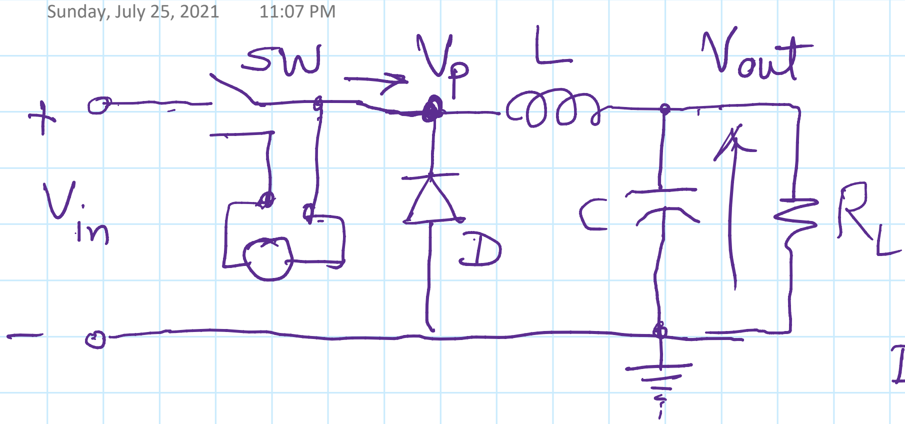
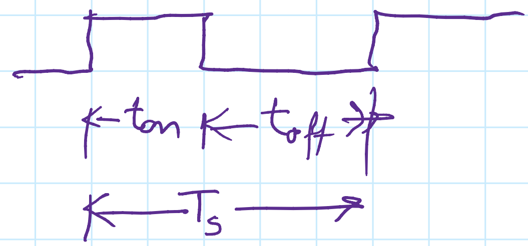
Buck Converter

Sunday, July 25, 2021 11:07 PM

Assume Cont. conduction mode ; Sw + Diode are ideal





$D = \dfrac{t_{on}}{T_s}$ D ⇒ Duty Ratio

When the switch is on $t = t_{on}$ ⇒ $t_{on} = DT_s$

Diode is OFF $V_p = \int_0^{t_{on}} V_{in} \cdot dt = V_{in} \times DT_s$; $V_{out} = V_C(t)$

When the Switch is OFF

Diode is ON $V_p = \int_{T_{off}} V_{in}\, dt = V_{in}(1-D)T_s = 0$

$V_{out} = V_c(t)$

∴ If V_L avg = 0 Over One Switching Cycle ⇒ $V_{P(avg)} = V_{out}$

∴ $D = V_{out}/V_{in}$

Assumption → (i) The SW and D are ideal

Property of L and C

(ii) The average inductor voltage during a complete cycle is zero

(iii) the average Cap. voltage during one Complete switching cycle is zero

(iv) The load current is constant with switching ripples - $-(I_0)$

- We can

Let inductor current ripple is K % of I_0

Let inductor current ripple is K % of I_o

The capacitor voltage ripple is r % of V_{out}

Typically K is 10 % to 20 % of I_o → $K_{max} = 20\%$

Typically r is 2 % to 5 % of V_{out} — $r_{max} = 5\%$

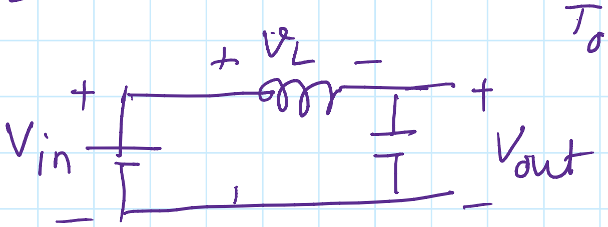
a) To find L value Let $K = 0.1$ (10 %)

The volt-second product is zero over a complete cycle

$$v_L = L\, \frac{di}{dt} = L\, \frac{\Delta I}{\Delta t}$$

If we consider on time K is per unit

$$v_L = (V_{in} - V_{out}) = L\, \frac{K I_o}{T_{on}} = L\, \frac{K I_o}{D T_s} \quad \Big\}\; T_s = \frac{1}{f_s}$$



Equ ckt SW = ON D = OFF

$$\boxed{L = \frac{D\,(V_{in} - V_{out})}{K\, I_o \cdot f_s}}$$

D & K are in p.u.

$$L_{min} = \frac{D_{min}\,(V_{in(max)} - V_{out})}{(K\, I_o) \times f_s} \qquad D_{min} = \frac{V_{out}}{V_{in(max)}}$$

ΔI_L → $(K\, I_o)$

(b) To find C_{min} ⇒ Consider the case when SW is OFF, Diode ON

(b) To find C_{min}, consider the case when SW is OFF, Diode ON

The whole of inductor current is due to stored energy

$\therefore \quad i_C = C\dfrac{dv_c}{dt} = C\dfrac{\Delta V_o}{dt} \Rightarrow$

$i_c\,dt = C_{min}\,\Delta V_o$ = Area under the curve

$$\frac{1}{2}\times\frac{\Delta I_L}{2}\times\frac{T_s}{2} = C_{min}\,\Delta V_o$$

$$\therefore \quad \boxed{C_{min} = \frac{\Delta I_L}{8 f_s \cdot \Delta V_o}}$$

$\Delta I_L = K\, I_o$

$\Delta V_o = r\, V_{out}$

K and r are in p.u.

(c) Average Switch current

$$D = \frac{V_{out}}{V_{in}} = \frac{I_{in}}{I_{out}}$$

$$I_{SW(ave)} = I_{in\,(Ave)}$$

$$V_{out}\times I_{out} = P_{out} = V_{in\,(min)}\times I_{in\,(Ave)}$$

$$\therefore \quad I_{in\,(Ave)} = \frac{P_{out}}{V_{in\,(min)}}$$

(d) The average Diode Current

The Diode carries Current only during OFF time

$\therefore \quad I_{Diode(Ave)} = I_{out}\,(1-D\ldots)$

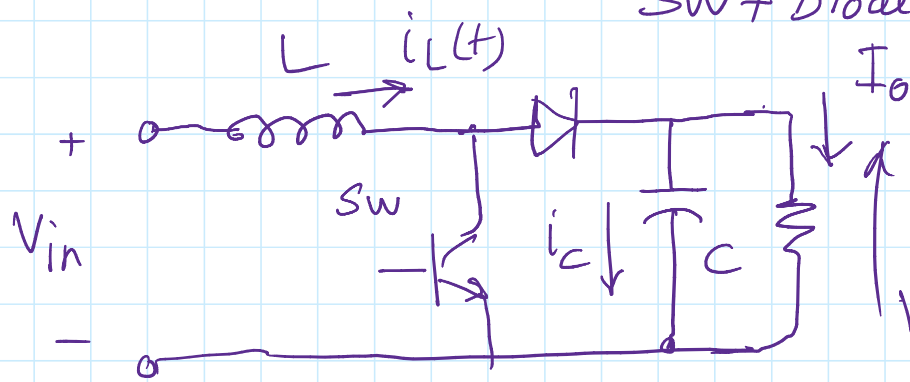
$\therefore \quad I_{diode(Ave)} = I_{out}(1 - D_{min})$

Boost Converter

Monday, July 26, 2021 12:30 AM

Assume Continuose Conduction Mode

SW + Diode are ideal



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

$$V_{out} = V_c(t)$$

★ When the Switch is ON, $t_{on} = DT_s$ the inductor Stores energy : $V_{SW} = 0$ ideally $V_L(t) = V_{in}$

the inductor current does not transfer its energy to the output load since the diode is off

the capacitor Supplies its stored energy to the load (Discharges)

★ When the Switch is OFF $(1-D)T_s = t_{off}$

The inductor transfers its stored energy to the load, the Diode is ON and also charges the Capacitor from Supply input

ⓐ To find L

$v_{L\,(ave)} = 0$ $\quad$ v_L during ON state

$$v_L = V_{in}$$

$$v_L = L \frac{di}{dt} = L \frac{\Delta I_L}{D \cdot T_s} = V_{in}$$

$$L \frac{di}{dt} \qquad \frac{}{D \cdot T_s} \qquad = V_{in}$$

$$\therefore \boxed{L = \frac{D\, V_{in}}{\Delta I_L \cdot f_s}}$$

ΔI_L can be expressed as $k\, I_{out}$; $D \Rightarrow$ Per unit Duty

f_s is in Hz

(b) To find C value $\longrightarrow$

During SW ON state $\rightarrow$ (DT_s)

Capacitor current is

$$i_c(t) = C \frac{dv_c}{dt} = \frac{C\, \Delta V_O}{D \cdot T_s} = I_{out}$$

$$\therefore \boxed{C = \frac{D\, I_O}{f_s\, \Delta V_O}}$$

$\Delta V_O = r \times V_{out}$

r is per unit O/p voltage ripple

(c) Average Switch Current $= D \cdot I_{input}$

$$V_{in} \times I_{in} = V_{out} I_{out} = P_{out}$$

$$I_{SW(Ave)} = D \times \frac{P_{out}}{V_{in}}$$

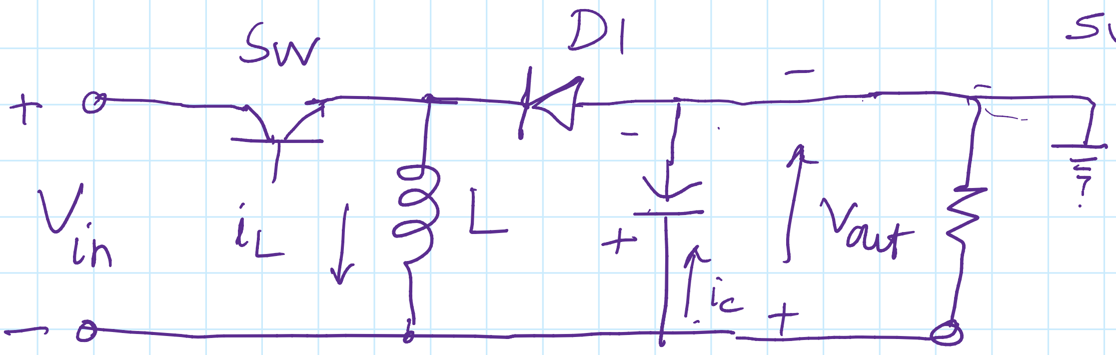
d- The average Diode Current is

$$I_{Diode\,(Ave)} = (1-D)\, I_{in} = (1-D)\frac{P_{out}}{V_{in}}$$

Buck-Boost Converter

Monday, July 26, 2021 1:01 AM

Assume Continuous Current Conduction mode and SW + Diode are ideal



The voltage transfer Ratio is

$$V_{out}/V_{in} = -\frac{D}{1-D}$$

For $D > 0.5$ $\longrightarrow$ $V_{out} > V_{in}$ Boost Mode

For $D < 0.5$ $\longrightarrow$ $V_{out} < V_{in}$ Buck Mode

For $D = 0.5$ $\longrightarrow$ $V_{out} = V_{in}$

- During SW ON state

  inductor stores energy since D1 is OFF

  Only Cap stored energy is transferred to the load with appropriate polarity

- During SW OFF state, Diode D_1 starts conducting

  . The inductor supplies / transfer the stored energy to the load, the inductor current completes energy to the load, the inductor current completes its path through diode, which is ON during this period

The capacitor also gets charged during this process –

If $D > 0.5$ → the inductor stores more energy and hence boost action is possible

If $D < 0.5$ → The inductor stores less energy and hence buck action is possible –

ⓐ To find L

Consider the period when SW is ON

$$V_L(t) = V_{in} = L \frac{di}{dt} = L \frac{\Delta I_L}{D \cdot T_s}$$

$$\therefore \boxed{L = \frac{V_{in} \cdot D}{\Delta I_L \cdot f_s}}$$

$\Delta I_L = K I_o$

K is per unit ripple

V_{in} may vary from $V_{in(min)}$ to $V_{in(max)}$ – which gives us D_{max} & D_{min}

$$D_{min} = \frac{V_{out}}{V_{in(max)} + V_{out}}$$

V_{out} is constant in all operations

in (max) ... in all operations

$$D_{max} = \frac{V_{out}}{V_{in(min)} + V_{out}}$$

$$\therefore \boxed{L_{min} = \frac{V_{in(max)}\, D_{min}}{\Delta I_L \cdot f_s}} \qquad \Delta I_L = K I_o$$

(6) To find C

The capacitor will discharge its energy during SW = ON and diode is OFF

$$i_c(t) = I_{out} = C\frac{dv_c}{dt} = \frac{C\,\Delta V_o}{D \cdot T_s}$$

$$\therefore \boxed{C = \frac{D\, I_{out}}{\Delta V_o \cdot f_s}}$$

$$C_{min} = \frac{D_{min} \times I_{out}}{\Delta V_o \cdot f_s} \qquad \Delta V_o = r\, V_{out}$$

r = Per unit O/p voltage ripple

ripple

(c) What is the average Switch Current?

$$I_{SW(ave)} = I_{in(ave)}$$

$$P_{out} = V_{out} \cdot I_{out} = V_{in} \cdot I_{in(ave)}$$

The average Switch current would also vary for Dmin and Dmax

$$\therefore \quad I_{SW(ave)} = \frac{P_{out}}{V_{in(min)}} \rightarrow \text{Worst case scenario}$$

(d) What is the average Diode current?

$$I_{diode(ave)} = I_{c(ave)} + I_{out}$$

$$I_{c(ave)} = 0 \quad \text{over a complete cycle}$$

$$\therefore \quad I_{diode(ave)} = I_{out} = \frac{P_{out}}{V_{out}}$$