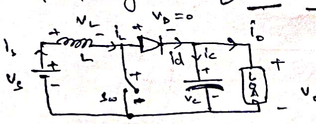
Electric Vehicles

Step-Up Regulator [Boost Converter]

Max' Power Point Tracking Prgm.

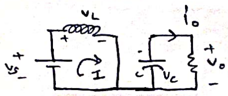
optimize power through switch.



$\boxed{i_d = i_c + i_o}$

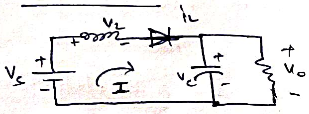
Working of Boost Converter switch is ON / OFF

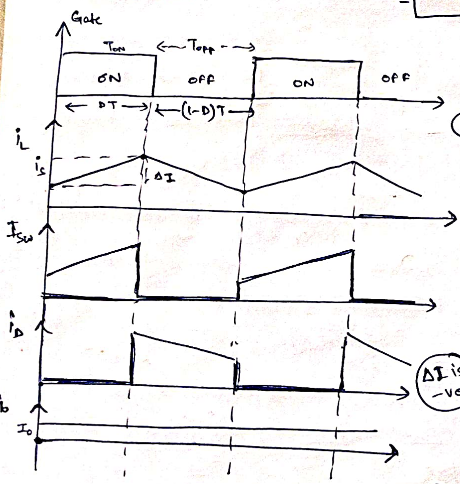
switch ON



LSD

switch OFF





ΔI +ve

$V_s - V_L = 0$

$V_s = L\frac{di}{dt}$

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

$T_{ON} = \frac{L\Delta I}{V_s}$ — ①

$V_s - V_L - V_0 = 0$

ΔI is -ve

$V_s + L\frac{\Delta I}{T_{off}} - V_0 = 0$

$T_{off} = \frac{V_0 - V_s}{L\Delta I}$ — ②

① & ②

$L\Delta I = V_s \cdot T_{ON} = T_{off}(V_0 - V_s)$

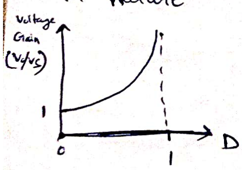
$\Rightarrow V_s \cdot DT = (V_0 - V_s)(1-D)T$

$\Rightarrow \frac{V_0 - V_s}{V_s} = \frac{D}{1-D}$

$\Rightarrow \boxed{\frac{V_0}{V_s} = \frac{1}{1-D}}$

Since $0 < D < 1$, so $\boxed{V_0 \geq V_s}$ step up

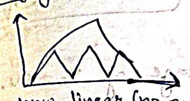
(2) Input current is continuous in nature



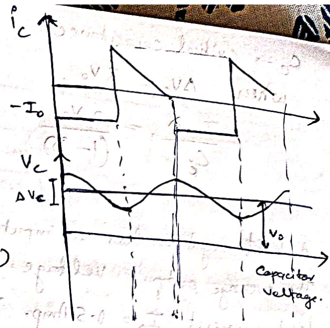
$\Delta I_L = \frac{V_s\, D \cdot T_0}{L} = \frac{V_s \cdot D}{fL}$

Find ΔI & ΔV_c

charging & Discharging



may draw linear (no parabola)



add $T_{ON} + T_{OFF} = T$

$\frac{L\Delta I}{V_s} + \frac{L\Delta I}{(V_0 - V_s)} = \frac{1}{f}$ $\Rightarrow$ $\Delta I = \frac{(V_s - V_0)V_s}{fLV_0}$

$\Rightarrow$ $\Delta I = \left(\frac{V_s}{V_0}\right)\left(\frac{1}{fL}\right)(V_s - V_0)$

$\Delta I = \frac{V_s D}{fL}$ Ripple in Input Current

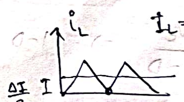
\# $V_c = \frac{1}{c}\int i_c\,dt$

$\Delta V_c = \frac{1}{C}\int_0^{T_{ON}} I_0\,dt = \frac{I_0}{C} \cdot T_{ON} = \frac{I_0}{C} \cdot \frac{D}{f}$

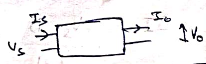
$\boxed{\Delta V_c = \frac{I_0 \cdot D}{fC}}$

\# Critical Values of L & C

when $i_{L(min)} = 0$



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



$\boxed{V_s \cdot I_s = V_0 \cdot I_0}$ energy cons.

$\Delta I = 2I_L = 2I_s$

$\Rightarrow \frac{V_s D}{L_c f} = 2 \times \left(\frac{V_0 \cdot I_0}{V_s}\right)$

$\Rightarrow \frac{V_s D}{L_c f} = 2 \times \frac{\cancel{V_s}}{\cancel{V_s}\,(1-D)} \cdot I_0$

$\Rightarrow \boxed{L_c = \frac{V_s \cdot D \cdot (1-D)}{2 \times I_0 \times f}}$

Critical inductance.

$C_c \to$ Critical capacitance.

When $\Delta V_c = 2V_0$

$$\frac{I_0 \cdot D}{C_c f} = \frac{2V_s}{(1-D)} \Rightarrow \boxed{C_c = \frac{I_0 \cdot D \cdot (1-D)}{2 \cdot V_s \cdot f}}$$

Power Electronics

A boost regulator has an input voltage of $V_s = 5V$. The average output voltage is ($15V = V_0$). Average load current $I_0 = 0.5$ Amp. The switching frequency is $f = 25KHz$. If $L = 150\mu H$, $C = 220\mu F$

Determine:

(a) Duty cycle (D)

(b) Ripple current of Inductor (ΔI)

(c) Peak current of Inductor

(d) Ripple Voltage of Filter Capacitor (ΔV_c)

(e) Critical Value of L_c & C_c

(a) $V_0 = \frac{V_s}{1-D} \Rightarrow 1-D = \frac{V_s}{V_0} = \frac{1}{3}$ $\quad D = \frac{2}{3} = 0.67$

(b) $\Delta I = \frac{V_s \cdot D}{f \cdot L} = \frac{5 \cdot \frac{2}{3}}{25.K} \cdot \frac{1}{150\mu} = \frac{10^3}{5} \times \frac{2}{3} \times \frac{1}{150}$

$\boxed{\Delta I = 0.88 \text{ A}}$

(c) $I_{peak (L)} = I_s + \frac{\Delta I}{2} = \frac{V_0 I_0}{V_s} + \frac{0.88}{2} = 1.5 + 0.45$
$= 1.95 A$

(d) $\Delta V_c = \frac{I_0 D}{fC} = \frac{0.5 \times \frac{2}{3}}{25.K} \times \frac{1}{220\mu} = \frac{10^3 \times 1}{25 \times 220} = \cancel{0.181}$

60.61 mV

(e) $L_c = \frac{5 \times 2/3 \times 1/3}{2 \times 0.5 \times 25K} = \frac{1}{5} \times \frac{2}{9} \times 10^{-3} = 44\mu H$

$C_c = \frac{0.5 \times 2/3 \times 1/3}{2 \times 5 \times 25K} = 0.44 \mu F.$

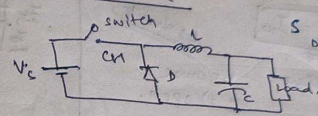
Buck Converter

Unacademy Power Electronics

S D L

Step Down Chopper

DC-DC Converter

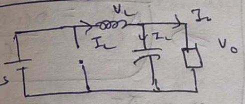


$0 < t < T_{ON} \Rightarrow CH \Rightarrow ON \quad D \Rightarrow OFF$

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

$D = \frac{T_{ON}}{T}$ Duty Cycl.

$0 < t < T_{ON}$ (CH = ON)

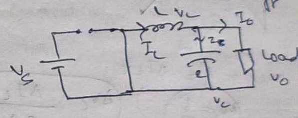


KCL $I_L = I_C + I_0$

KVL $V_L = (V_S - V_0)$

$T_{ON} < t < T$

CH = off



KCL $\to I_L = I_C + I_0$

KVL $\to V_L = -V_0$

- for inductor, Volt Sec Balance. (VSB)

$\Rightarrow L\frac{di}{dt} = V_L$ charging = Discharding. {stability}

$\Delta i = 0$

$\Rightarrow \int di = \int \frac{V_L}{L} dt$ $\to \int V_L dt = 0$

in Capacitor, Amp-sec Balance. $\quad$ $\Delta V_c = 0$

$I_c = C\frac{dv_c}{dt}$ $\quad \int dv_c = \frac{1}{C}\int I_c \, dt$

$\oint I_c dt = 0$ avg current cap current $= 0$

Avg o/p voltage (VSB)

$\int V_L dt = 0$

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

$\cancel{(V_s D_0)} \cancel{D = } V_0$

$\boxed{V_0 = D V_S}$ $\quad \boxed{V_0 < V_s}$

Avg inductor current

$\int I_c\,dt = 0$

$(I_L - I_0)T_{ON} + (I_L - I_0)(T - T_{ONN}) = 0$

$\boxed{I_{L_{avg}} = I_0}$

L : short

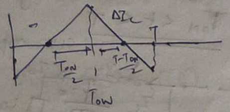
Avg = DC value

because C ⇒ open.

AC current

Ripple in o/p voltage

$I_c = I_L - I_0$ ← draw graph



area $= Q = \Delta I_L t$

$\Delta V_C = \frac{Q}{C}$ ⇒ $\Delta V_C = \frac{\Delta I_L}{8fC}$

Ripple in o/p voltage.

Critical Inductance

$I_{L_{min}} = \frac{\Delta I_L}{2}$ $I_{min} = 0$

$I_0 = \frac{D(1-D)V_s}{2fL_c}$

$\frac{DV_s}{R} = \frac{V_0}{\cancel{R}} = \frac{D(1-D)\cancel{V_s}}{2fL}$

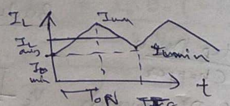
$L_C = \frac{(1-D)R}{2f}$

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

$I_{D(rms)} = I_{L(avg)}\sqrt{1-D}$

Ripple in inductor current

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



$0 < t < T_{ON}$

$V_L = L\frac{\Delta I_L}{T_{ON}} = V_s - V_0$

$\Delta I_L = \frac{(V_s - V_0)}{L} DT$

⇒ $\Delta I_L = \frac{D(1-D)V_s}{fL}$

max ΔI_L $\frac{dI_L}{dD} = 0$

at $D = 1/2$

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

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

max ripple

Critical Capacitance

$(V_{0(min)} = 0) \rightarrow V_0 - \frac{\Delta V_0}{2} = $

$V_0 - \frac{\Delta V_0}{2} = 0$

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

$DV_s = \frac{\Delta I_L}{2 \cdot 8fC} = \frac{V_s D(1-D)}{16 f^2 C L}$

$C_c = \frac{1}{4fR}$

Buck Boost Converter

L b/w source and load.

polarity of V_0 is different wrt V_s

$V_0 = \frac{V_s \cdot D}{1-D}$

$0 < D < 0.5$: $V_0 < V_s$ Buck SD

$0.5 < D < 1$ $V_0 > V_s$ Boost SU

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

$\Delta I_L = \frac{DV_s}{fL}$ (Boost)

$\boxed{\Delta V_c = \frac{I_0 D}{fC}}$ Boost

L_c & I_C same as Boost

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

Avg ~~supply current~~

$V_s I_s = V_0 I_0$

Multiphase. Buck Converter. (Interleave)

Parallel → conn. connection.

Motor, Inverter, Charger, Fuel Tank, Engine, Control Module.

- Chargers Standards
  - → CCS
  - → Chademo
  - → SAE J1772
  - → Tesla Supercharger

Wireless chargers → Inductive, Resonant (Magnetic)

Grid: infinite energy source.

Ayush Tomar

Energy Sources

$E = U + \frac{1}{2}mv^2 + mgh$

$E = \frac{1}{2}Li^2 + \frac{1}{2}CV^2$

Mag. En Electrical Energy

$P_{loss} = \alpha P^2 + P_0(SoE(t))$

↓ State of energy

$P = \frac{dE}{dt}$ W, KWh

→ $E_{loss\,cycle} = \int P_{loss} = \alpha P^2 + P_0\, SoE(t)\, dt$

⇒ $SoE(t) = SoE(t_0) + \frac{\int P(t) - P_{loss}(t)\,dt}{E_{stored}}$

→ $\eta_{round} = \frac{\text{Energy Delivered}}{\text{Energy Supplied}}$

Energy Supplied = 10 Kwh. $SoC = 1 - DOD$

Energy Stored = 9 wh.

Energy Delivered during Dischr = 8.5 Kwh.

$$\eta_{Round\ trip} = \frac{\text{Energy Delivered}}{\text{Energy Supplied}} \times 100$$

$$\eta_{Round\ Trip} = \frac{8.5}{10} \times 100 = 85\%$$

$I = C\frac{dv}{dt}$ V_C

$DoD = \frac{\int i_{dis}\, dt}{capacity}$ 5hrs 60Am hr.

(1) $= \frac{\text{Initial} - \text{Final}}{\text{Initial}} \times 100 = \left(\frac{100-60}{100}\right) \times 100 = 40\%$

(1) DoD after 5hrs = 40%.

(2) $SoC = \frac{\text{Remain capacity}}{\text{Initial capacity}} = \frac{60}{100} \times 100 = 60\%$

$= 1 - DoD = 0.6 \times 100$

(3) Average Current Drawn 12V, 100 Ah

$$I = \frac{P}{V} = \frac{500}{12} = \frac{125}{3} = 41.67\,A$$

(4) ~~Power = VI/t~~ Same power

$\rightarrow$ 60 Ah = 41.67 × t

$$t = \frac{60}{125} \times 3 = \frac{12 \times 3}{25} = \frac{36}{25} = 1.45\,A$$

SAE J1772 Chademo Combined charging system. CCT

Buck $V_o = DV_S$, $\Delta I_L = \frac{D(1-D)V_s}{fL}$, $\Delta V_C = \frac{\Delta I_L}{8fC}$, SDL

$(I_{sw})_{avg} = DI_L$, $(I_D)_{avg} = (1-D)I_L$, $C_c = \frac{1}{4fR}$ $\boxed{I_o = I_L}$

Boost LSD

$V_o = \frac{V_s}{1-D}$ | $I_L = \frac{I_o}{1-D}$ | $\Delta I_L = \frac{DV_s}{fL}$ | $\Delta V_C = \frac{I_o D}{fC}$

switch & diode current same $L_c = \frac{R(1-D)^2 D}{2f}$, $C_c = \frac{D}{2fR}$ $V_o = \frac{\Delta V_o}{2}$

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

Buck Boost

$V_o = \frac{D}{1-D} V_s$ | rest all boost  Pulse width = Toff Boost, BB

= Ton in Buck

$V_o = \frac{DV_s}{1+\frac{r}{R}}$ | $V_o = \frac{V_s}{(1-D) + \frac{r}{R(1-D)}}$ | $\frac{V_o}{V_s} = \frac{D}{(1-D) + \frac{r}{R(1-D)}}$

PFC $P_{AC} = V_{AC} \times I_{AC}$ $V_{AC} = \sqrt{2} V_{ph} \cos\theta$

$P_{AC} = 2 V_{ph} I_p \cos^2\theta$ $I_{AC} = \sqrt{2} I_{ph} \cos\theta$

$\boxed{\langle P_{AC} \rangle = V_{ph} I_{ph}}$ Boost Diode

low freq DC link power $P_D = V_{DC} \times I_D$ $I_{DC} = \frac{V_{ph} I_{ph}}{V_{dc}}$

Duty cycle of Boost Switch

$$D = 1 - \frac{V_{AC}}{V_{DC}} = 1 - \frac{\sqrt{2} V_{ph} \cos\theta}{V_{DC}}$$

$\rightarrow I_{peak} = \sqrt{2} I_{ph}$

$\rightarrow \Delta I_{L\,(P-P)} = r_i\, I_{ph(peak)}$

• peak to peak ripple current

$$\Delta I_L(\theta) = \frac{V_{AC} \cdot D}{fL} \Leftarrow (\text{Boost})$$

Loss in Bridge = 4 × Single Diode

Avg Current in Rectifier

$I_{Diode} = \frac{\sqrt{2}}{\pi} I_{ph}$ Power rating of PFC = $V_{ph} \cdot I_{ph}$

$I_{RMS\ Diode} = \frac{I_{ph}}{\sqrt{2}}$

Power factor Correction

• Switch & Diode Avg current

$i_S = D \times I_{AC} \Rightarrow \langle I_S \rangle = I_{pn}\left(\frac{2\sqrt{2}}{\pi} - \frac{V_{pn}}{V_{dc}}\right)$

(Diode) $i_D = (1-D)\, i_{AC}$ $\qquad \langle I_D \rangle = \frac{V_{pn} I_{pn}}{V_{dc}}$

• RMS

$I_{S(RMS)} = I_{pn}\sqrt{1 - \frac{8\sqrt{2}}{3\pi}\frac{V_{pn}}{V_{dc}}}$ $\qquad I_{DC\ link\ capacitor} = \sqrt{I_{D_{RMS}}^2 - I_{D_{(DC)}}^2}$

$I_{D(RMS)} = I_{ph}\sqrt{\frac{8\sqrt{2}}{3\pi}\frac{V_{pn}}{V_{dc}}}$

MOSFET loss

$P_S = R_{DS} \times I_{S(rms)}^2$

Diode conduction loss $\quad P_D = V_f\, I_{D(dc)} + r_f\, I_{D(RMS)}^2$

Super Capacitor

→ regenerative breaking, start stop of EV, electrical energy + uses ions (lithium

• high capacitance (3000F)
low voltage 2.5–2.7

$R_p \to$ self discharg

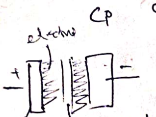
$R_s \hookrightarrow$ charging & discharging

$C = C_0 + C_u = C_0 + KV$ (C_u → voltage dependent)

$Q = CV \qquad I = \frac{dQ}{dt}$

$I_c = \underbrace{(C_0 + 2K)}_{\text{current capacitance}}\frac{dV}{dt} \leftarrow \boxed{I = C_{eq}\frac{dV}{dt}}$

Cp



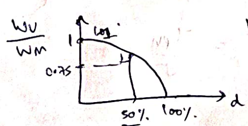
$W = \int P\,dt = \int V_i I_c\,dt$

Energetic capacitan

$W = \frac{1}{2}\left[C_0 + \frac{4}{3}KV\right]V^2$

$W_u = \frac{1}{2}C\left(V_{max}^2 - V_{min}^2\right) \qquad W_u = W_{max}\left(1 - \frac{d^2}{100^2}\right)$

discharge ratio $(d) = \frac{V_{min}}{V_{max}} \times 100$



$N = \frac{W_R}{W_u}$

V ↓ (charge), V ↑ (discharge)

relaxation phenomena → dynamic variation of properties of SC | due to charge mitigation.

charging

$\boxed{V_c = V_i + \frac{1}{C}\int I_c\,dt}$

$d_i = \frac{V_i}{V_M} \times 100$

$d_f = \frac{V_f}{V_M} \times 100$

$\frac{d_f V_{max}}{100} = \frac{d_i V_M}{100} + \frac{I_c}{C} T_{ch}$

$\boxed{T_{ch} = \frac{(d_f - d_i)}{100}\frac{V_M C}{I_c}}$

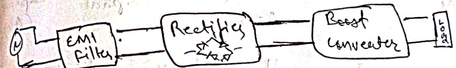
$W_{Loss} = I^2 R\, \Delta T$

$\Rightarrow W_{loss} = I_c V_M C \cdot R \frac{(d_f - d_i)}{100}$

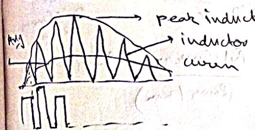
same for discharge just $d_i \rightleftharpoons d_f$

Disadv
- high self-discharge
- low voltage of cell
- cannot be used for AC

Adv
- high capacitance
- longer life cycle.
- rapid charging
- high power storage



Single phase Boost



PFC $\quad L = \frac{\sqrt{2}\, V_{in} D_{min}}{f_s \Delta I_L}$

Igbt → insulated gate bipolar transistor.

Energy Sources

Power → W, KW, MW
Energy → J, KWh.

• $E = U + mgh + \frac{1}{2}mv^2$

$E = \int P\,dt$

• $E = E_{mag} + E_{ele}$

• $E = \frac{1}{2}LI^2 + \frac{1}{2}CV^2$

$P_{Loss} = \underset{\substack{\downarrow \\ \text{charge discharge loss}}}{\alpha P^2} + P_0\underset{\substack{\downarrow \\ \text{state of energy}}}{[SoE(t)]}$

$SoE(t) = SoE(t_0) + \frac{\int [P(t) - P_{loss}(t)]\,dt}{E_{stored}}$

Electrical
chemical
magnetic
Air, water, wheels Rotat

Round trip efficiency $= \frac{E_d}{E_{ch}}$ (E_d → recovered during discharg; E_{ch} → spent in charge)

$$DoD = \frac{\text{Energy Extracted}}{\text{Capacity}}$$

depth of discharge

$$SoC = \frac{\text{Cap} - \text{Extracted}}{\text{Cap.}}$$

State of charge

Batteries

- Lithium Ion
- Nickel Metal Hydride (NiMH)
- Solid State

- High energy density
- efficient
- long cycles

no enviro impact
high cost
heat issues

NiMH → less env impact
↓
Hybrid EV

NiCd
aviation, portable electronics, power tools
good at low temp
toxic cadmium
↓
Oldest before Li

Durable
Safe
cost

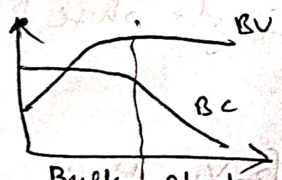
Nickel Oxide Hydro

expensive
low den

Solid state
- uses electrolytes
- Safe

Charging Cycle ⇒ adding ee to battery to q charge

Constant current
Constant voltage



Discharging
→ drawing ee from battery to power device

$E = V \times Q$
Energy KWh — Storage capaci
Velty N(V)
Capacity (Ah)

- $SoC = \frac{Q_{rem}}{Q_{Total}} \times 100$
- $E_{ren} = \eta_{reg} \times \frac{1}{2} m v^2$

Battery Discharg Rate

- $\text{Distance} = \frac{\text{Avl. Energy}}{(\text{Power} / \text{Km})}$
- $I_{dis} = \frac{P}{V}$

General

noise less
Smart grid

- reduce emmissions
- cost effective in long run
- renewable source
- Life cycle assessm

better vehicle dynamics

tax incentives

lower carbon foot
No air pol

low maintainence

- range problem
- battery replacem costy
- limited infrastructure to charge

High initial cost
Heat

$7 < P < 22$ Normal Power charg AC/DC

$22 < P < 200$ KW High Power Chargin DC

- Motor
- Battery Pack
- fuel Tank
- Engine
- Inverter
- Controller
- Battery Mgmt
- Charger

2W < 1-2 KWh
3W — 3-8
4W — 21
4W(2) — (30-80)

Privat
Public
Semi

Regen Breaking Syst