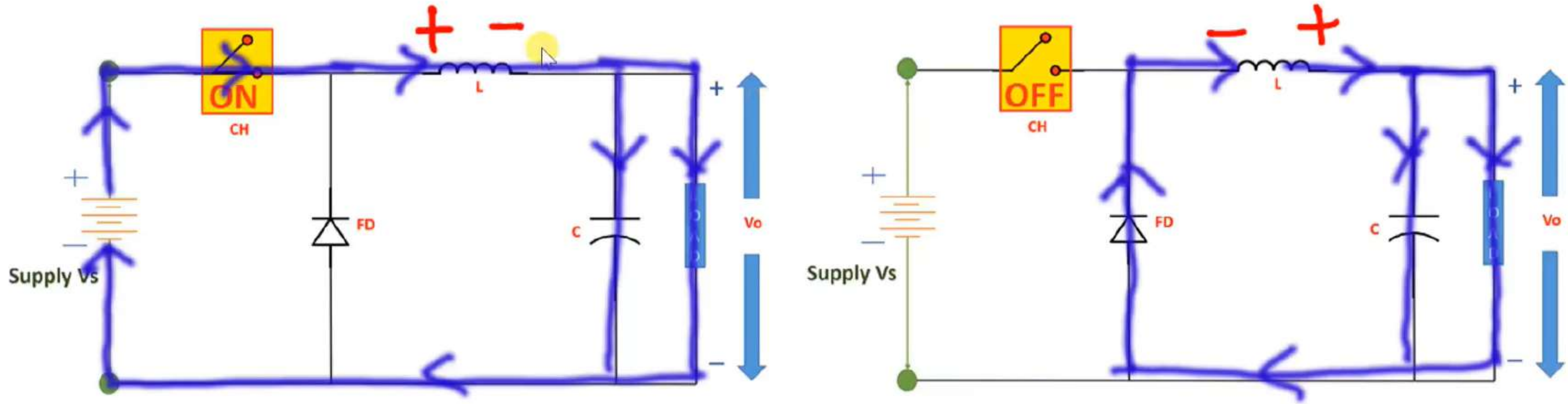
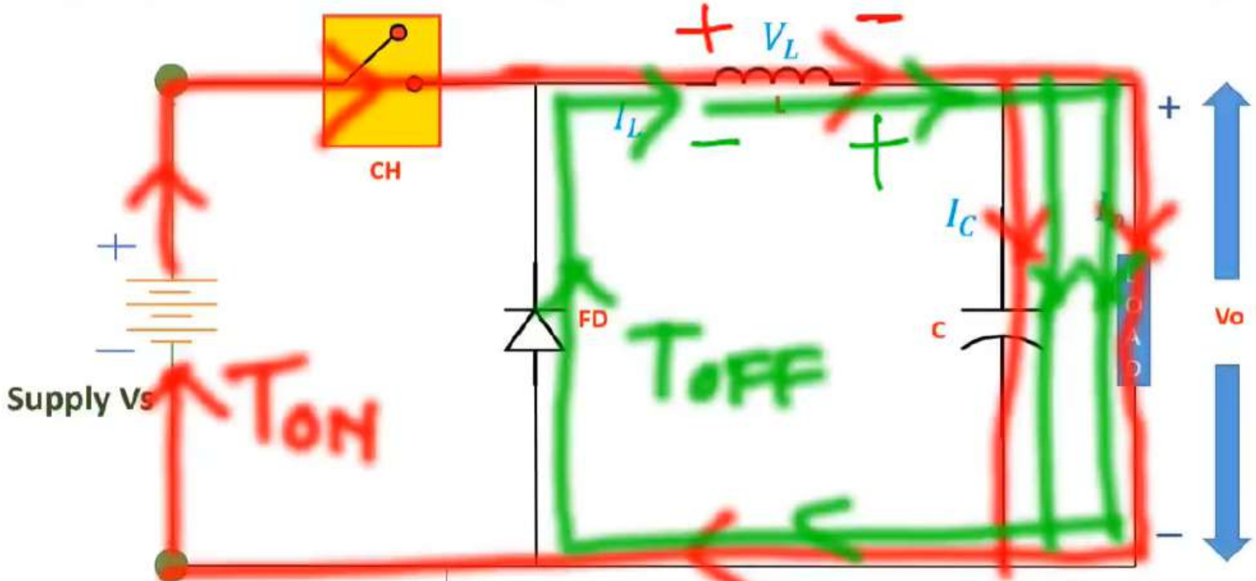
Basics of Buck Converter

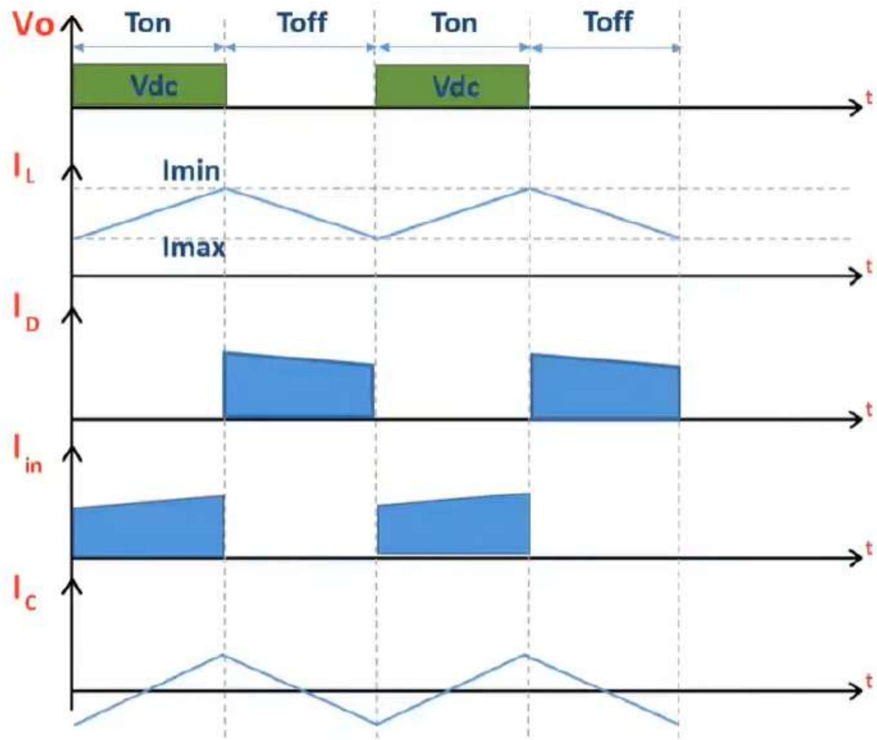
- It is step down DC to DC converter.
- Here, voltage will get step down (while current gets step up) at load.
- Buck converter can be highly efficient (higher then 90%).
- We can use it in computer from main supply (12V) to USB, DRAM and CPU (1.8V to 4.2V)
- We can make effective SMPS by buck converter.

Modes of Buck Converter



Parameters of Buck Converter





When Chopper is ON

$$V_{L(ON)} = V_s - V_o$$

$$I_{C(ON)} = I_L - I_o$$

When Chopper is OFF

$$V_{L(OFF)} + V_o = 0$$

$$V_{L(OFF)} = -V_o$$

$$I_{C(OFF)} = I_L - I_o$$

Volt Sec Balance

$$\therefore V_{L(ON)} \times T_{ON} + V_{L(OFF)} \times T_{OFF} = 0$$

$$\therefore (V_s - V_o) \times DT + -V_o \times (1 - D)T = 0$$

$$\therefore V_o = DV_s$$

Here value of duty cycle is always there in between 0 to 1.

So this type of chopper is referred as step down chopper.

Ampere Sec Balance

$$\therefore I_{C(ON)} \times T_{ON} + I_{C(OFF)} \times T_{OFF} = 0$$

$$\therefore (I_L - I_o) \times DT + (I_L - I_o) \times (1 - D)T = 0$$

$$\therefore I_L = I_o$$

So from this we can say average value of capacitor current is zero.

So it is used filter DC components at output

KREATRYX

GATE Self Study Plan

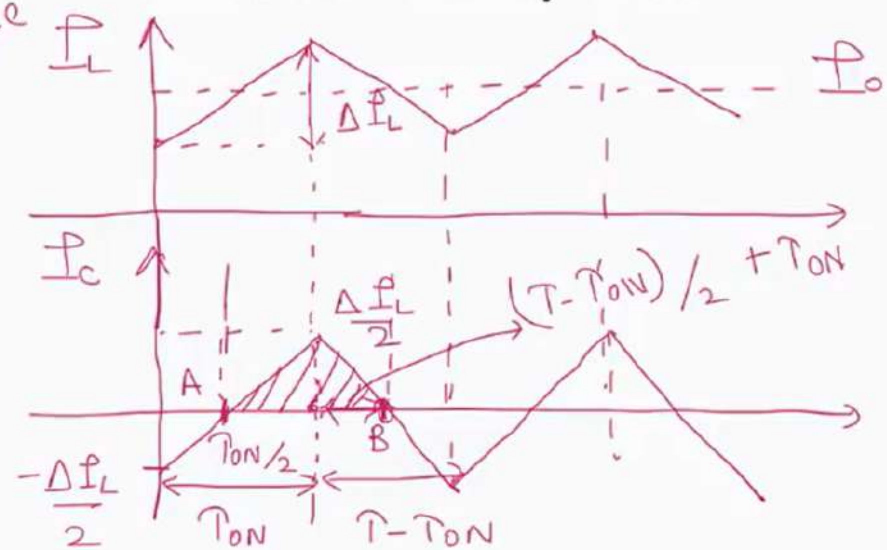
Ripple in o/p voltage

$I_C = I_L - I_o$

$I_C > 0$

$C\frac{dV_C}{dt} > 0$, $V_C \uparrow$

charging



$$\boxed{\Delta V_C = \frac{D(1-D)V_S}{8f^2LC}}$$

$$\frac{T+T_{ON}}{2} = B$$

Interval of charging

$$T_{ch} = \underbrace{\frac{T+T_{ON}}{2}}_{B} - \underbrace{\frac{T_{ON}}{2}}_{A} = T/2$$

Charging: Vmin to Vmax

area under current = charge

$$\Delta Q = \frac{1}{2}\,\frac{\Delta I_L}{2} \times T/2 = \frac{\Delta I_L}{8f}$$

$$\Delta V_c = \Delta Q/C = \frac{\Delta I_L}{8fC}$$

GATE

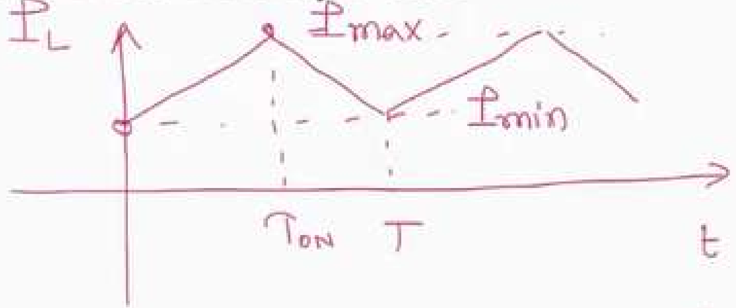
GATE Self Study Plan

Ripple in inductor current

$$\Delta I_L = I_{max} - I_{min}$$

$$V_L = V_s - V_o > 0 \quad 0 < t < T_{ON}$$

$$V_L = -V_o < 0 \quad T_{ON} < t < T$$



$$\Delta I_L = \frac{D(1-D)V_s}{fL} \qquad \left(T = \tfrac{1}{f}\right)$$

$$\Delta I_L = f(D)$$

$$\frac{d\Delta I_L}{dD} = 0$$

$$\frac{d}{dD}\left(D - D^2\right) = 0$$

$$1 - 2D = 0$$

$$D = 0.5$$

$$(\Delta I_L)_{max} = \frac{0.5 \times 0.5\, V_s}{fL}$$

$$= \frac{V_s}{4fL}$$

$0 < t < T_{ON}$

$$L\,\frac{\Delta I_L}{T_{ON}} = V_s - V_o$$

$$\Delta I_L = \frac{(V_s - V_o)\,T_{ON}}{L}$$

$$= \frac{(V_s - DV_s)\,DT}{L}$$

GATE Self Study Plan

KREATRYX

Average switch current

$0 < t < T_{ON}$: SW $\Rightarrow$ ON

$$I_{SW} = I_L$$

$$(I_{SW})_{avg} = \frac{I_L \times T_{ON}}{T} = D I_L$$

$$= D I_o$$

$$I_o = V_o/R \quad [\text{R, load}]$$

RL

$$= \frac{V_o - E}{R} \quad [\text{RE, RLE load}]$$

Average diode current

$T_{ON} < t < T$: D $\Rightarrow$ ON

$$I_D = I_L$$

$$(I_D)_{avg} = \frac{I_L (T - T_{ON})}{T}$$

$$= I_L (1 - D)$$

$$I_L = I_o$$

$$(I_D)_{avg} = I_o (1 - D)$$

GATE Self Study Plan

Avg. $V_0 \Rightarrow$ volt-sec balance

Avg. $I_L \Rightarrow$ amp-sec balance

$\Delta I_L \Rightarrow \quad L\dfrac{\Delta I_L}{DT} = V_L$

$\Delta V_0 \Rightarrow$ using I_C

$(I_{sw})_{avg} \Rightarrow I_L$

$(I_D)_{avg} \Rightarrow I_L$

$L_C \Rightarrow I_L = \dfrac{\Delta I_L}{2}$

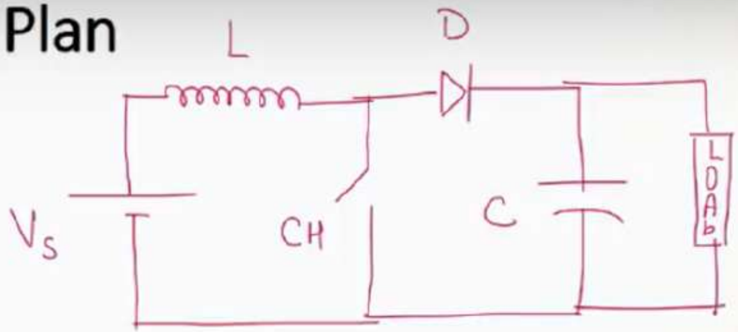
$C_C : V_0 \Rightarrow \dfrac{\Delta V_0}{2}$

Boost Converter in Power Electronics for GATE (EE) Preparation

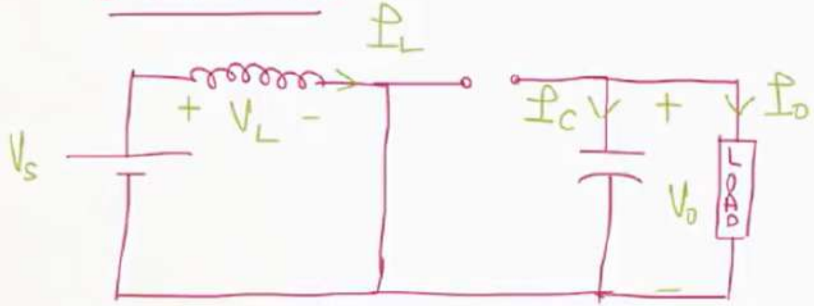
KREATRYX

GATE Self Study Plan

Boost Converter



$0 < t < T_{ON}$



$V_L = V_s$

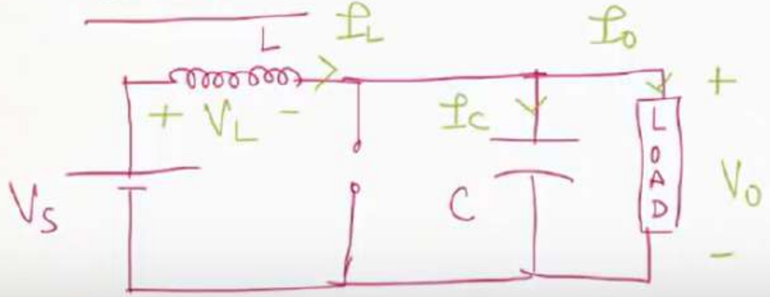
$I_C = -I_o$

$0 < t < T_{ON}$: CH $\Rightarrow$ ON D $\Rightarrow$ OFF

$T_{ON} < t < T$: CH $\Rightarrow$ OFF D $\Rightarrow$ ON

duty cycle. $D = T_{ON}/T$

$T_{ON} < t < T$



$I_C = I_L - I_o$

$V_L = V_s - V_o$

GATE Self Study Plan

Average V_0 : volt-sec balance

$$\int V_L \, dt = 0$$

$$(V_s) T_{ON} + (V_s - V_0)(T - T_{ON}) = 0$$

$$(V_s) DT + (V_s - V_0)(1-D) T = 0$$

$$V_s[\cancel{D} + 1 - \cancel{D}] - V_0(1-D) = 0$$

$$V_0 = \frac{V_s}{1-D} \; ; \; D < 1 \quad 1-D < 1$$

$V_0 > V_s$ (step-up chopper)

Average I_L : amp-sec balance

$$\int I_c \, dt = 0$$

$$(-I_0)(DT) + (I_L - I_0)(1-D) T = 0$$

$$I_L(1-D) - I_0(D + 1 - D) = 0$$

$$I_L = \frac{I_0}{1-D}$$

$$I_0 = \frac{V_0}{R} \quad [R \; \& \; RL]$$

$$= \frac{V_0 - E}{R} \quad [RE \; \& \; RLE]$$

GATE Self Study Plan

Ripple in Inductor current

$V_L = V_s \qquad 0 < t < DT$

$$\frac{L(I_{max} - I_{min})}{DT} = V_s$$

$$\Delta I_L = \frac{DT\,V_s}{L} = \frac{D V_s}{f L}$$

$$I_{max} = I_L + \frac{\Delta I_L}{2}$$

$$I_{min} = I_L - \Delta I_L/2$$

$$\Delta V = \frac{D I_o}{f C}$$

Ripple in o/p voltage

$I_c = -I_o < 0 \qquad 0 < t < DT$

↳ cap. discharges

$$\frac{C(V_{min} - V_{max})}{DT} = -I_o$$

$$\frac{C[-\Delta V]}{DT} = -I_o$$

Boost Converter in Power Electronics for GATE (EE) Preparation

KREATRYX

GATE Self Study Plan

Average switch current

SW : ON $\quad 0 < t < DT$

$$I_{sw} = I_L$$

$$(I_{sw})_{avg} = \frac{I_L \times DT}{T}$$

$$= D I_L$$

Average Diode current

D : ON $\quad DT < t < T$

$$I_D = I_L$$

$$(I_D)_{avg} = \frac{I_L (T - DT)}{T} = I_L (1 - D)$$

Critical Inductance

$$I_L = \frac{\Delta I_L}{2}$$

$$\frac{I_o}{1-D} = \frac{DV_s}{2fL_c}$$

$$\frac{V_o}{(1-D)R} = \frac{DV_s}{2fL_c}$$

$$\frac{V_s/(1-D)}{(1-D)R} = \frac{DV_s}{2fL_c}$$

$$L_c = \frac{R(1-D)^2 D}{2f}$$

GATE

24/70

12:33 / 14:23

Boost Converter in Power Electronics for GATE (EE) Preparation

KREATRYX

GATE Self Study Plan

Critical capacitance

$$V_o = \frac{\Delta V_o}{2}$$

$$\frac{V_s}{1-D} = \frac{D I_o}{2fC}$$

$$\frac{V_s}{(1-D)} = \frac{D V_o}{2fRC}$$

$$\frac{V_s}{(1-D)} = \cancel{V_o} = \frac{D \cancel{V_o}}{2fRC}$$

$$C_c = \frac{D}{2fR}$$

GATE

25/70

13:40 / 14:23

Buck-Boost Converter | Power Electronics | GATE (EE)

KREATRYX

GATE Self Study Plan

Average o/p voltage : Volt-sec balance

$$\int V_L \, dt = 0$$

$$(V_s)[DT] + (-V_o)[T-DT] = 0$$

$$V_s \cdot D = V_o(1-D)$$

$$V_o = \frac{D}{1-D} V_s \quad > 0$$

$0 < D < 0.5$ $\quad V_o < V_s$: Buck / step-down

$0.5 < D < 1$ $\quad V_o > V_s$: Boost / step-up

Avg. I_L : ampere-sec balance

$$\int I_c \, dt = 0$$

$$I_o(DT) + (I_o - I_L)(T-DT) = 0$$

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

$$I_L = \frac{I_o}{1-D}$$

$I_o = V_o/R$ [R & RL load]

$I_o = \frac{V_o - E}{R}$ [RE

GATE

27/70

7:24 / 15:13

Buck-Boost Converter | Power Electronics | GATE (EE)

KREATRYX

GATE Self Study Plan

Ripple in I_L

$V_L = V_s \quad 0 < t < DT$

$V_L > 0$: L charges

$$L \frac{(I_{max} - I_{min})}{DT} = V_s$$

$$L \frac{(\Delta I_L)}{DT} = V_s$$

$$\Delta I_L = \frac{DV_s}{fL}$$

$$I_{max} = I_L + \Delta I_L/2$$

$$I_{min} = I_L - \Delta I_L/2$$

Ripple in V_o

$I_c = I_o > 0 \quad 0 < t < DT$

$I_c > 0$: C charges

$$C \frac{(V_{max} - V_{min})}{DT} = I_o$$

$$C \frac{(\Delta V_o)}{DT} = I_o$$

$$\Delta V_o = \frac{I_o D}{fC}$$

$$(V_o)_{max} = V_o + \frac{\Delta V_o}{2}$$

$$(V_o)_{min} = V_o - \frac{\Delta V_o}{2}$$

GATE

28/70

9:56 / 15:13

GATE Self Study Plan

Avg. switch current

SW : ON $\quad 0 < t < DT$

$$I_{SW} = I_L$$

$$(I_{SW})_{avg} = \frac{I_L (DT)}{T}$$

$$= D I_L$$

Avg. Diode current

D : ON $\quad DT < t < T$

$$I_D = I_L$$

$$(I_D)_{avg} = \frac{I_L (T - DT)}{T} = (1-D) I_L$$

Critical Inductance (L_C)

$$I_L = \frac{\Delta I_L}{2}$$

$$\frac{I_0}{1-D} = \frac{DV_S}{2f L_C}$$

$$\frac{V_0}{(1-D)R} = \frac{DV_S}{2f L_C}$$

$$\frac{\cancel{DV_S}}{(1-D)^2 R} = \frac{\cancel{DV_S}}{2f L_C}$$

$$L_C = \frac{(1-D)^2 R}{2f}$$

Buck-Boost Converter | Power Electronics | GATE (EE)

KREATRYX

GATE Self Study Plan

Critical capacitance (C_c)

$$V_0 = \frac{\Delta V_0}{2}$$

$$\frac{D}{1-D} V_s = \frac{D I_0}{2fC} = V_0$$

$$\frac{D I_0}{2fC} = I_0 R$$

$$C_c = \frac{D}{2fR}$$

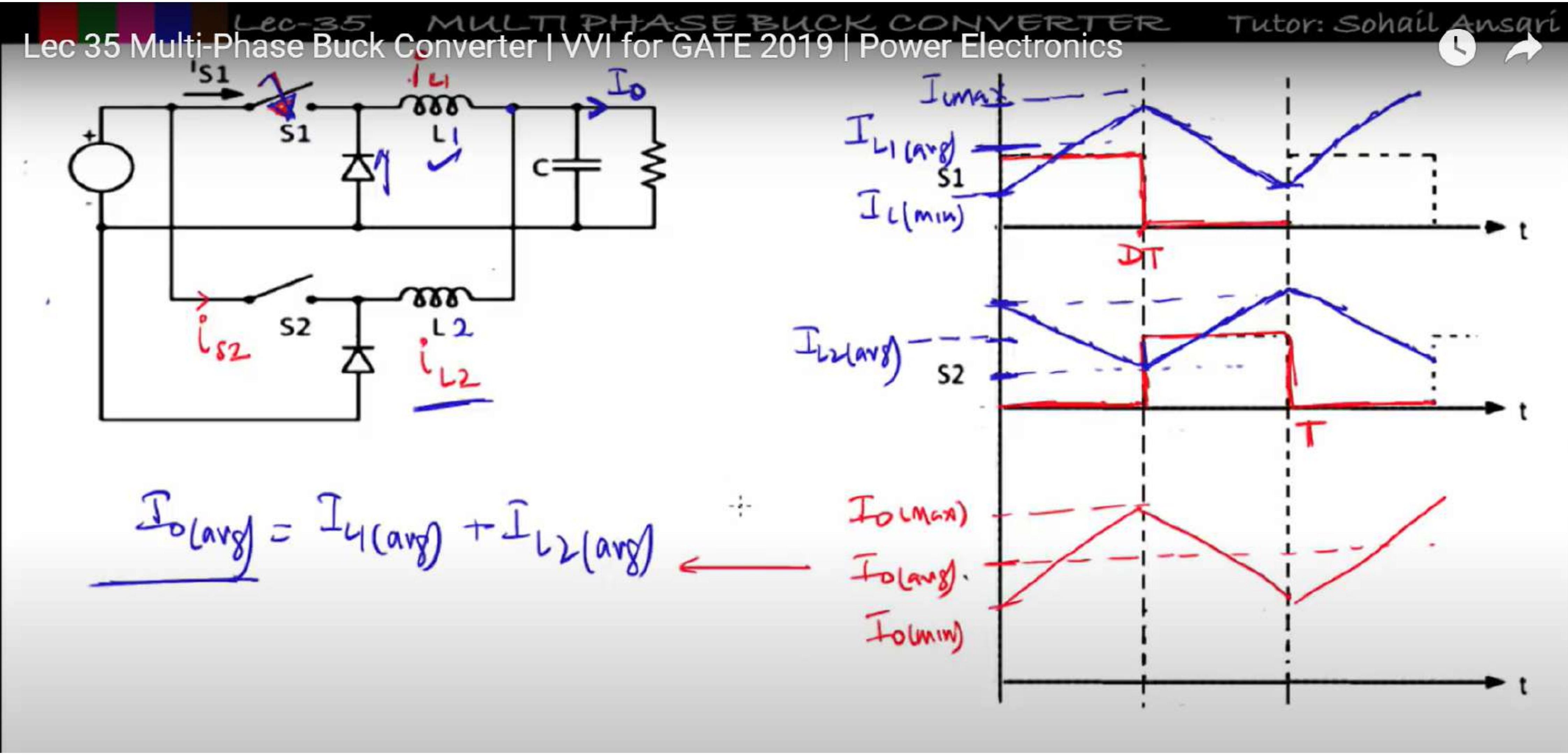
Avg. supply current : energy conservations

$$V_s (I_s)_{avg} = V_0 I_0$$

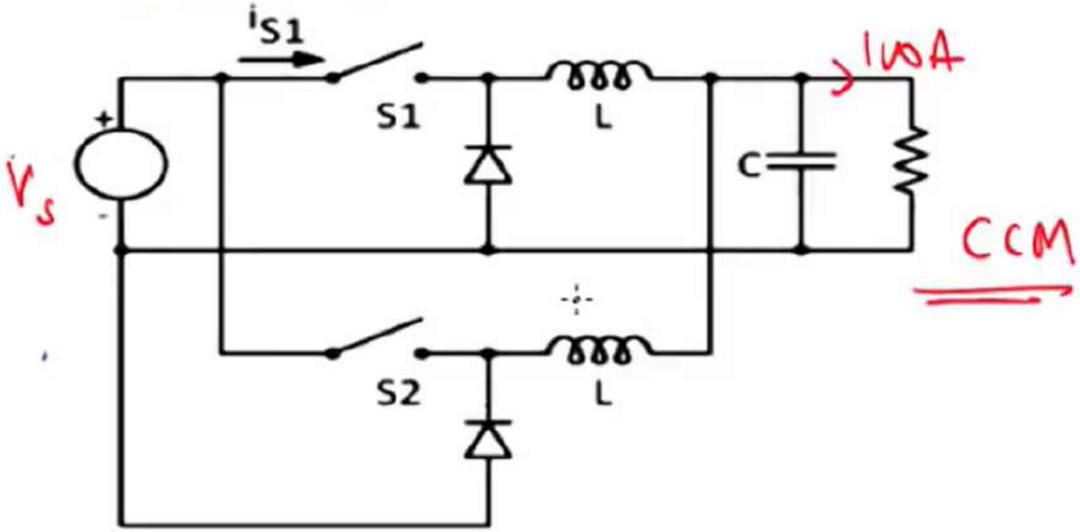
$$(I_s)_{avg} = \frac{D}{1-D} I_0 \quad : \text{Buck - Boost}$$

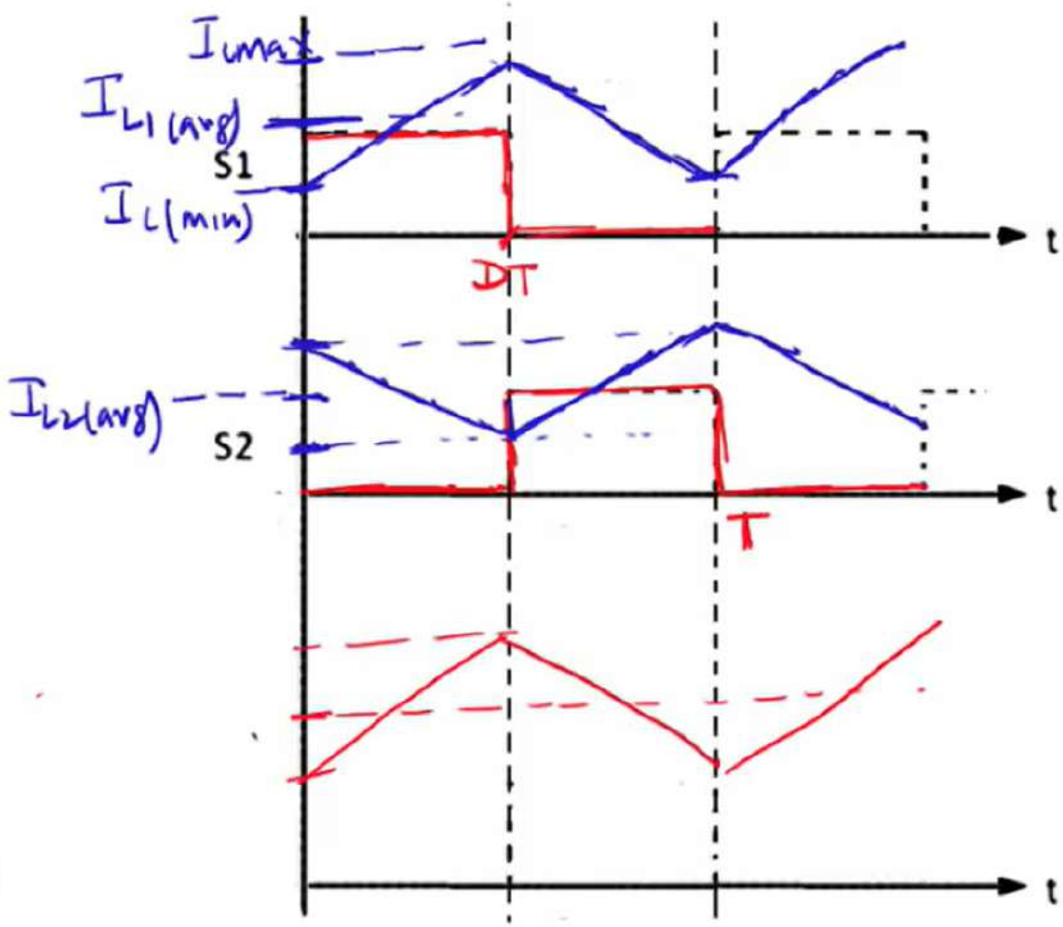
$$(I_s)_{avg} = \frac{I_0}{1-D} \quad : \text{Boost}$$

$$(I_s)_{avg} = D I_0 \quad : \text{Buck}$$



Lec 35 Multi-Phase Buck Converter | VVI for GATE 2019 | Power Electronics
Lec-35 MULTI PHASE BUCK CONVERTER
Tutor: Sohail Ansari
i_{S1}
S1
i_{L1}
L1
I_o
C
S2
i_{S2}
L2
i_{L2}
$I_{L\,max}$
$I_{L1(avg)}$
$I_{L(min)}$
S1
DT
t
$I_{L2(avg)}$
S2
T
t
$I_{o(max)}$
$I_{o(avg)}$
$I_{o(min)}$
t
$I_{o(avg)} = I_{L1(avg)} + I_{L2(avg)}$





Conclusion

1. load sharing
2. Size reduces
3. $V_o = DV_s$

Q: $V_s = 12V$

$V_o = 5V$

$R_o = 500\Omega$

$\Delta V = 20mV$

$f_{sw} = 25KHz$

$\Delta I = 0.8A$

(a) $D = 0.417$

(b) $L = 145.83\,\mu H$

(c) $C = 200\,\mu F$

(D) $L_c = ?$

$C_c = ?$

$$\Delta V_c = \frac{0.8*1}{8*C*f_{sw}}$$

$$C = \frac{0.8}{20*10^{-3}*8*25*10^{3}}$$

$$= 200\mu F$$

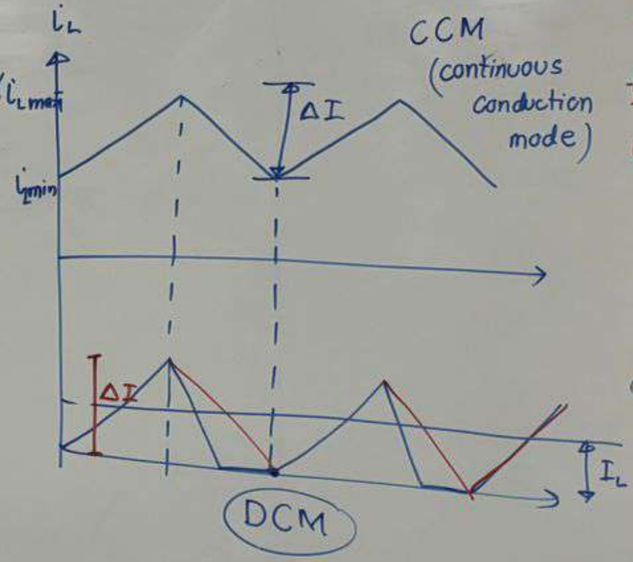
Critical Inductance :-

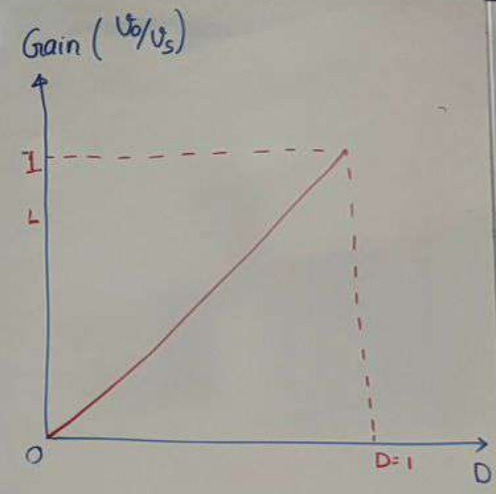
$$\Delta I = I_L*2 = I_o*2$$

$$\Rightarrow \frac{V_s(1-D)\cancel{D}}{L_c*f_{sw}} = 2*\frac{V_o}{R} = \frac{2*\cancel{D}V_s}{R}$$

$$\Rightarrow \boxed{L_c = \frac{(1-D)R}{2f_{sw}}}$$

$$\boxed{C_c = \frac{(1-D)}{16Lf_{sw}^2}}$$

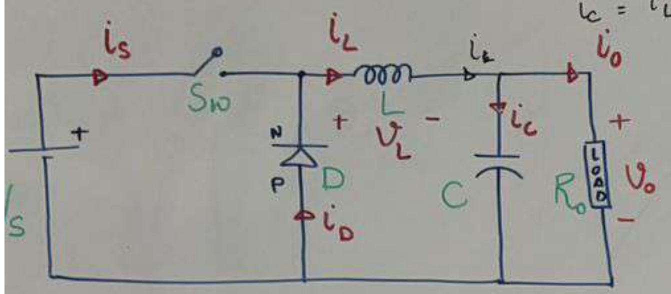




Step-down (Buck Converter) :-

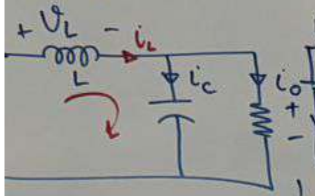
$i_L = i_o + i_c$

$i_c = i_L - i_o$

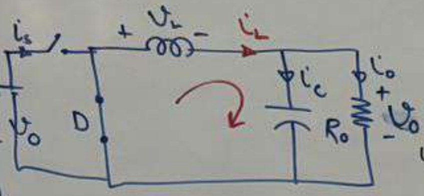


D = duty ratio = $\frac{T_{ON}}{T_{ON}+T_{OFF}} = \frac{T_{ON}}{T}$

Sw - ON



Sw - OFF

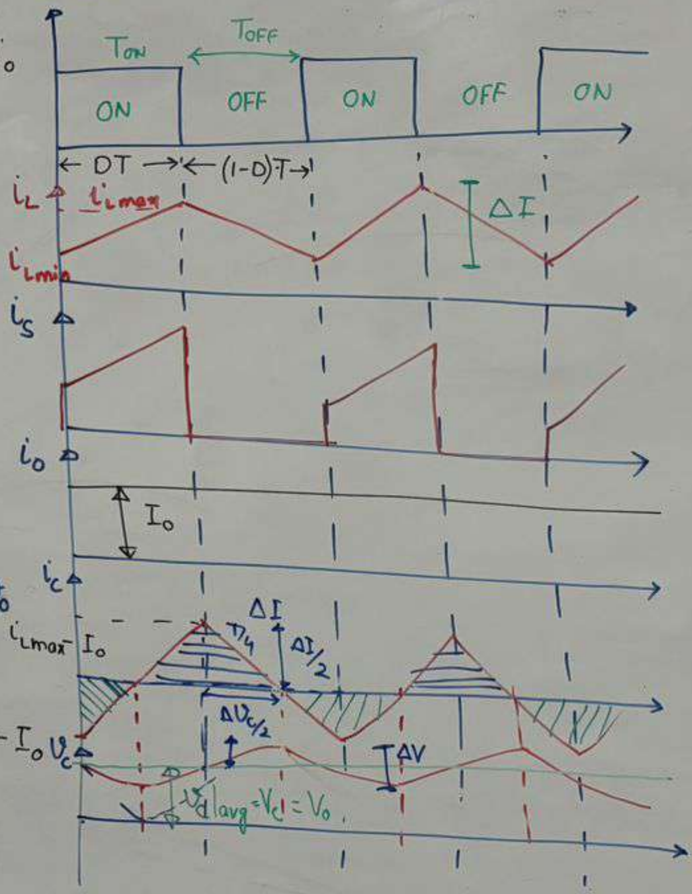


$\Delta I = \frac{(V_s - V_o)}{L} * T_{ON}$ — ①

$\Delta I = \frac{V_o * T_{OFF}}{L}$ — ②

$\boxed{V_o = D * V_s}$ — (A)

Gate



from ① and ② :-

$$T_{ON} = \frac{L\Delta I}{V_s - V_o}$$

$$T_{OFF} = \frac{L\Delta I}{V_o}$$

$$T = T_{ON} + T_{OFF} = \frac{1}{f_{sw}} = L\Delta I\left\{\frac{1}{V_s - V_o} + \frac{1}{V_o}\right\}$$

$$T = L\Delta I\left\{\frac{\cancel{V_o} + V_s - \cancel{V_o}}{(V_s - V_o)V_o}\right\}$$

$$\boxed{\Delta I = \frac{(V_s - V_o)V_o}{V_s * L * f_{sw}}}$$

$$\boxed{\Delta I = \frac{V_s(1-D) * D}{L * f_{sw}}}$$

$$\Delta V_c = \frac{1}{C}\int i_c\,dt$$

$$\Delta V_c = \frac{1}{C}\int_0^{T/4} \frac{\Delta I}{2} * dt$$

$$\Delta V_c = \frac{1}{C} * \frac{\Delta I}{2} * \frac{T}{4}$$

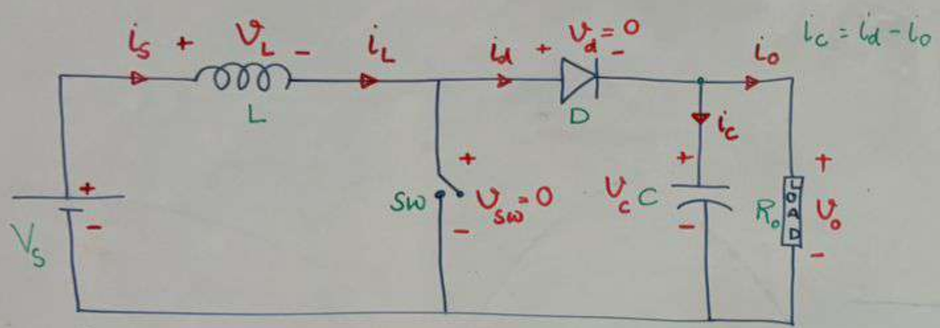
$$\Delta V_c = \frac{\Delta I\, T}{8C}$$

$$\boxed{\Delta V_c = \frac{V_s(1-D) * D}{C L * f_{sw}^2 * 8}}$$

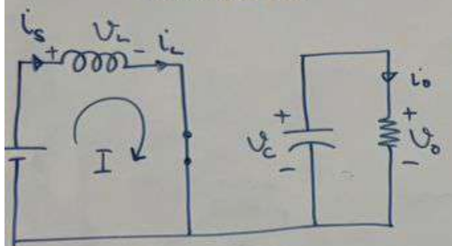
Boost Converter (Step-up regulator):-

$i_d = i_o + i_c$

$i_c = i_d - i_o$



Switched ON



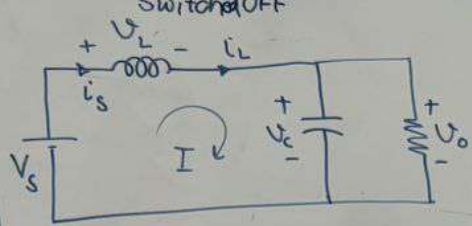
$V_s - V_L = 0$

$\Rightarrow V_s - L*\frac{di}{dt} = 0$

$\Rightarrow V_s - L*\frac{\Delta I}{T_{ON}} = 0$

$V_s = \frac{L\Delta I}{T_{ON}}$ — (1)

Switched OFF

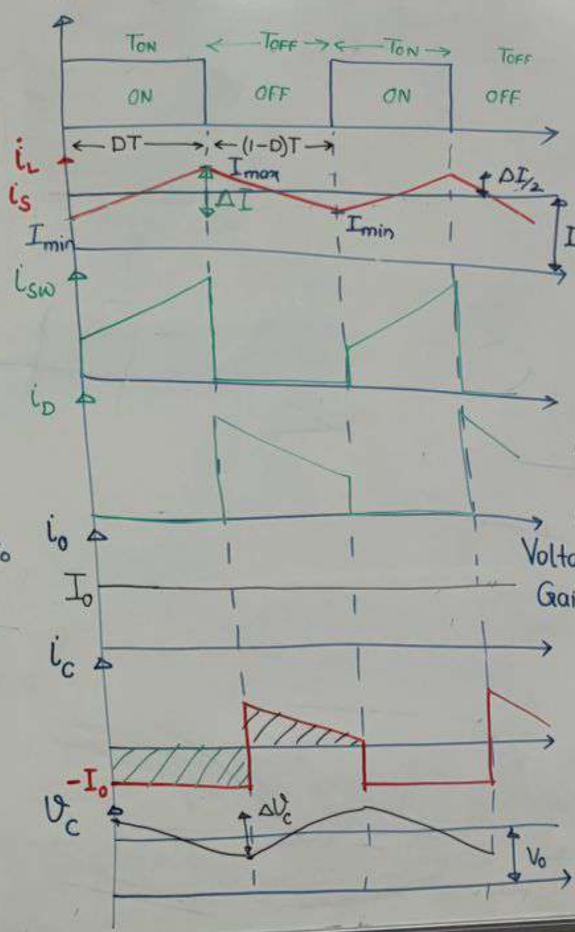


$V_s - V_L - V_o = 0$

$\Rightarrow V_s - L\frac{di}{dt} - V_o = 0$

$\Rightarrow V_s + L*\frac{\Delta I}{T_{OFF}} - V_o = 0$

$L*\frac{\Delta I}{T_{OFF}} = V_o - V_s$ — (2)



$L\Delta I = V_s * T_{ON} = (V_o - V_s)T_{OFF}$

$\Rightarrow V_s * DT = (V_o - V_s)(1-D)T$

$\Rightarrow V_s * D = V_o - V_s - DV_o + DV_s$

$V_s = V_o(1-D)$

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

Since, $0 < D < 1$

(1) $\boxed{V_o \geq V_s}$

(2) Input current is continuous in nature