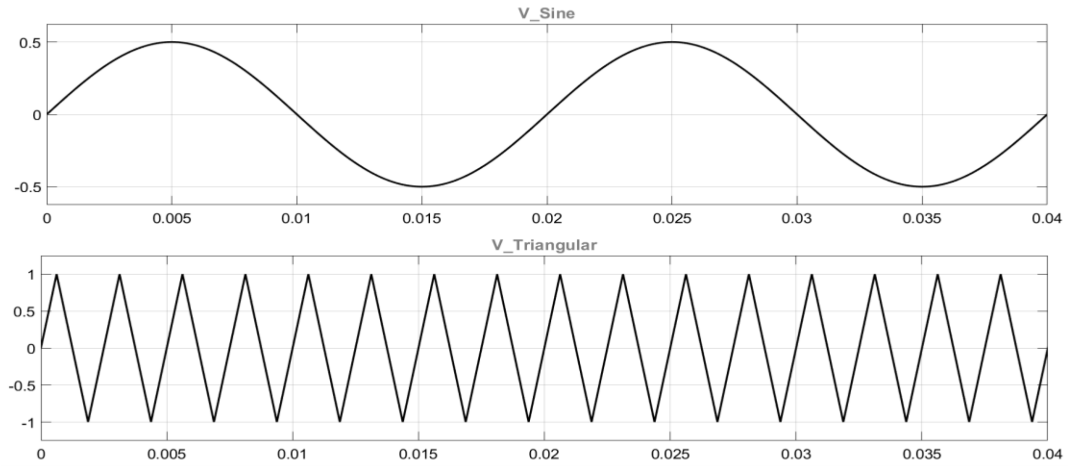
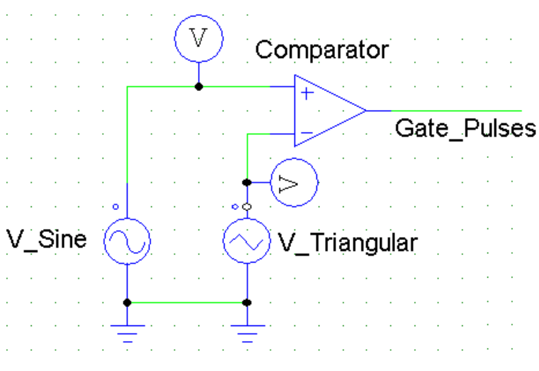
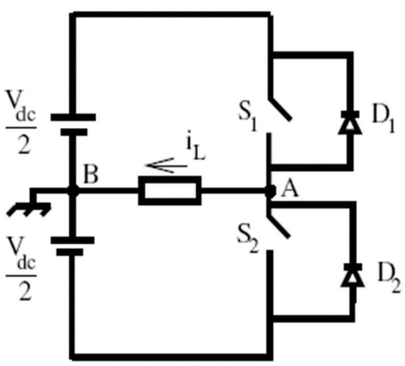
# EE103 Tutorial 2: Energy Systems

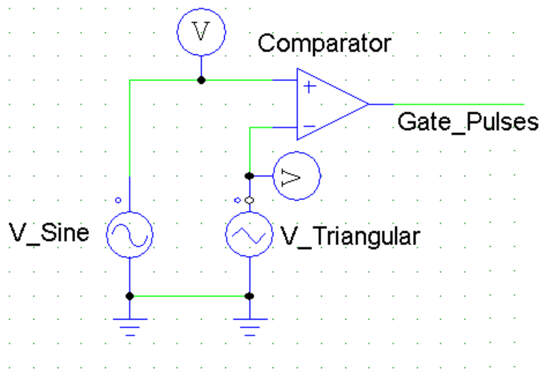
1. A Buck converter is operating with input voltage 30 V and output voltage 12 V. A 2.4Ω resistor is connected across the output terminals. The inductor value is 360µH and switching frequency is 10 kHz also assume the output voltage to be constant and circuit has reached steady state.
    a. Calculate the required Duty Cycle.
    b. Draw the inductor current waveform.(mark the relevant points on the waveform)
    c. Now assume that the load resistor is replaced with another resistor of value 12 Ω. Draw the inductor current waveform for this case. (mark the relevant points on the waveform)
    d. If we further increase the load resistance beyond 12 Ω, comment what would happen.
2. A Boost converter is operating with input voltage 12 V and output voltage 24 V. A 12 Ω resistor is connected across the output terminals. The inductor value is 300 µH and switching frequency is 10 kHz also assume the output voltage to be constant and circuit has reached steady state.
    a. Calculate the required Duty Cycle.
    b. Draw the inductor current waveform.(mark the relevant points on the waveform)
    c. Now assume that the load resistor is replaced with another resistor of value 48 Ω. Draw the inductor current waveform for this case. (mark the relevant points on the waveform)
    d. If we further increase the load resistance beyond 48 Ω, comment what would happen.
3. Draw the output $V_{AB}$ for the given circuit, which is shown below, given the wave forms of V_Sine and V_Triangular are as follows. Given that $V_{dc}$=200V and Gate_Pulses signal is given to $S_1$. (mark the relevant points on the waveform)



4. A single-phase induction motor is being fed by an inverter which is implementing V/F control. Assuming the motor runs at its rated speed when the reference sine wave has an amplitude of 0.9 and frequency 50Hz. Draw the output waveform of the inverter when the motor is running at half its rated speed. Assume the V_Triangular signal has the amplitude of 1 and frequency of 500Hz.(mark the relevant points on the waveform)




5. A Boost converter is operating with input voltage of 10 V and output voltage of 20 V. The value of the inductor is 500 μH and switching frequency is 10 kHz. A 10 ohm resistor is connected across the output terminals. Assume that the output voltage is constant.

(a) Determine the average current through the inductor, and peak-to-peak value of the inductor current.

(b) For what value of load resistance, does the minimum value of inductor current becomes zero (current is just continuous)?

(c) If the switching frequency is increased to 50 kHz, what is the peak-to-peak value of the inductor current? What conclusions can you make based on the results as compared to 10 kHz switching frequency?

1. A Buck converter is operating with input voltage 30 V and output voltage 12 V. A 2.4Ω resistor is connected across the output terminals. The inductor value is 360µH and switching frequency is 10 kHz also assume the output voltage to be constant.
   a. Calculate the required Duty Cycle.

$$V_o = DV_{DC}$$
$$D = \frac{12}{30} = 0.4$$

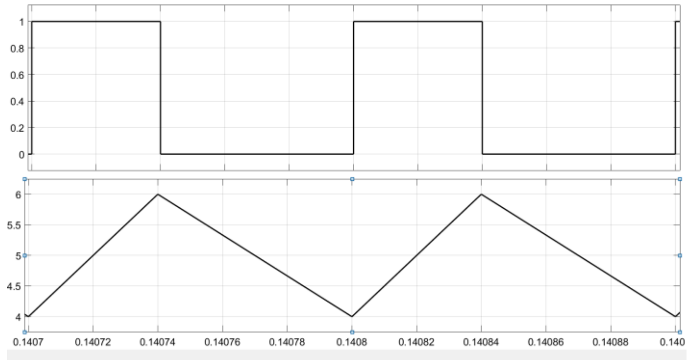
   b. Draw the inductor current waveform.(mark the relevant points of the waveform)

$I_L$ average $= I_{LOAD} = 12/2.4 = 5A$

When S is off Voltage across inductor is $V_o$

$$V_L = V_o = L\frac{di}{dt} = L\frac{\Delta i}{(1-D)\,T_s} \Rightarrow \Delta i = \frac{12 * 0.6 * 10^{-4}}{360 * 10^{-6}} = 2A$$

$$i_{Lmax} = I_{Lavg} + \frac{\Delta i}{2} = 5 + 1 = 6A \qquad i_{Lmin} = I_{Lavg} - \frac{\Delta i}{2} = 5 - 1 = 4A$$



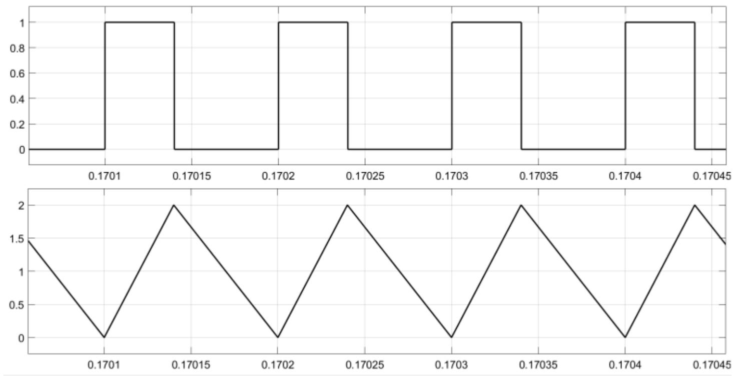

   c. Now assume that the load resistor is replaced with another resistor of value 12Ω. Draw the inductor current waveform for this case. (mark the relevant points of the waveform)

$I_L$ average $= I_{LOAD} = 12/12 = 1A$

When S is off Voltage across inductor is $V_o$

$$V_L = V_o = L\frac{di}{dt} = L\frac{\Delta i}{(1-D)\,T_s} \Rightarrow \Delta i = \frac{12 * 0.6 * 10^{-4}}{360 * 10^{-6}} = 2A$$

$$i_{Lmax} = I_{Lavg} + \frac{\Delta i}{2} = 1 + 1 = 2A \qquad i_{Lmin} = I_{Lavg} - \frac{\Delta i}{2} = 1 - 1 = 0A$$



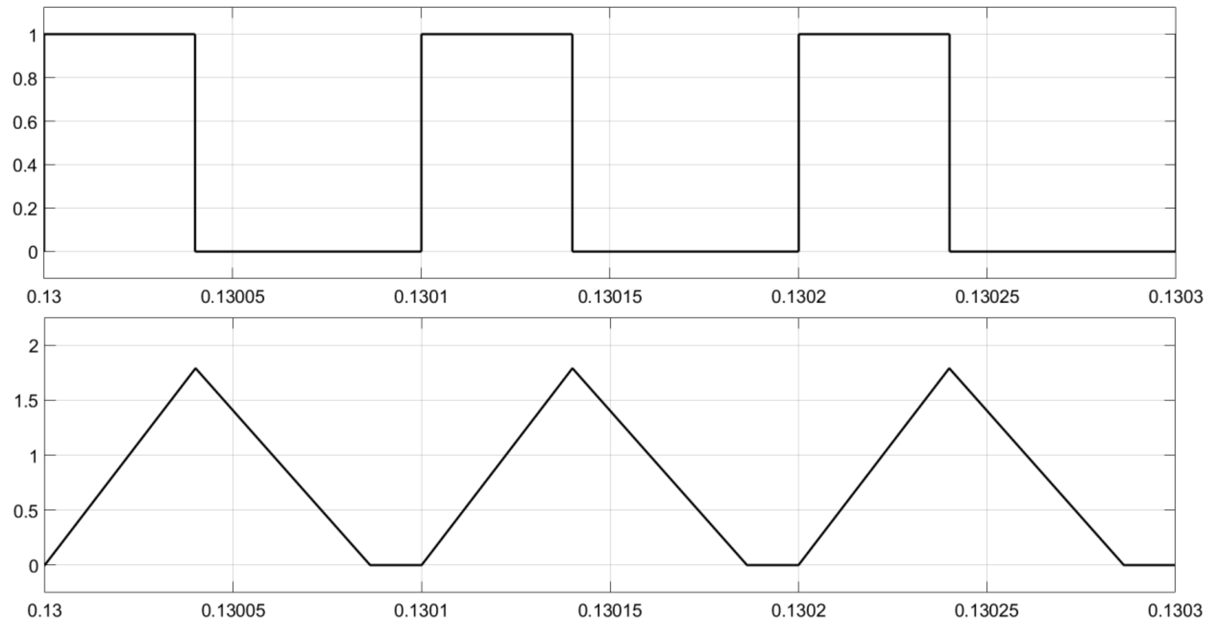
d. If we further increase the load resistance beyond 12 Ω, comment what would happen.
When we further try to reduce the load (increase resistance) the $i_{Lmin}$ current will become negative. Which is not possible hence the inductor will go into Dis-continuous mode of operation as shown below.

$I_L$ average $=I_{LOAD}=12/18=0.66A$

When S is off Voltage across inductor is $V_o$

$$V_L = V_o = L\frac{di}{dt} = L\frac{\Delta i}{(1-D)\,T_s} \Rightarrow \Delta i = \frac{12 * 0.6 * 10^{-4}}{360 * 10^{-6}} = 2A$$

$$i_{Lmax} = I_{Lavg} + \frac{\Delta i}{2} = 0.66 + 1 = 1.66A \qquad i_{Lmin} = I_{Lavg} - \frac{\Delta i}{2} = 0.66 - 1 = -0.34A$$



2. A Boost converter is operating with input voltage 12 V and output voltage 24 V. A 12Ω resistor is connected across the output terminals. The inductor value is 300μH and switching frequency is 10 kHz also assume the output voltage to be constant.
   a. Calculate the required Duty Cycle.

$$V_o = \frac{1}{1-D} V_{IN}$$

$$1 - D = \frac{12}{24} = 0.5 \Rightarrow D = 0.5$$

   b. Draw the inductor current waveform.(mark the relevant points of the waveform)

$$V_{IN}I_{IN}=V_oI_o=V_o^2/R=24^2/12=48W$$

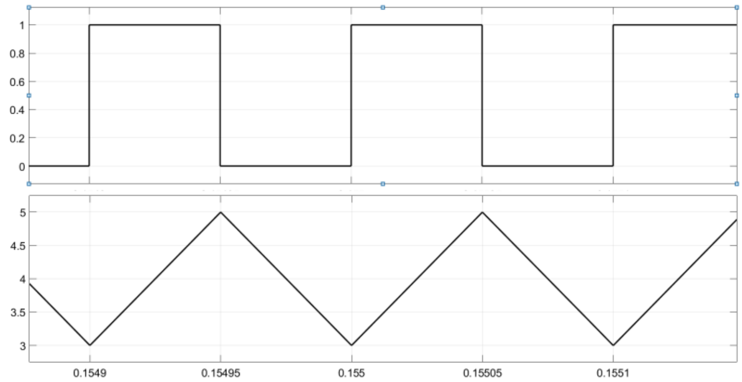
$$I_{IN}=48/12=4A$$

$$I_L \text{ average } =I_{IN}=4A$$

When S is ON Voltage across inductor is $V_{IN}$

$$V_L = V_{IN} = L\frac{di}{dt} = L\frac{\Delta i}{D\,T_s} \Rightarrow \Delta i = \frac{12 * 0.5 * 10^{-4}}{300 * 10^{-6}} = 2A$$

$$i_{Lmax} = I_{Lavg} + \frac{\Delta i}{2} = 4 + 1 = 5A \qquad i_{Lmin} = I_{Lavg} - \frac{\Delta i}{2} = 4 - 1 = 3A$$




   c. Now assume that the load resistor is replaced with another resistor of value 48Ω. Draw the inductor current waveform for this case. (mark the relevant points of the waveform)

$$V_{IN}I_{IN}=V_oI_o=V_o^2/R=24^2/48=12W$$

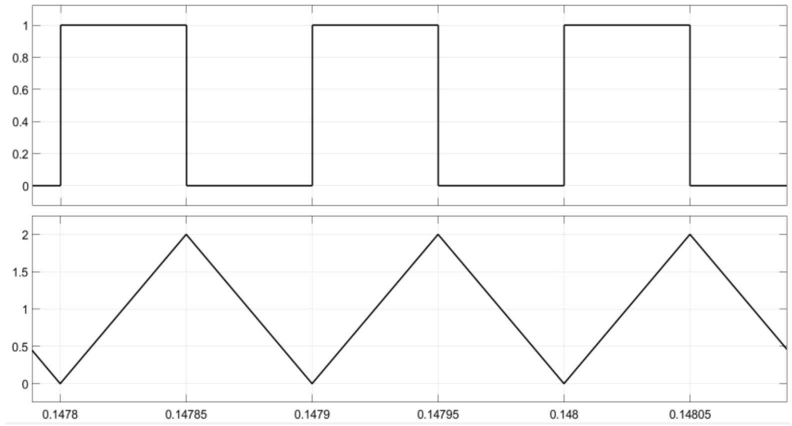
$$I_{IN}=12/12=1A$$

$$I_L \text{ average } =I_{IN}=1A$$

When S is ON Voltage across inductor is $V_{IN}$

$$V_L = V_{IN} = L\frac{di}{dt} = L\frac{\Delta i}{D\,T_s} \Rightarrow \Delta i = \frac{12 * 0.5 * 10^{-4}}{300 * 10^{-6}} = 2A$$

$$i_{Lmax} = I_{Lavg} + \frac{\Delta i}{2} = 1 + 1 = 2A \qquad i_{Lmin} = I_{Lavg} - \frac{\Delta i}{2} = 1 - 1 = 0A$$




d. If we further increase the load resistance beyond 12 Ω, comment what would happen.
When we further try to reduce the load (increase resistance) the $i_{Lmin}$ current will become negative. Which is not possible hence the inductor will go into Dis-continuous mode of operation as shown below.

$$V_{IN}I_{IN}=V_oI_o=V_o^2/R=24^2/60=9.6W$$

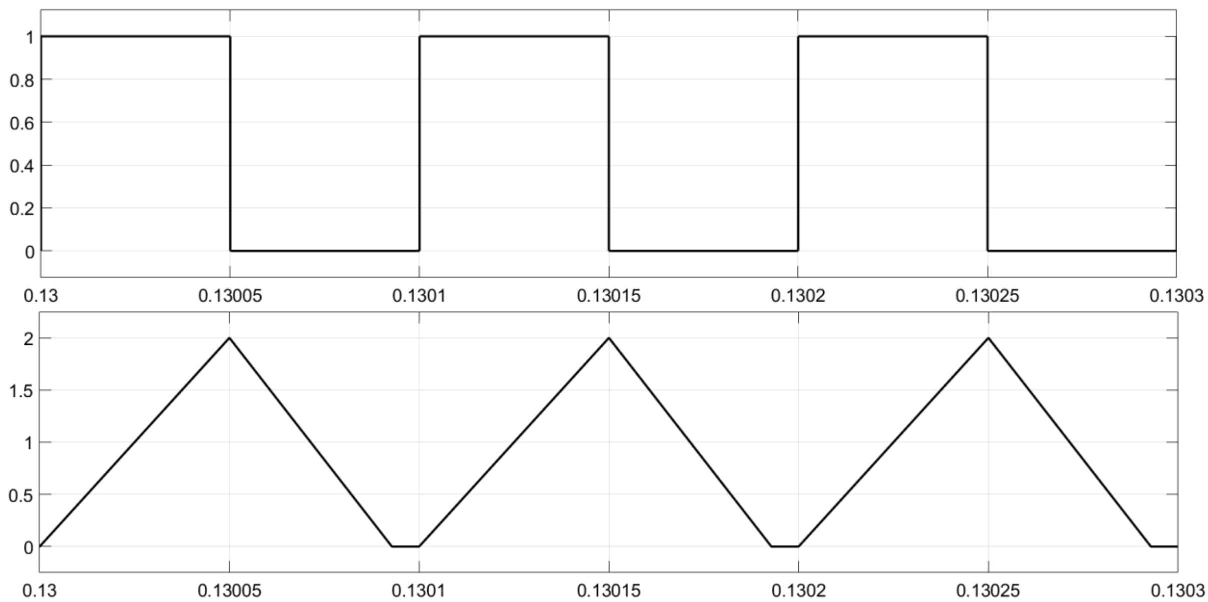
$$I_{IN}=9.6/12=0.8A$$

$$I_L \text{ average} = I_{IN}=0.8A$$

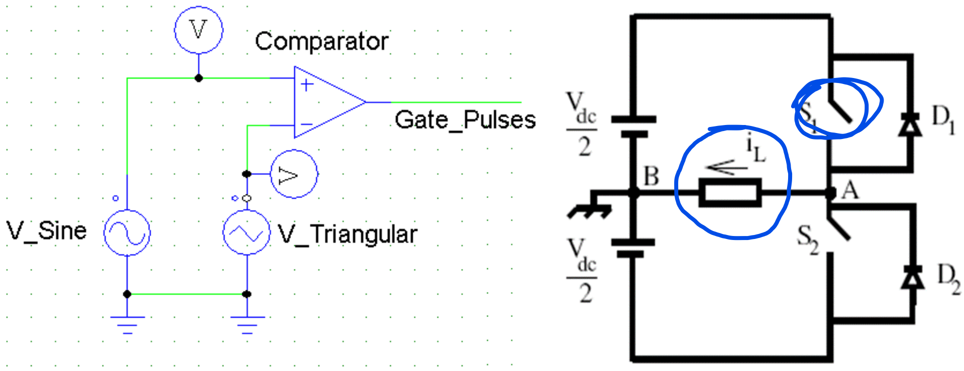
When S is ON Voltage across inductor is $V_{IN}$

$$V_L = V_{IN} = L\frac{di}{dt} = L\frac{\Delta i}{D\,T_s} \Rightarrow \Delta i = \frac{12 * 0.5 * 10^{-4}}{300 * 10^{-6}} = 2A$$

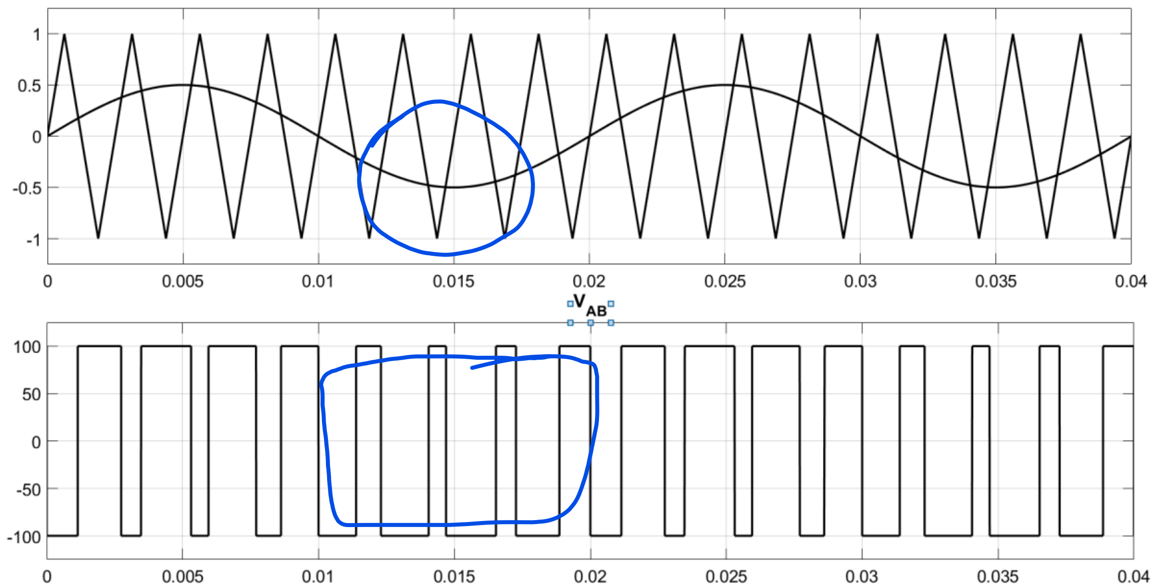
$$i_{Lmax} = I_{Lavg} + \frac{\Delta i}{2} = 0.8 + 1 = 1.8A \qquad i_{Lmin} = I_{Lavg} - \frac{\Delta i}{2} = 0.8 - 1 = -0.2A$$



3. Draw the output $V_{AB}$ for the given circuit which is shown below, given the wave forms of V_Sine and V_Triangular are as follows. Given that $V_{dc}$=200V and Gate_Pulses signal is given to $S_1$.

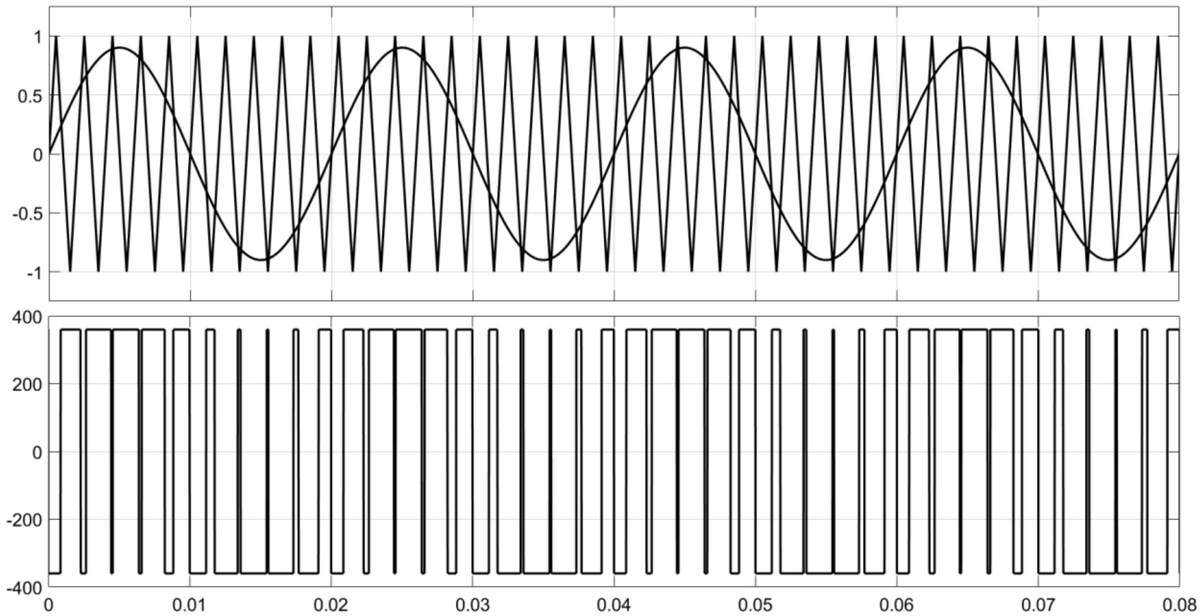



As shown in the figure the comparator will go to positive saturation when V_Sine is greater than V_Triangular and this signal is fed to $S_1$ and the complimentary signal is given to $S_2$. Hence the $V_{AB}$ will be +100V when $S_1$ is on and -100V when $S_2$.



4. A single-phase induction motor is being fed by an inverter which is implementing V/F control. Assuming the motor runs at its rated speed when the reference sine wave has an amplitude of 0.9 and frequency 50Hz. Draw the output waveform of the inverter when the motor is running at half its rated speed. Assume the triangular wave has the amplitude of 1 and its frequency is 500Hz.(mark the relevant points on the waveform)

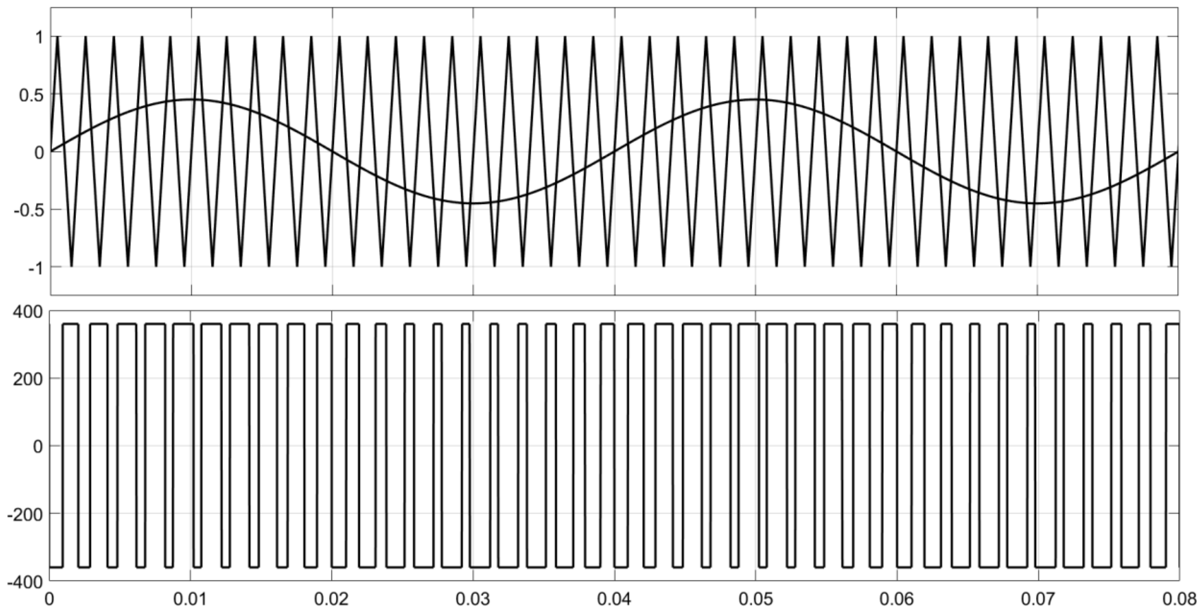
At rated speed $V\_sine=0.9\sin((2\pi f\_rated)*t)$ and $f\_rated=50Hz$




Now for half the rated speed $f=f\_rated/2=50/2=25Hz$

as V/F control is implemented the voltage also has to become half i.e. $|V\_sine|=0.9/2=0.45$

$V\_sine=0.45\sin((2\pi f)*t)$



5 Sol.

(a) $D = 0.5$, $I_{LOAD,Avg} = \frac{20}{10} = 2A$

$I_{L,avg} = I_{INPUT,avg} = \frac{I_{LOAD,AVG}}{1-D} = 4A$

$V = L\frac{\Delta I}{\Delta t} \Rightarrow \Delta I = \frac{10 \times 50\times10^{-6}}{500\times10^{-6}} = 1A$

(b) $I_{L,min} = 0 \Rightarrow I_{L,max} = I_{L,min} + \Delta I$
$= 1A$

$\therefore I_{L,Avg,Discont} = 0.5A$

$\therefore I_{LOAD,avg,dis} = (1-D)\cdot I_{L,Avg,Dis}$
$= 0.25A$

$\therefore$ Required $R_L = \frac{20V}{0.25A} = 80\Omega$

(c) $f_{sw} = 50kHz$

$\therefore T_{ON} = 10\mu s.$

$\Delta I = 10 \times \frac{10\times10^{-6}}{500\times10^{-6}} = 0.2A$

Conclusion: ① $\uparrow f_{sw} \rightarrow \Delta I \downarrow$

② for the same ripple current, size of inductor can be reduced..