UNIT-III

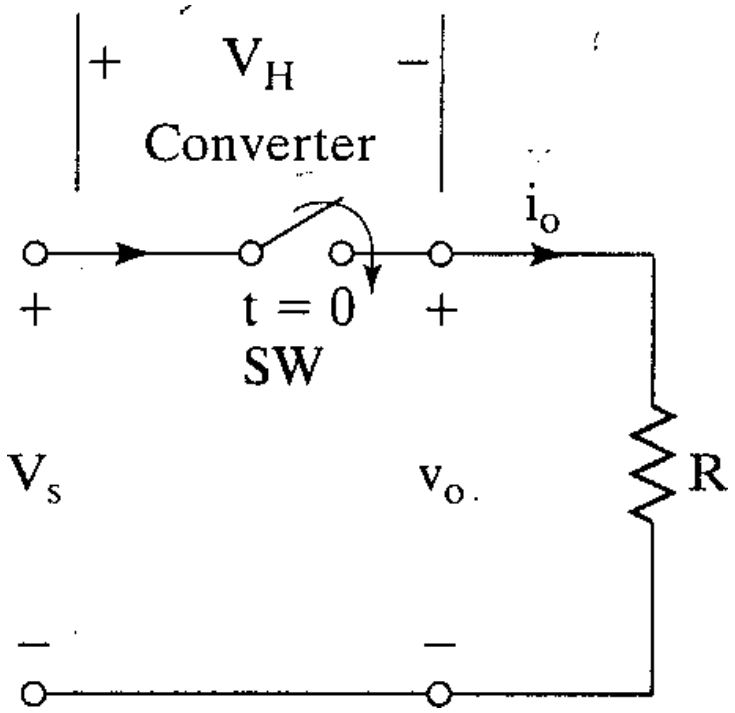
DC-DC Converters (Chopper/SMPS)

Prepared by
Ch. Prasanna.
Assistant Professor, EEE

DC-DC Converters

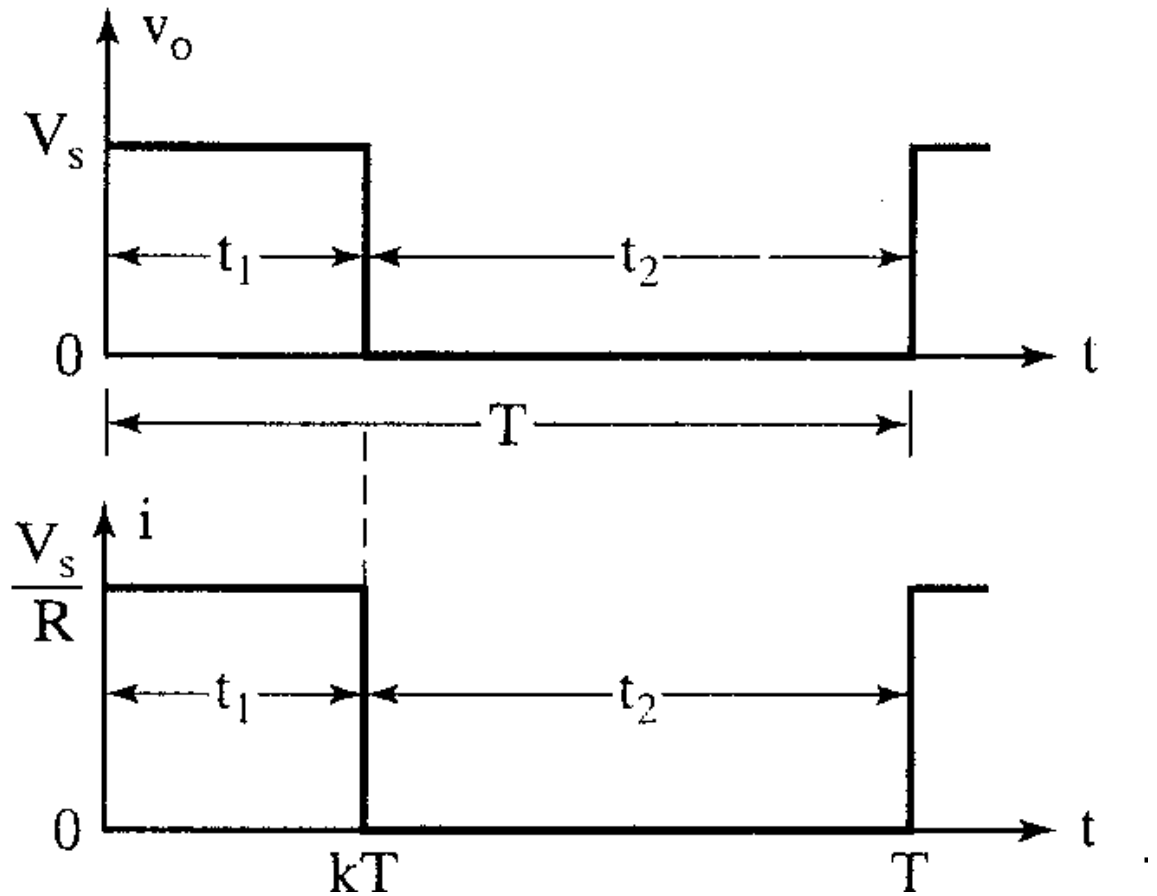
- Convert a fixed DC Source into a Variable DC Source
- DC equivalent to an AC transformer with variable turns ratio
- Step-up and Step-down versions
- Applications
  - Motor Control
  - Voltage Regulators

Step-down Operation

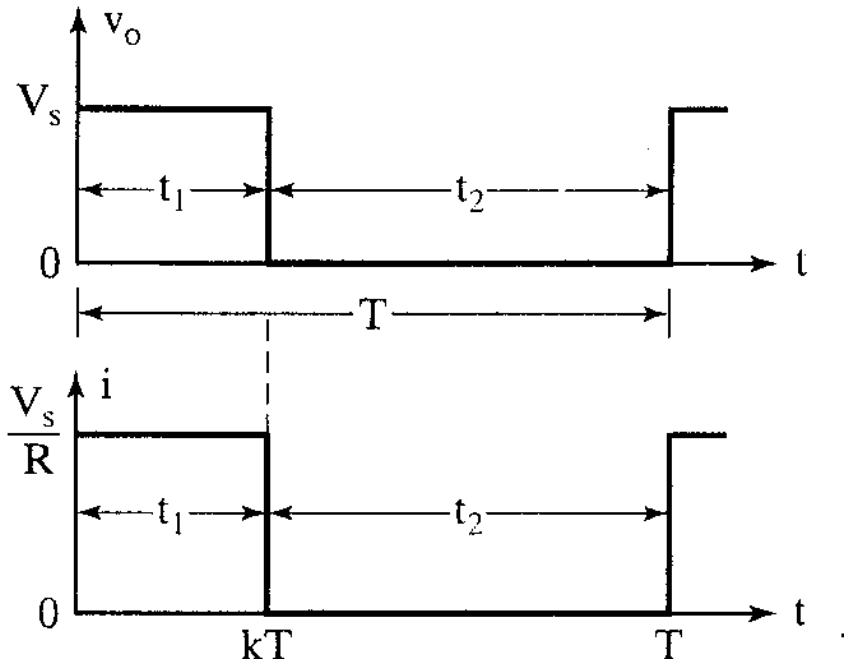


- Switch SW is known as a “Chopper”
- Use BJT, MOSFET, or IGBT
- Close for time t_1
  - V_S appears across R
- Open for time t_2
  - Voltage across R = 0
- Repeat
- Period $T = t_1 + t_2$

Waveforms for the Step-Down Converter



Average Value of the Output Voltage



$$V_a = \frac{1}{T}\int_0^{t_1} v_O dt$$

$$V_a = \frac{1}{T}\int_0^{t_1} V_S dt$$

$$V_a = \frac{t_1}{T}V_S = ft_1V_S$$

$$\boxed{V_a = kV_S}$$

Average Value of the Load Current

$$I_a = \frac{V_a}{R} = \frac{kV_S}{R}$$

$T = period$

$$k = \frac{t_1}{T} = dutycycle$$

$f = frequency$

rms Value of the output voltage

$$V_O = \left(\frac{1}{T} \int_0^{kT} v_O^2 dt \right)^{\frac{1}{2}}$$

$$V_O = \left(\frac{1}{T} \int_0^{kT} V_S^2 dt \right)^{\frac{1}{2}}$$

$$V_O = \sqrt{k} V_S$$

If the converter is “lossless”, $P_{in} = P_{out}$

$$P_{in} = \frac{1}{T}\int_0^{kT} v_O i dt$$

$$P_{in} = \frac{1}{T}\int_0^{kT} \frac{v_O^2}{R} dt$$

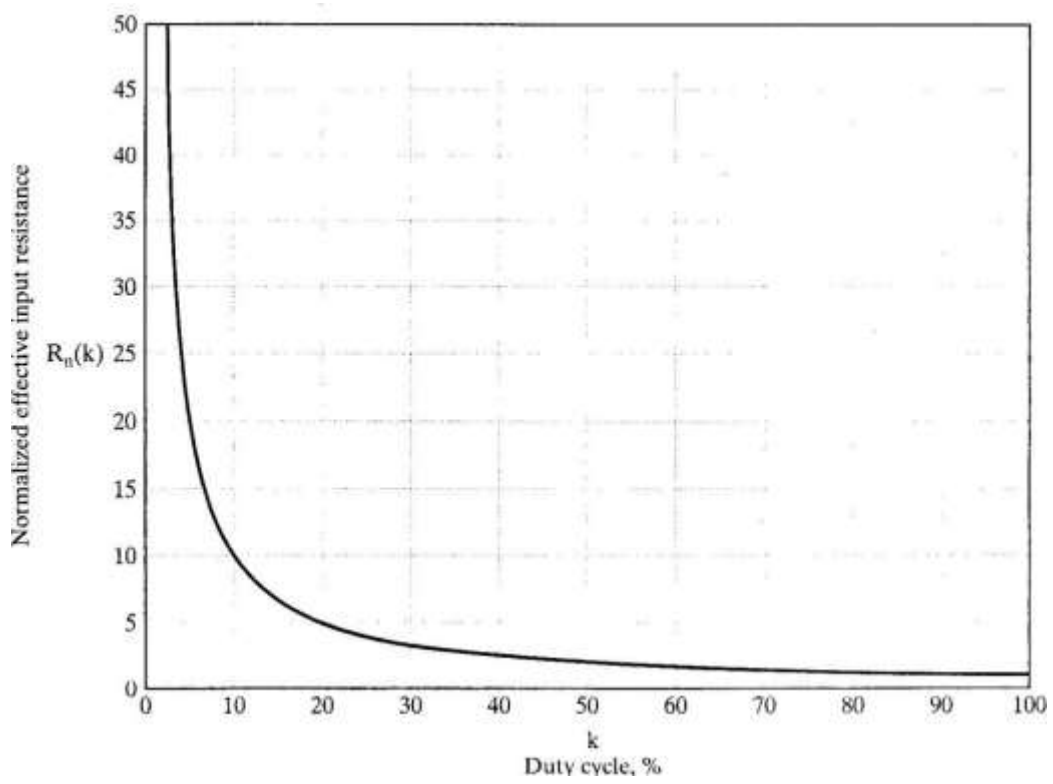
$$P_{in} = \frac{1}{T}\frac{V_S^2}{R} kT$$

$$P_{in} = k\frac{V_S^2}{R}$$

Effective Input Resistance seen by V_S

$$R_i = \frac{V_S}{I_a} = \frac{V_S}{k\dfrac{V_S}{R}}$$

$$R_i = \frac{R}{k}$$

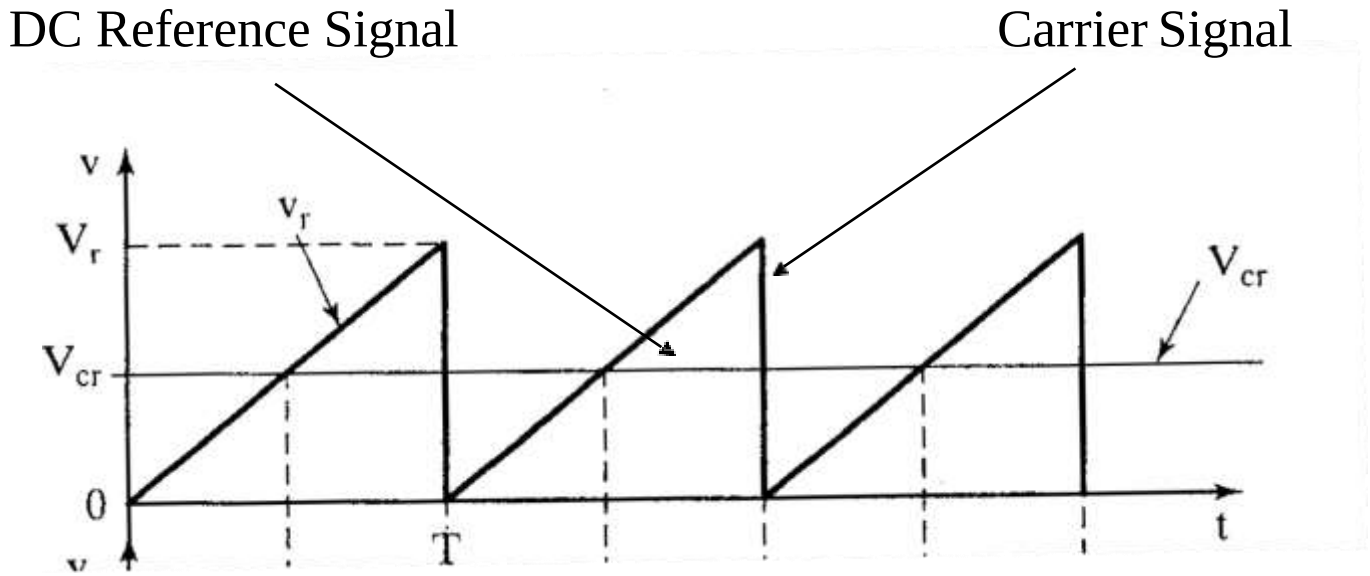


Modes of Operation

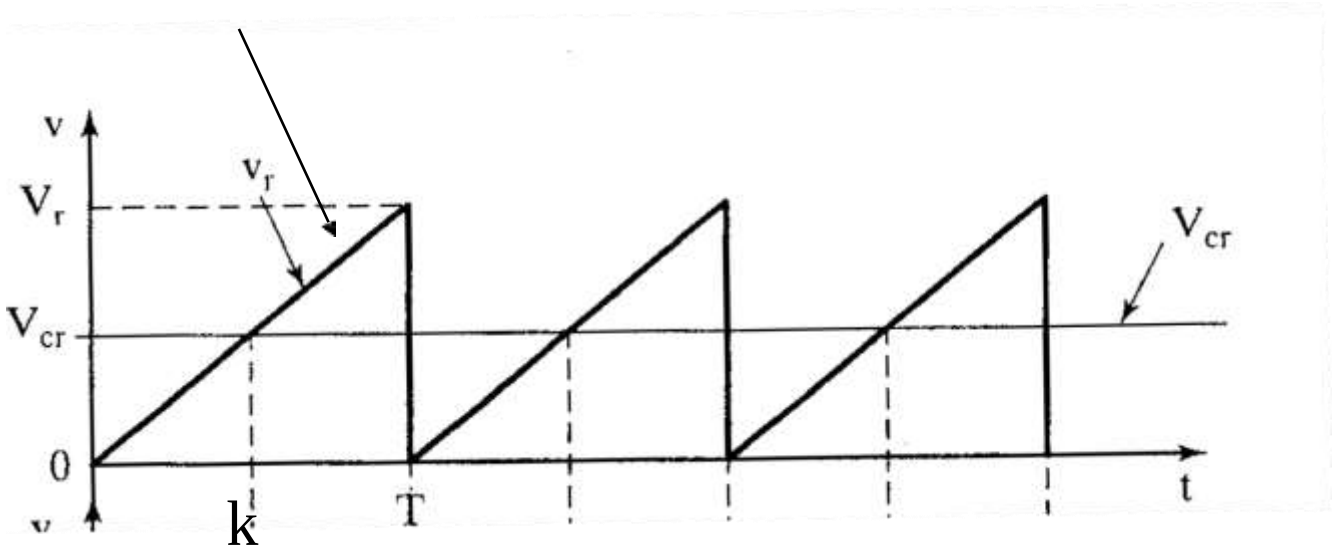
- Constant – frequency operation
  - Period T held constant, t_1 varied
  - Width of the pulse changes
  - "Pulse-width modulation", PWM
- Variable -- frequency operation
  - Change the chopping frequency (period T)
  - Either t_1 or t_2 is kept constant
  - "Frequency modulation"

Generation of Duty Cycle

- Compare a dc reference signal with a saw-tooth carrier signal



$$v_r = \frac{V_r}{T} k$$

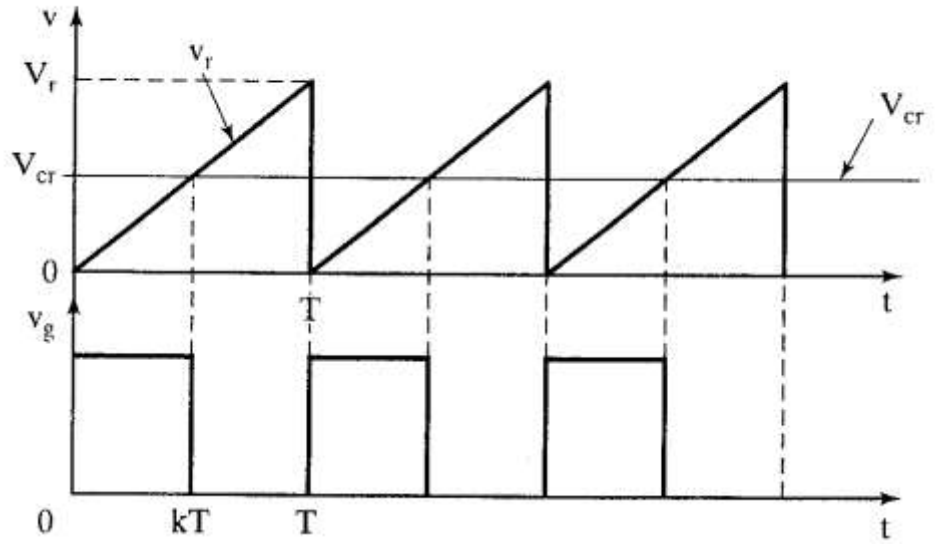


$$v_r = V_{cr} @ t = kT$$

$$V_{cr} = \frac{V_r}{T} kT$$

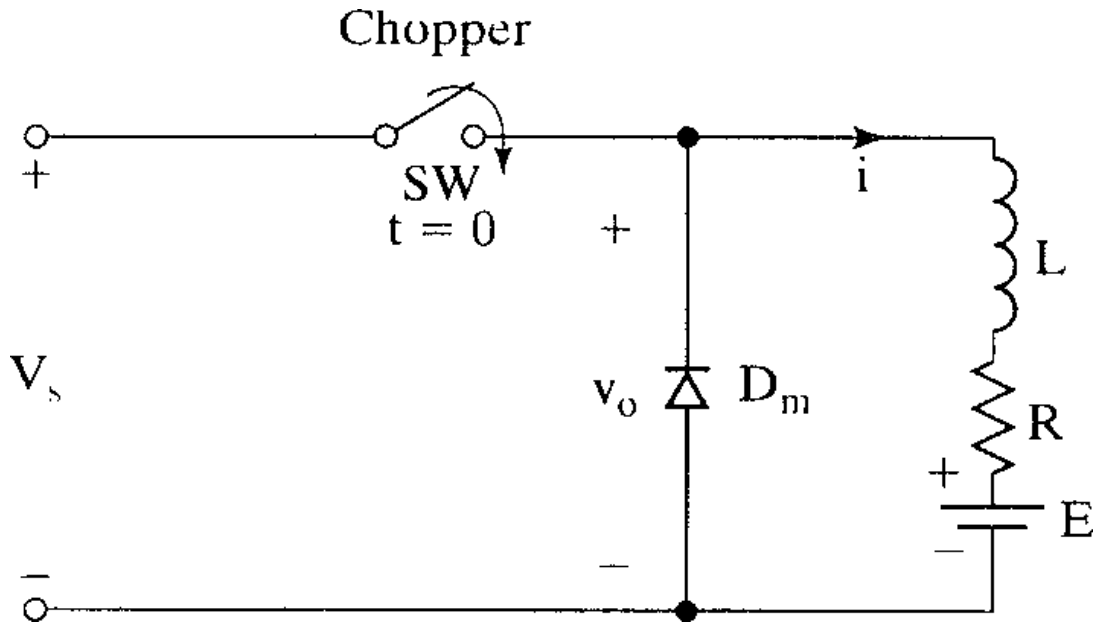
$$k = \frac{V_{cr}}{V_r} = M$$

To generate the gating signal

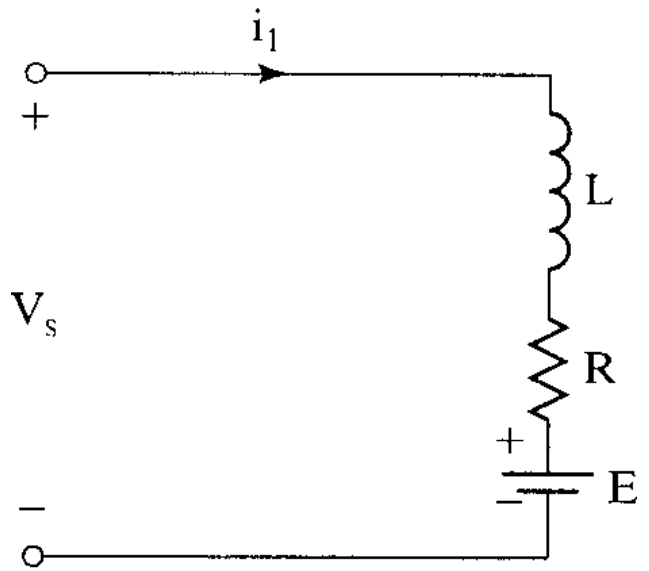


- Generate the triangular waveform of period T, v_r, and the dc carrier signal, v_{cr}
- Compare to generate the difference v_c - v_{cr}
- Apply to a “hard limiter” to “square off”

Step-Down Converter with RL Load



Mode 1: Switch Closed



Mode 1

$$V_S = Ri_1 + L\frac{di_1}{dt} + E$$

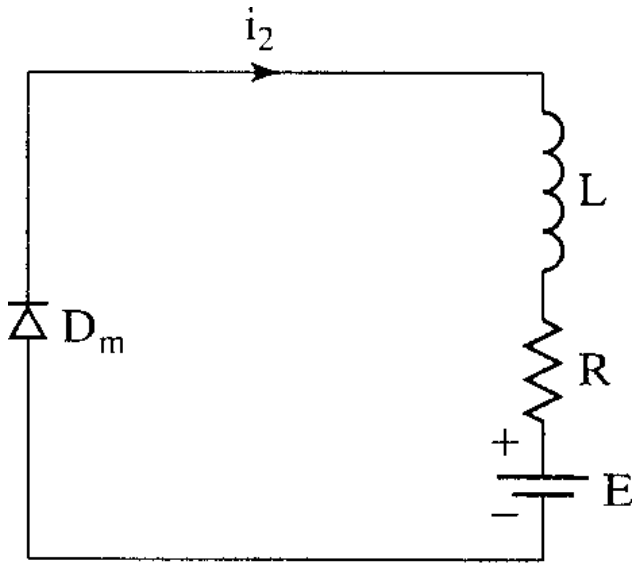
$$i_1(t)_{(t=0)} = I_1$$

$$i_1(t) = I_1 e^{-\frac{R}{L}t} + \frac{V_S - E}{R}\left(1 - e^{-\frac{R}{L}t}\right) \quad t \le t_1(kT)$$

$$t = t_1 = kT$$

$$i_1(kT) = I_2$$

Mode 2: Switch Open



Mode 2

$$0 = Ri_2 + L\frac{di_2}{dt} + E$$

$$i_2(t=0) = I_2$$

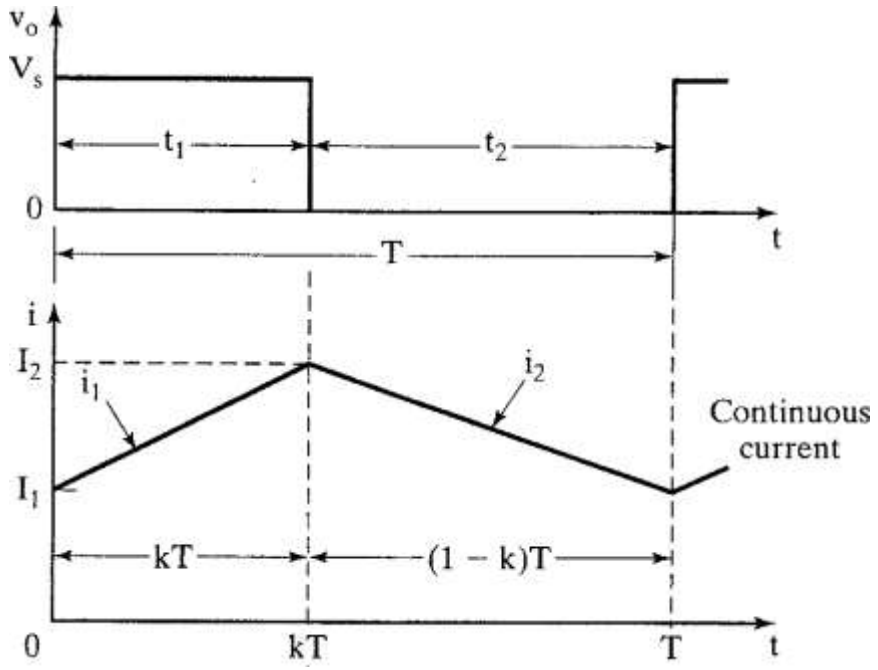
$$i_2(t) = I_2 e^{-\frac{R}{L}t} - \frac{E}{R}\left(1 - e^{-\frac{R}{L}t}\right)$$

$$0 \le t \le t_2 = (1-k)T$$

$$@t = t_2 = (1-K)T$$

$$i_2(t_2) = I_3 = I_1$$

Current for “Continuous” Mode



$$I_1 = \frac{V_S}{R}\left(\frac{e^{kz}-1}{e^{z}-1}\right) - \frac{E}{R}$$

$$I_2 = \frac{V_S}{R}\left(\frac{e^{-kz}-1}{e^{z}-1}\right) - \frac{E}{R}$$

$$z = \frac{TR}{L}$$

$$\Delta I = \frac{V_S}{R}\left[\frac{1-e^{-kz}}{1-e^{-z}} + e^{-z} - e^{-(1-k)z}\right]$$

$$\Delta I_{max} \cong \frac{V_S}{4fL}$$

For Continuous Current

$$I_1 \geq 0$$

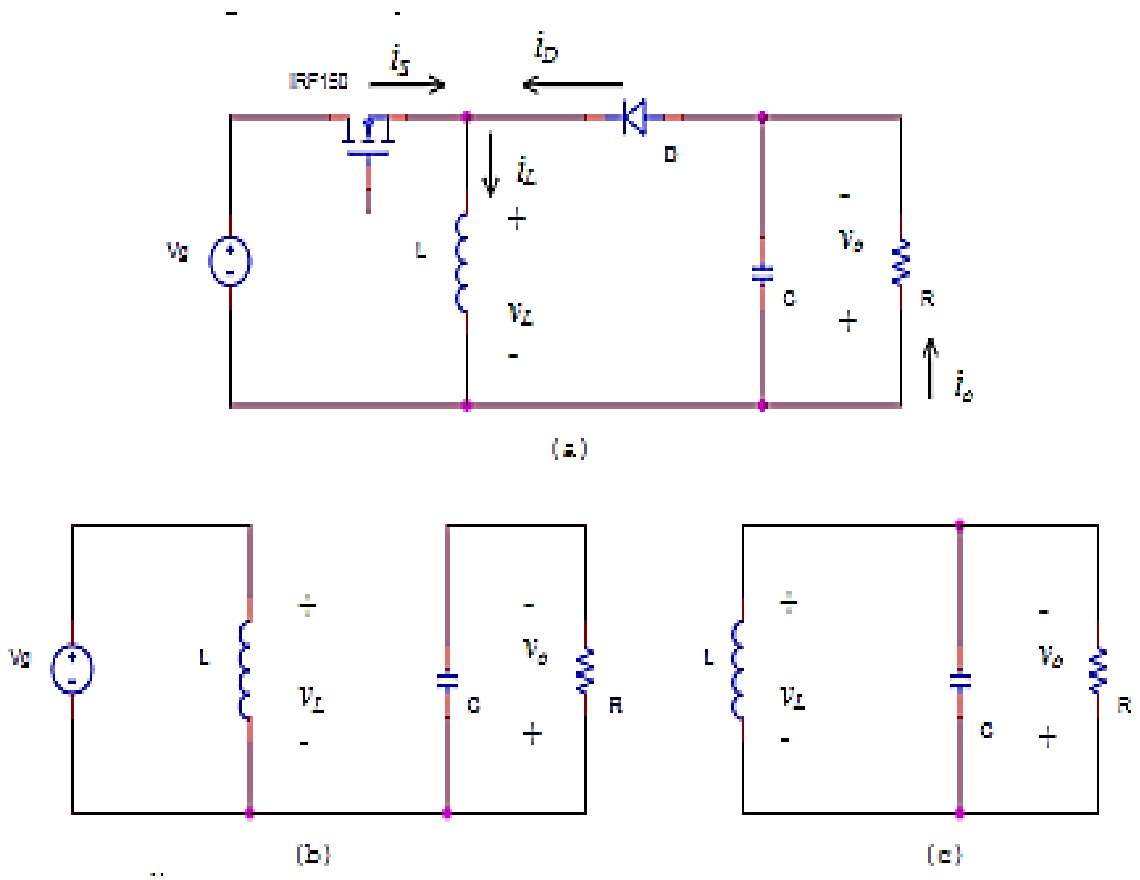
$$\left[\frac{e^{kz}-1}{e^{z}-1} - \frac{E}{V_S}\right] \geq 0$$

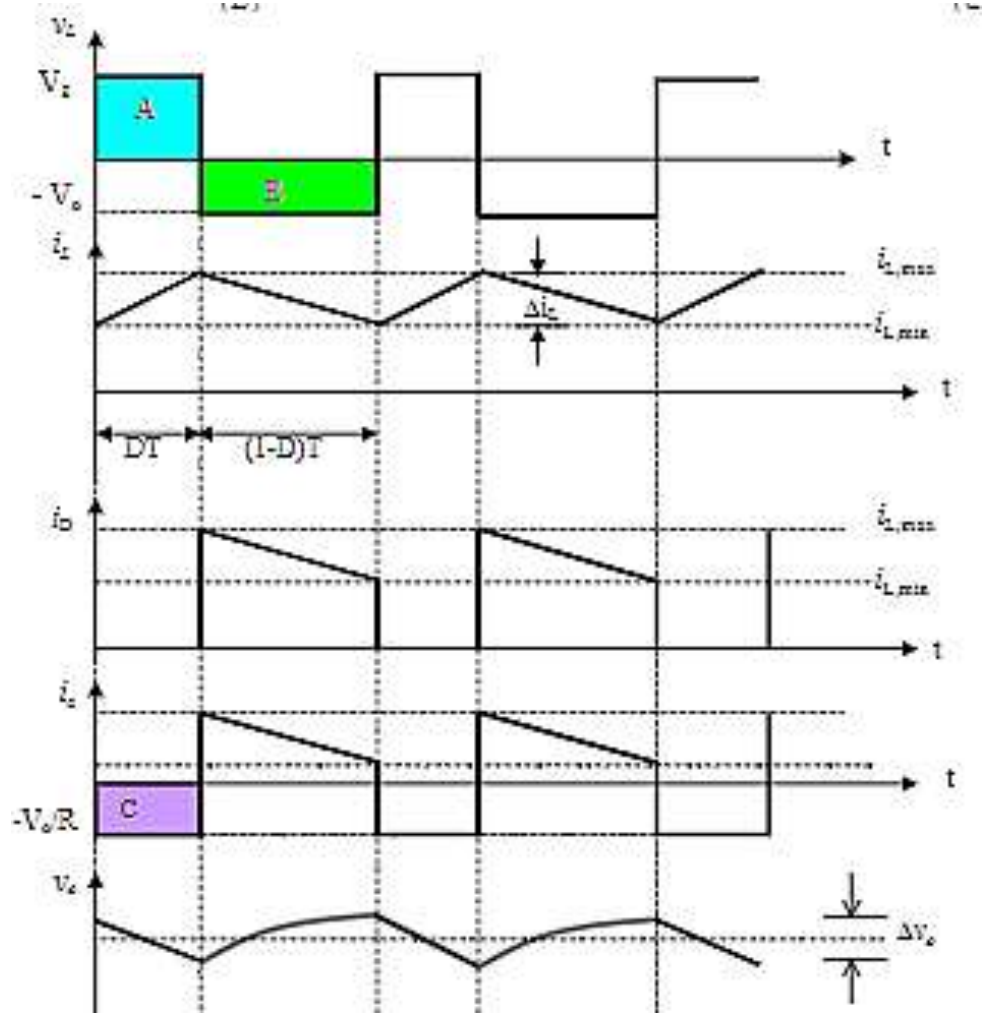
Define the load emf ratio

$$x = \frac{E}{V_S}$$

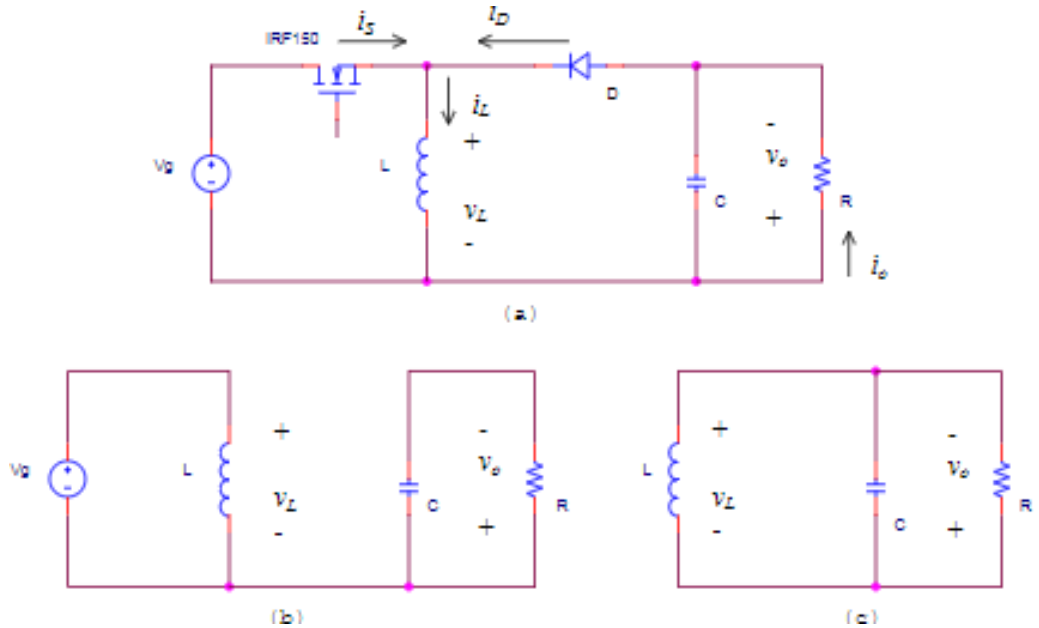
$$x = \frac{E}{V_S} \leq \frac{e^{kz} - 1}{e^{z} - 1}$$

Boost converter operation

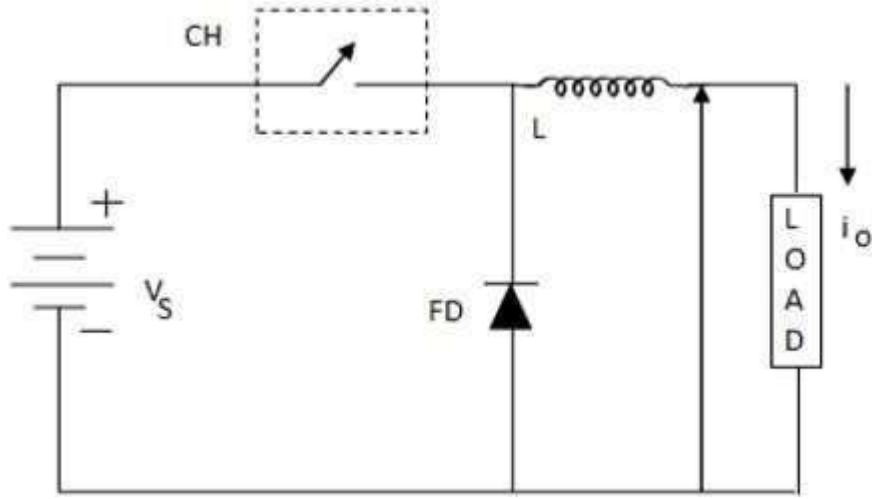


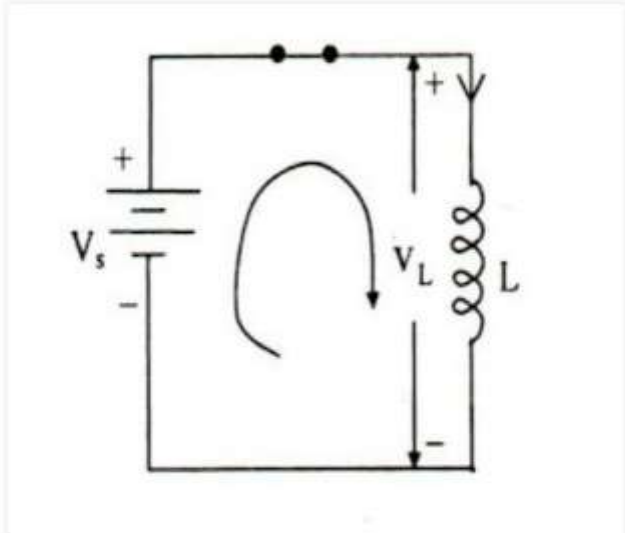

v_L
V_i
A
t
$-V_o$
B
i_L
$i_{L,max}$
Δi_L
$i_{L,min}$
t
DT
(1-D)T
i_D
$i_{L,max}$
$i_{L,min}$
t
i_c
t
$-V_o/R$
C
v_o
ΔV_o

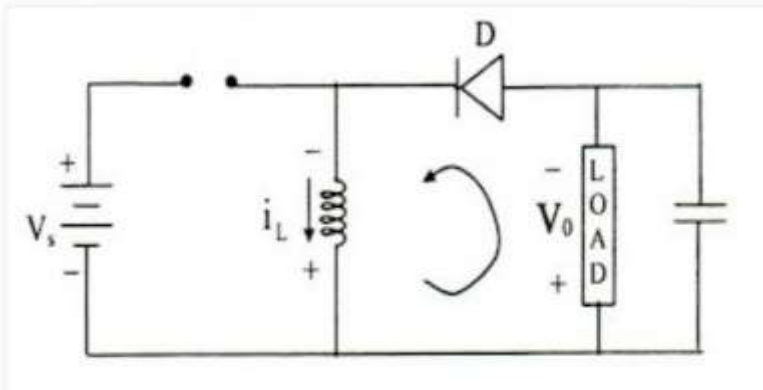
Step Up/ Step Down Chopper

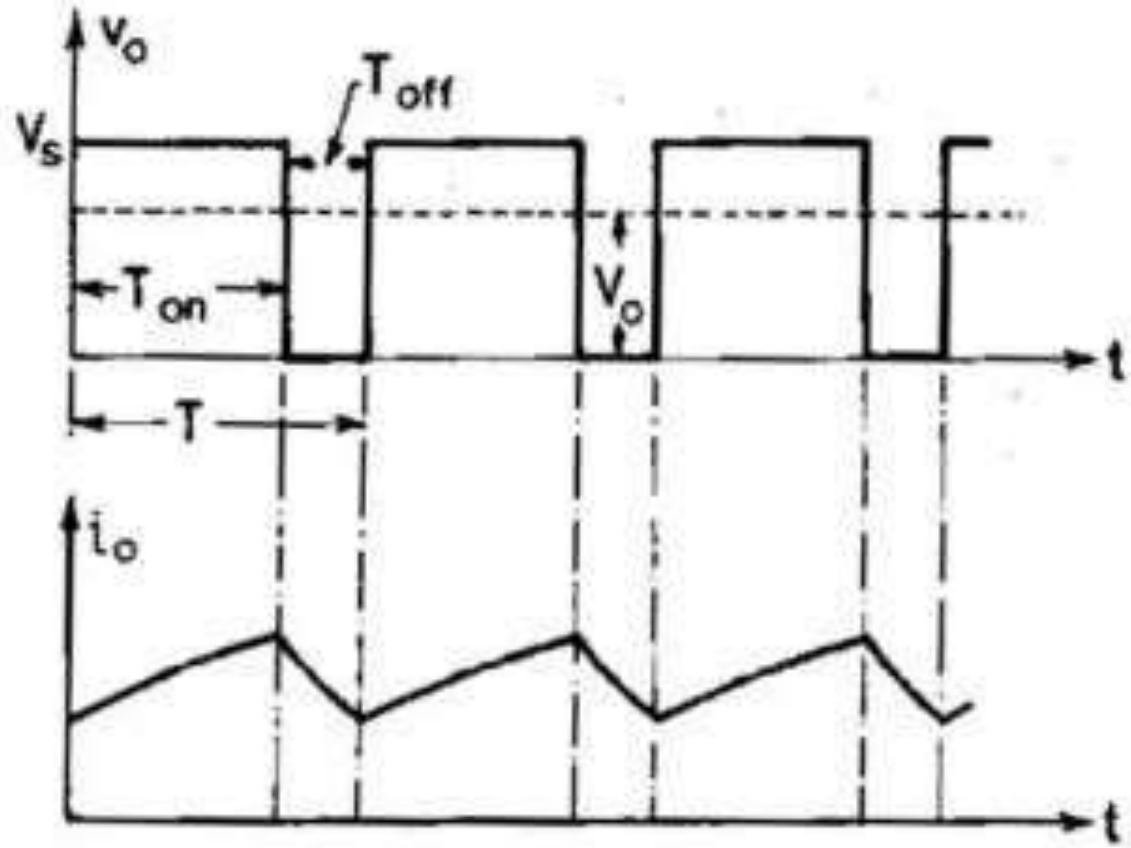


Step Down Chopper








v_o
T_{off}
V_s
T_{on}
V_o
t
T
i_o
t