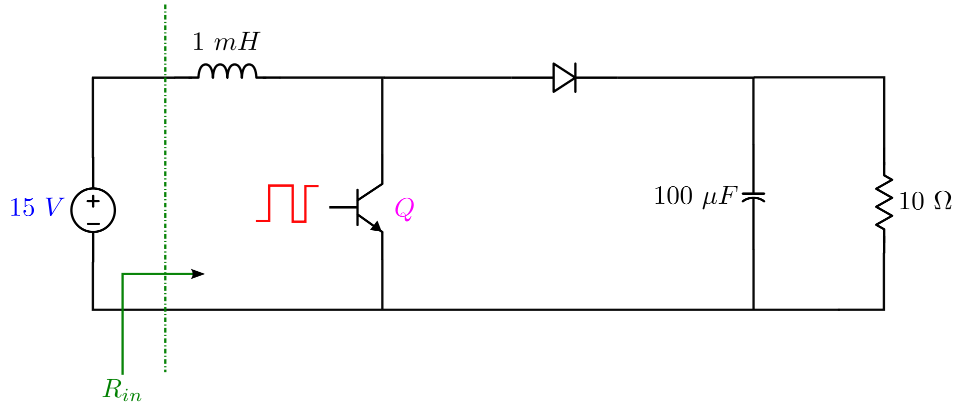
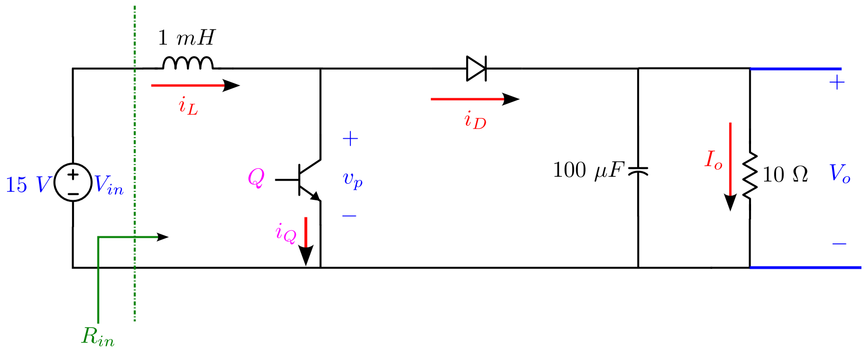
Question 1: Numerical type

Consider a boost converter shown in the circuit schematic. Switch Q is operating at 25 kHz with a duty cycle of 0.6. Assume the diode and switch to be ideal. Under steady-state conditions, the average resistance, R_{in}, as seen by the source is ___________ Ω. (Round off to two decimal places)



Solution: Answer Range (1.55 - 1.65)



The output voltage of the boost converter can be calculated as

$$V_o = \frac{1}{1-D} \times V_{in} = \frac{15}{1-0.6} = 37.5\ V$$

Thus, the load current, I_o, is

$$I_o = \frac{V_o}{10} = 3.75\ V$$

By small ripple approximation we can derive

$$I_o = (1-D)I_L$$

Where, I_L is the average value of the inductor current, i_L. Thus, we can calculate I_L as

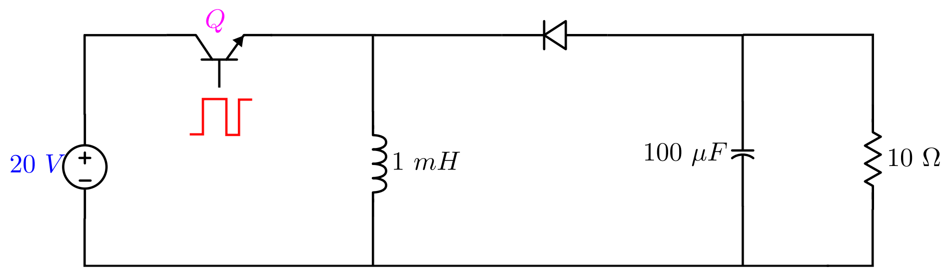
$$I_L = \frac{I_o}{(1-D)} = 9.375\ A$$

I_L is the average current as seen by the source V_{in}. Thus, the average value of resistance as seen by the source is

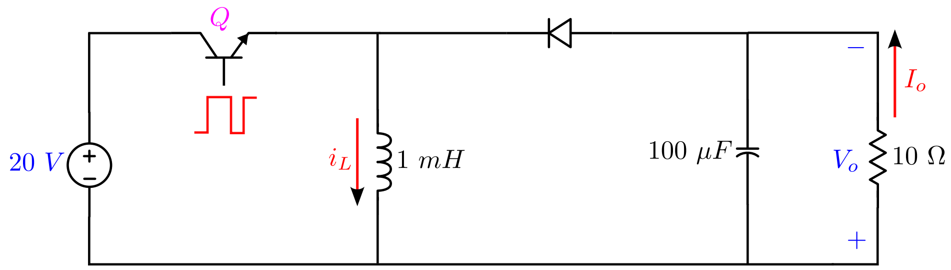
$$R_{in} = \frac{V_{in}}{I_L} = 1.6\ \Omega$$

Question 2: Numerical type

Consider the buck-boost converter as shown in the circuit schematic below. Switch Q is operating at 25 kHz and 0.75 duty-cycle. Assume diode and switch to be ideal. Under steady-state conditions, the average current flowing through the inductor is ____________ A.



Solution: Answer range (24-24)



The output voltage of a buck-boost converter is given by

$$V_o = \frac{D}{1-D} V_{in} = \frac{0.75}{1-0.75} \times 20 = 60\ V$$

The output current, I_o, can then be calculated as

$$I_o = \frac{V_o}{10} = 6\ A$$

Now, by small ripple approximation we can write

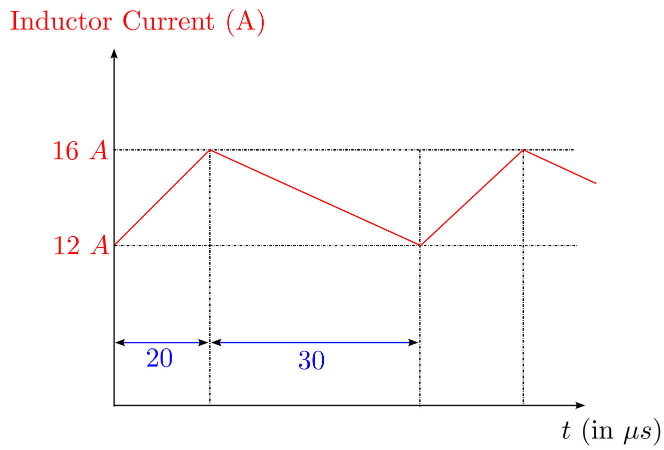
$$I_o = (1-D) I_L$$

Where, I_L is the average value of the inductor current i_L. Thus, we can calculate the average value of the inductor current as

$$I_L = \frac{I_o}{(1-D)} = 24\ A$$

Question 3: Numerical type

The steady-state current flowing through the inductor of a DC-DC buck-boost converter is shown below. If the peak-to-peak ripple in output voltage of converter is 1 V, then the value of the output capacitor, in μF, is _______________ (round off to nearest integer).



Solution: Answer range (167-169)

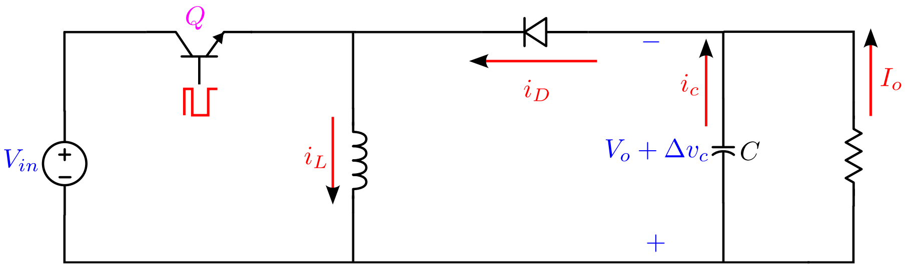


Fig. a

The waveform of the inductor current, i_L, diode current, i_D, and capacitor ripple current, i_c are shown in the Fig . b.

The average value of i_D is the load current I_o and is indicated by a dotted blue line in the Fig . b. Thus, we can calculate I_o as

$$I_o = \frac{1}{50}\left(12 \times 30 + \frac{1}{2} \times 30 \times 4\right) = 8.4\ A$$

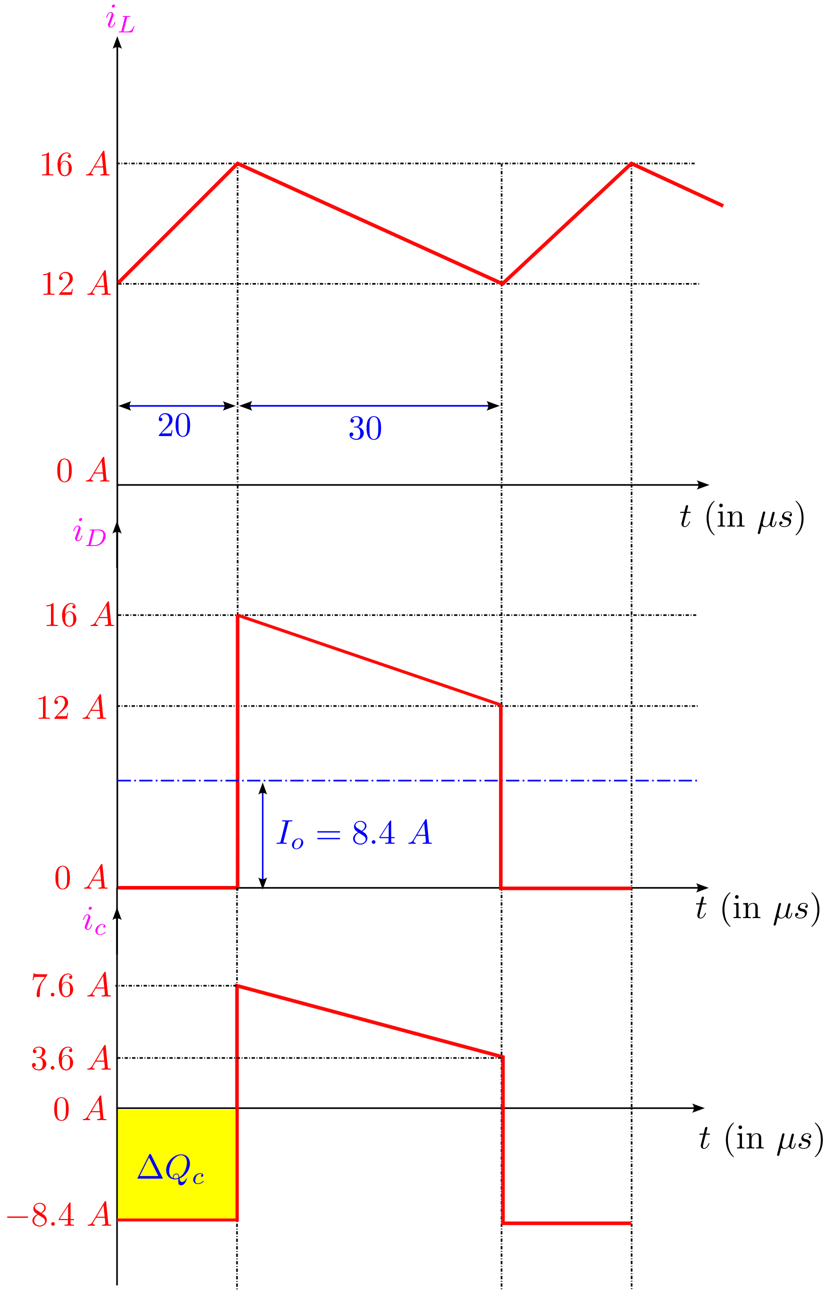
The ripple current flowing through the capacitor can be obtained by subtracting the load current I_o from the diode current as shown in Fig. b. (Since net charge stored in the capacitor over a cycle is 0 Columb, or in other words, average current through the capacitor is 0 A). The charge stored in the capacitor (ΔQ_c) during the on time of the switch is indicated by the shaded yellow area in Fig . b.

We can determine (ΔQ_c) as

$$\Delta Q_C = C(\Delta v_c) = 8.4 \times 20\ \mu C$$

Thus, output capacitor filter requirement is

$$C = \frac{8.4 \times 20}{\Delta v_c} = 168\ \mu F$$

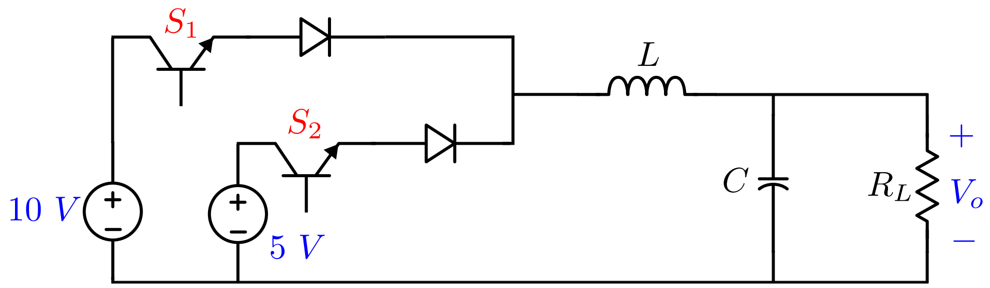


i_L
16 A
12 A
20
30
0 A
t (in μs)
i_D
16 A
12 A
$I_o = 8.4\ A$
0 A
t (in μs)
i_c
7.6 A
3.6 A
0 A
t (in μs)
ΔQ_c
$-8.4\ A$

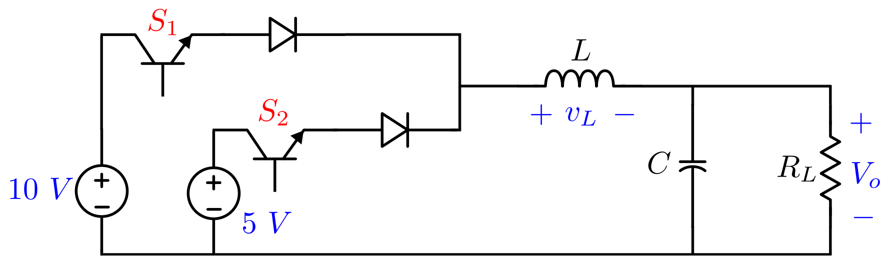
Fig. b

Question 4: Numerical type

The circuit shown in the figure is meant to supply a resistive load R_L from two separate DC voltage sources. The switches S_1 and S_2 are controlled so that only one of them is ON at any instant. S_1 is turned on for 0.2 ms and S_2 is turned on for 0.3 ms in a 0.5ms switching cycle time period. Assuming continuous conduction of the inductor current and negligible ripple on the capacitor voltage, the output voltage V_o (in volts) across R_L is ___________.



Solution: Answer range (6.99 - 7)



During $0 < t < 0.2\ ms$, the switch S_1 is on. Thus, the voltage across the inductor during this period is

$$v_L = 10 - V_o$$

During $0.2\ ms < t < 0.5\ ms$, the switch S_2 is on. Thus, the voltage across the inductor during this period is

$$v_L = 5 - V_o$$

Now, applying volt-sec balance across the inductor we can write

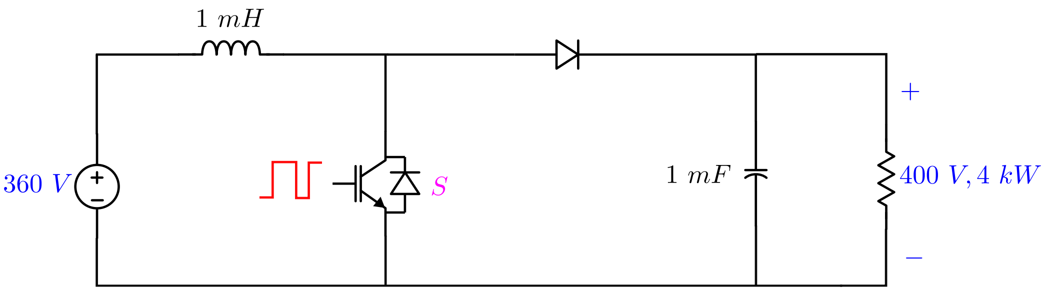
$$(10 - V_o) \times 0.2 + (5 - V_o) \times 0.3 = 0$$

Solving the above equation, we get

$$V_o = 7\ V$$

Question 5: Numerical type

A DC-DC boost converter as shown in the figure below is used to boost 360 V to 400 V at a power of 4kW. All devices are ideal considering continuous inductor current, the rms current in the solid-state switch (S), (in Amperes) is _______________. (Neglect the ripple in Inductor Current)



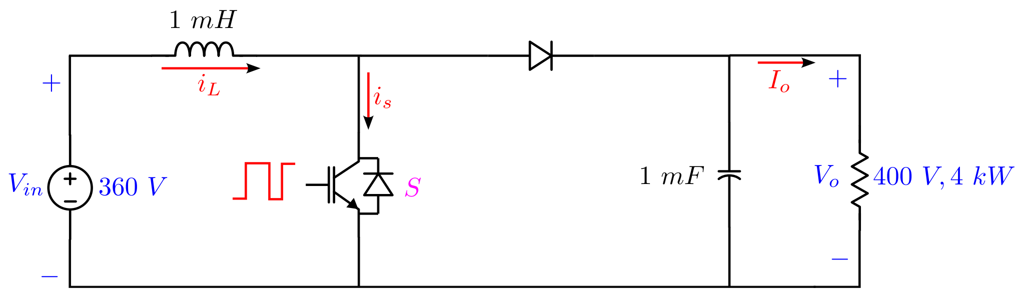
Solution: Answer range (3.0 – 4.0)

The output power is given as

$$P_o = V_o I_o = 4 \times 10^3\ W$$

From the input and output voltages of the boost converter we can calculate the duty ratio, D, as

$$D = 1 - \frac{V_{in}}{V_o} = 0.1$$



The average value of the load current can then be calculated as

$$I_o = \frac{P_o}{V_o} = \frac{4 \times 10^3}{4 \times 10^2} = 10\ A$$

Now, as the semiconductor switches are considered ideal, we can neglect the losses in these devices. Thus, we can equate the input power to output power as shown below

$$P_{in} = P_o = 4 \times 10^3\ W$$

The average value of inductor current can be written as

$$I_L = \langle i_L \rangle_{avg} = \frac{P_{in}}{V_{in}} = 11.11\ A$$

The rms value of the current flowing through the switch 'S' can be calculated as follows

$I_{s,rms} = \sqrt{D}\ I_L = 3.51\ A$ **(Neglecting Ripple in Inductor current. You can draw the waveform for the switch current and then calculate rms value and you will get the same expression)**

Question 6:

A chopper is employed to charge a battery as shown in the figure below. The charging current is 5 *A*. *The duty ratio is* 0.2. *The chopper output voltage is also shown in figure. The peak-to-peak ripple current in the charging current is*

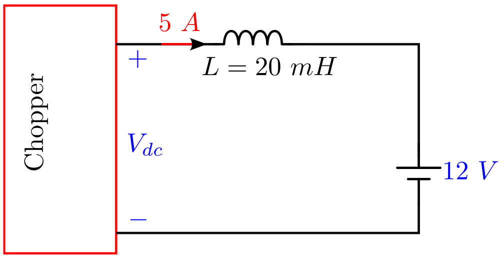


Fig. (a)

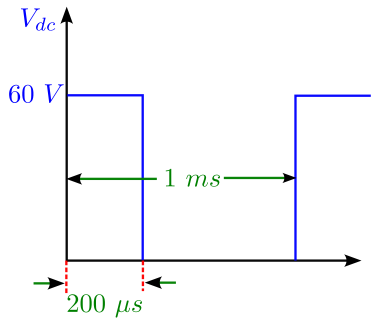


Fig. (b)

(a) 0.48 A
(b) 1.2 A
(c) 0.24 A
(d) 0.96 A

Solution: Correct option is (a)

For the time interval $0 < t < 200\ \mu s$, the voltage across the inductor can be calculated as

$$v_L = 60 - 12 = L\frac{\Delta i_L}{\Delta t}$$

Therefore, the ripple current can be calculated as

$$\Delta i_L = \frac{48}{L} \times \Delta t = \frac{48}{20 \times 10^{-3}} \times 200 \times 10^{-6} = 0.48\ A$$

Question 7:

A step-down chopper operates from a dc voltage source, V_s, feeds a dc motor armature with a back emf of E_b. From oscilloscope traces, it is found that the armature current increases for time, t_r, falls to zero over the time, t_f, and remains zero for the time, t_o, in every chopping cycle, then the average dc voltage across the freewheeling diode is: [Assume Diode forward drop to be 0V]

(a) $\frac{V_s t_r}{t_r+t_f+t_o}$

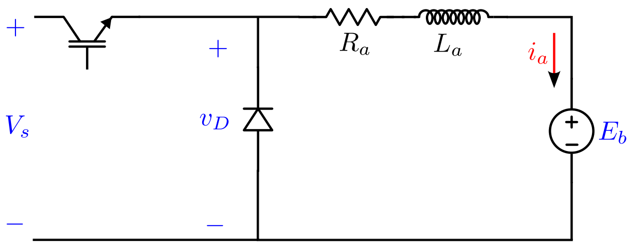
(b) $\frac{V_s t_r+E_b t_f}{t_r+t_f+t_o}$

(c) $\frac{V_s t_r+E_b t_o}{t_r+t_f+t_o}$

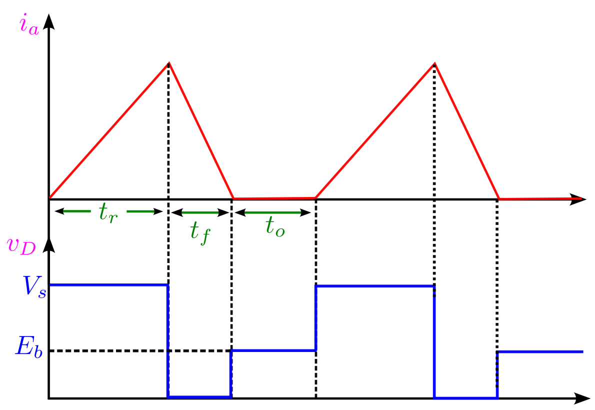
(d) $\frac{V_s t_r+E_b(t_f+t_o)}{t_r+t_f+t_o}$

Solution: Correct option is (c)

A dc motor armature is excited from a step-down chopper. The equivalent circuit is shown in the schematic below



The waveforms of the armature current, i_a, and the diode voltage, v_D, is shown in the figure below:



The average value of voltage across the diode can be calculated from the waveform of v_D as

$$V_D = \langle v_D \rangle_T = \frac{V_s t_r + E_b t_o}{t_r + t_f + t_o}$$

Question 8: Numerical type

The semiconductor switch shown in the Fig. (a) is operated at a frequency of 20 kHz and duty ratio of 0.5. The circuit operates in steady state, $V_1 = 100\ V$ and $V_2 = 275\ V$. The diagram of inductor current I_L is shown in Fig. (b). The value of βT is _______ μs.

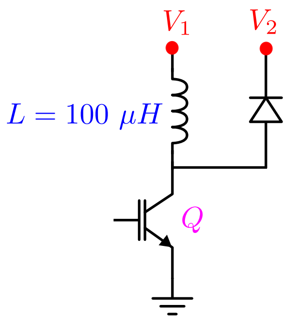


Fig. (a)

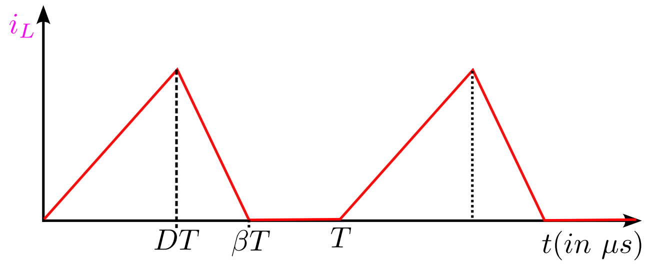
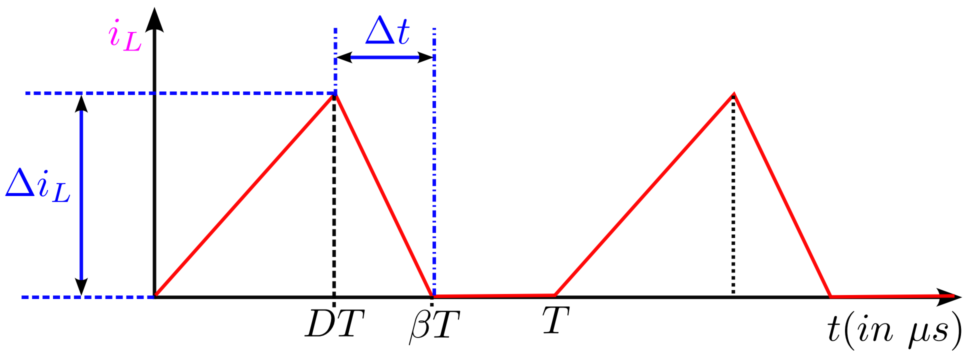


Fig. (b)

Solution: Answer range (38 - 40)



When the switch Q is on the voltage across the inductor can be written as

$$v_L = V_1 = 100 = L \times \frac{\Delta i_L}{DT}$$

Thus, the ripple current in the inductor, Δi_L, can be evaluated as

$$\Delta i_L = \frac{100}{L} \times DT = 25\ A$$

Now, as the switch Q turns off, the diode starts conducting and the voltage across the inductor becomes

$$v_L = V_1 - V_2 = -175 = -L \times \frac{\Delta i_L}{\Delta t}$$

Negative sign is taken as the slope is negative. Now, Δt can be calculated as

$$\Delta t = \frac{L\ \times \Delta i_L}{175} = 14.29\ \mu s$$

Now, we have

$$\beta T = \Delta t + DT = 39.28\ \mu s$$

Question 9: Numerical type

In continuation with previous question, if $V_2 = 300\ V$, what is the power transferred (in Watts) from the dc voltage source V_1 to dc voltage source V_2. Assume the controlled and uncontrolled switches to be ideal.

Solution: Answer range (936-938)

In the previous question we have found that

$$\Delta i_L = \frac{100}{L} \times DT = 25\ A$$

Now, when the switch Q is turned off,

$$v_L = V_1 - V_2 = -200 = -L \times \frac{\Delta i_L}{\Delta t}$$

Thus, Δt can be calculated as

$$\Delta t = \frac{L\ \times \Delta i_L}{200} = 12.5\ \mu s$$

The switch is switched at 20 kHz. Thus, the time-period (T) can be calculated as

$$T = \frac{1}{20 \times 10^3} = 50\ \mu s$$

Thus, the average value of the inductor current can be calculated as

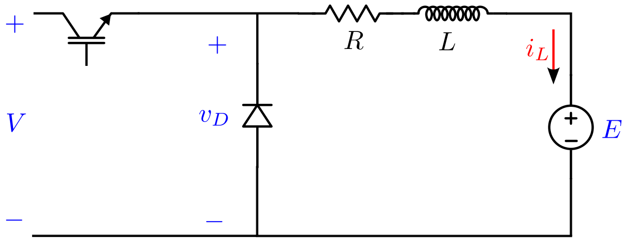
$$I_L = \langle i_L \rangle_{avg} = \frac{1}{50}\left(\frac{1}{2} \times (DT + \Delta t) \times \Delta i_L\right) = 9.375\ A$$

Thus, power transferred from voltage source V_1 to V_2 can be calculated as

$$P = I_L \times V_1 = 9.375\ \times 100 = 937.5\ W$$

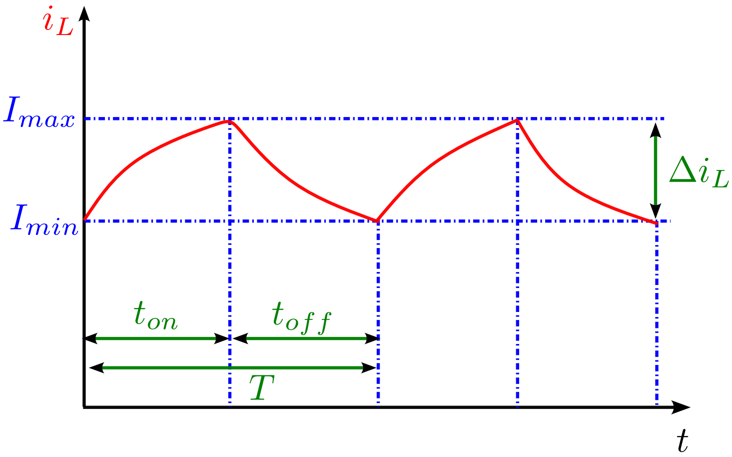
Question 10:

A DC chopper feeds an RLE load as shown in the figure below. The value of E is increased by 20%, the current ripple



- *(a) Increases by 20%*
- *(b) Decreases by 20%*
- *(c) Increases by 10%*
- *(d) Remains same*

Solution: Correct option is (d)



The expression for I_{max} can be derived as

$$I_{max} = \frac{V}{R}\left[\frac{1 - e^{-t_{on}/t_a}}{1 - e^{-T/t_a}}\right] - \frac{E}{R}$$

Where $t_a = \frac{L}{R}$ is the time constant of the circuit.

The expression for I_{max} can be derived as

$$I_{min} = \frac{V}{R}\left[\frac{e^{t_{on}/t_a} - 1}{e^{T/t_a} - 1}\right] - \frac{E}{R}$$

Thus, the inductor current ripple can be calculated as

$$\Delta i_L = I_{max} - I_{min} = \frac{V}{R}\left[\frac{1 - e^{-\frac{t_{on}}{t_a}}}{1 - e^{-\frac{T}{t_a}}}\right] - \frac{V}{R}\left[\frac{e^{\frac{t_{on}}{t_a}} - 1}{e^{\frac{T}{t_a}} - 1}\right]$$

Thus, the ripple current is independent of 'E'.

[Hint for Derivation: For T_{ON} and T_{OFF} draw the 2 circuits. First consider the T_{ON} circuit (which is an RL circuit with 2 sources V and E), solve for i_L, with initial condition as I_{min}. In the expression

obtained for i_L substitute $t=t_a$ to obtain I_{max}. Then consider the T_{OFF} circuit (which is an RL circuit with just E as source. Ignore diode drop), solve for i_L, with initial condition as I_{max}. In the expression obtained for i_L, substitute $t=T$ to obtain I_{min}. Then you can solve for I_{max} and I_{min}.]