IIT ROORKEE

NPTEL ONLINE CERTIFICATION COURSE

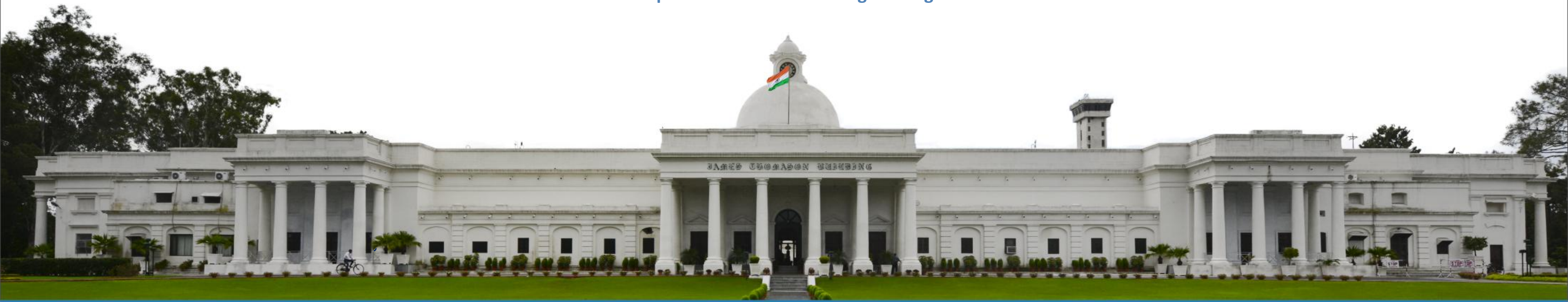
Charging Infrastructure

Lecture-33

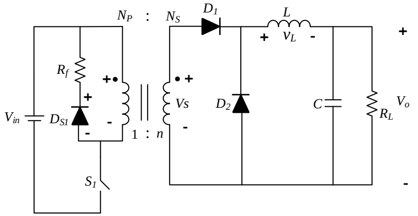
Switching Loss

Dr. Apurv Kumar Yadav

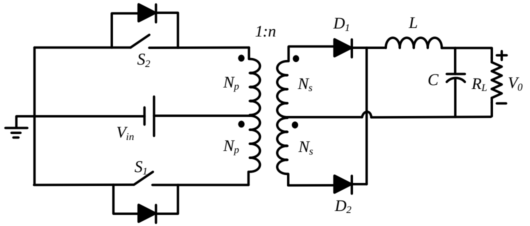
Department of Electrical Engineering



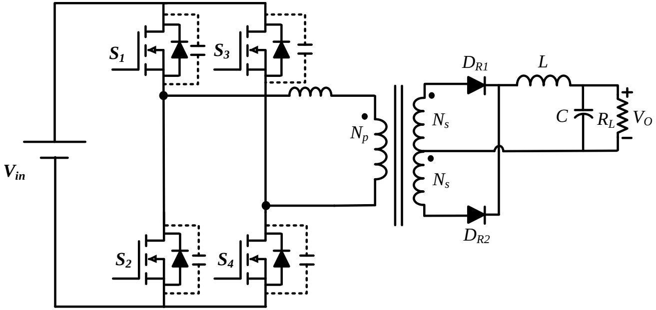
Recap



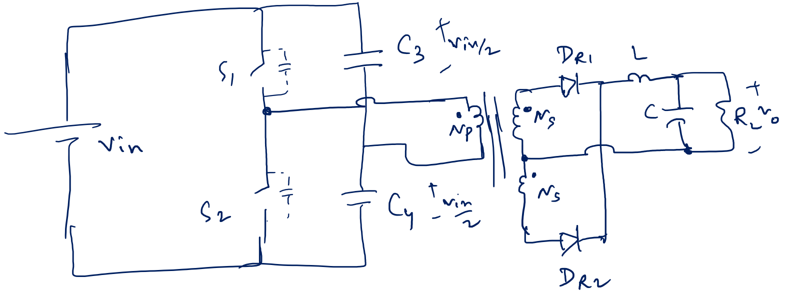
forward converter



push-pull converter

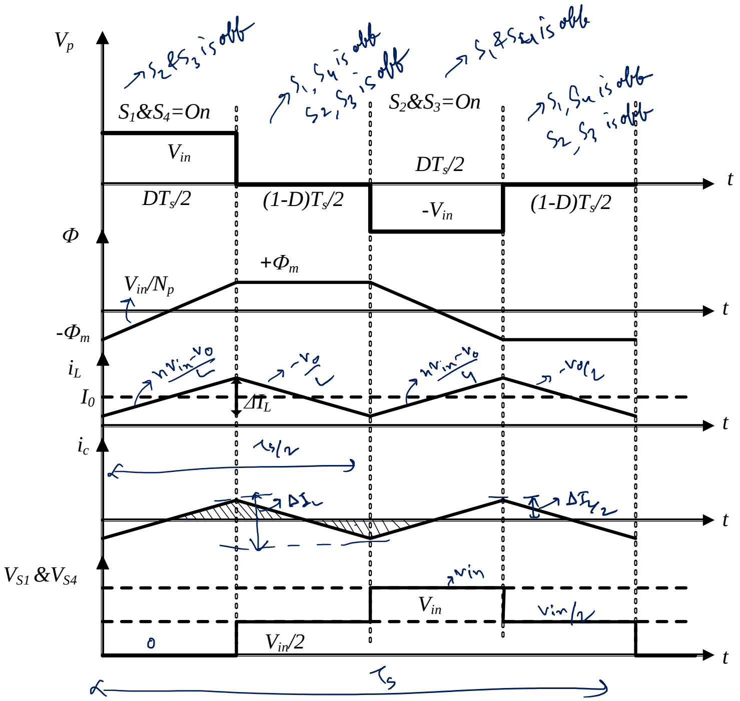


full-bridge



half-bridge

Recap



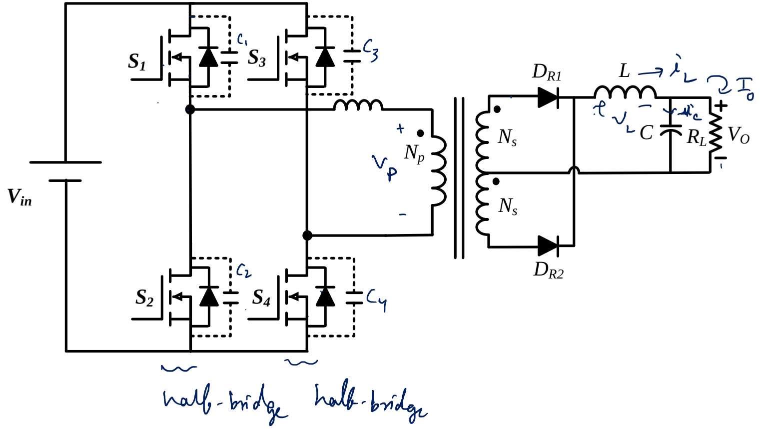
$\frac{N_s}{N_p} = n$

$\frac{DT_s}{2}$ period, $v_L = nV_{in} - v_o$

$\frac{(1-D)T_s}{2}$ period, $v_L = -v_o$

$\frac{DT_s}{2}$ period $v_L = nv_{in} - v_o$

$\frac{(1-D)T_s}{2}$ period $v_L = -v_o$

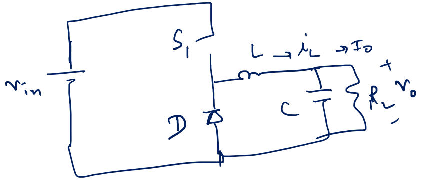


$$\Rightarrow (nv_{in}-v_o)\frac{DT_s}{2} + (-v_o)\frac{(1-D)T_s}{2} = 0$$

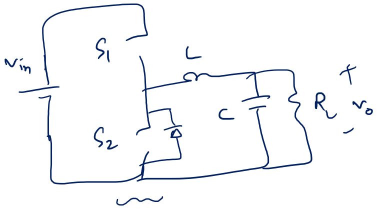
$$\Rightarrow v_o = nv_{in}D$$

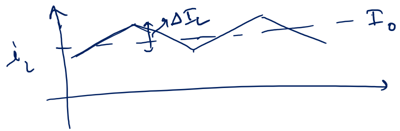
Switching Loss

Let us take a simple buck converter

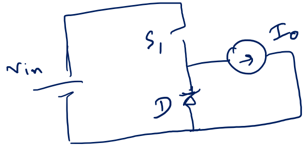


⇒





⇒



$f_{sw}\uparrow$; $A_c \downarrow$; $L \,\&\, C \propto \frac{1}{f_{sw}}$ ⇒

Smaller inductor & Capacitor (filter)

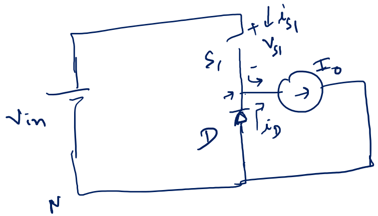
$A_c = \frac{V}{N \Delta B f_{sw}}$ ⇒ $L = \frac{n v_{in} D(1-D)}{2 f_{sw} \cdot \Delta i_L}$

full-bridge converter $\left\{ C = \frac{\Delta i_L}{8(2 f_{sw}) \cdot \Delta v_o} \right.$

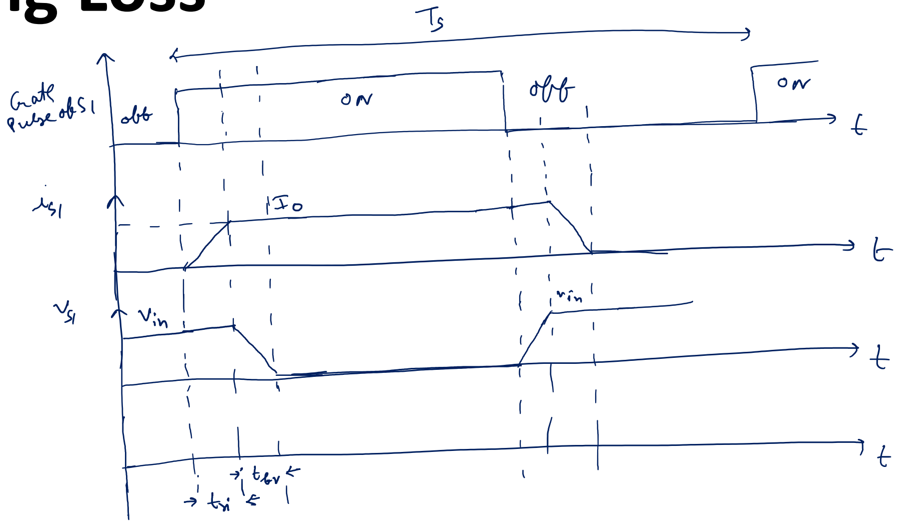
Size of Power Converter $\propto$ size of $\underbrace{L, C, \text{HF transformer}}_{\text{Passives}}$

$f_{sw}\uparrow$; size of Passives $\downarrow$; size of Power converter $\downarrow$

Switching Loss



$I_o = i_{s1} + i_D$



$t_{sw(on)} = t_{ri} + t_{fv}$

$T_s = 1/f_{sw}$

When, $0 < t < t_{ri}$

$\Rightarrow \; i_{s1}(t) = \dfrac{I_o}{t_{ri}} \cdot t$

$\Rightarrow \; v_{s1}(t) = V_{in}$

$\Rightarrow$ Energy loss during t_{ri} period

$$E_{tri} = \int_0^{t_{ri}} i_{s1}(t) \cdot v_{s1}(t) \cdot dt$$

$$\Rightarrow \; E_{tri} = \int_0^{t_{ri}} \frac{I_o}{t_{ri}} t \cdot V_{in} \cdot dt = \frac{V_{in} I_o}{t_{ri}} \int_0^{t_{ri}} t \cdot dt$$

$$\Rightarrow \; E_{tri} = \frac{V_{in} \cdot I_o}{t_{ri}} \cdot \frac{t_{ri}^2}{2} = \frac{V_{in} \cdot I_o}{2} \cdot t_{ri} \longrightarrow (1)$$

When $0 < t < t_{fv}$

$i_{S_1}(t) = I_o$

$v_{S_1}(t) = V_{in} - \dfrac{V_{in} \cdot t}{t_{fv}}$

$\Rightarrow$ Energy loss during 't_{fv}' period

$$\Rightarrow E_{t_{fv}} = \int_0^{t_{fv}} v_{S_1}(t) \cdot i_{S_1}(t) \cdot dt$$

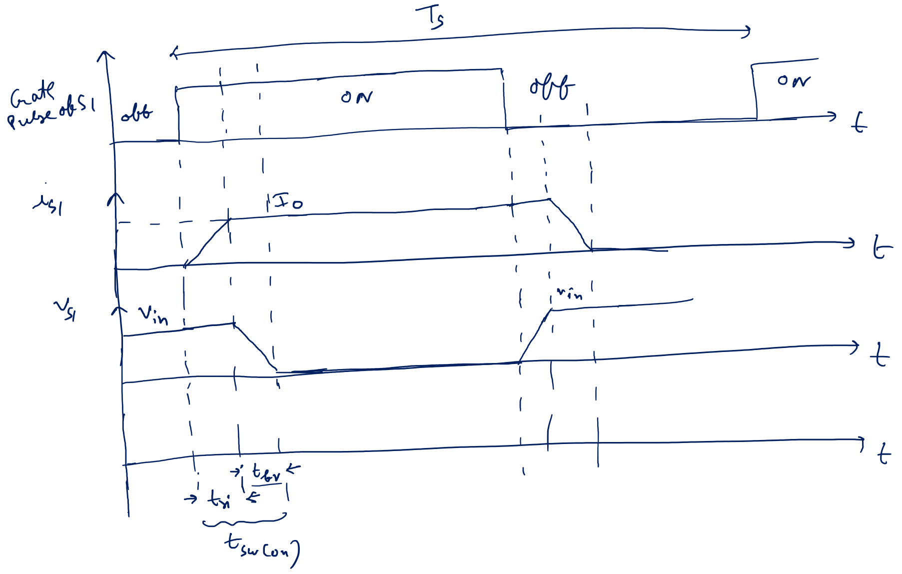
$$= \int_0^{t_{fv}} \left(V_{in} - \frac{V_{in}}{t_{fv}} \cdot t\right) \cdot I_o \cdot dt$$

$$= V_{in} \cdot I_o \int_0^{t_{fv}} \left(1 - \frac{t}{t_{fv}}\right) \cdot dt$$

$$= V_{in} I_o \left[\int_0^{t_{fv}} 1 \cdot dt - \int_0^{t_{fv}} \frac{t \cdot dt}{t_{fv}} \right]$$

$$= V_{in} I_o \left[\left[t \right]_0^{t_{fv}} - \left[\frac{t^2}{t_{fv} \, 2} \right]_0^{t_{fv}} \right] = V_{in} I_o \left[t_{fv} - \frac{t_{fv}}{2} \right]$$

$$E_{t_{fv}} = \frac{V_{in} I_o t_{fv}}{2} \longrightarrow (2)$$



Energy loss during $t_{sw(on)}$

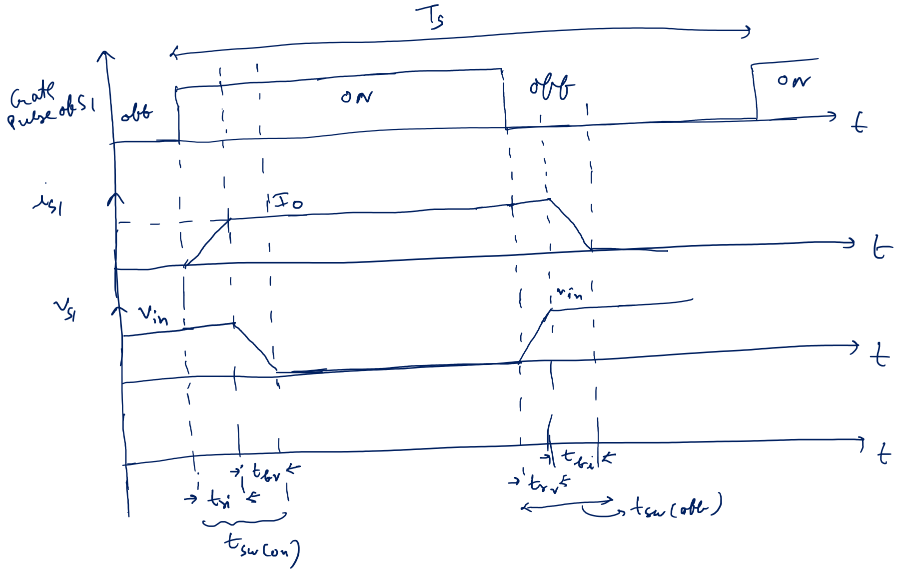
$$E_{on} = E_{tri} + E_{tfv}.$$

$$= \frac{V_{in} \cdot I_o}{2} \left(t_{ri} + t_{fv} \right) \quad \text{(from eq 1 \& 2)}$$

$$E_{on} = \frac{V_{in} \cdot I_o}{2} t_{sw(on)}$$

$\Rightarrow$ The power loss during switching ON $\Rightarrow P_{sw,on} = \dfrac{V_{in} \cdot I_o}{2} \dfrac{t_{sw(on)}}{T_s}$

$$\Rightarrow P_{sw,on} = \frac{V_{in} I_o}{2} t_{sw(on)} \cdot f_{sw} \longrightarrow (3)$$



During switching-off

when $0 < t < t_{rv}$

$$i_{s_1}(t) = I_o$$

$$v_{s_1}(t) = \frac{V_{in} t}{t_{rv}}$$

$\Rightarrow$ Energy loss during t_{rv}

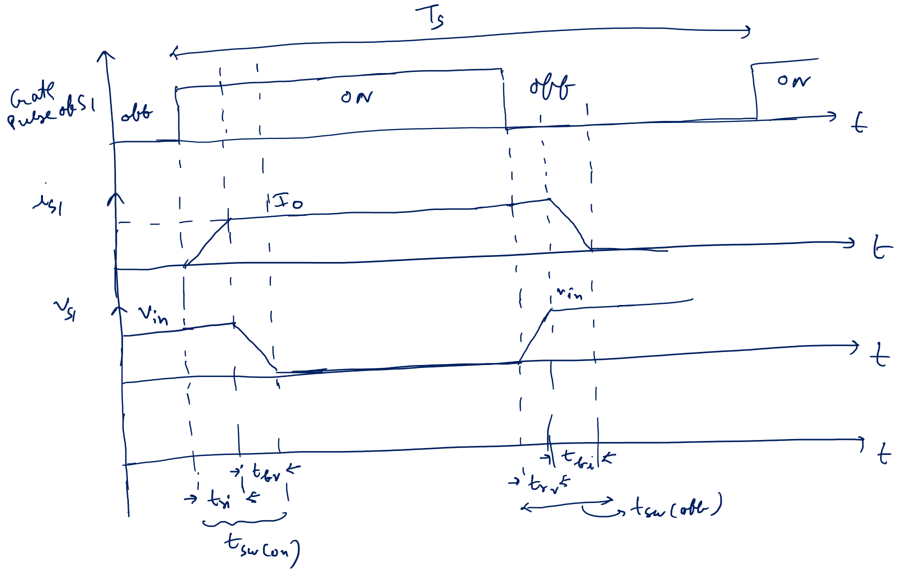
$$\Rightarrow E_{trv} = \int_0^{t_{rv}} i_{s_1}(t) \cdot v_{s_1}(t) \cdot dt = \int_0^{t_{rv}} V_{in} \cdot I_o \cdot \frac{t}{t_{rv}} \cdot dt = \frac{V_{in} \cdot I_o}{t_{rv}} \left. \frac{t^2}{2} \right]_0^{t_{rv}}$$

$$\Rightarrow E_{trv} = \frac{V_{in} I_o t_{rv}}{2}$$

When $0 < t < t_{fi}$

$\Rightarrow i_{s_1}(t) = I_o - \frac{I_o t}{t_{fi}}$

$\Rightarrow v_{s_1}(t) = v_{in}$



$\Rightarrow$ Energy loss during t_{fi}, $E_{t_{fi}} = \int_0^{t_{fi}} i_{s_1}(t) \cdot v_{s_1}(t) \cdot dt$

$$= \int_0^{t_{fi}} \left(I_o - \frac{I_o t}{t_{fi}}\right) v_{in} \cdot dt$$

$$= v_{in} I_o \int_0^{t_{fi}} 1 \cdot dt - \frac{1}{t_{fi}} \int_0^{t_{fi}} t \cdot dt$$

$$= v_{in} \cdot I_o \left[t\Big]_0^{t_{fi}} - \frac{1}{t_{fi}} \cdot \frac{t^2}{2} \Big]_0^{t_{fi}} \right]$$

$$= v_{in} \cdot I_o \left[t_{fi} - \frac{t_{fi}}{2} \right]$$

$$E_{t_{fi}} = \frac{v_{in} I_o t_{fi}}{2} \longrightarrow (4)$$

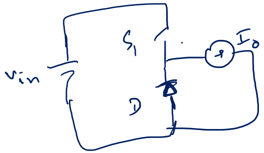
$\Rightarrow$ Energy loss during turn-off $\Rightarrow E_{sw(off)} = \frac{V_{in} I_o}{2} (t_{rv} + t_{fi})$ (from eq. (3) & (4))

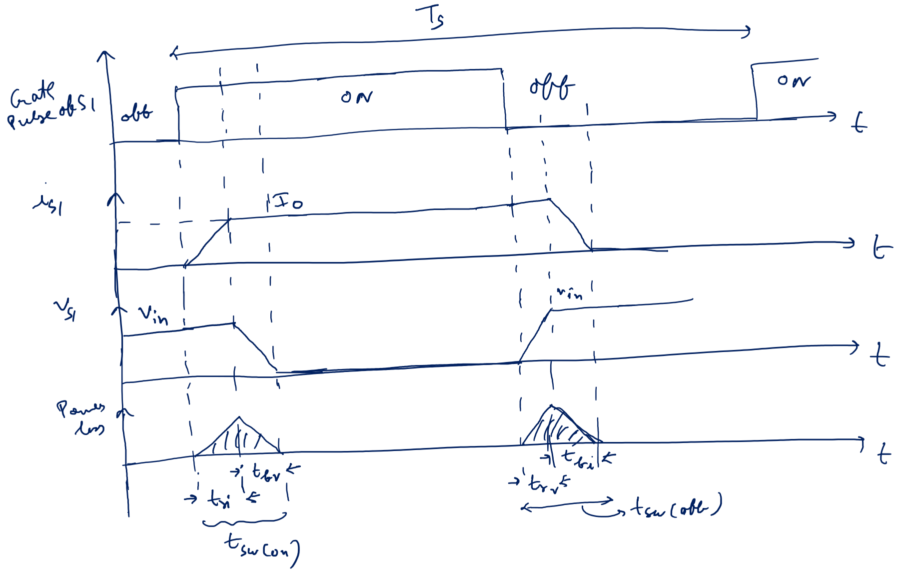
$$= \frac{v_{in} I_o}{2} t_{sw(off)}$$

$\Rightarrow$ Power loss during turn-off $= \frac{v_{in} I_o}{2} t_{sw(off)} \cdot f_{sw} \longrightarrow (5)$

→ The power loss during switching, $P_{sw} = P_{sw(on)} + P_{sw(off)}$

$$P_{sw} = \frac{V_{in} I_o}{2}\left(t_{sw(on)} + t_{sw(off)}\right) f_{sw}$$





→ Switching loss depends on

→ Switching frequency

→ The blocking voltage

→ the current during switching instant

→ time required for turning on & turning off

Thank You