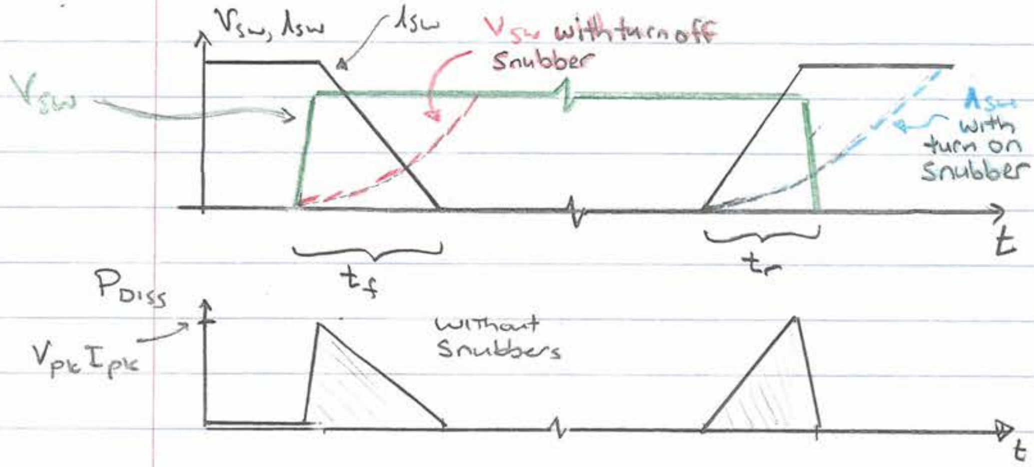
★ NOTE: SHOW DEMO OF HARD-SWITCHED WAVEFORMS AT START

6.334 Lecture Notes — Soft switching # 1

Review: Switching loss + snubbers

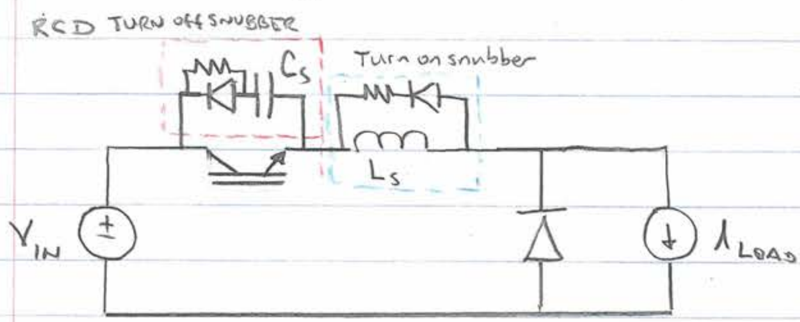


Put up initial things on board before class...

The voltage / current overlap (without snubbers) has three deleterious effects:

1. Loss + limited η + f_{sw} (overlap + capacitive discharge loss)
2. EMI due to high di/dt + dv/dt
3. switching locus may exceed SOA + $\frac{di}{dt}, \frac{dv}{dt}$ limits allowed

Snubbers mitigate these effects, but (typically) add losses



Today: Soft-switching techniques try to mitigate these effects <u>without</u> adding loss.

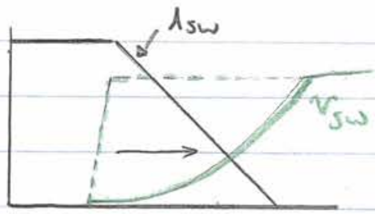
General methods: "Zero voltage" switching (ZVS) / "Zero current" switching (ZCS) } can be applied at turn on and/or turn off

⇒ Turn off snubber looks like ZVS in the limit
⇒ Turn on snubber looks like ZCS in the limit
} But we need to <u>recover</u> the snubber energy!

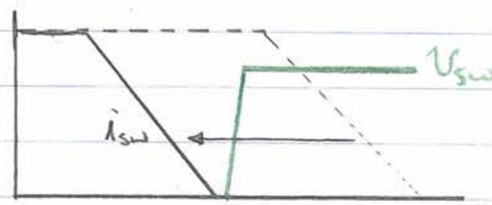
Soft Switching:

ZERO VOLTAGE | **ZERO CURRENT**

TURN OFF

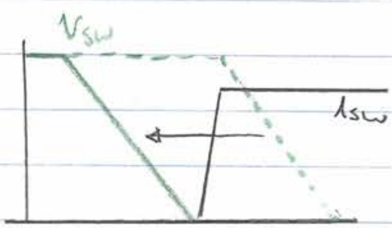


★ DELAY V-rise on switch

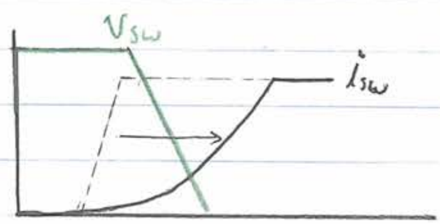


★ MAKE current in switch → 0 **BEFORE** turning off switch

TURN ON



★ make switch voltage go to zero before switch turn on



★ Delay current rise on switch

- So, we can reduce overlap loss by either delaying voltage or current rise in the switch, or by arranging the switching event to take place when voltage and/or current will naturally be zero.

- These techniques typically require additional control or circuit complexity, or may add conduction loss or peak device stress, but the tradeoff may often be worth it!

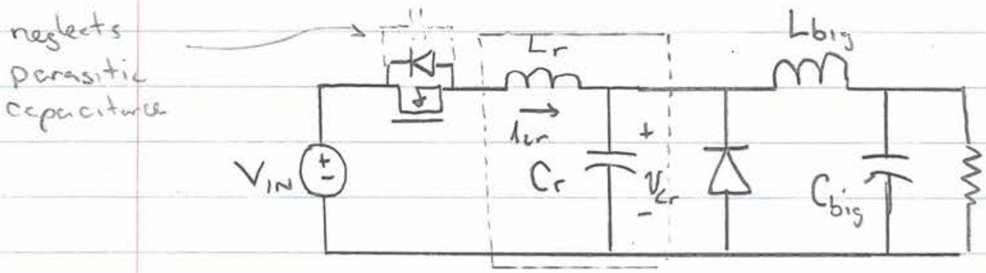
- ZVS turn on additionally reduces capacitor discharge loss (important at very high frequencies) while ZCS turn on reduces loss in parasitic inductance.

- Varying degrees of "softness" exist, depending on the degree to which waveform rises are delayed, slopes at transitions, etc.

6.334 Lecture Notes — Soft switching # 1

Example: <u>ZCS Quasi-Resonant Buck Converter</u> (full wave)

→ See handout/overhead



go through operational cycle: Main switch turns on ZCS
main switch/diode turns off ZCS
Diode turns on ZCS
Diode turns off ZCS

V_{out} controlled by f_{sw} control / pulse density modulation

Show experimental waveforms at light, heavy load

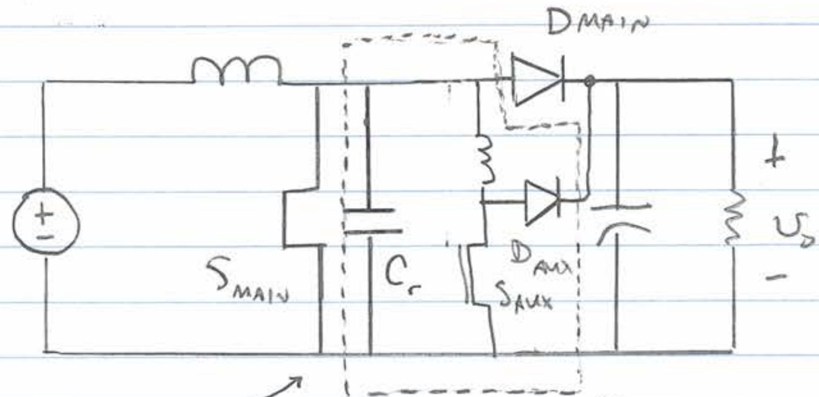
Advantages: smooth (mostly soft) waveform transitions
low switching losses to moderate frequencies

Disadv:
- ZCS turn on still loses junction cap energy
- ZCS turn off of device can still have ringing w/ device junction cap
- High conduction losses (compared to PWM) due to resonant action & energy slosh
- diode voltage rating 2X
- requires frequency control over very wide range

EXAMPLE: ZVT Boost Converter

Add an auxiliary circuit to the conventional PWM boost converter to enable the main devices to have ZVS switching

→ The auxiliary "Baby boost" circuit is <u>not</u> fully soft switched, but has a low rating.



- Auxiliary circuit operates only @ switching transitions
  - → Allows ZVS switching of main switch and diode
  - → especially valuable @ high output voltage where Main diode reverse recovery (+ switch capacitive discharge loss) are important.

- Auxiliary circuit is not fully soft switched (compromise between full soft switching + hard switching
  - → ZCS turn on of S_{AUX}, but capacitive discharge remains
  - → SCS turn off of D_{AUX},
  - → loss is limited because auxiliary circuit elements can be small.