IIT ROORKEE

NPTEL ONLINE CERTIFICATION COURSE

Charging Infrastructure

Lecture-34

Soft Switching In Half Bridge Configuration

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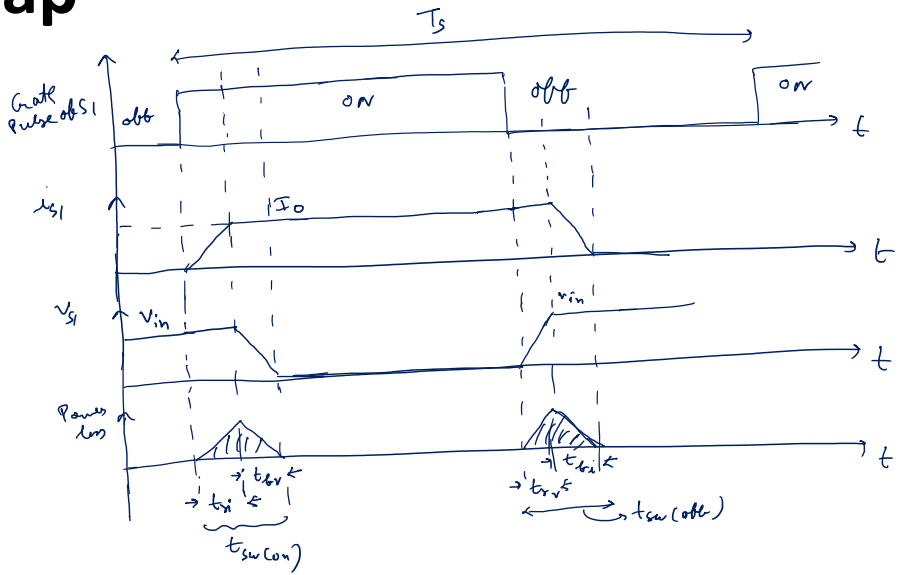
Recap

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

- Switching loss depends on
  - Switching frequency
  - The blocking voltage
  - The current during switching instant
  - time required for turning-on & turning-off



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

$$t_{sw(off)} = t_{rv} + t_{fi}$$

$$P_{sw} = P_{sw(on)} + P_{sw(off)}$$

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

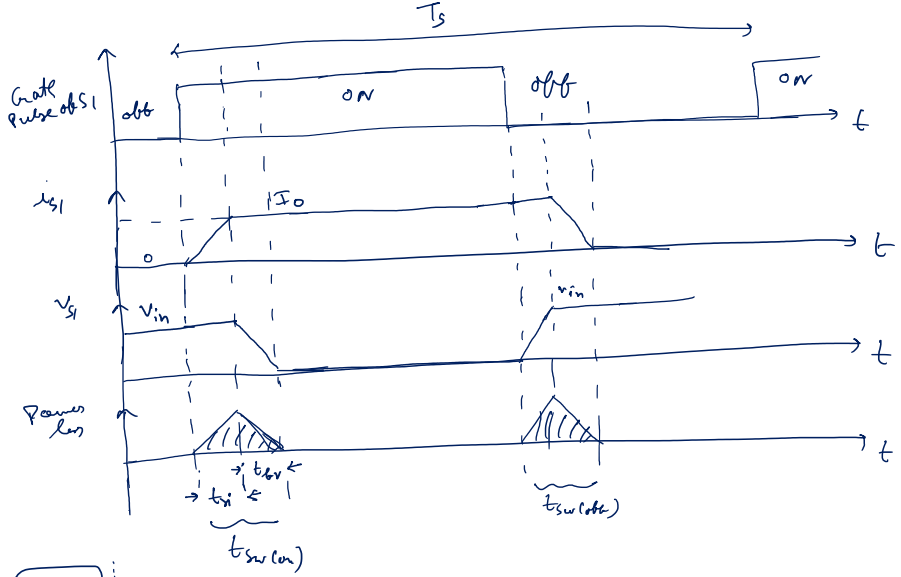
during $t_{sw(on)}$ & $t_{sw(off)}$ following takes places

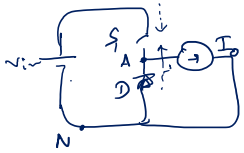
- The loss → reduced η → limits f_{sw}
- $\frac{\Delta V}{\Delta t}$ → (v_{in}) ≈ $\frac{dv}{dt}$, $\frac{di}{dt}$
  Δt → (how fast the switch S_1 is getting ON)
- Electromagnetic interference due to $\frac{dv}{dt}$, $\frac{di}{dt}$
- high $\frac{dv}{dt}$, $\frac{di}{dt}$ there are $\frac{dv}{dt}$ & $\frac{di}{dt}$ related problems

→ To reduce P_{sw}, the $t_{sw(off)}$ & $t_{sw(on)}$ need to be reduced
however it leads to higher $\frac{di}{dt}$ & $\frac{dv}{dt}$

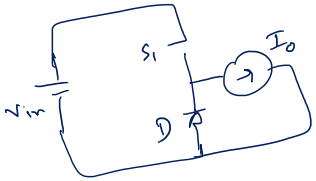
$\frac{dv}{dt}$ → false turn-on of the devices

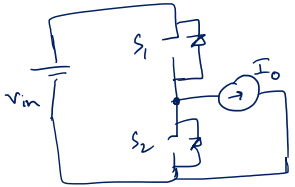
$\frac{di}{dt}$ → oscillation in Gate-Source voltage

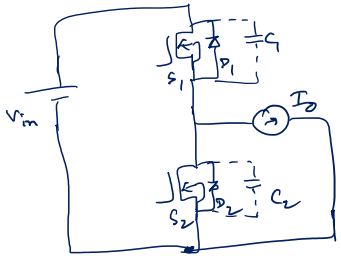




V_{AN} → V_{in} voltage will come
→ 0 to V_{in}





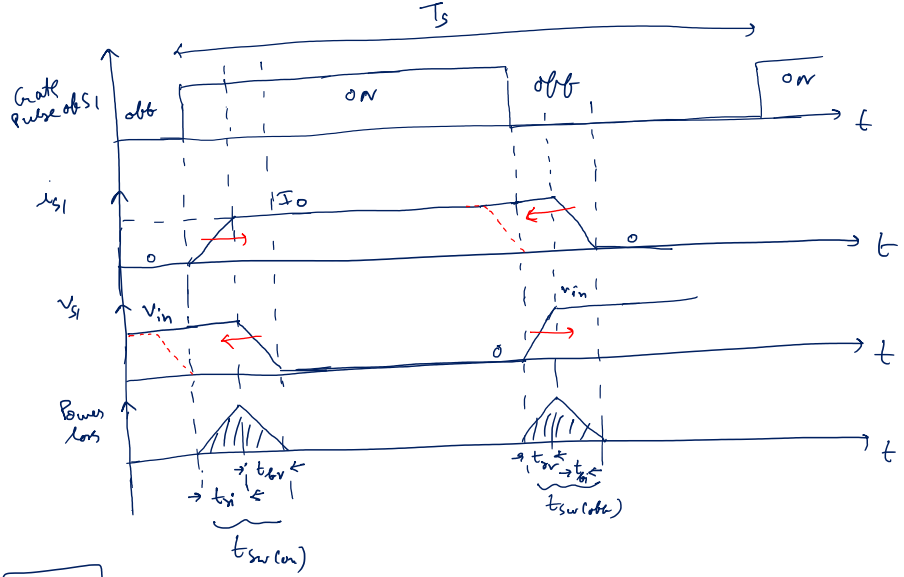


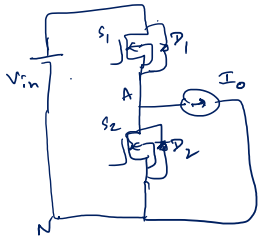
C_1, C_2 are the output capacitance of MOSFETs S_1 & S_2

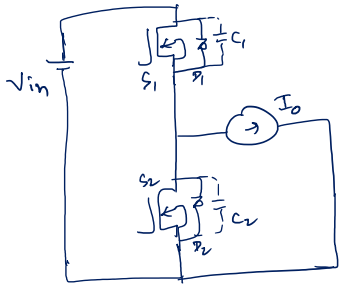
$$P_{sw} = P_{sw(on)} + P_{sw(off)}$$

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

- During turn-on, if somehow we ensure that voltage falls to zero, before current start rising, then the $t_{sw(on)}$ period can be avoided (overlapping of current rise & voltage fall can be avoided).
  - $P_{sw(on)} = 0$
  - Zero voltage switching → turn-on
- During turn-off, if somehow we ensure that current goes to zero, before voltage start rising, then the $t_{sw(off)}$ (overlapping period of current fall and voltage rise) can be avoided
  - $P_{sw(off)} = 0$
  - Zero current switching — turn-off







S_1 & S_2 are complementary to each other; and there is deadtime during transition from off to on

$S_1 = 1, \quad S_2 = 0$

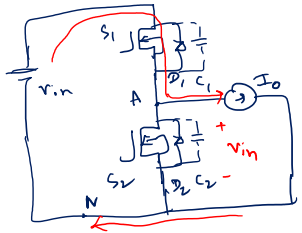
$\longrightarrow$ deadtime

$S_1 = 0, \quad S_2 = 1$

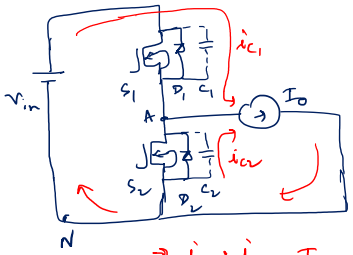
S_1 is turned ON ; S_2 is turned ON

S_1 is turned off S_2 is turned off

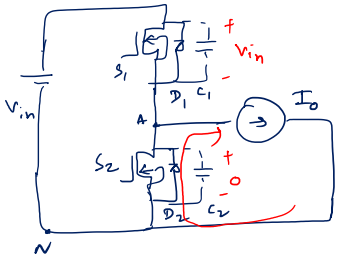
S_1 is turned-off $\Rightarrow$ S_1 goes from ON to off



$\Rightarrow$



$\Rightarrow$



S_1 is ON

S_2 is off

$V_{AN} = V_{in}$

Deadtime

S_1 is off & S_2 is off

$\Rightarrow i_{C_1} + i_{C_2} = I_0$

C_2 is discharging

C_1 is charging

$V_{C_2} \downarrow$; $V_{C_1} \uparrow$

V_{AN} is reducing

$I_0 = i_{D_2}$

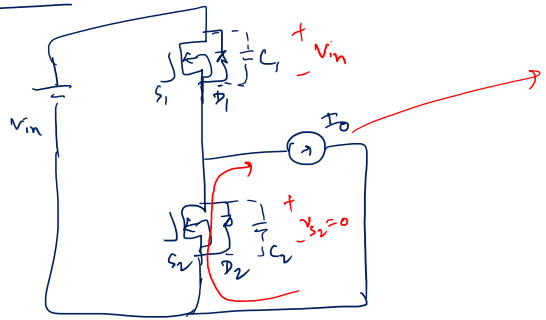
$V_{C_2} = 0$; $V_{C_1} = V_{in}$

$V_{S_2} = 0$

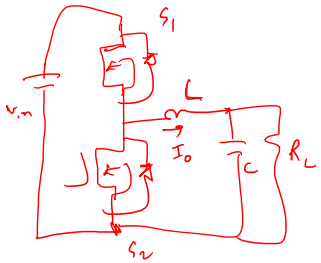
$V_{AN} = 0$

$\Rightarrow$ $\frac{dv}{dt}$ is limited $\Rightarrow$ $\frac{dv}{dt} = \frac{I_0}{C_1 + C_2}$

turning ON 'S_2' (Gate Pulse to S_2)



$i_{S_2} = I_0$



ZVS of Switch 'S_2' during turn-on of 'S_2'

Soft-switching of 'S_2'

⇒ $P_{sw(on)} = 0$; limited $\frac{dv}{dt} = \frac{I_0}{C_1 + C_2}$

⇒ Sufficient deadtime is provided such that V_{C_2} goes to '0', simultaneously V_{C_1} goes to V_{in} ⇒ required condition

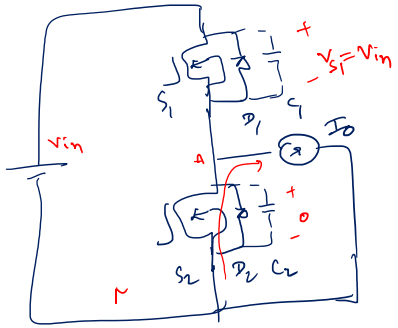
C_1 is charging to V_{in} (from 0) & C_2 is discharging from (V_{in} to 0), thus

Energy in capacitance = $\frac{1}{2} C_1 V_{in}^2 + \frac{1}{2} C_2 V_{in}^2$

Energy associated with 'I_0' flowing through inductor 'L' = $\frac{1}{2} L I_0^2$

⇒ The necessary condition is $\boxed{L I_0^2 > C_1 V_{in}^2 + C_2 V_{in}^2}$

When S_1 is turning ON (going from off to ON)

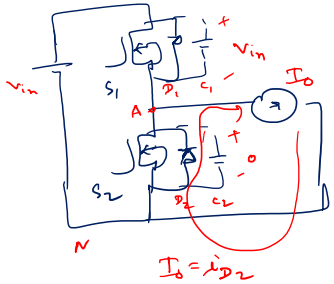


S_1 is off

S_2 is ON

$I_0 = i_{S_2}$

$V_{AN} = 0$



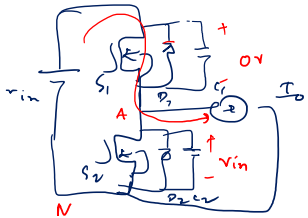
$I_0 = i_{D_2}$

S_1 is OFF

S_2 is OFF

deadtime

$V_{AN} = 0$



$I_0 = i_{S_1}$

Some non-zero $P_{sw(on)}$

S_1 is ON

S_2 is OFF

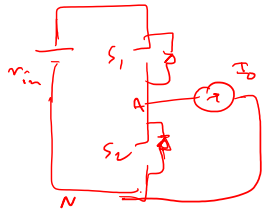
$\Rightarrow V_{AN} = V_{in}$

$\Rightarrow$ Some non-zero $P_{sw(on)}$

$\Rightarrow$ high $\frac{dv}{dt}$

$\Rightarrow$ hard-switching of S_1

- S_1 turns ON with hard-switching
- S_2 turns ON with Soft-switching (ZVS)



- ZCS is difficult for Voltage Source fed half-bridge converters since they have non-zero current coming out of its pole.
- ZCS is possible only if during operation of circuit I_o goes to zero for eg, DCM, FB converters operation.

Thank You