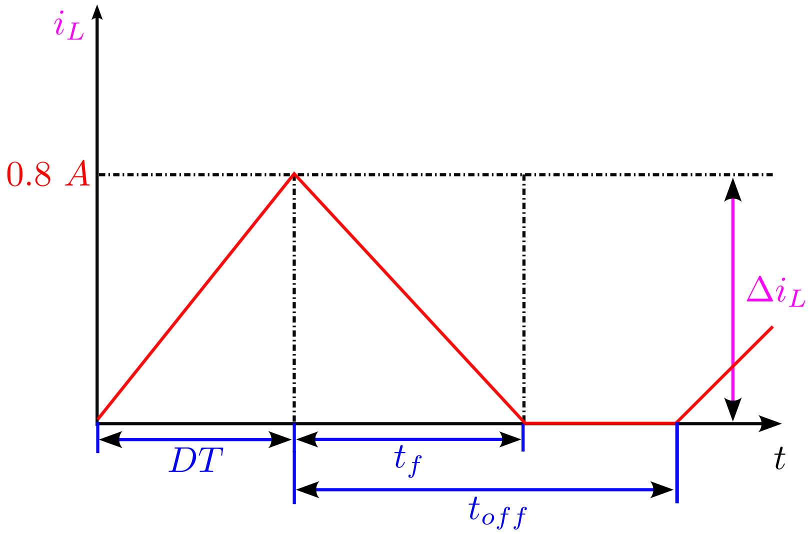
$$t_f = \frac{L\times \Delta i_L}{100} = 40\ \mu s$$

The off period of the switch S can be calculated as

$$t_{off} = (1-D)\frac{1}{f_{sw}} = 120\ \mu s$$

As $t_{off} > t_f$, the inductor current is discontinuous as shown in the figure below. Thus, the average value of the inductor current can be calculated as

$$I_L = \frac{1}{T}\times\left[\frac{1}{2}\times DT\times \Delta i_L + \frac{1}{2}\times t_f \times \Delta i_L\right] = 0.24\ A$$

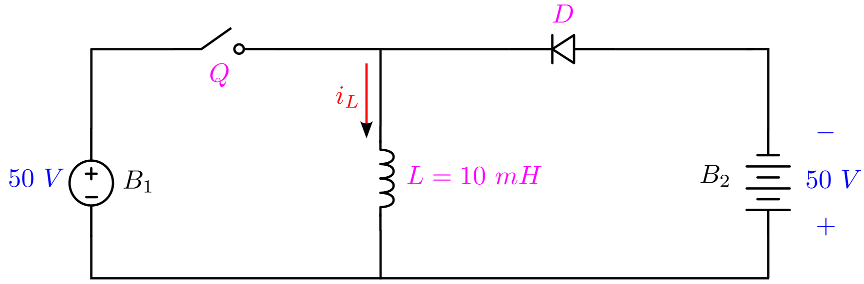


Thus, the power transferred from B_1 to B_2 is

$$P = I_L \times 50 = 12\,W$$

Question 5:

In the dc-dc converter shown in the figure below, the switch, Q, is switched at a frequency of 10 kHz with a duty ratio of 0.6. All the components of the circuit are ideal and the initial current in the inductor is 0 A. Energy stored in the inductor in mJ (rounded off to 2 decimal places) at the end of 10 complete switching cycles is ______________.



Solution: Answer range (4.95-5.05)

The initial current of the inductor, $I_{LO} = 0\ A$.

In the on period of the first cycle the increase in inductor current, Δi_{L1}, can be calculated as

$$\Delta i_{L1} = \frac{50}{L} \times t_{on} = \frac{50}{L} \times DT = 0.3\ A$$

In the off period of the first cycle the decrease in inductor current, $-\Delta i_{L2}$, can be calculated as

$$-\Delta i_{L2} = -\frac{50}{L} \times t_{off} = \frac{50}{L} \times (1 - D)T = -0.2\ A$$

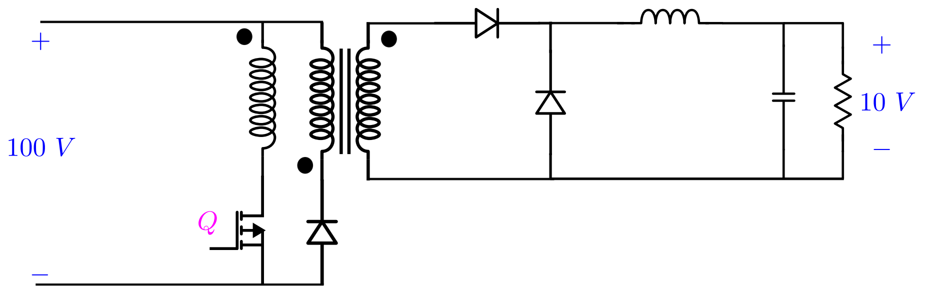
Thus, we can conclude that in every cycle during the ON period of switch Q the inductor current increases by 0.3 A and during the off period of switch the inductor current decreases by 0.2 A. Thus, net increase in the inductor current at the end of each cycle is 0.1 A. Thus, at the end of 10 complete switching cycles the inductor current increases by $10 \times 0.1\ A = 1\ A$. As the initial inductor current was 0 A. The inductor current at the end of 10 complete cycles is 1 A.

Thus, the energy stored in the inductor at the end of 10 complete cycles can be calculated as

$$E = \frac{1}{2} \times L \times i_L^2 = \frac{1}{2} \times 10 \times 10^{-3} \times 1 = 5\ mJ$$

Question 6

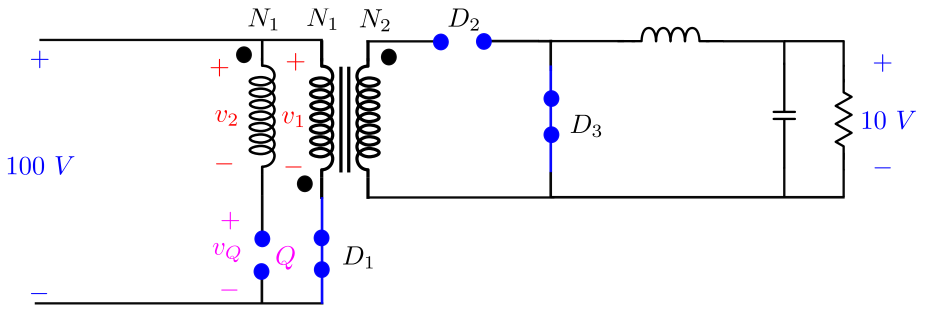
*In a forward converter supplying a 10 V load from 100 V unregulated source, a bifilar wound demagnetizing winding is used to reset the core flux. If the leakage inductance as seen from the primary side is negligible, then what is the voltage stress (in Volts) on the primary switch Q? [Assume all the switches to be ideal.]*________________.



Solution: Answer range (200-200)

As the demagnetizing winding is a bifilar wound winding it has the same number of turns as the primary winding.

To find the voltage stress across the switch Q we need to find the voltage across the switch when the switch is off and the core flux is being reset. The circuit therefore becomes as shown below



As switch Q is off and the diode D_1 is on, therefore

$$v_1 = 100\ V$$

Based on the dot polarity we can write

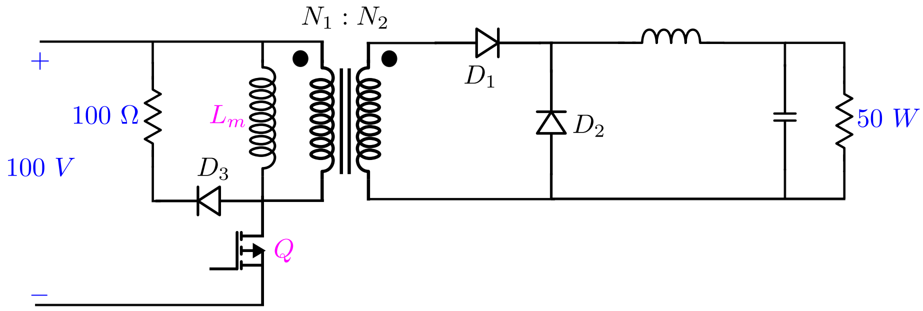
$$v_2 = -v_1 = -100\ V$$

Thus, the voltage across the switch Q is

$$v_Q = 100 - v_2 = 200\ V$$

Question 7:

A forward converter operates from an input voltage of 100V and supplies 50W load. The power semiconductor switch is operating at 20kHz and 50% duty cycle. The magnetizing inductance (L_m) of the forward converter is 5 mH. A diode and a resistor is used across the primary winding for free-wheeling action. The resistor in the free-wheeling circuit has a value of 100 Ω. The wattage rating of the resistor should be greater than what value?



Solution: Answer range (12-13)

When the switch Q is turned off, the diode D_3 is turned on and the energy in the magnetizing inductance is dissipated in the resistance 100 Ω. The magnetizing inductance stores energy during the on period of the switch. During the on period of the switch Q the voltage across the magnetizing inductance can be written as

$$v_L = 100 = L_m \frac{I_{m,pk}}{t_{on}} = L_m \frac{I_{m,pk}}{DT}$$

Where, $I_{m,pk}$ is the peak value of the magnetizing current flowing through the magnetizing inductance L_m.

$$I_{m,pk} = \frac{100 \times D \times T}{L_m} = 0.5\ A$$

Thus, the energy stored in the magnetizing inductance can now be calculated as

$$E = \frac{1}{2} \times L_m \times {I_{m,pk}}^2 = 0.625\ mJ$$

Thus, the power that needs to be dissipated per cycle can be calculated as

$$P_{dis} = E \times f_{sw} = 12.5\ W$$

Question 8:

For a circuit realization of DC-DC converters which of the following rules are to be followed:

1. *Current source should not be open circuited*
2. *Voltage source should not be short circuited*
3. *Inductor currents should not be interrupted*
4. *Capacitor voltages should not be shorted*

(a) *Only 1 and 2*
(b) *Only 3 and 4*
(c) *Only 1,2 and 4*
(d) *All are true*

Solution: Correct option is (d)

Question 9:

A dc-to-dc chopper supplied from a fixed DC voltage source feeds a fixed resistive-inductive load. The chopper operates at 1kHz and 50% duty cycle. Without changing the value of the average DC current through the load, if it is desired to reduce the ripple of the load current, the control action needed will be

(a) Increase the chopper frequency keeping the duty cycle constant
(b) Increase the chopper frequency and duty cycle in equal ratio
(c) Decrease only the chopper frequency
(d) Decrease only the duty cycle

Solution: Correct option is (a)

The average load current can be expressed as

$$I_o = \frac{DV_{in}}{R}$$

So, if we want to keep the load current constant the duty ratio, D, must be kept constant.

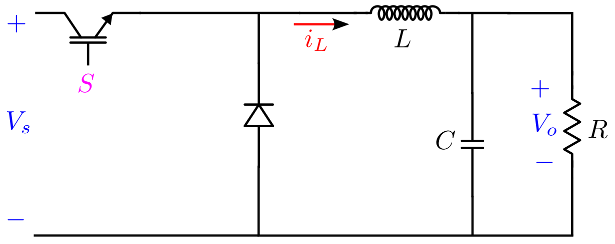
The expression for current ripple can be derived from transient analysis as

$$\Delta i_L \approx \frac{V_{in}}{4fL}$$

Thus, by increasing frequency current ripple can be reduced.

Question 10:

In the buck converter circuit shown in the figure below the input DC voltage has a constant value V_s. The output voltage V_o is assumed to be ripple free. The switch S is operated with a switching time period T and duty ratio D. What is the value of D at the boundary of continuous and discontinuous conduction of inductor current i_L.



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

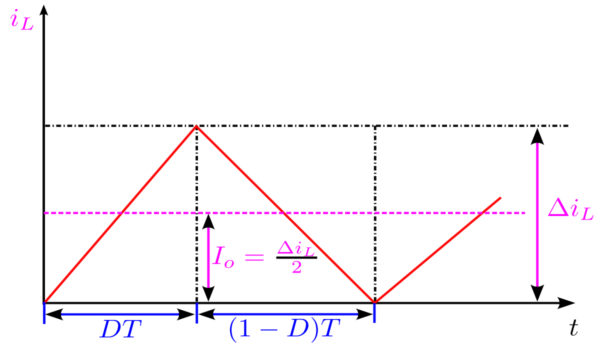
(b) $D = \frac{2L}{RT}$

(c) $D = 1 - \frac{2L}{RT}$

(d) $D = \frac{RT}{L}$

Solution: Correct option is (c)

The waveform of the inductor current, i_L will be as shown below



When the switch Q is off, the voltage across the inductor is given as

$$v_L = -L\frac{\Delta i_L}{(1-D)T} = -V_o$$

Thus, the inductor current ripple is given as

$$\Delta i_L = V_o\frac{(1-D)T}{L} = 2I_o$$

Thus, the load current is given by

$$\frac{V_o}{R} = V_o\frac{(1-D)T}{2L}$$

Thus, we have

$$D = 1 - \frac{2L}{RT}$$