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NPTEL ONLINE CERTIFICATION COURSE

Charging Infrastructure

Lecture-35

Modulation Strategies for PWM Full Bridge Converter

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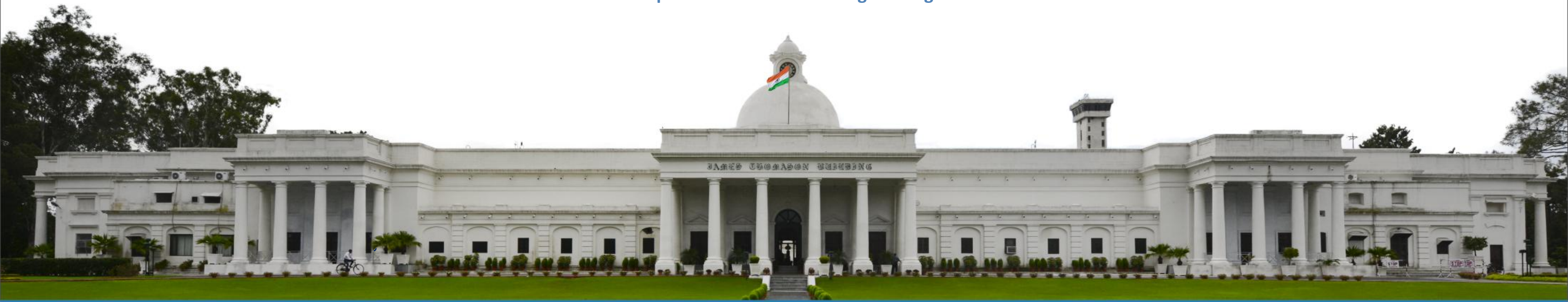
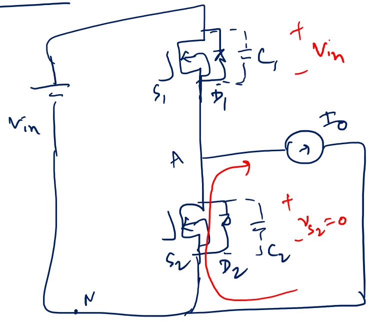


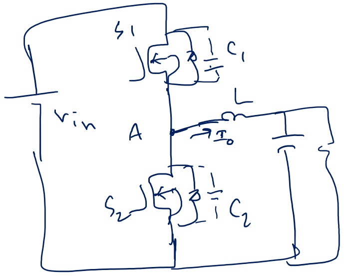
Recap

turning ON 'S_2' (Gate Pulse to S_2)



$i_{S_2} = I_0$

$\Rightarrow$



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

Soft-switching of 'S_2'

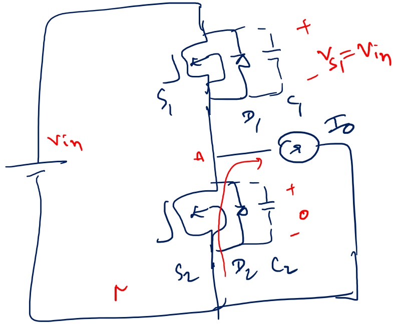
$\Rightarrow$ $P_{sw(on)} = 0$; limited $\frac{dv}{dt} = \frac{I_0}{C_1+C_2}$

Sufficient deadtime is provided such that V_{C_2} goes to '0', simultaneous V_{C_1} goes to V_{in} $\Rightarrow$ required condition

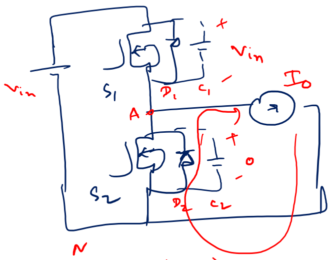
The necessary condition is $\boxed{L I_0^2 > C_1 V_{in}^2 + C_2 V_{in}^2}$ ✓

Recap

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

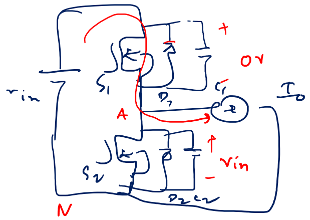


$\Rightarrow$



$I_0 = i_{D2}$

$\Rightarrow$



$I_0 = i_{S1}$

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

S_1 is off

S_2 is ON

$I_0 = i_{S2}$

$v_{AN} = 0$

S_1 is OFF

S_2 is OFF

deadtime

$v_{AN} = 0$

S_1 is ON

S_2 is OFF

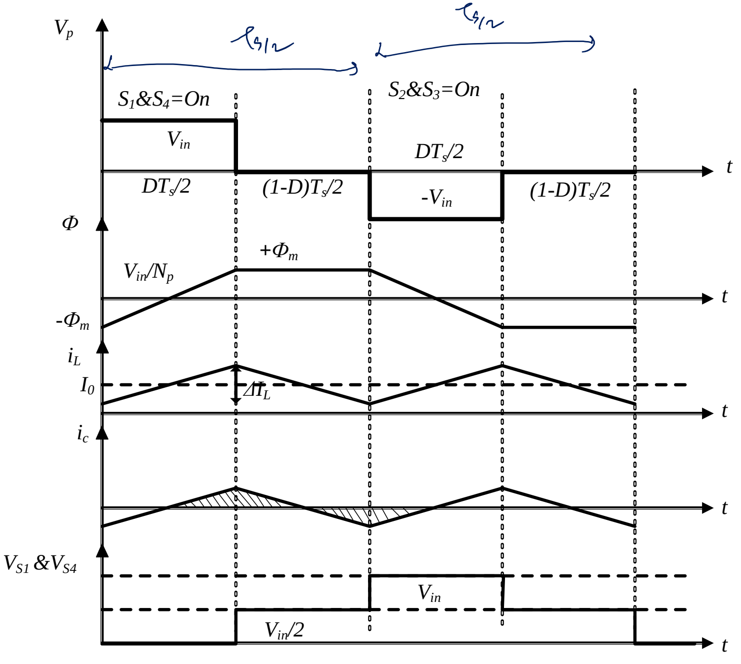
$\Rightarrow V_{AN} = V_{in}$

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

$\Rightarrow$ high dv/dt

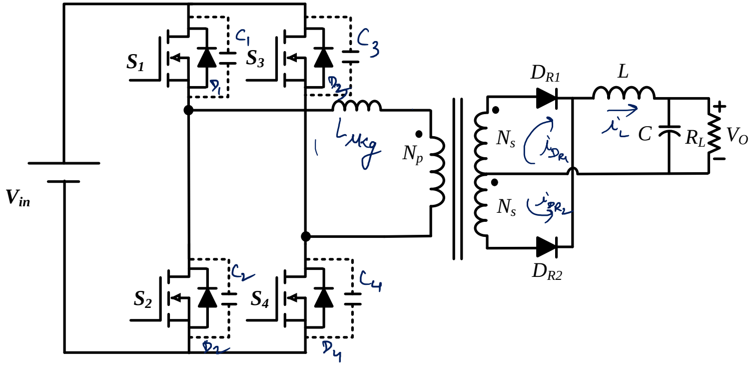
$\Rightarrow$ hard-switching of 'S_1'

Full-bridge Converter

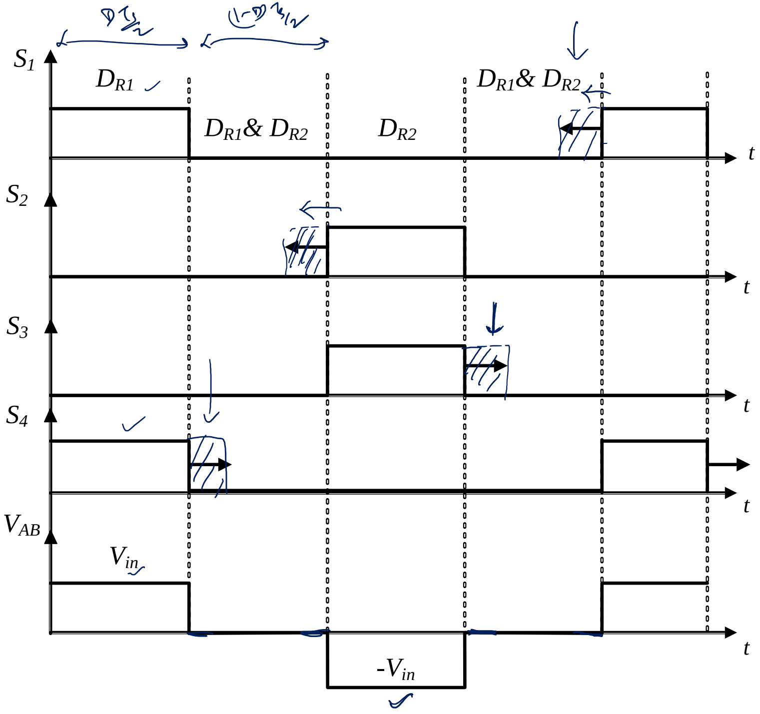


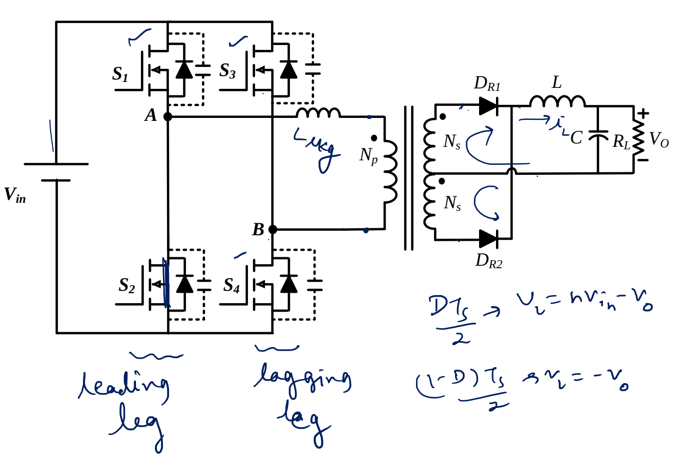
$n = \frac{N_s}{N_p}$

$V_o = n V_{in} D$



PWM Strategies





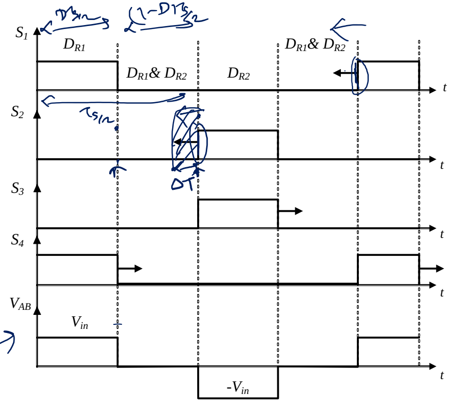
$\frac{DT_s}{2} \rightarrow v_L = nV_{in} - V_o$

$\frac{(1-D)T_s}{2} \rightarrow v_L = -V_o$

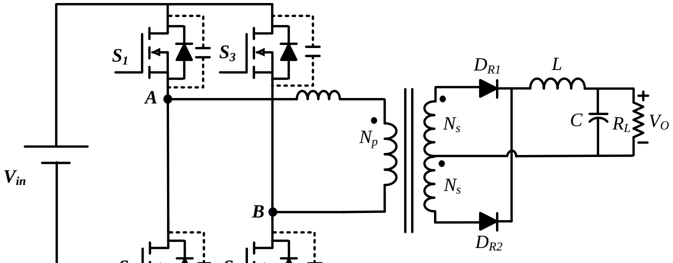
$V_o = nV_{in}D$

Source: Soft-Switching PWM Full-Bridge Converters: Topologies, Control, and Design by Xinbo Ruan

PWM Strategies



$v_0 = n V_{in} D$



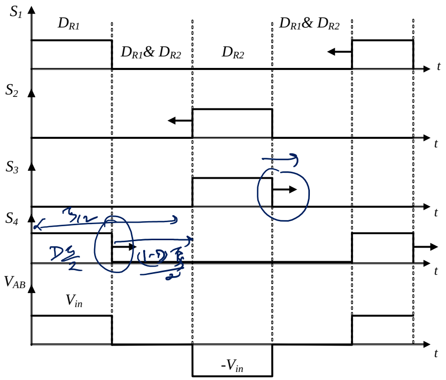
leading leg

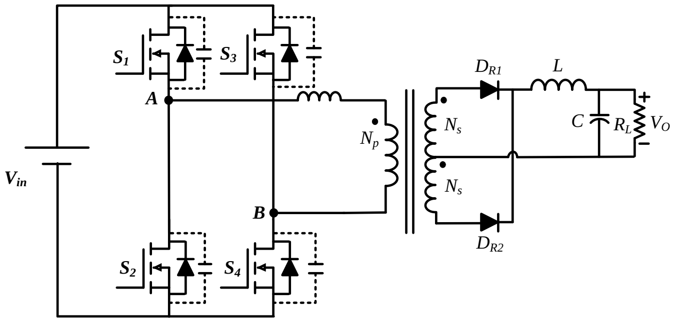
lagging leg

- Leading leg
  - 1: On-time is unchanged: $\frac{DT_s}{2}$ for S_1 & S_2
  - 2: Turn-on time of S_1 and S_2 switches are adjusted forward, but the on-time is less than $\frac{T_s}{2}$ $\left(\frac{DT_s}{2} + \Delta T\right)$ $\Delta T < \frac{(1-D)T_s}{2}$
  - 3: Turn-on time of S_1 and S_2 switches are adjusted forward to $\frac{T_s}{2}$ ✓ $\left(\frac{DT_s}{2} + \Delta T\right) \Rightarrow \Delta T = \frac{(1-D)T_s}{2} \Rightarrow t_{on(S_1,S_2)} = \frac{T_s}{2}$

Source: Soft-Switching PWM Full-Bridge Converters: Topologies, Control, and Design by Xinbo Ruan

PWM Strategies



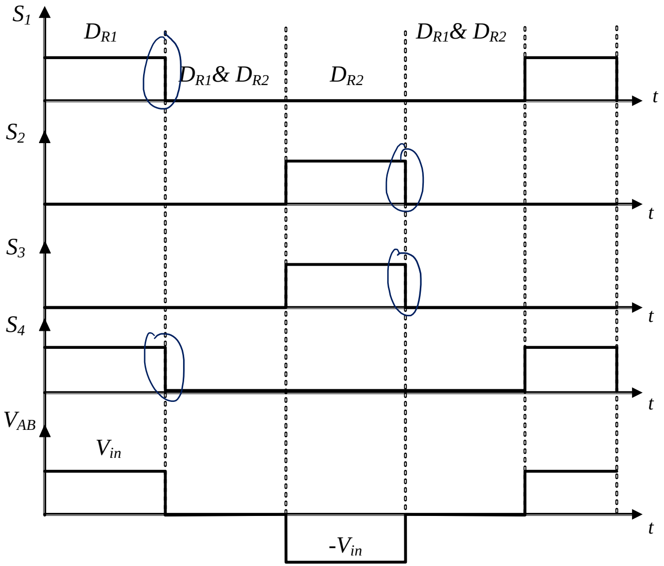


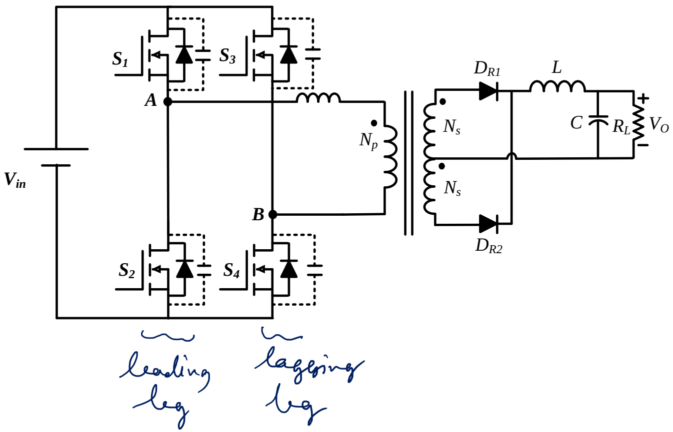
leading leg   lagging leg

- Lagging leg
  - A: On-time is unchanged: $\frac{DT_s}{2}$ S_3, S_4
  - B: Turn-on time of S_3 and S_4 switches are adjusted backward, but the on-time is less than $\frac{T_s}{2}$ $\left(\frac{DT_s}{2} + \Delta T\right) \rightarrow \Delta T < (1-D)\frac{T_s}{2}$
  - C: Turn-on time of S_3 and S_4 switches are adjusted backward to $\frac{T_s}{2}$ $\rightarrow \left(\frac{DT_s}{2} + \Delta T\right)$ such that $\Delta T = (1-D)\frac{T_s}{2}$

Source: Soft-Switching PWM Full-Bridge Converters: Topologies, Control, and Design by Xinbo Ruan

Modulation Method -1

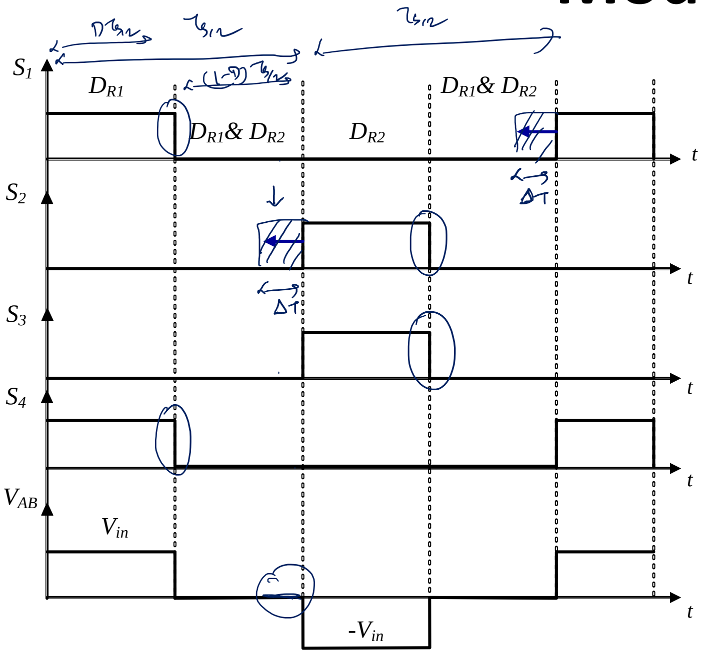




- 1A
- Diagonal switches turn-off at the same time

Source: Soft-Switching PWM Full-Bridge Converters: Topologies, Control, and Design by Xinbo Ruan

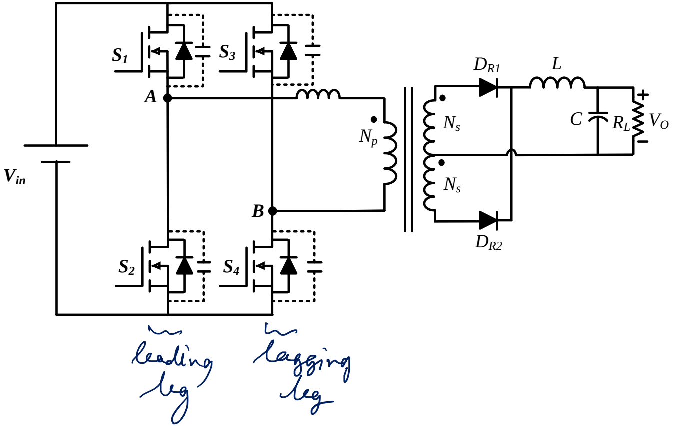
Modulation Method -2



$\Delta T < \frac{(1-D)T_s}{2}$

$\Rightarrow t_{on(S_1, S_2)} = \frac{DT_s}{2} + \Delta T$

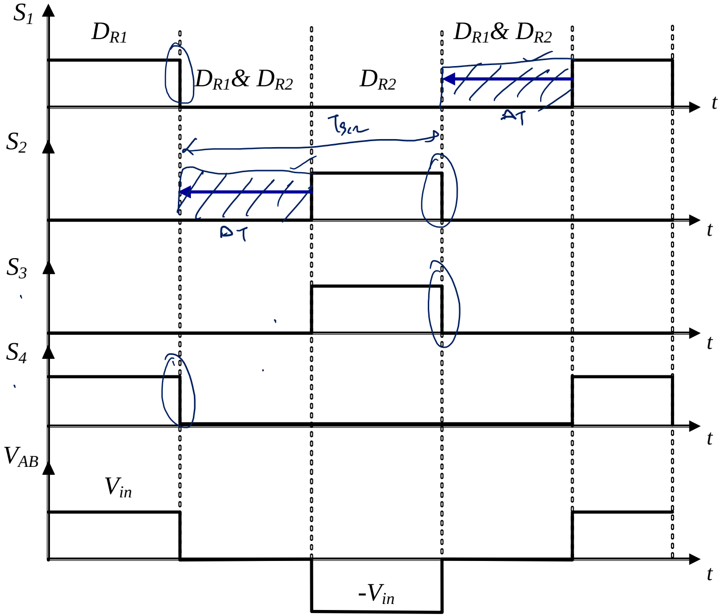
$V_o = nV_{in}D$



- 2A
- Diagonal switches turn-off at the same time

Source: Soft-Switching PWM Full-Bridge Converters: Topologies, Control, and Design by Xinbo Ruan

Modulation Method -3

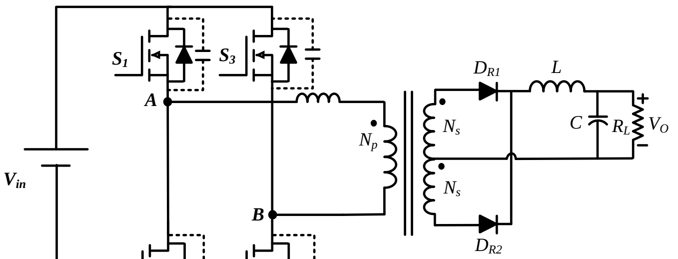


$\Delta T = \frac{(1-D)T_s}{2}$

$t_{on(S_1,S_2)} = \frac{DT_s}{2} + \frac{(1-D)T_s}{2}$

$= T_s/2$

$V_o = n V_{in} D$



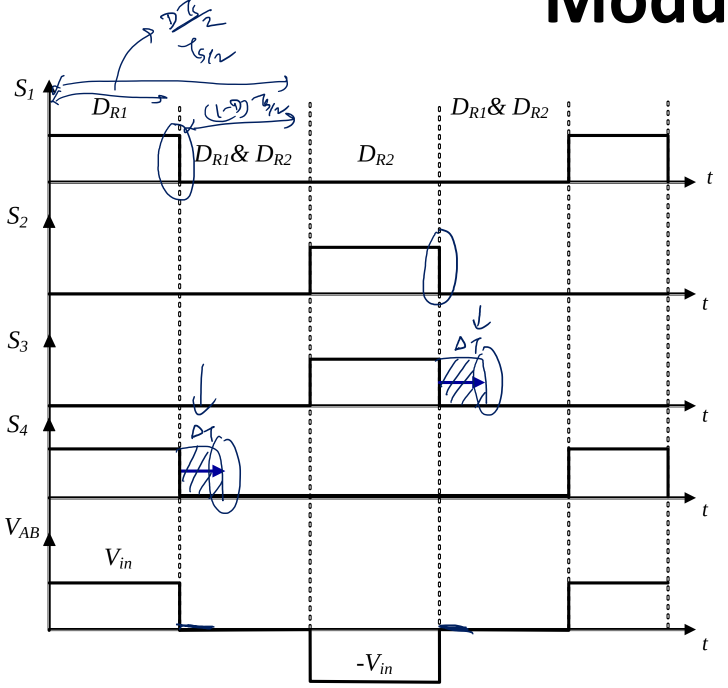
leading leg

lagging leg

- 3A
- Diagonal switches turn-off at the same time

Source: Soft-Switching PWM Full-Bridge Converters: Topologies, Control, and Design by Xinbo Ruan

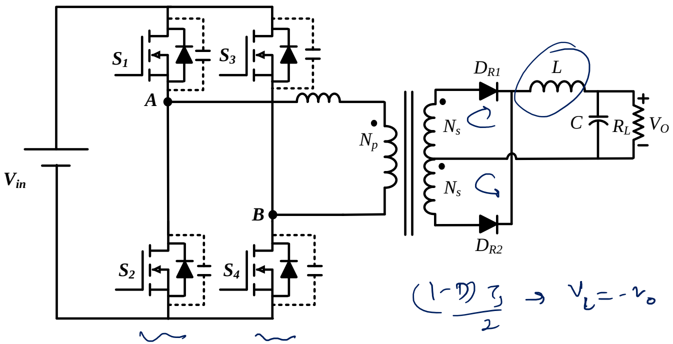
Modulation Method -4



$\Delta T < \frac{(1-D)T_s}{2}$

$\Rightarrow t_{on(S_3,S_4)} = \frac{DT_s}{2} + \Delta T$

$\boxed{V_o = nV_{in}D}$



$\frac{(1-D)T_s}{2} \rightarrow V_L = -V_o$

$\frac{DT_s}{2} \rightarrow V_L = nV_{in} - V_o$

leading leg

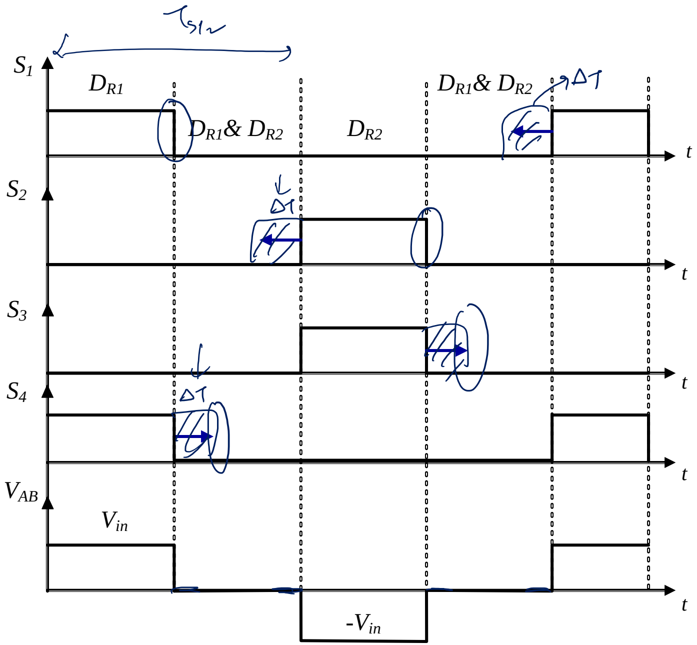
lagging leg

- 1B
- Diagonal switches turn-off at different time

$(S_1 \& S_4)$
$(S_2 \& S_3)$

Source: Soft-Switching PWM Full-Bridge Converters: Topologies, Control, and Design by Xinbo Ruan

Modulation Method -5

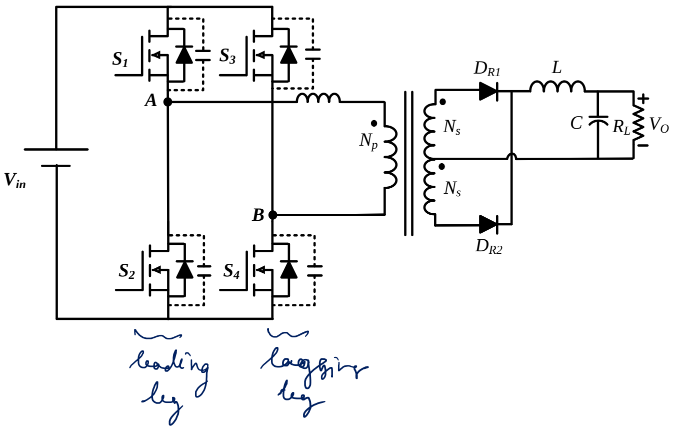


$\Delta T < \frac{(1-D)T_s}{2}$

$\Rightarrow t_{on} = \frac{DT_s}{2} + \Delta T$
(S_1, S_2, S_3, S_4)

$\Rightarrow$

$V_o = nV_{in} \cdot D$

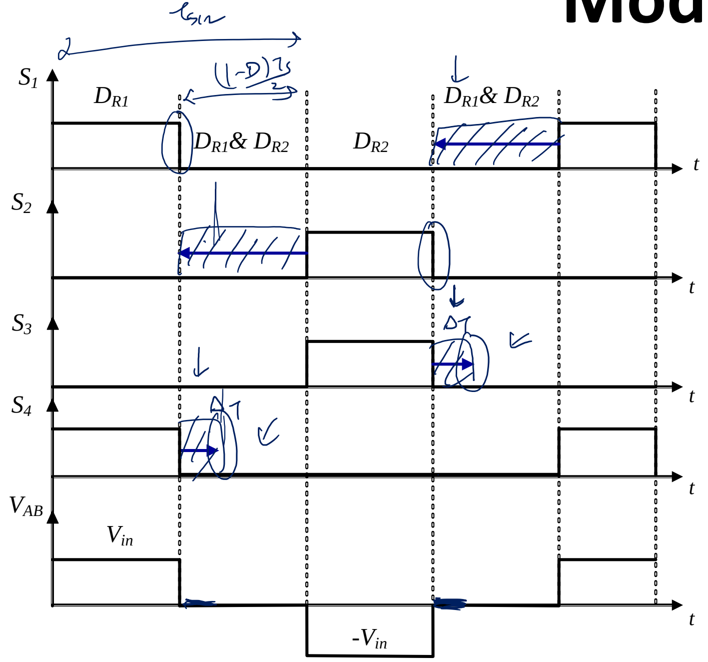


- 2B
- Diagonal switches turn-off at different time

$(S_1 \& S_4)$ $(S_2 \& S_3)$

Source: Soft-Switching PWM Full-Bridge Converters: Topologies, Control, and Design by Xinbo Ruan

Modulation Method -6

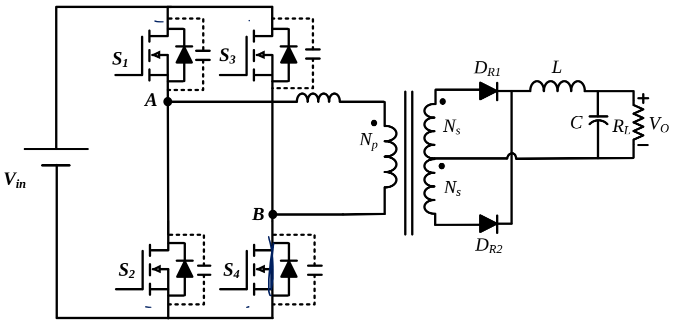


$t_{on(S_1,S_2)} = \frac{T_s}{2}$

$t_{on(S_3,S_4)} = \frac{DT_s}{2} + \Delta T$

$\Rightarrow \Delta T < \frac{(1-D)T_s}{2}$

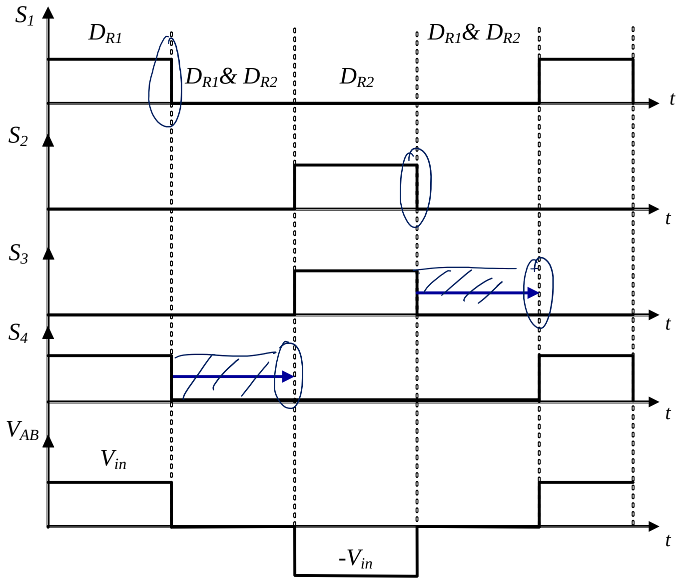
$\Rightarrow v_o = nV_{in}D$



- 3B
- Diagonal switches turn-off at different time

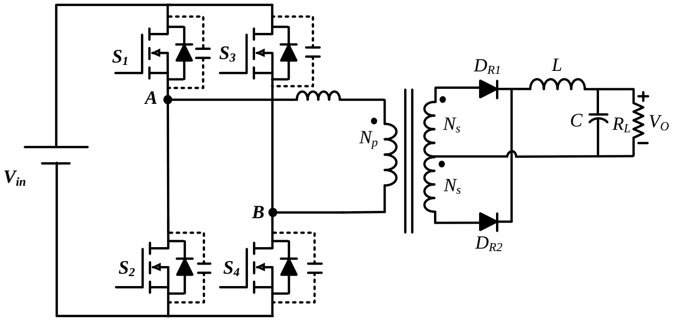
Source: Soft-Switching PWM Full-Bridge Converters: Topologies, Control, and Design by Xinbo Ruan

Modulation Method -7



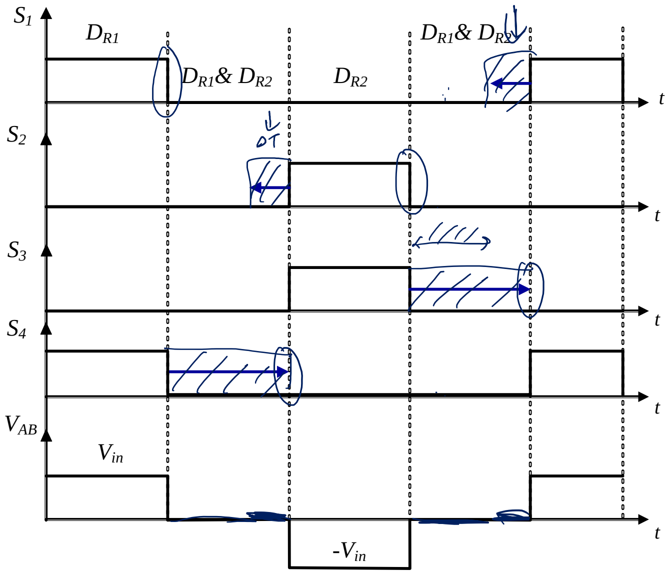
$\Rightarrow t_{on}(s_3, s_4) = \frac{T_s}{2}$

$\Rightarrow v_0 = n v_{in} D$



- 1C
- Diagonal switches turn-off at different time

Modulation Method -8

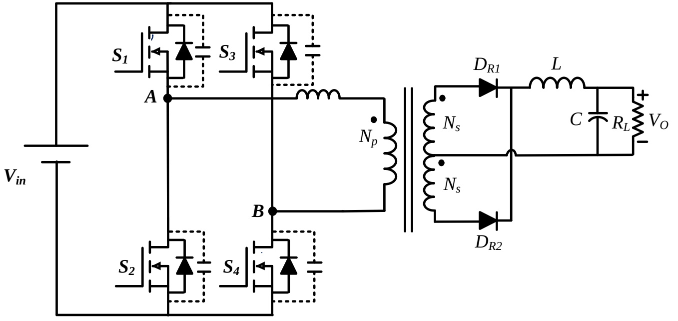


$t_{on}(S_3, S_4) = \frac{T_s}{2}$

or $t_{on}(S_1, S_2) = \frac{DT_s}{2} + \Delta T$

$\Delta T < \frac{(1-D)T_s}{2}$

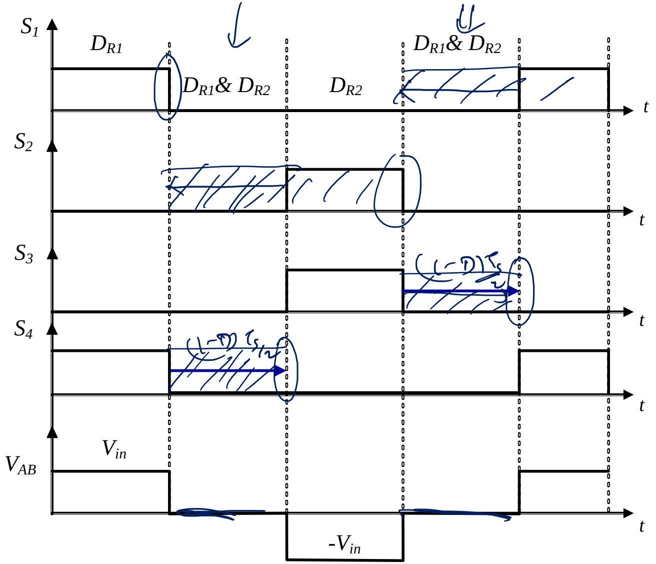
$V_o = n V_{in} D$



- 2C
- Diagonal switches turn-off at different time

Source: Soft-Switching PWM Full-Bridge Converters: Topologies, Control, and Design by Xinbo Ruan

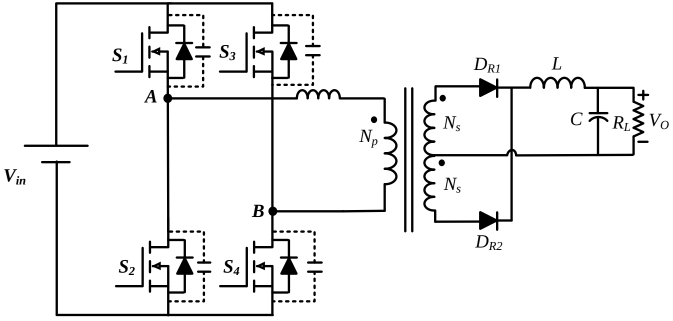
Modulation Method -9



$t_{on}(S_1, S_2, S_3, S_4) = \frac{T_s}{2}$

$\Delta T = \frac{(1-D)T_s}{2}$

$V_o = n V_{in} D$



- 3C
- Diagonal switches turn-off at different time

Source: Soft-Switching PWM Full-Bridge Converters: Topologies, Control, and Design by Xinbo Ruan

Two Types of PWM Strategies

- Type-1: Diagonal switches turns-off at the same time: Modulation method 1 to 3

- Type-2: Diagonal switches turns-off at different time: Modulation method 4 to 9

$V_0 = n V_{in} \cdot D$

Source: Soft-Switching PWM Full-Bridge Converters: Topologies, Control, and Design by Xinbo Ruan

Thank You