DC to DC Converter

Dr. D. S. More
Department of Electrical engg
W. C. E. Sangli
E-mail => dsm.wce@gmail.com

Introduction

Switched mode power supplies / Choppers.

$\rightarrow$ High power $\rightarrow$ D.C. motor speed control

Calcutta metro : 750V DC

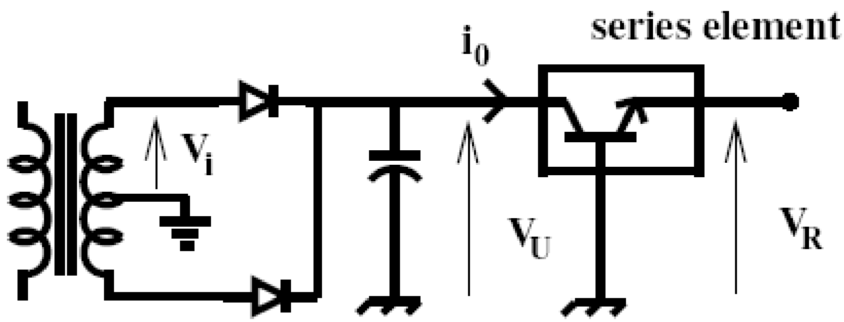
Bombay – Igatpuri : 1500V

Power supplies : In computers, any electronic equipments.

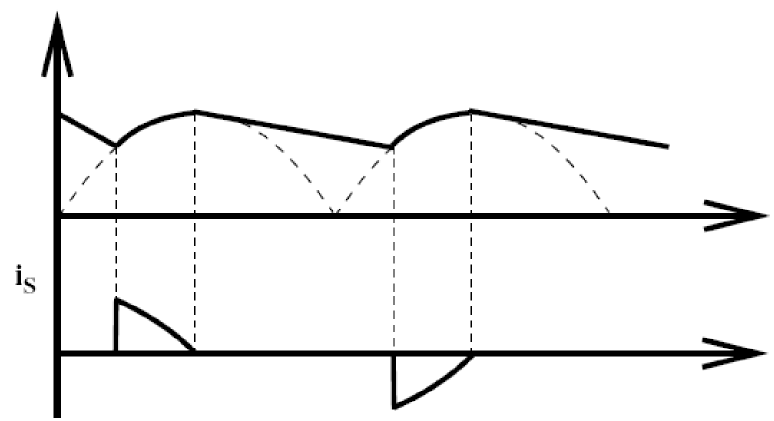
Linear Regulated Power Supply

- Voltage across

  C = V_U

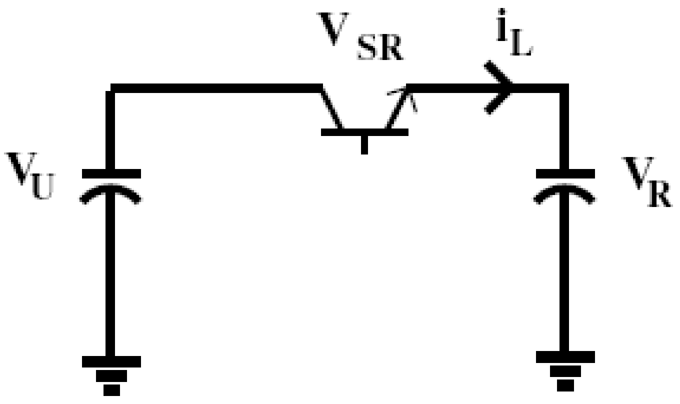


- Out put voltage = V_R



Linear Regulated Power Supply

In order to get regulated power supply, use series regulator.



$$V_{SR} = V_U - V_R$$

As $V_U \uparrow$, $V_{SR} \uparrow$

$\Rightarrow$ 7805 Regulator

$V_{U(min)} = 7.5V$ $\qquad V_R = 5V$

$V_{U(max)} = 35V$

Power loss in the device $= V_{SR} * i_L$

Linear Regulated Power Supply

- Disadvantages
- Voltage is dropped across series element & hence efficiency is low
- Requires 50 Hz transformer
- Source current contains harmonics
- large size of the capacitor
- Heat sink size increases.

Switch Mode Power Supply

- DC to DC converter
- Operating at high frequency 100KHz
- Transformer operating frequency is high, so cost and weight is low
- As frequency increases, No. of turns decreases and core loss increase
- Ferrite core transformer is used. Operating flux density => 0.2 to 0.25 T
- Values of L and C required are less

DC to DC Converters

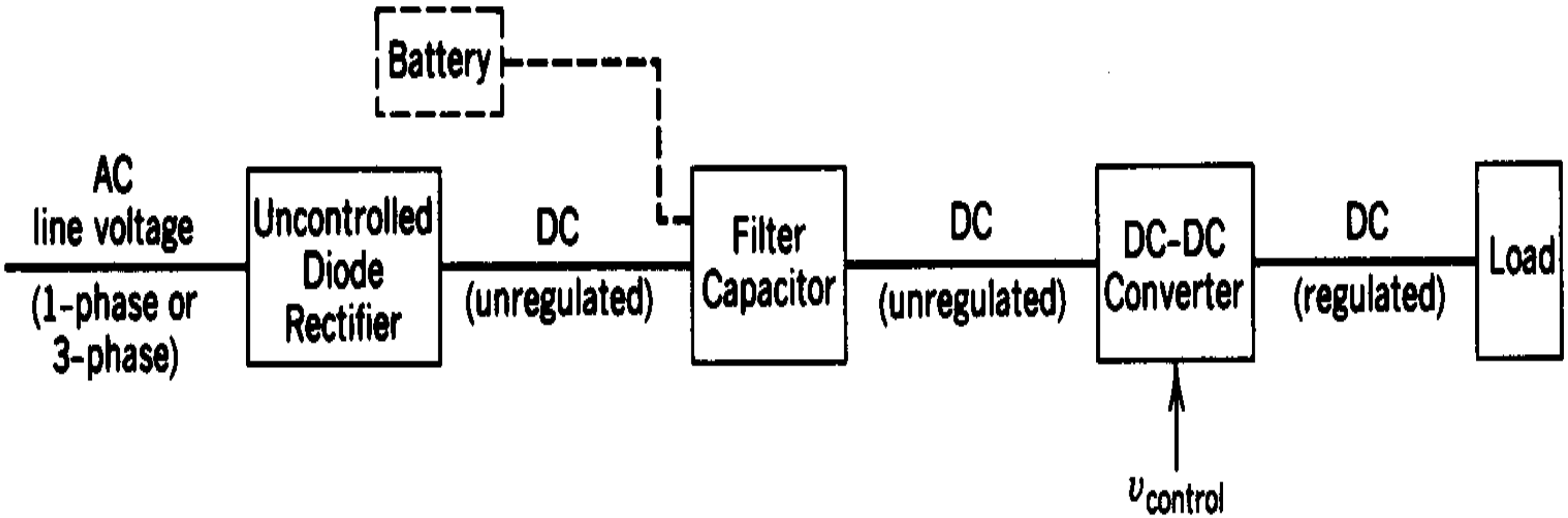


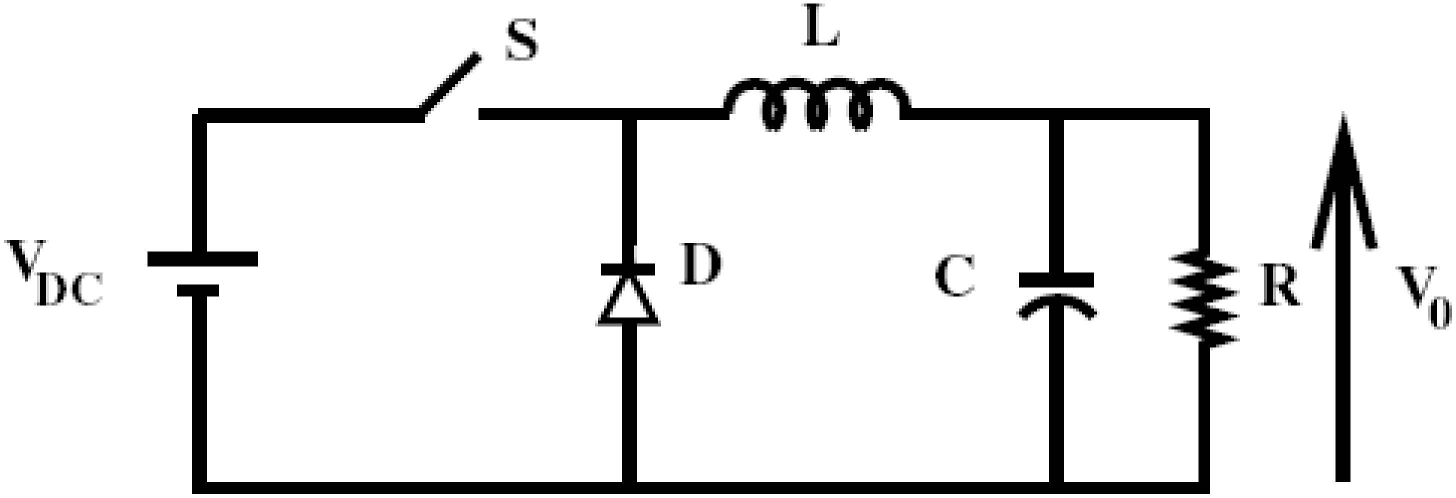
Figure 7-1 A dc–dc converter system.

DC to DC Converters-Classification

- Based on output voltage
- 1) Buck / step- down
- 2) Boost/ step-up
- Based on quadrant operation
- 1) Single quadrant dc to dc converter
- 2) Two quadrant dc to dc converter
- 3) four quadrant dc to dc converter

DC to DC buck converter

- It is also called as step-down chopper
- Output voltage (V_O) is less than input voltage(V_{DC})
- Circuit components are S, D, L and C

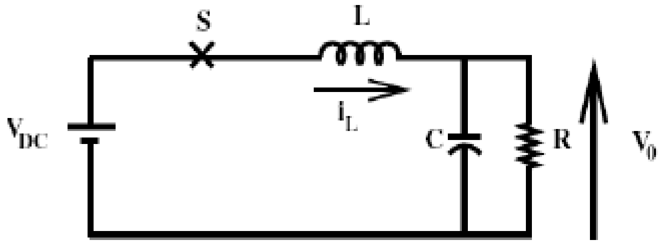


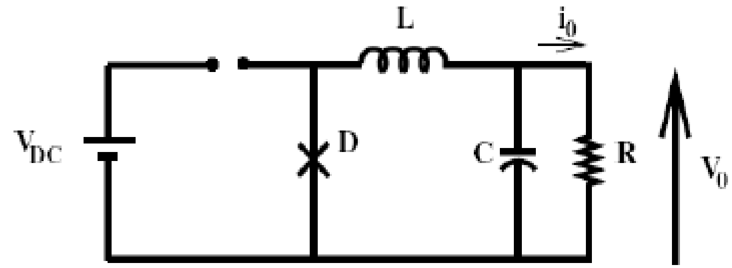
DC to DC Buck converter

'S' is switched at a very high frequency.

$S -$ ON for DT

$-$ OFF for $(1-D)T$





$$V_L = V_{DC} - V_0 \quad 0 < t < DT$$

$$= \text{Constant}$$

$i_L \uparrow$ Linearly

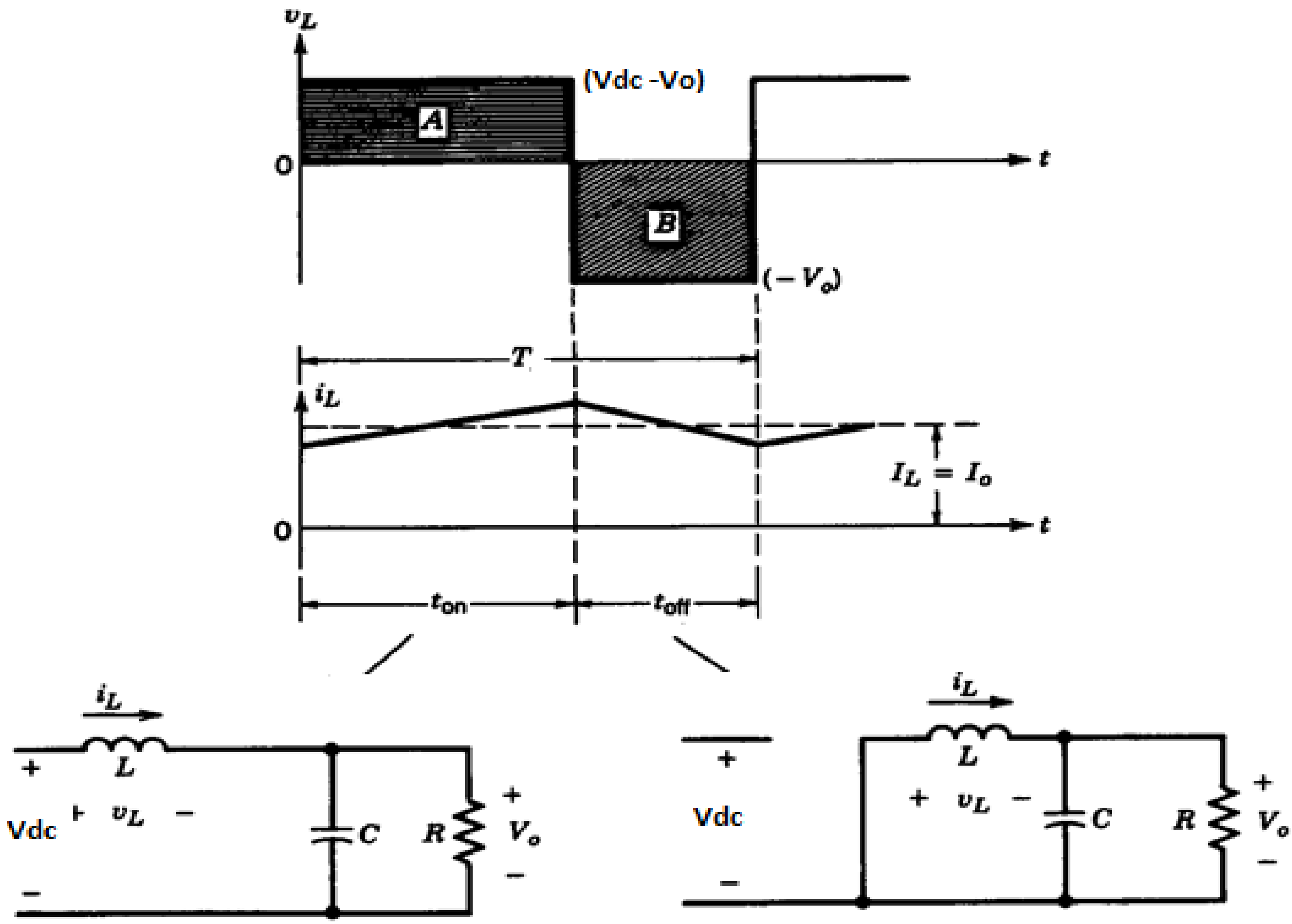
$$i_L = C\frac{dV_0}{dt} + \frac{V_0}{R}$$

$$V_L = -V_0 \qquad (1-D)T < t < T$$

$i_L \downarrow$ Linearly

$$i_L = C\frac{dV_0}{dt} + \frac{V_0}{R}$$

DC to DC buck converter

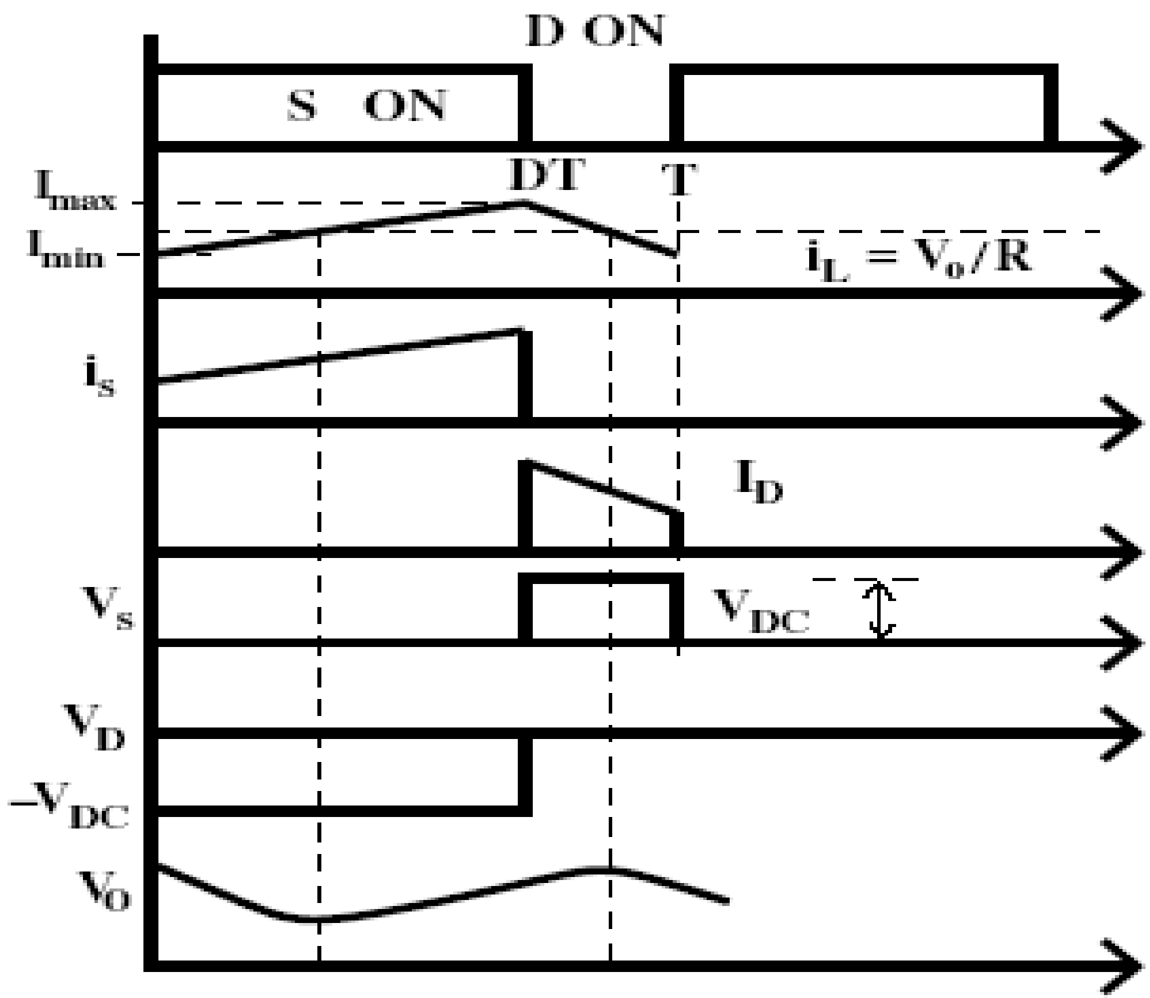


DC to DC buck converter

- Relationship between input and output voltage
- $D = T_{on} / T$
- Average voltage across inductor is zero.
- $(V_{DC}-V_O)\ DT = V_O(1-D)T$
- $DV_{DC}-V_OD = V_O-V_OD$
- $V_O = D\ V_{DC}$

DC to DC Buck Converter

- Assume the inductor current (I_L) is continuous



DC to DC Buck converter

Neglect losses

Input power = Output power.

$V_{DC}\ I_S = V_0\ I_0$

$= D\ V_{DC} I_0$

$\therefore\ I_S = D\ I_0$

Avg. source current < Avg. load current.

$\Rightarrow$ Similar to step-down transformer.

Source current waveform jumps from peak to zero.

$\Rightarrow$ peak value of $i_S > I_S$

$\Rightarrow$ L-C filter at the input side.

DC to DC Buck converter

Discontinuous Conduction:

Inductor current 'i_L' and NOT I_0.

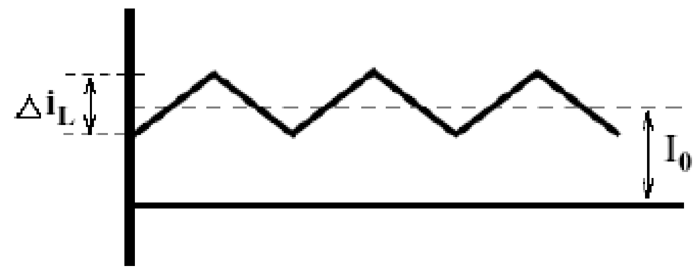
$$I_0 = \frac{V_0}{R}.$$

Now i_L is continuous if

$$\frac{V_0}{R} \geq \frac{\Delta i_L}{2}$$

$$\frac{D\,V_{DC}}{R} \geq \frac{V_{DC}}{2L}(1-D)\,DT$$

$$\therefore\ R \leq \frac{2L}{(1-D)T} = R_{CR}$$



$$I_{max} = I_{min} + \frac{(V_{DC}-V_O)\,DT}{L}$$

$$I_{max} - I_{min} = \frac{(V_{DC}-V_O)\,DT}{L}$$

DC to DC Buck converter

If load $R > R_{CR}$,

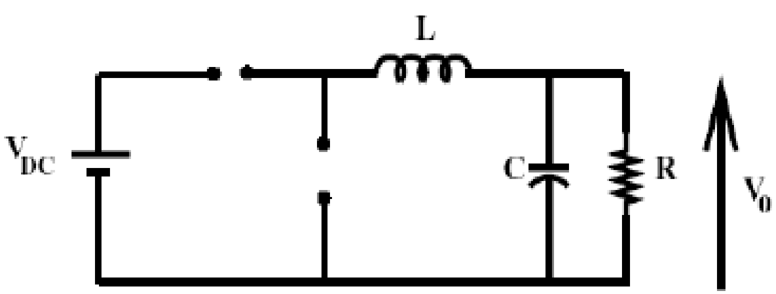
i_L is DISCONTINUOUS.

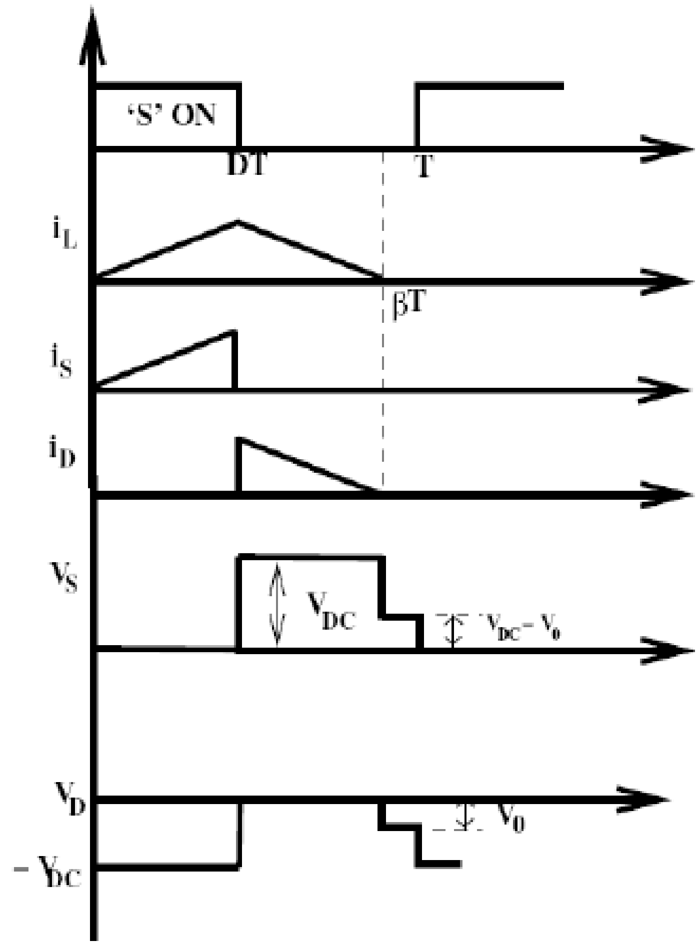
$\Rightarrow$ $i_L = 0$ for finite time.

i_S starts from zero.

If i_L is continuous, $V_0 = D\ V_{DC}$

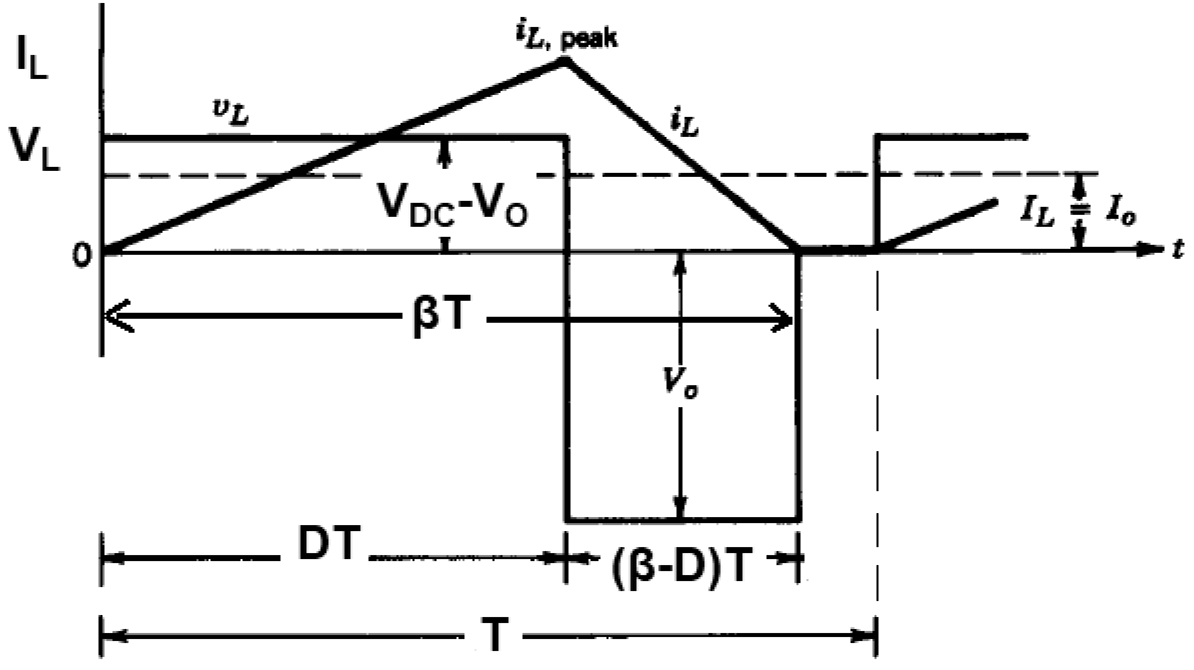
$\Rightarrow$ Independent of I_0





DC to DC Buck converter

- o/p voltage with discontinuous conduction

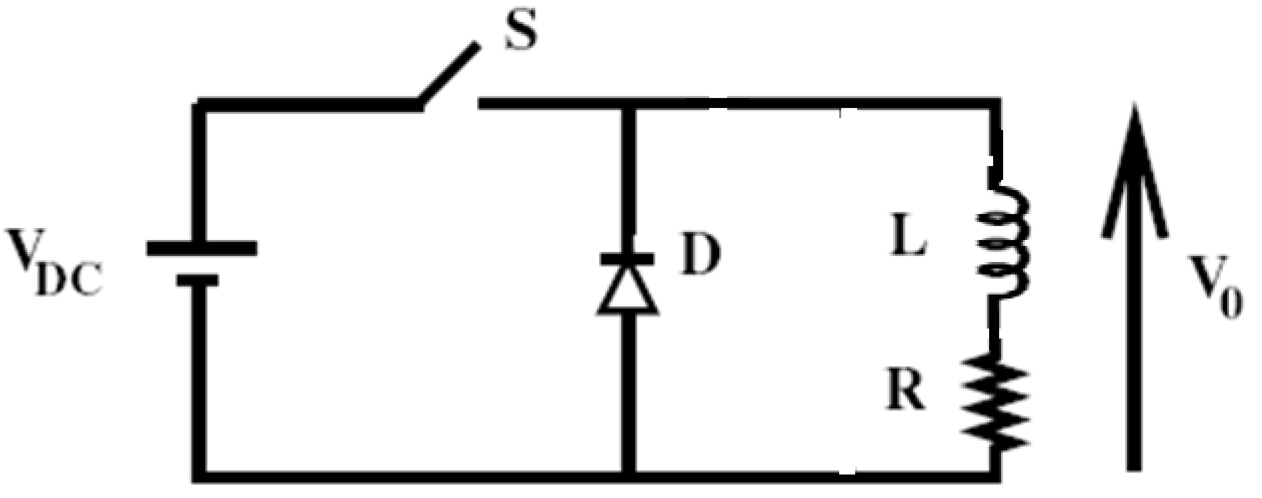


DC to DC Buck converter

- o/p voltage with discontinuous conduction
- $(V_{DC}-V_O)\,DT = V_O\,(\beta-D)\,T$
- $(V_{DC}-V_O)\,D = V_O\,(\beta-D)$
- $V_{DC}\,D = V_O\,\beta$
- $V_O= DV_{DC}/\,\beta$

DC to DC Buck converter

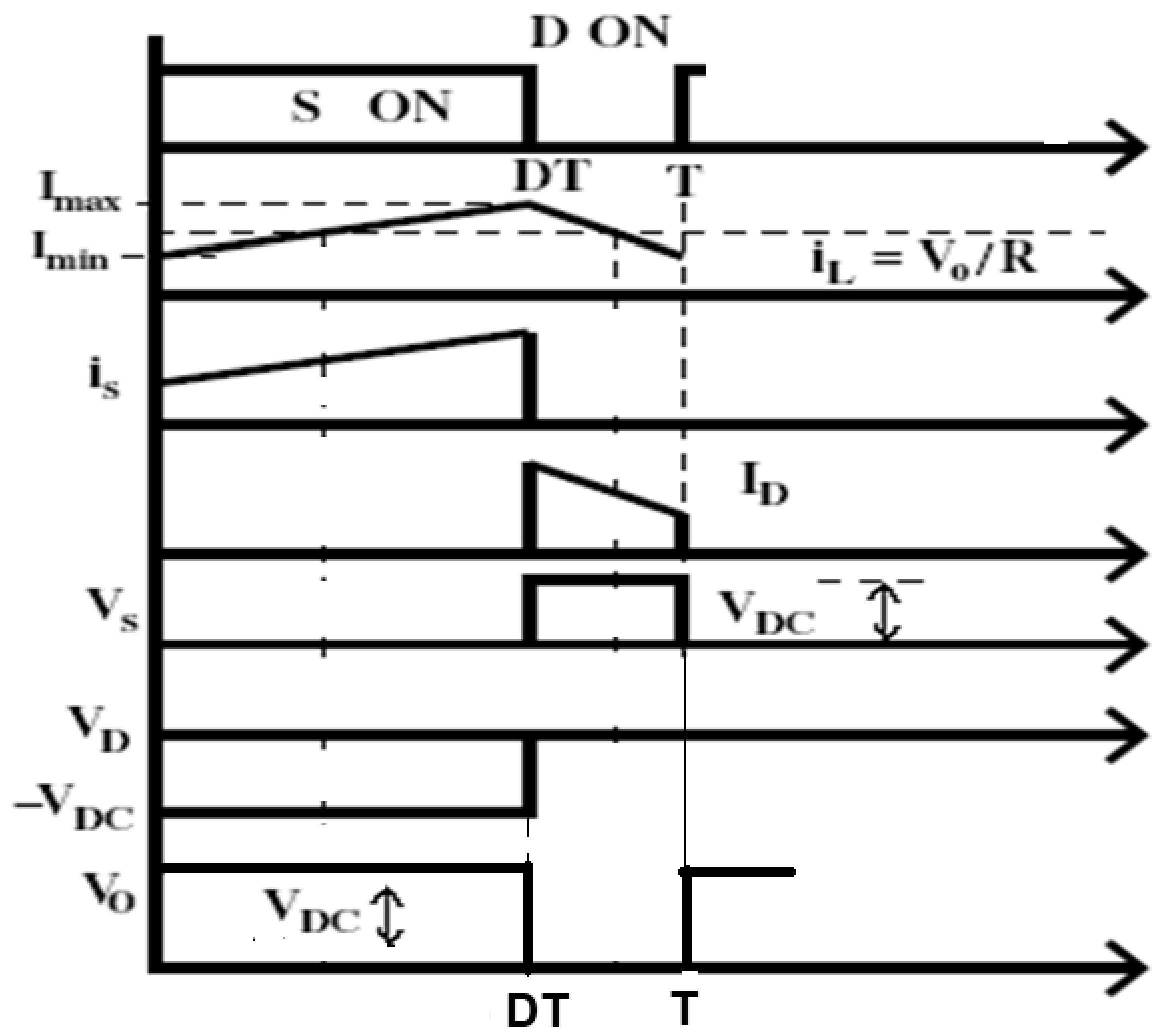
- Type A chopper
- In some applications LC filter is not required



- In this case load is RL load

Type A chopper

- Waveforms

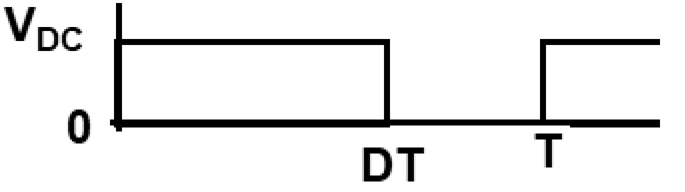


- $$V_O = \frac{D\,T\,V_{DC}}{T}$$

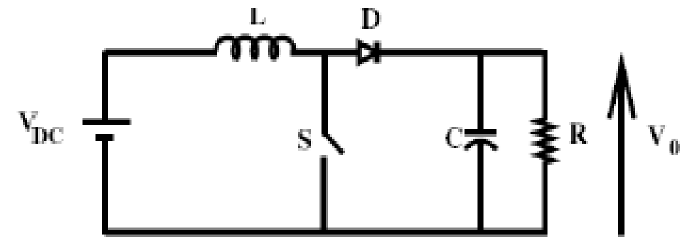
$$V_O = D\,V_{DC}$$

Type A chopper : Numerical Problem

- Type A chopper is supplied from 100 V DC supply and is connected to R =10 Ω and operating at 0.7 duty cycle. Determine i) average DC voltage ii) Power dissipated in R load and iii) ripple content in DC O/P voltage.
- Average voltage = 70 V
- Rms voltage =83.66 V
- Form factor = 83.66/70 = 1.195
- Ripple content = $\sqrt{1.195^2 - 1}$ = 0.6542
- % ripple = 65.42%
- Power dissipated in R Load = Vdc(rms)^2/R
- Power dissipated in R load = 699.89 W



Boost Converter : Continuous Mode

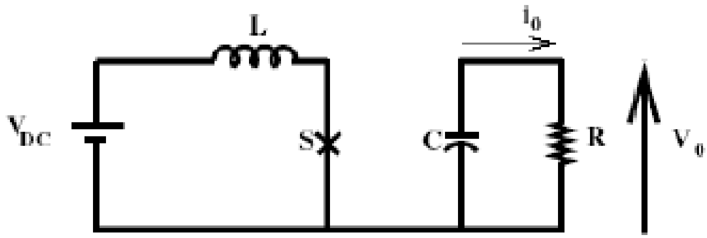


Boost Converter

All components are ideal.

V_0 & V_{DC} are constant and ripple free.

Close S : for DT

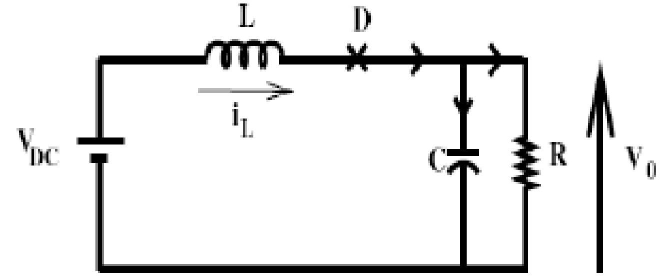


$V_L = V_{DC}$

$\therefore\ i_L \uparrow$ linearly.

$$i_0 = -C\frac{dV_0}{dt} = \frac{v_0}{R}$$

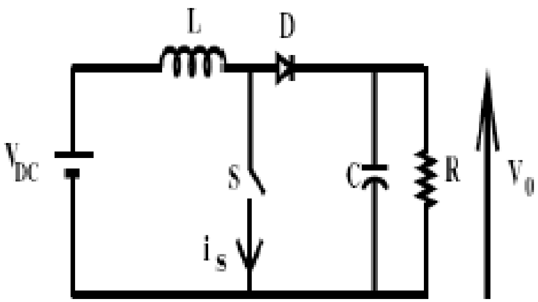
Open S

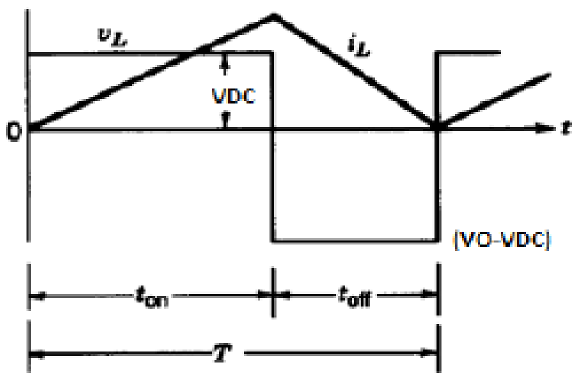


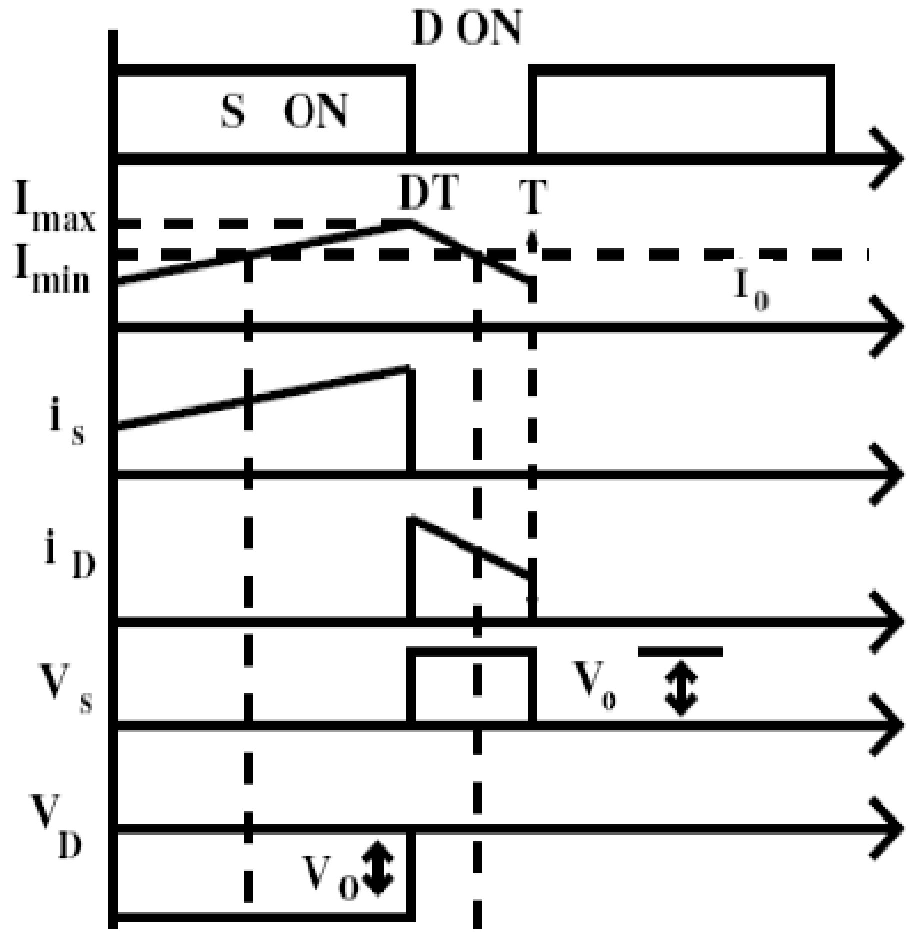
$v_L = V_{DC} - V_0$

$$C\frac{dV_C}{dt} + \frac{V_0}{R} = i_L$$

Boost Converter : Continuous mode



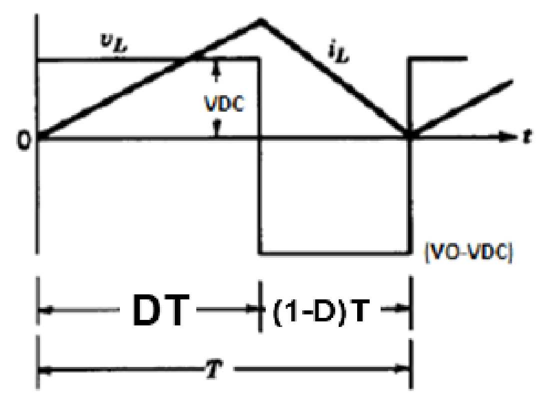




Source current and Inductor current is same

Boost Converter : continuous Mode

- Average Voltage drop across L is zero
- $V_{DC}\,DT = (V_O - V_{DC})(1-D)T$
- $V_{DC}\,D = (V_O - V_{DC})(1-D)$
- $V_{DC}\,D = V_O\,(1-D) - V_{DC} + V_{DC}\,D$
- $V_O\,(1-D) = V_{DC}$
- $V_O = V_{DC}/(1-D)$



Boost Converter : Continuous Mode

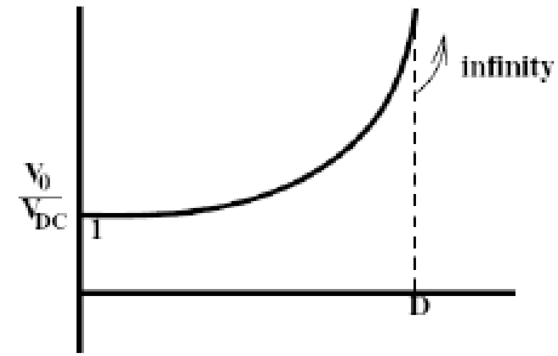
Capacitor supplies power to the load.

$V_S = 0$

$V_D = -V_0$

avg. voltage across 'L' = 0.

$$V_0 = \frac{V_{DC}}{(1-D)}$$



System is loss-less.

$$V_{DC}\, I_S = V_0\, I_0$$

$$\therefore\ I_S = \frac{V_0}{V_{DC}} * I_0 = \frac{I_0}{(1-D)}$$

Boost Converter : Critical load Resistance

- $I_s = I_O/(1-D)$
- $I_O = V_O/R \quad = V_{DC}/[(1-D)R]$

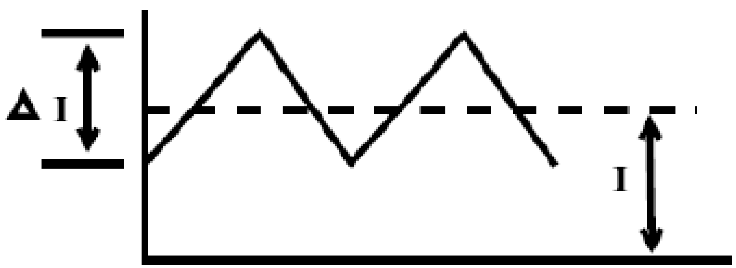
- $I_s = V_{DC}/[(1-D)^2R]$

- $I_{max} = I_{min} + (V_{DC}/L)\ DT$
- $I_{max} - I_{min} = (V_{DC}/L)\ DT$
- $\Delta\ I_L \ = (V_{DC}/L)\ DT$

Boost Converter : Critical load Resistance

Discontinuous current:

Av. value of source I = inductor $I = \dfrac{V_{DC}}{R(1-D)^2}$



The above I is always $+$ve

if $\quad > \dfrac{\Delta I}{2}$

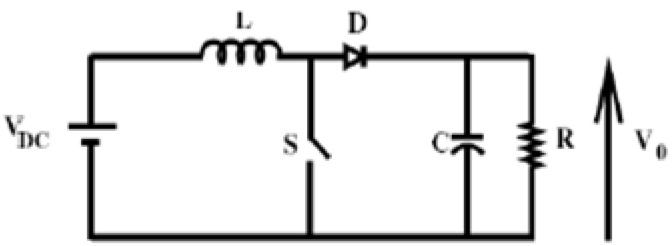
$> \dfrac{V_{DC}}{2\,L} DT$

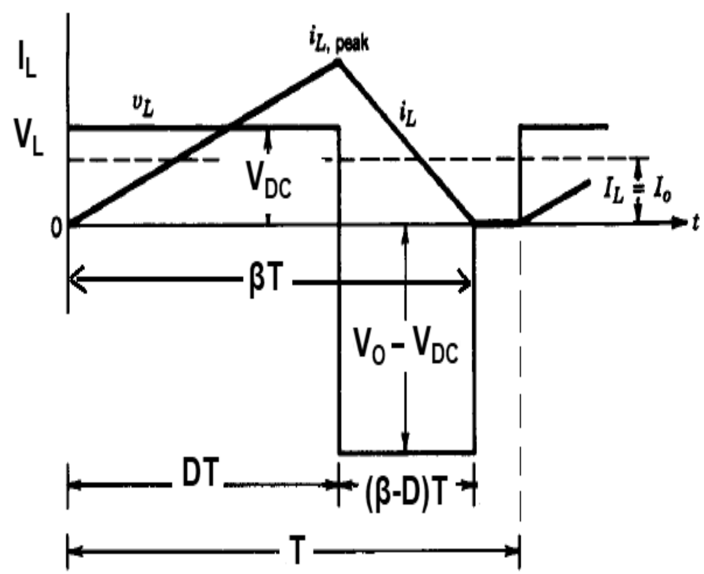
$\therefore R_{CR} \le \dfrac{2L}{(1-D)^2 DT}$

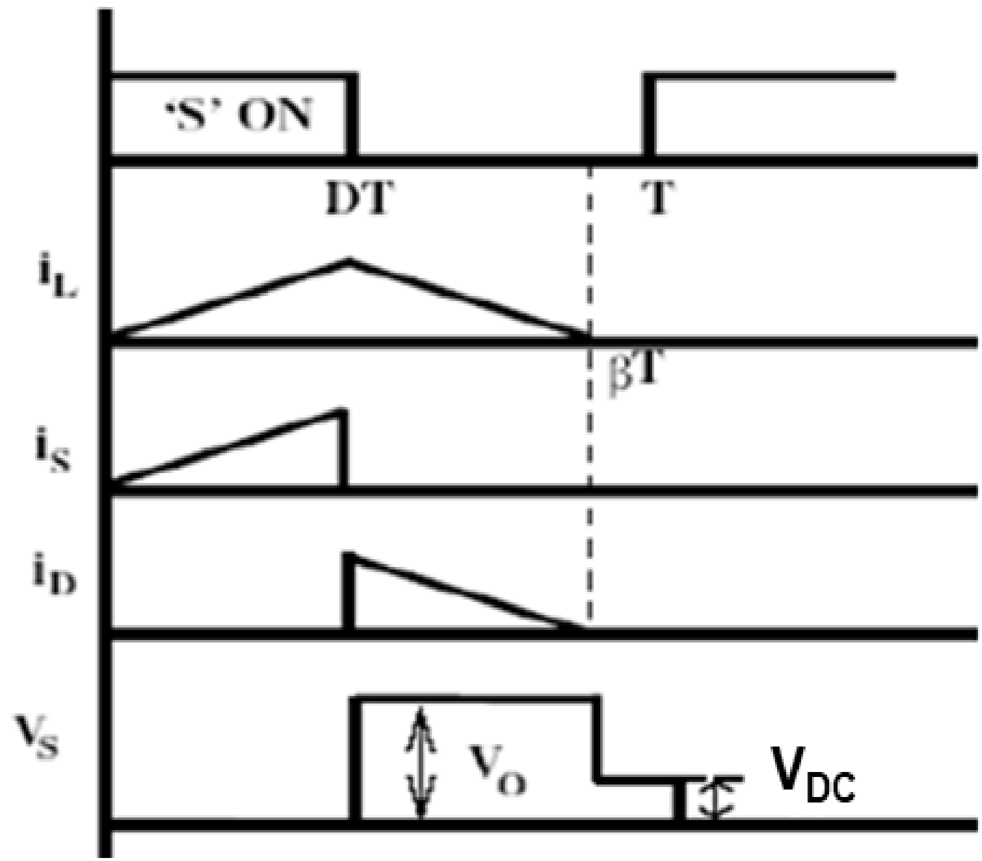
If load $R > R_{CR}$

Inductor $I \Rightarrow$ Discontinuous

Boost Converter : Discontinuous mode





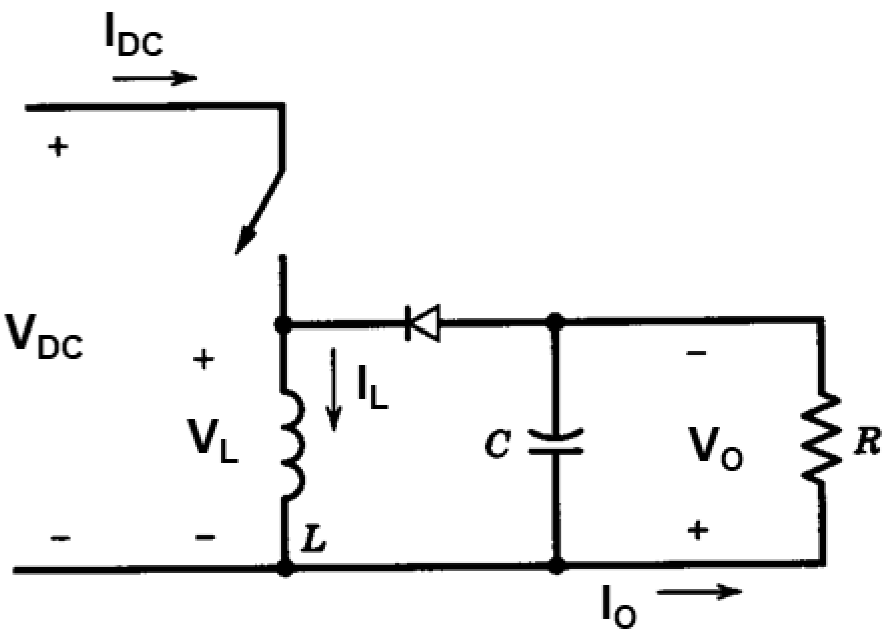


Boost Converter : Discontinuous Mode

- Average Voltage drop across L is zero
- $V_{DC}\,DT = (V_O - V_{DC})(\beta - D)T$
- $V_{DC}\,D = (V_O - V_{DC})(\beta - D)$
- $V_{DC}\,D = V_O\,(\beta - D) - \beta\,V_{DC} + V_{DC}\,D$
- $V_O\,(\beta - D) = \beta\,V_{DC}$
- $V_O = \beta/(\beta - D)\,V_{DC}$

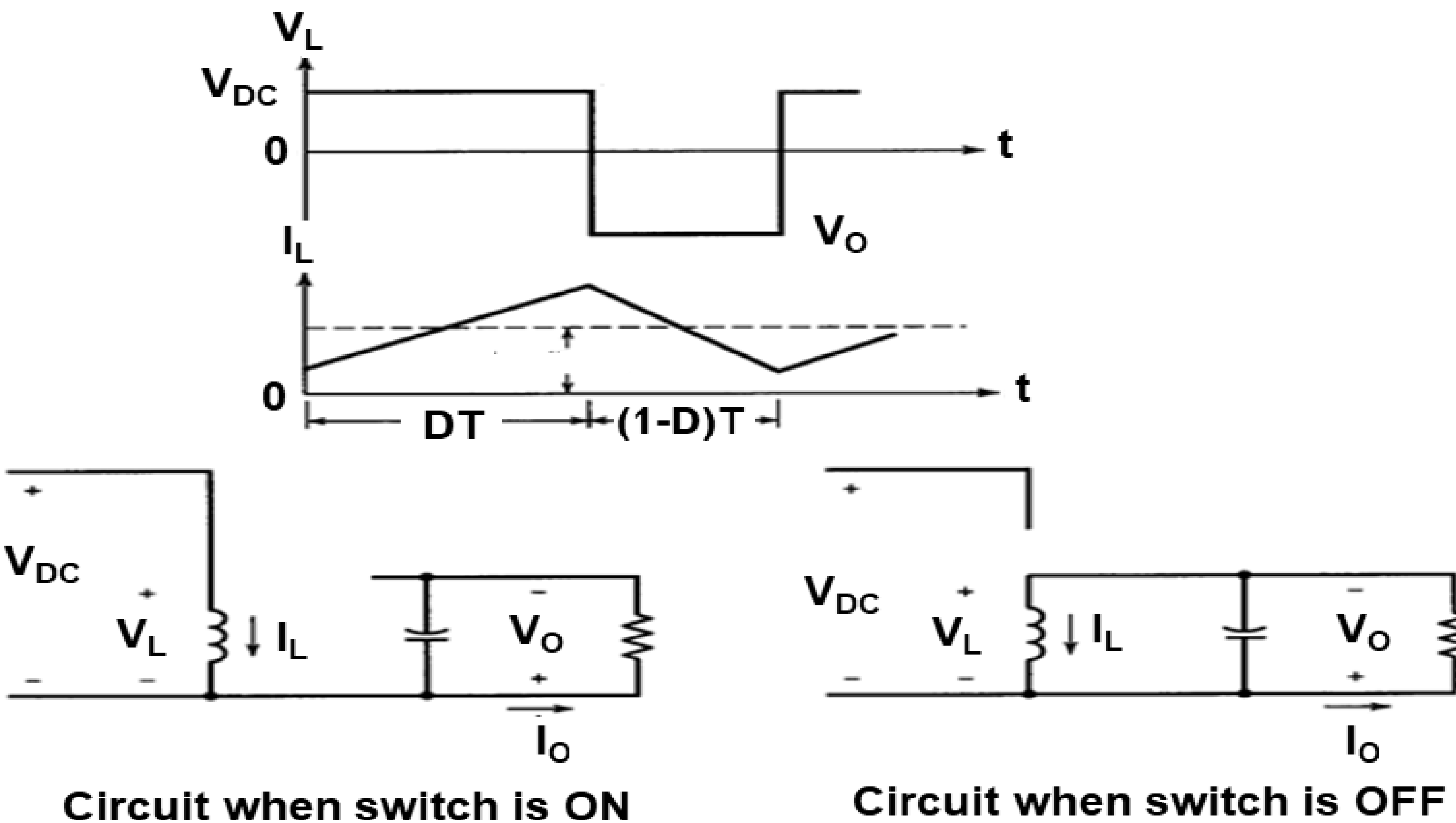
Buck-boost DC to DC Converter

- Output voltage can be higher or lower than input voltage
- Provides –Ve polarity O/P



Buck-boost DC to DC Converter

- Continuous conduction mode



Buck-boost DC to DC Converter

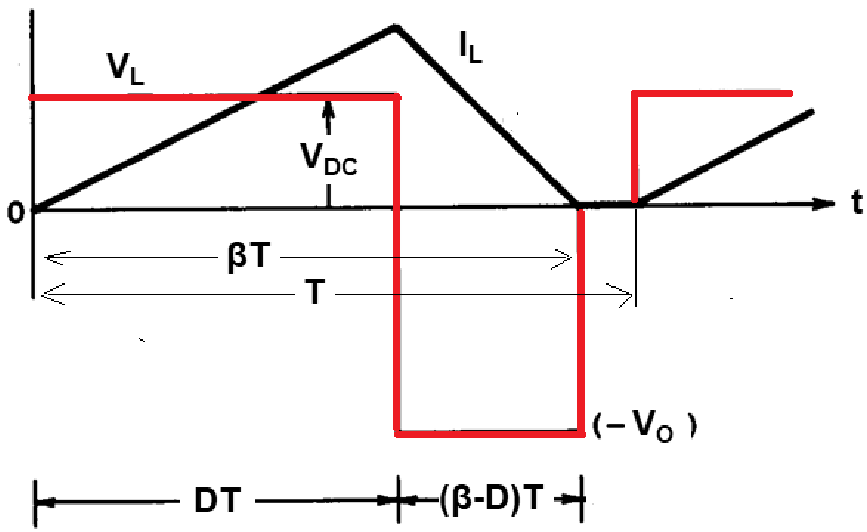
- Average voltage across inductor is zero.

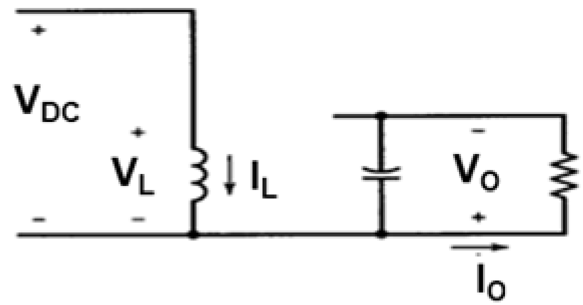
- $V_{dc} D T = V_o (1-D)T$
- $V_o = D/(1-D)\, V_{dc}$
- $V_o/V_{dc} = D/(1-D)$

- $I_o/I_d = (1-D)/D$
- Source current is discontinuous

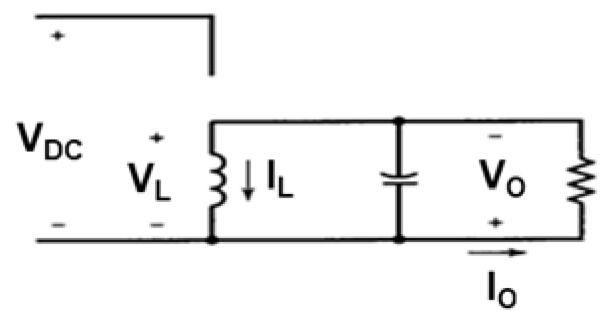
Buck-boost DC to DC Converter

- Discontinuous conduction





Circuit when switch is ON



Circuit when switch is OFF

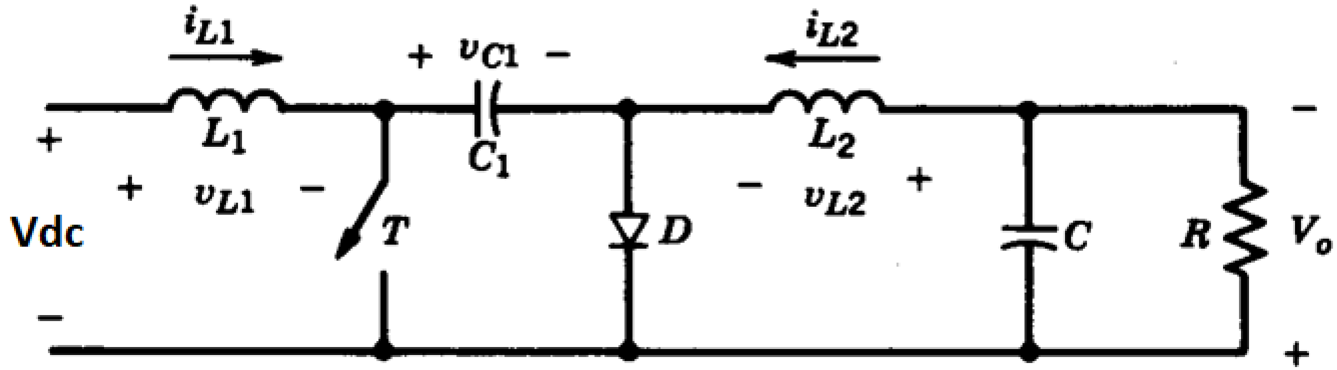
Buck-boost DC to DC Converter

- Average voltage across inductor is zero.
- $V_{DC}\,D\,T = V_O\,(\beta\text{-}D)\,T$
- $V_{DC}\,D = V_O\,(\beta\text{-}D)$

$$V_O = \frac{D}{(\beta\text{-}D)}\,V_{DC}$$

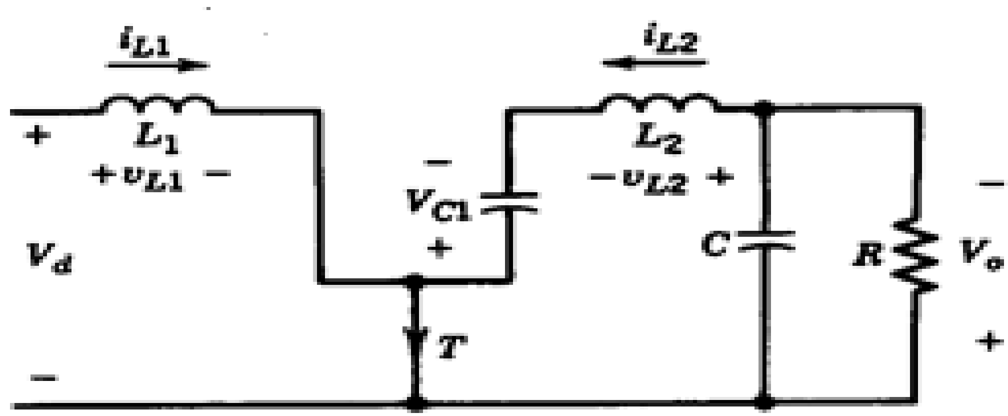
Cuk Converter

- Output voltage can be lower or higher than input voltage
- It provides negative polarity output
- Average voltage V_{L1} and V_{L2}=0
- $V_{C1} = V_{DC} + V_O$
- V_{C1} remains approximately constant



Cuk Converter

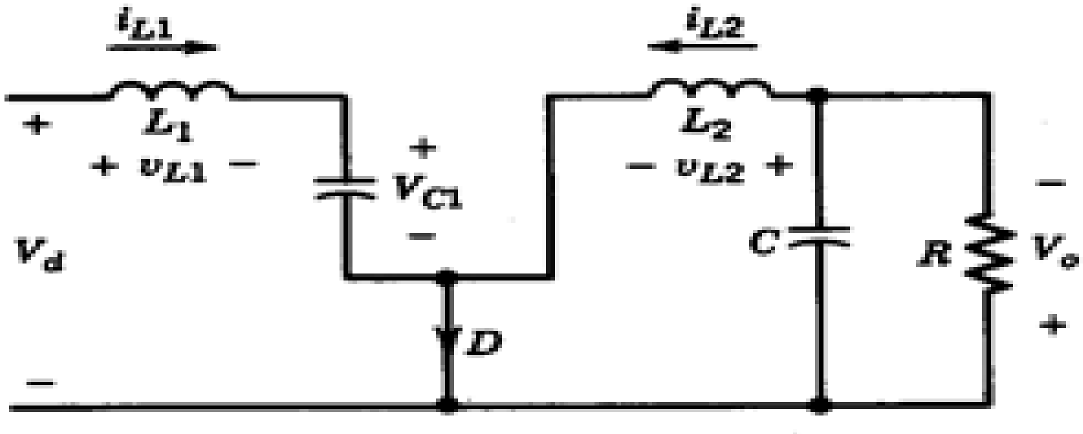
- When switch is on



- Current through L_1 will increase. $V_{L1} = V_d$
- V_{C1} is greater than V_O hence current though L_2 also increases. $V_{L2} = V_{C1} - V_O$
- L_1 receives energy from source
- C_1 will supply energy to load and L_2

Cuk Converter

- When switch is off

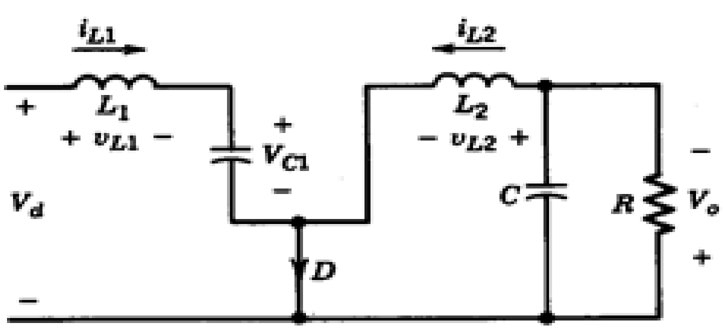


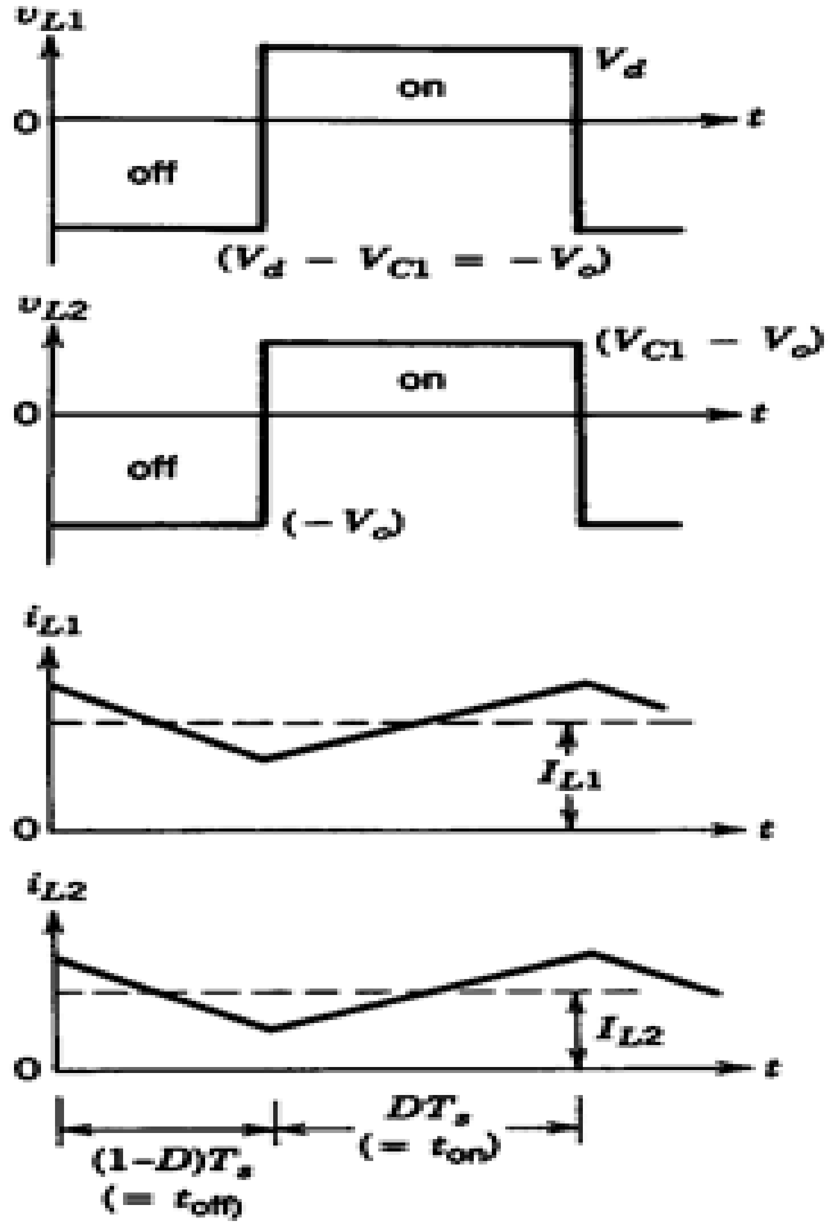
- L_1 will charge to C_1, I_{L1} decreases
- Voltage across $L_1 = -(Vd-V_{C1})$
- L_2 provides energy to load
- Voltage across $L_2 = -V_O$

Cuk Converter

- When S is OFF

- Capacitor voltage is assumed constant

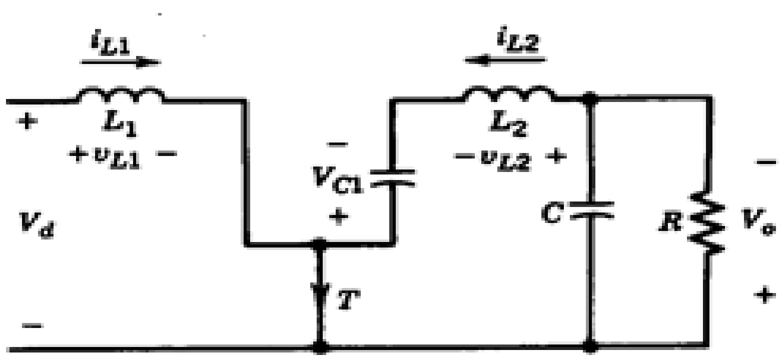


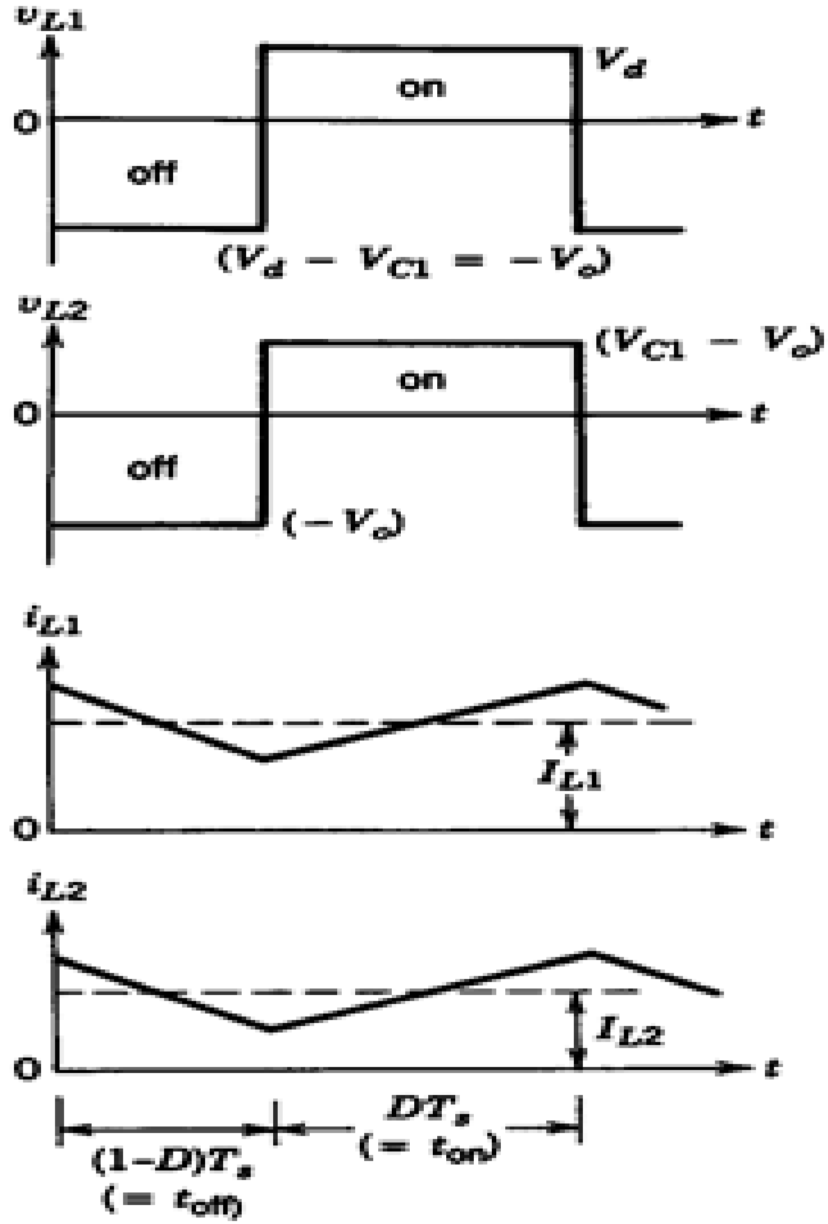


Cuk Converter

- When S is ON

- Capacitor voltage is assumed constant





Cuk Converter

- It provides negative polarity output
- When switch is on
- $V_{L1} = V_d$ and $V_{L2} = V_{C1} - V_O$
- When switch is off
- $V_{L1} = V_{C1} - V_d$ and $V_{L2} = V_O$
- Average voltage drop across L_1 is zero
- $V_d D T = (V_{C1} - V_d)(1-D) T$
- $V_{C1} = V_d /(1-D)$

Cuk Converter

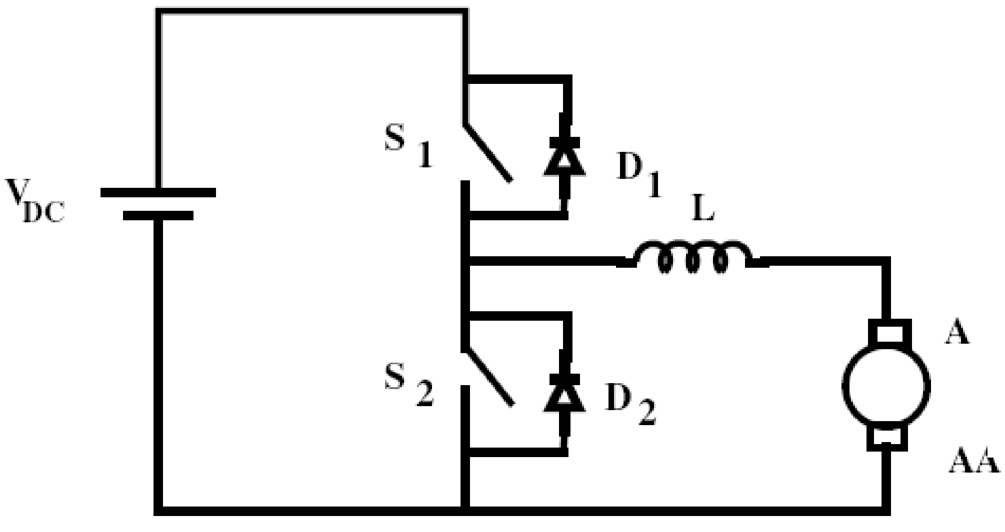
- Average voltage drop across L_2 is zero
- $(V_{C1}-V_O)\,DT = V_O(1-D)\,T$
- $V_O = D\,V_{C1}$
- Substuting value of V_{C1}

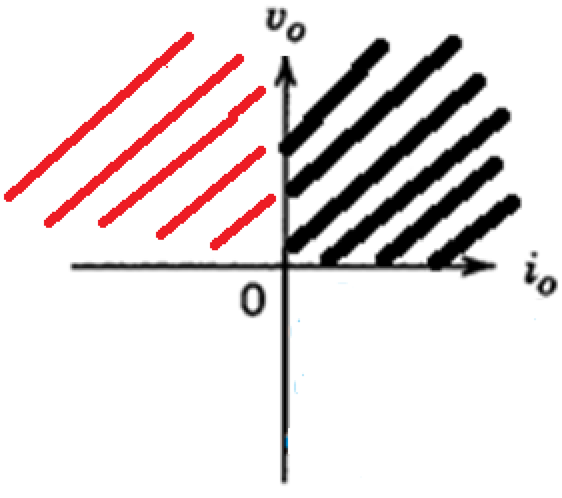
$$V_O = \frac{D}{(1-D)}\,Vd$$

- It is a buck boost converter

Two quadrant DC to DC Converter

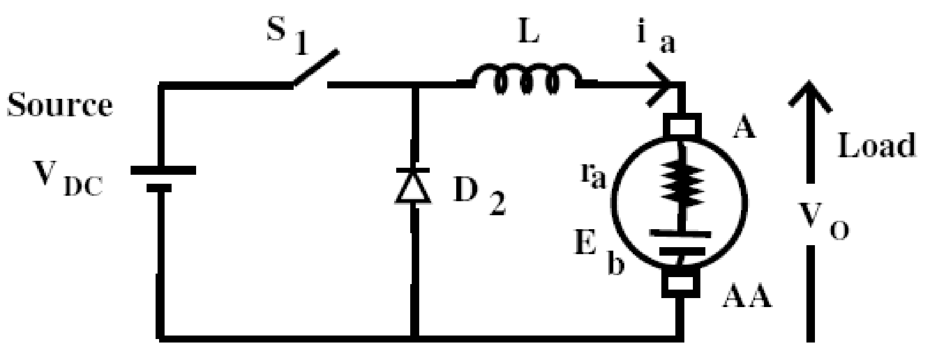
- Two quadrant operation

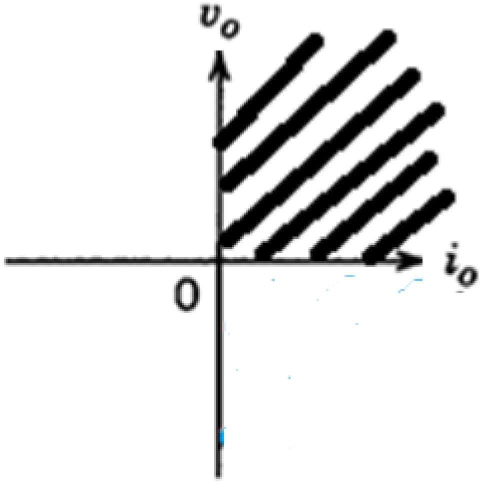




Two quadrant DC to DC Converter

- First quadrant operation
- S_2 is kept off and S_1 is controlled

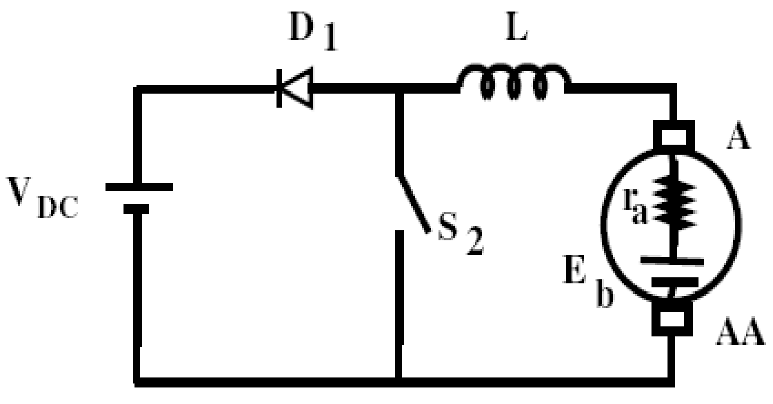


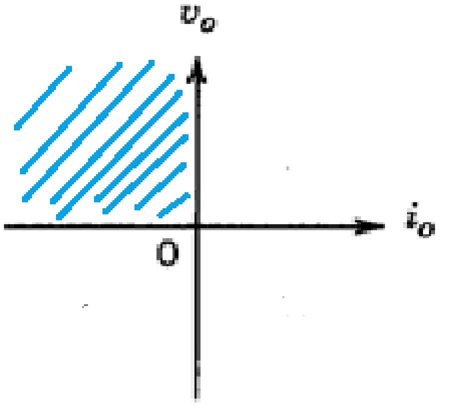


- It works as a buck converter.
- Output voltage supplied to armature of motor is controlled by controlling duty ratio.

Two quadrant DC to DC Converter

- Second Quadrant operation
- S_1 is kept off and S_2 is controlled

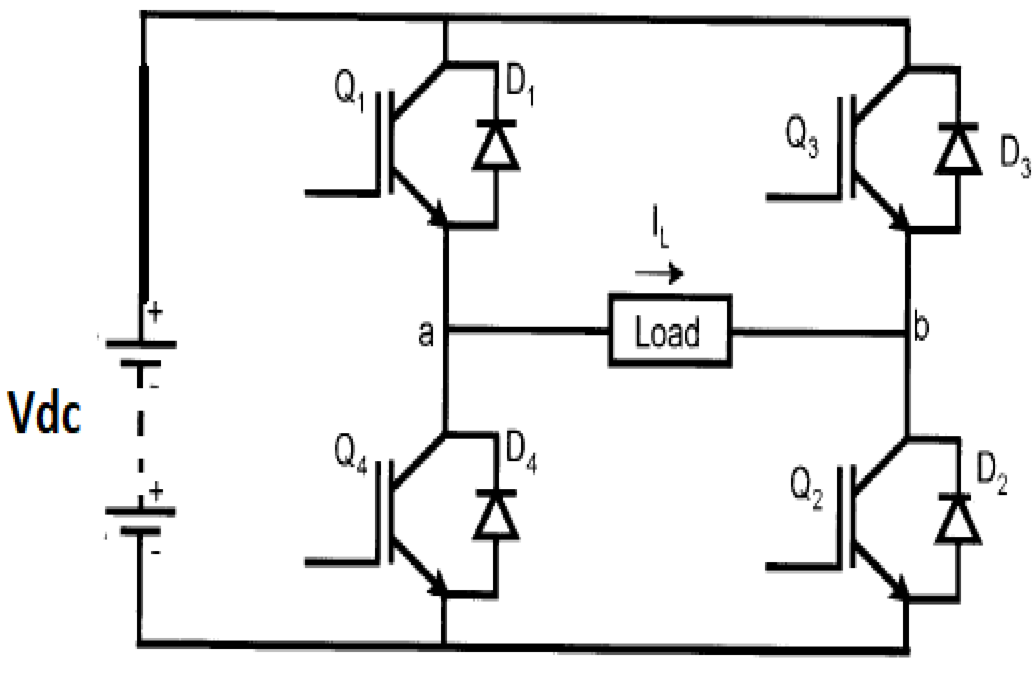


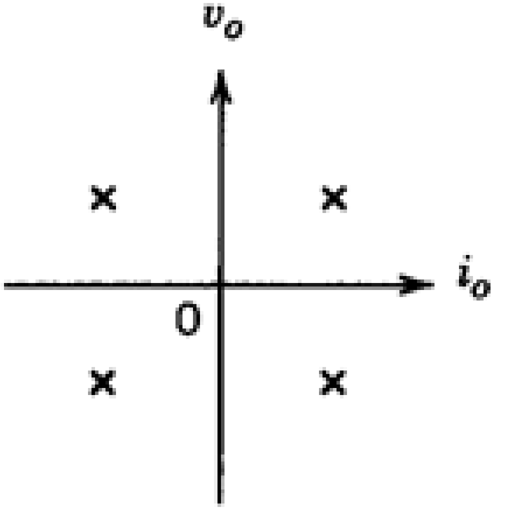


- It works as a boost converter, providing regenerative braking of separately excited DC Motor

Four quadrant DC to DC Converter

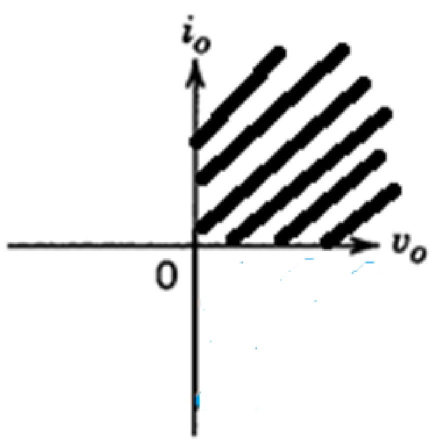
- It is also called as class E chopper

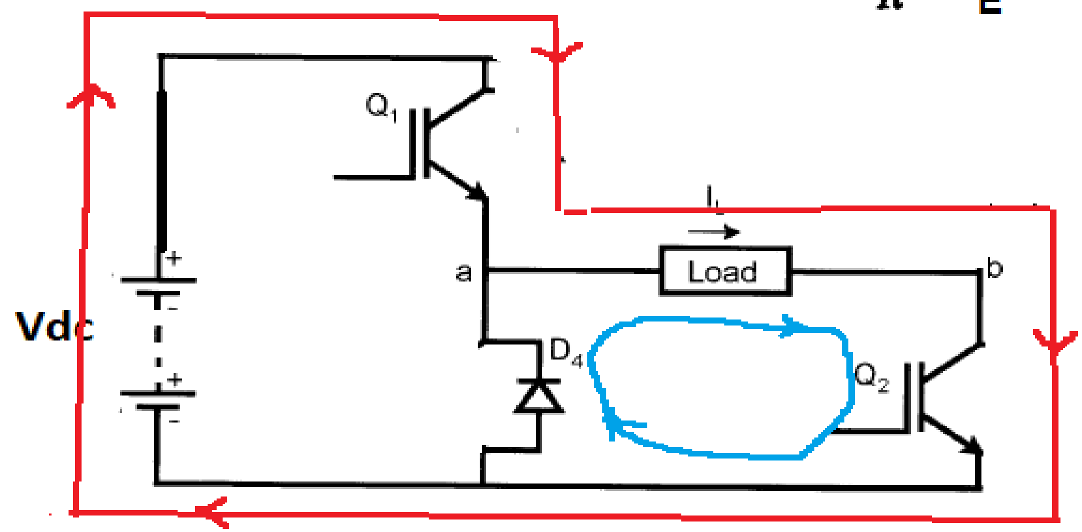




Four quadrant DC to DC Converter

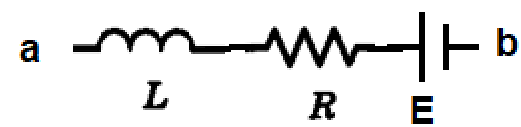
- First quadrant operation
- Works as buck converter
- Q2 is continuously on , Q1 is controlled
- Q3 and Q4 are continuously off

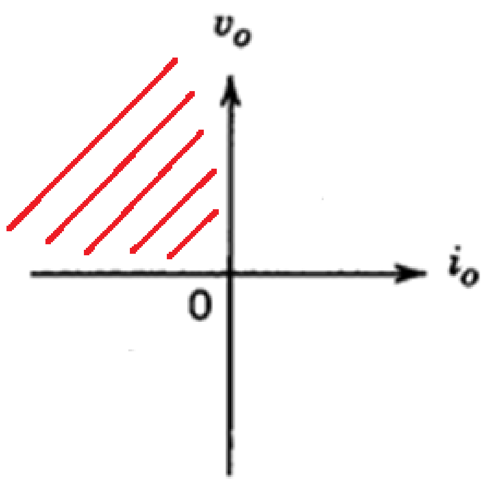


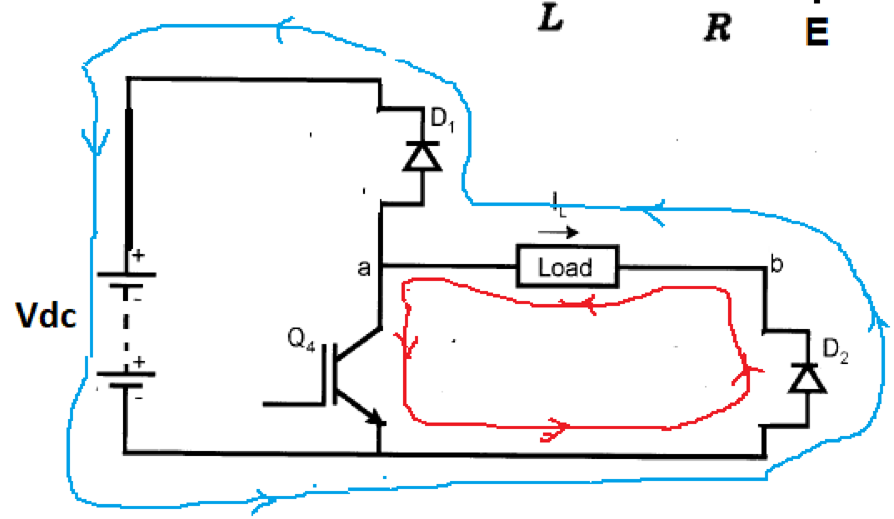


Four quadrant DC to DC Converter

- Second quadrant operation
- Load should be RLE type
- Q4 is controlled, Q1,Q2, Q3 continuously off
- Works as boost converter. feeding power back to supply

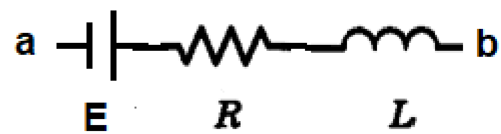


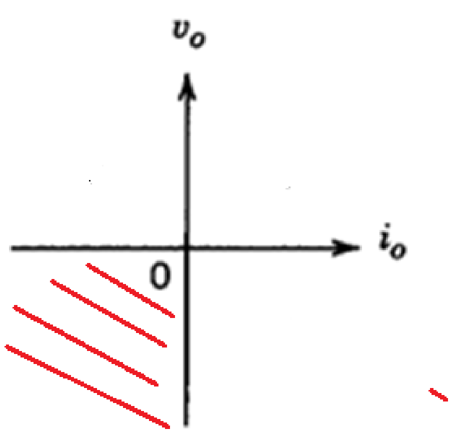


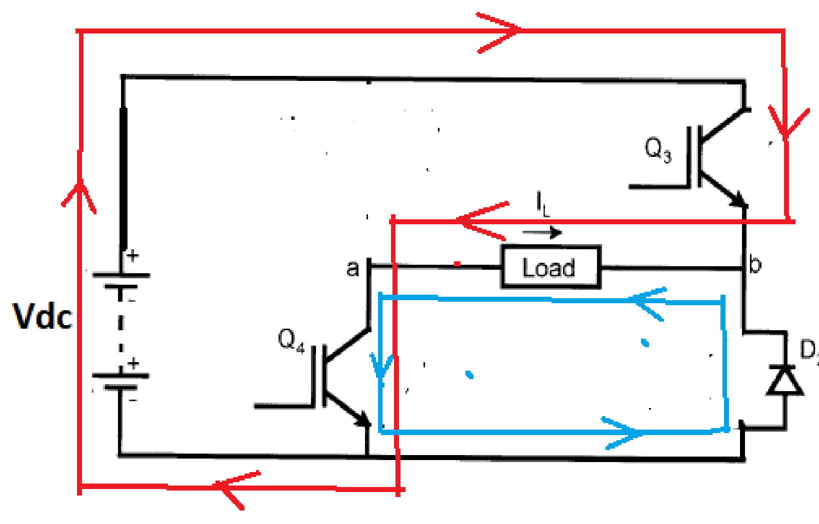


Four quadrant DC to DC Converter

- Third quadrant operation
- Works as buck converter
- Q4 is continuously on , Q3 is controlled
- Q1and Q 2 are continuously off.

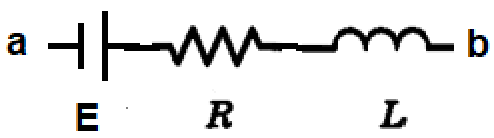


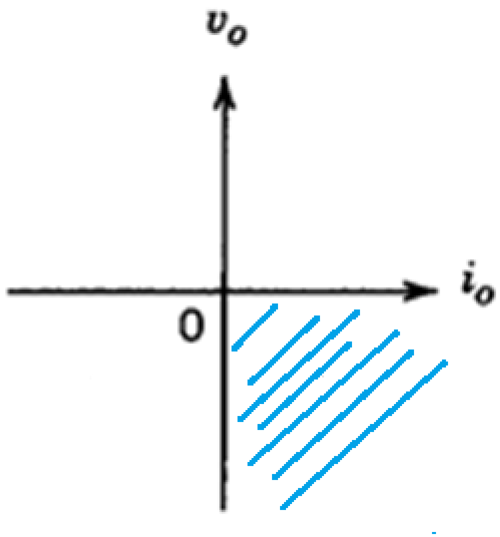


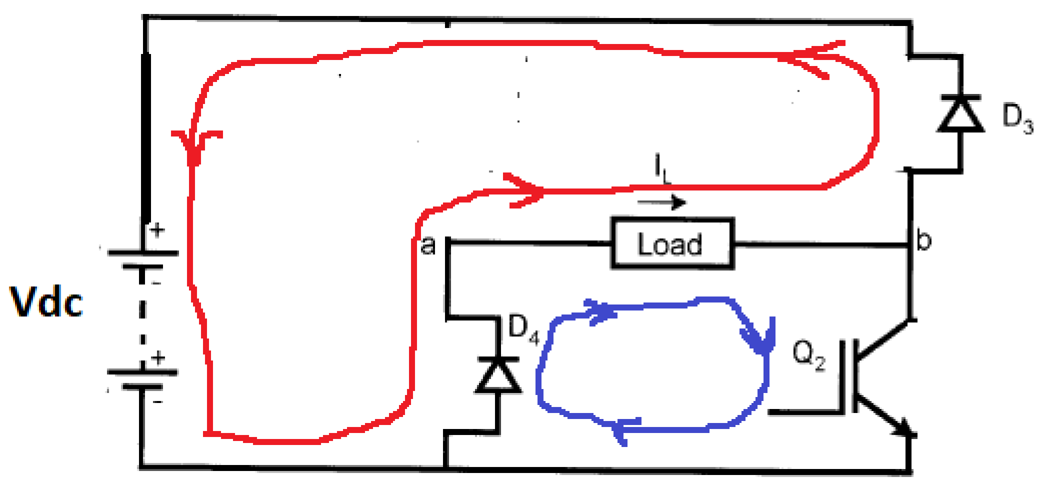


Four quadrant DC to DC Converter

- fourth quadrant operation
- Works as boost converter
- Q2 is controlled. Q1,Q3 and Q4 are off.
- Load should be RLE

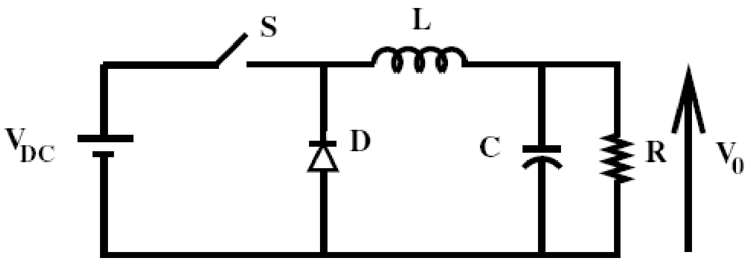


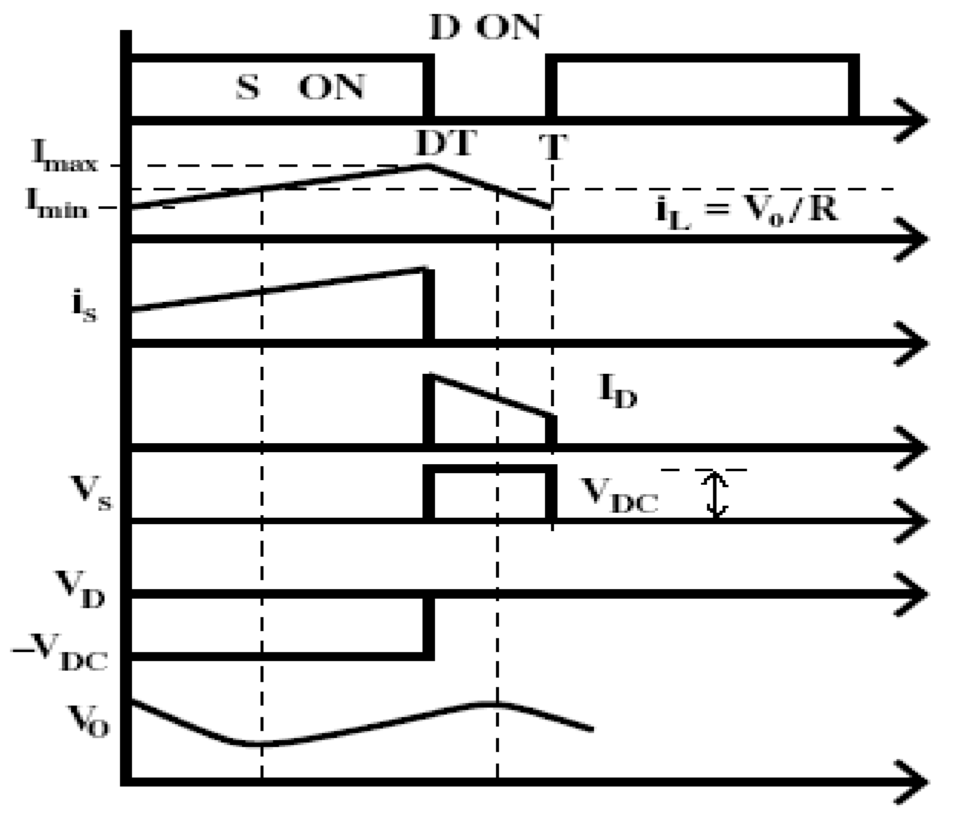




DC to DC Buck Converter

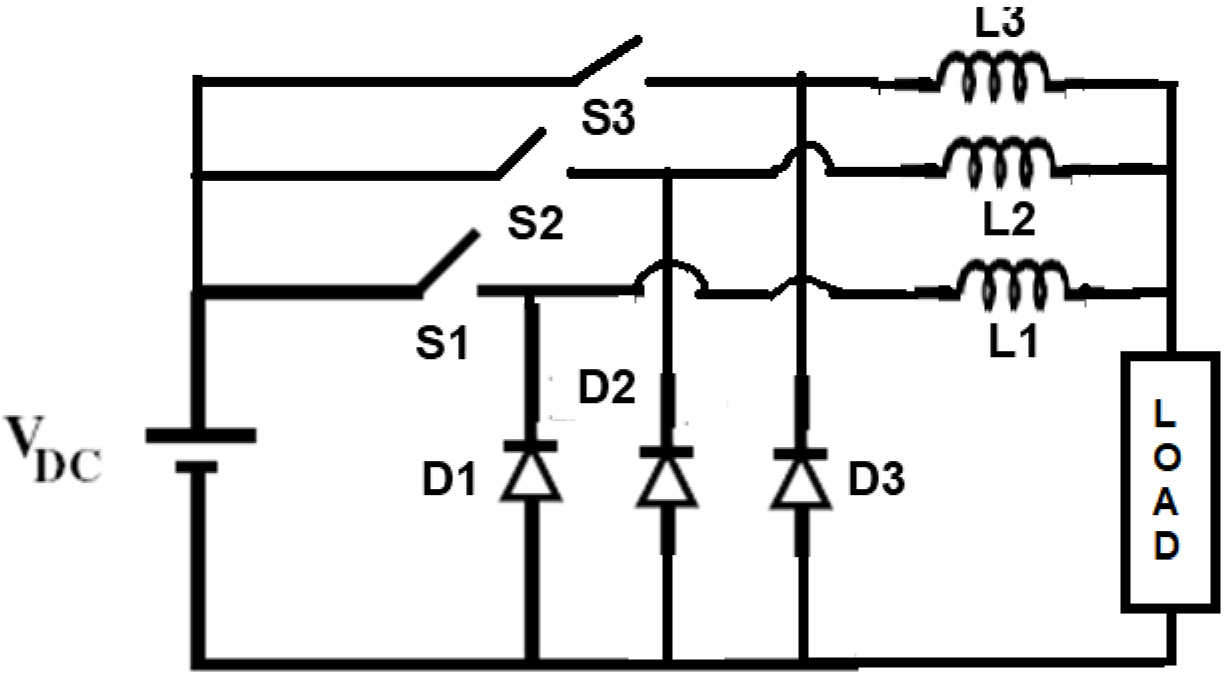
- Assume the inductor current (I_L) is continuous





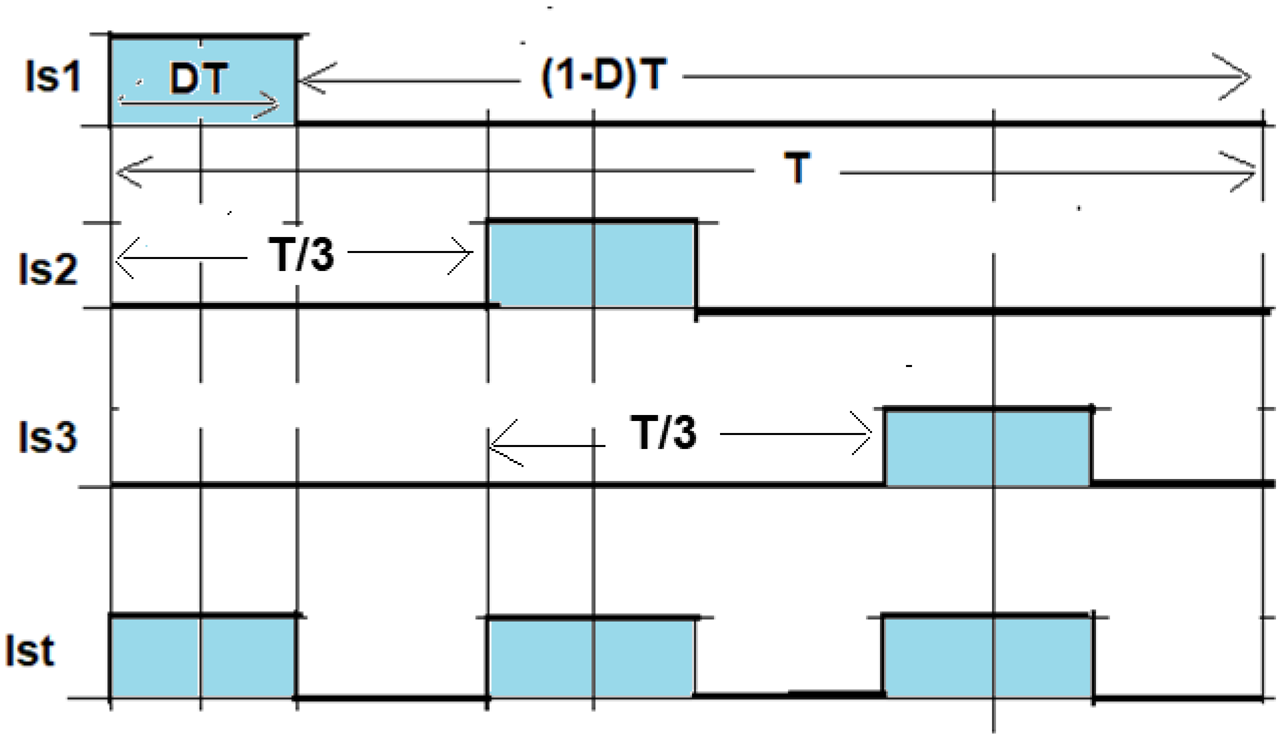
Multi Phase choppers

- Type A chopper connected in parallel to supply a common load
- Any numbers of type A can be connected in parallel



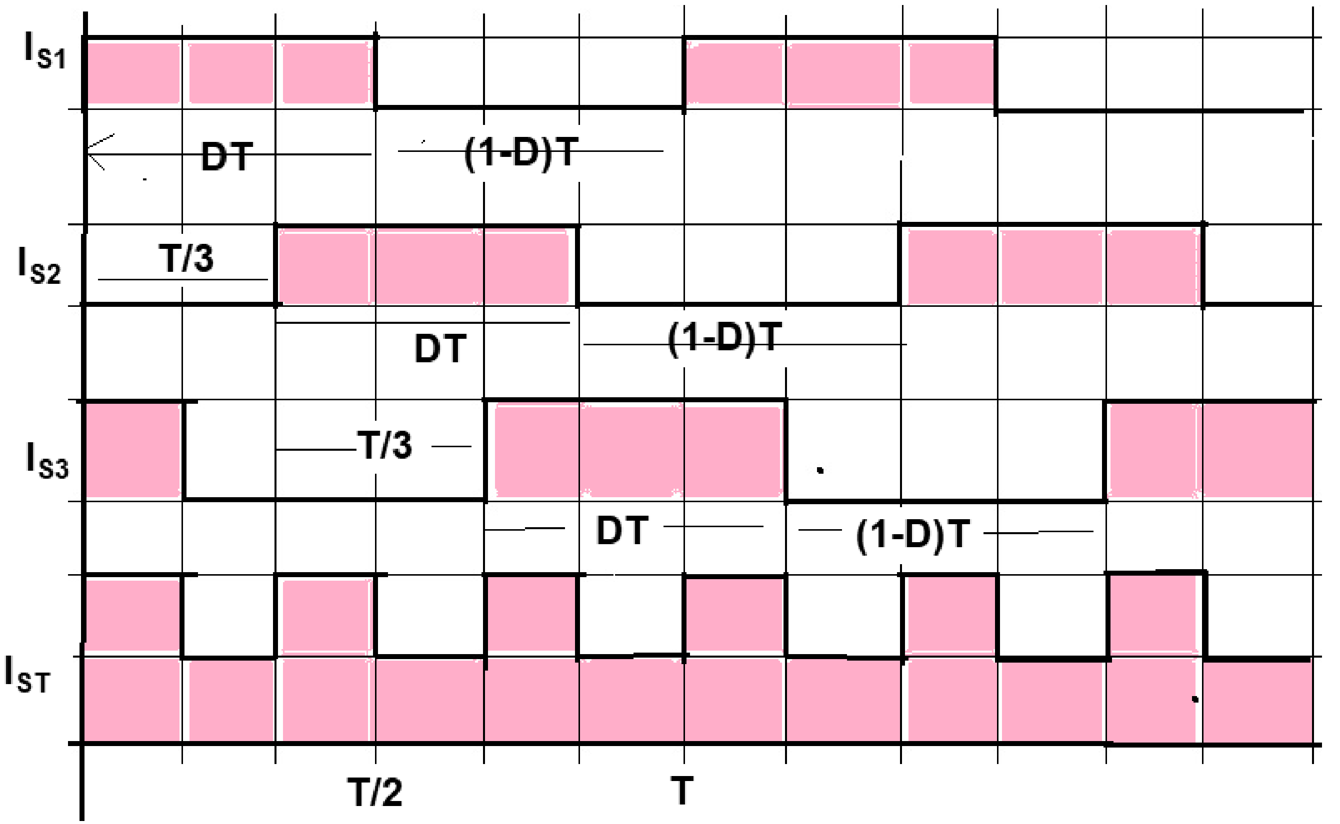
Multi Phase choppers : Operating Modes

- In-phase operation
- Phase shifted operation D= 0.15



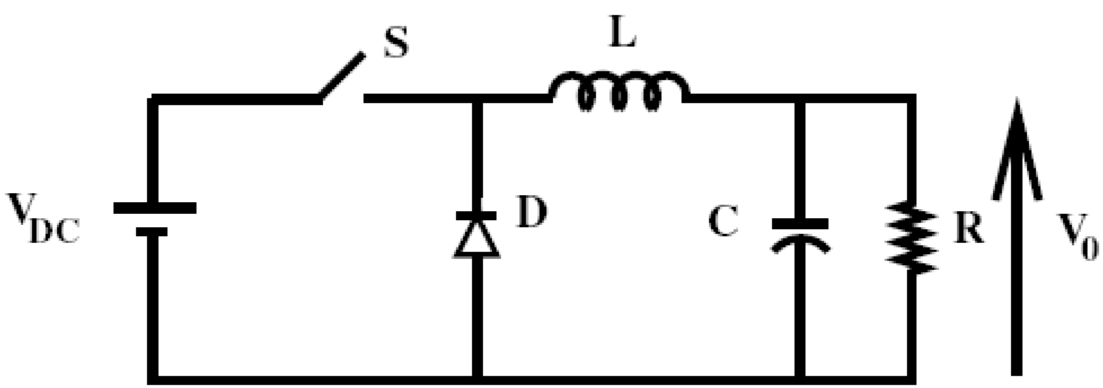
Multi Phase choppers : Operating Modes

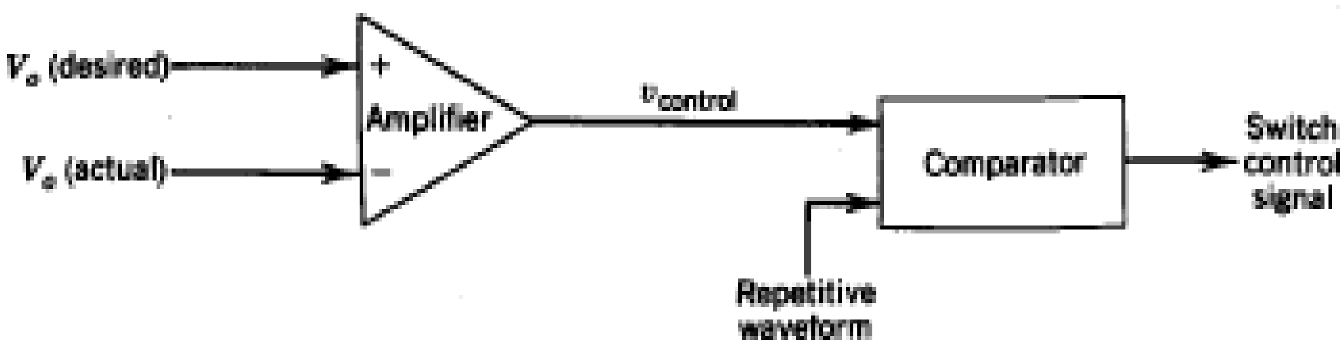
- Phase shifted operation D= 0.5



Close loop control

- **Buck Converter**

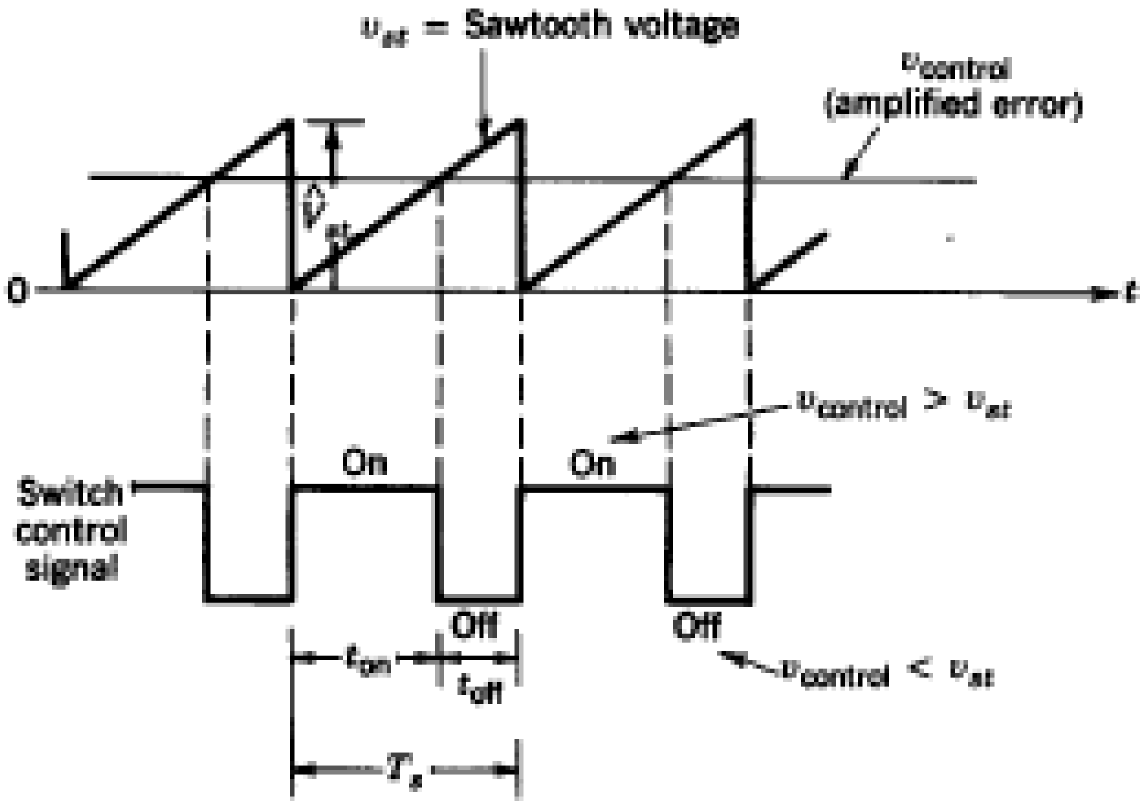




- **Amplifier => PI OR PID controller**

Close loop control

- **Buck Converter**



Conclusion

- DC to DC converter should be operated at high switching frequency to reduce the size of L and C
- DC to DC converters finds the application in dc servo drives which requires very fast response.
- DC servo drives finds applications in robotics and position control.

THANKS !

Any Questions?

Close loop control

- V_L I_L V_{DC} V_O I_O βT $(\beta\text{-}D)T$ D1 D2 D3 S1 S2 S3
- DT
- (1-D)T L1 L2 L3 T/3 I_{S1} I_{S2} I_{S3} I_{ST}
- 0 I_{DC}
- T T/2 DT (1-D)T
- Circuit when switch is ON

- Circuit when switch is OFF