An Overview of Forward Converter with Various Reset Schemes

By

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Features of Forward Converter

- One of fundamental topologies
- Most commonly used topology
- Applicable power level from a few Watts to a couple of Kilo-Watts
- Appears simple but difficult to optimize design
- Where are you on skill 1-10?

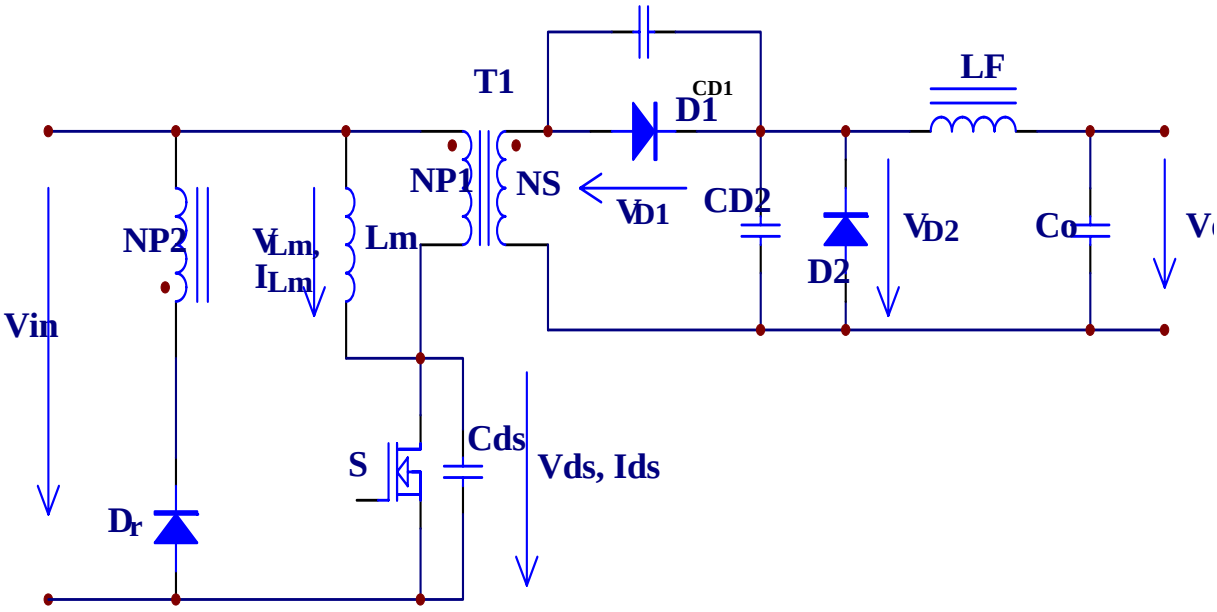
Test

1. How does the B-H curve in the 3rd winding reset forward converter look?
2. Which secondary diode is subject to higher switching loss?
3. Can the resonant reset forward converter operate with ZVS?
4. Can two-switch forward converter operate at greater than 50% duty cycle?
5. Does the clamp diode in active-clamp forward converter suffer from reverse-recovery problem?

Variations of Forward Topology

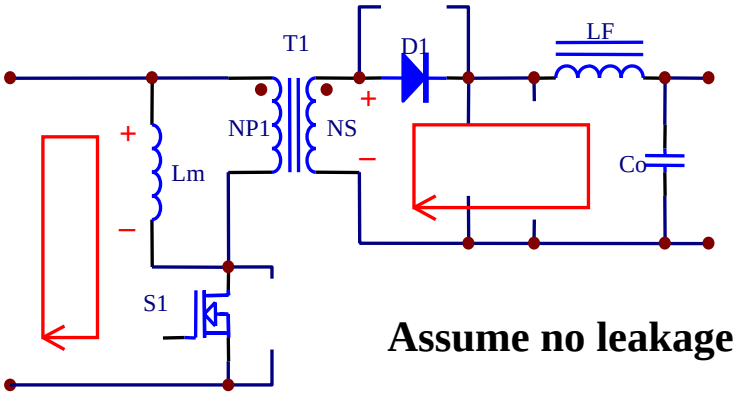
- Third Winding Reset Forward
- Zener Clamp Forward
- R-C-D Clamp Forward
- Active Clamp Forward
- Resonant Reset Forward
- Two Switch Forward
- ZCS Quasi-Resonant Forward
- ZVS Quasi-Resonant Forward
- ZVS Multi-Resonant Forward
- ZVT Forward
- ……

Third Winding Reset Forward



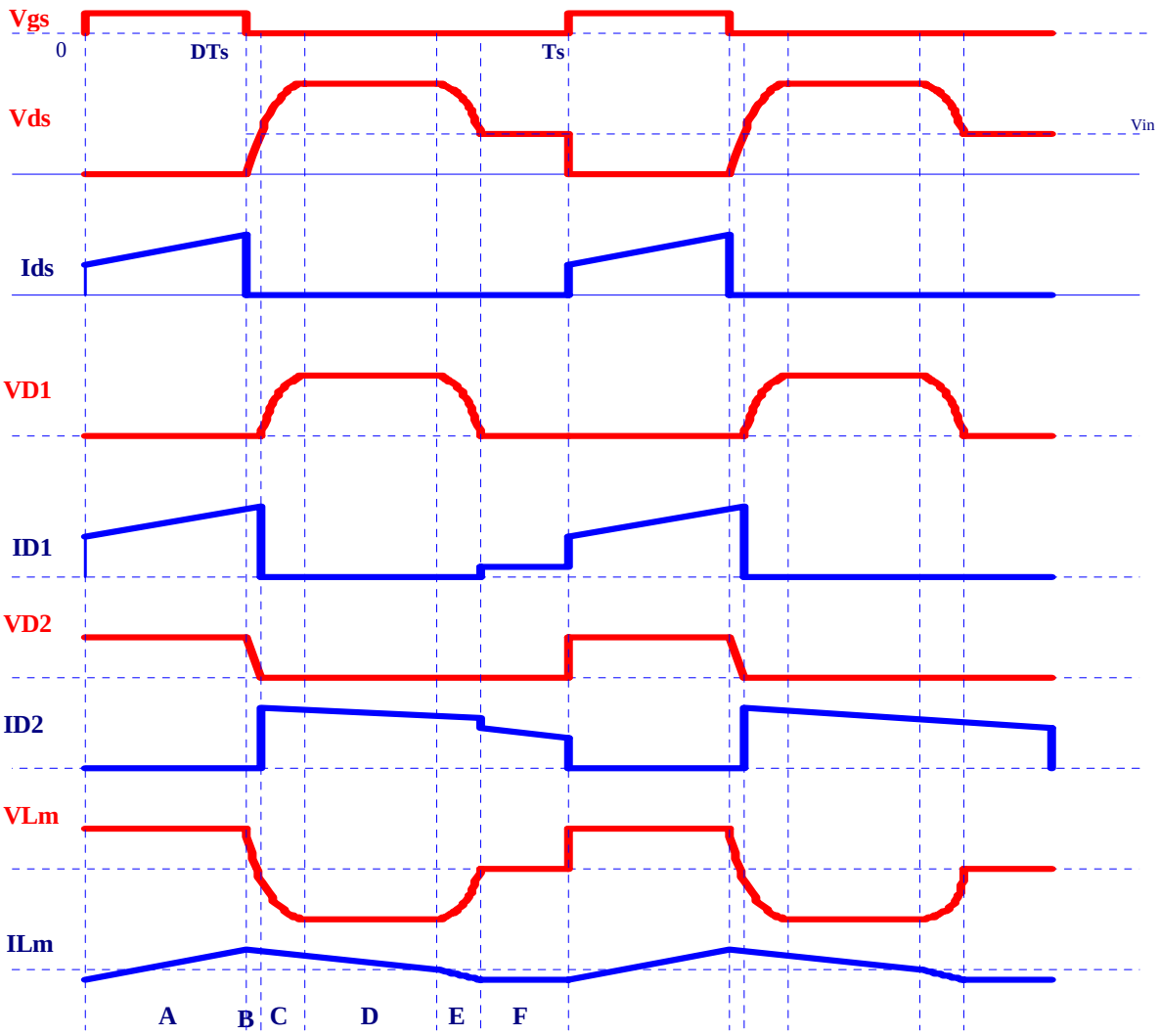
- How does B-H curve look?

Operating Stage A

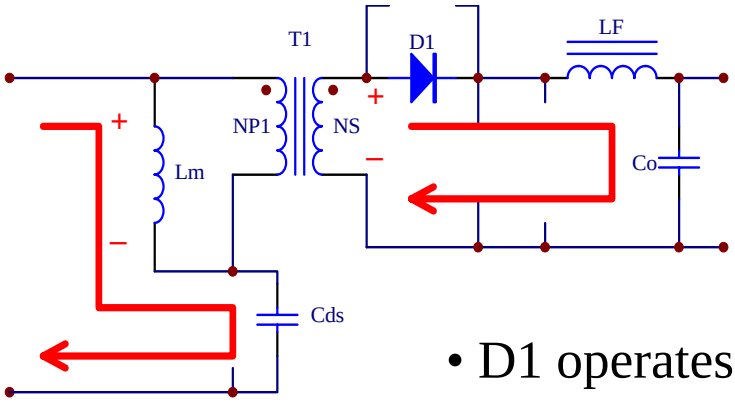


Assume no leakage

A

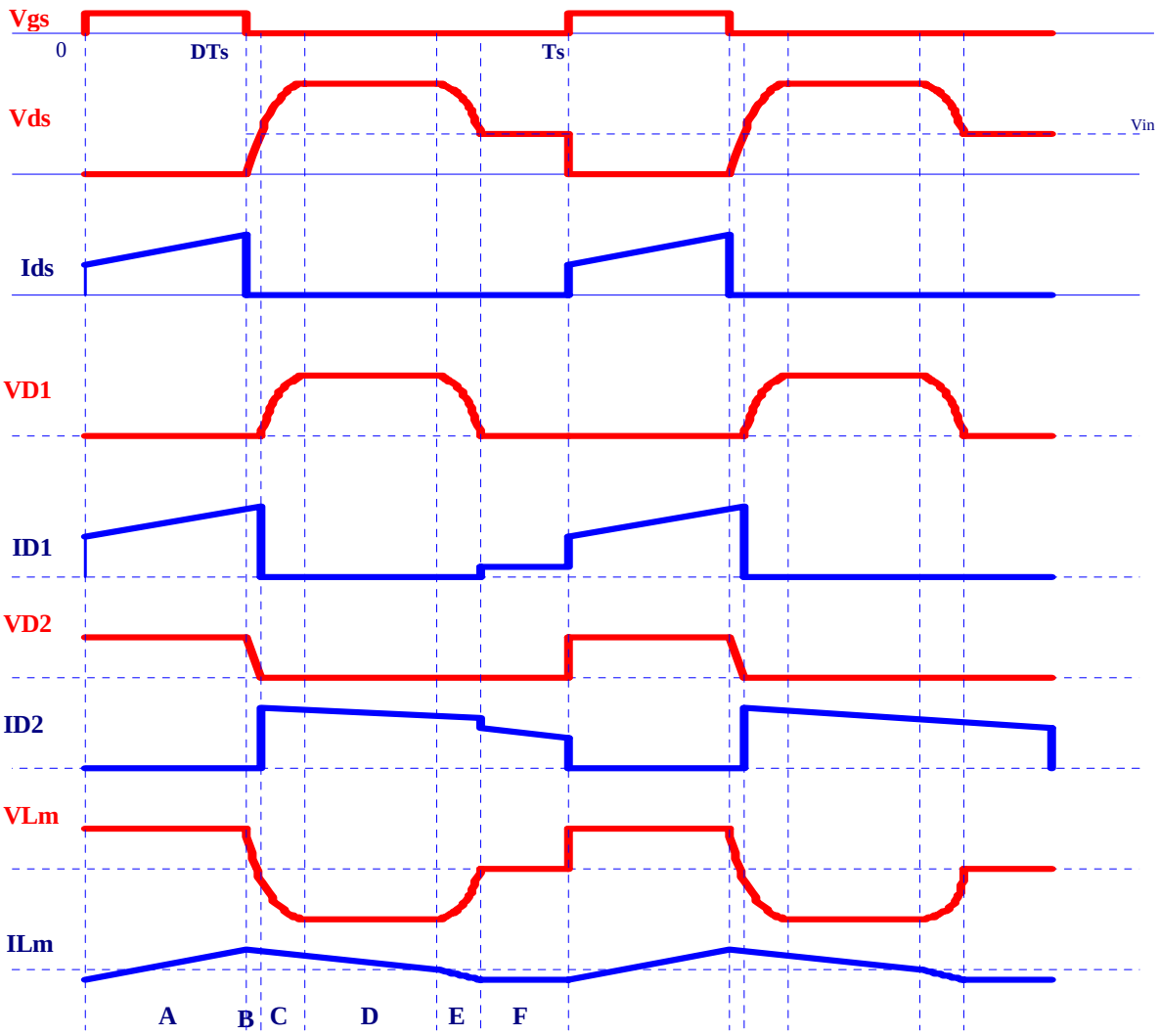


Operating Stage B

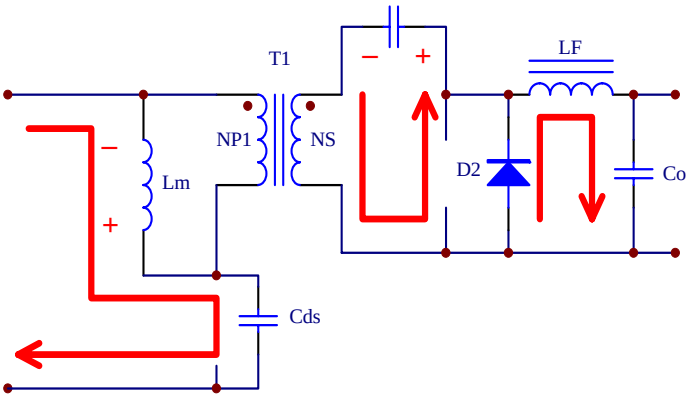


- D1 operates with ZVS

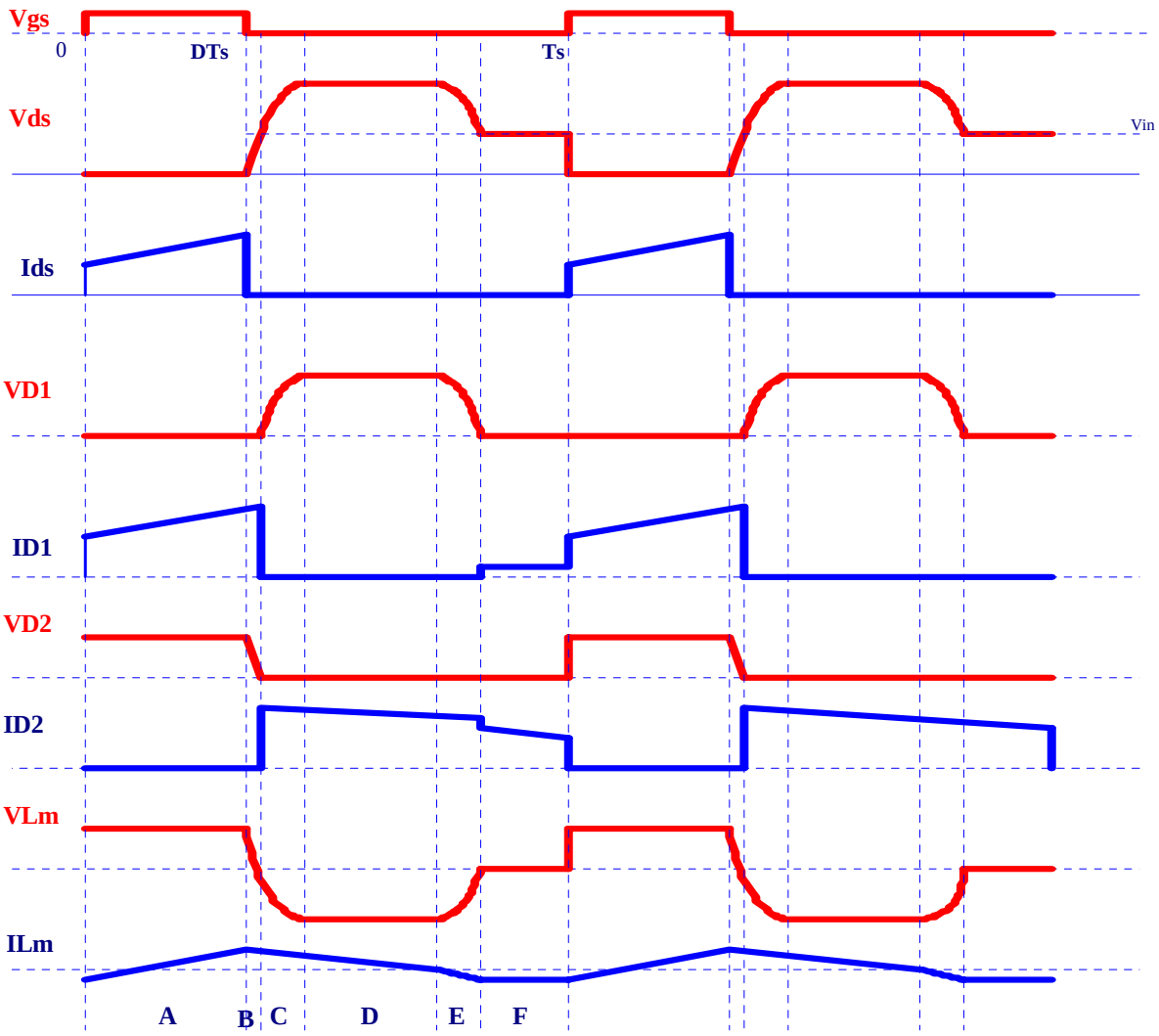
B



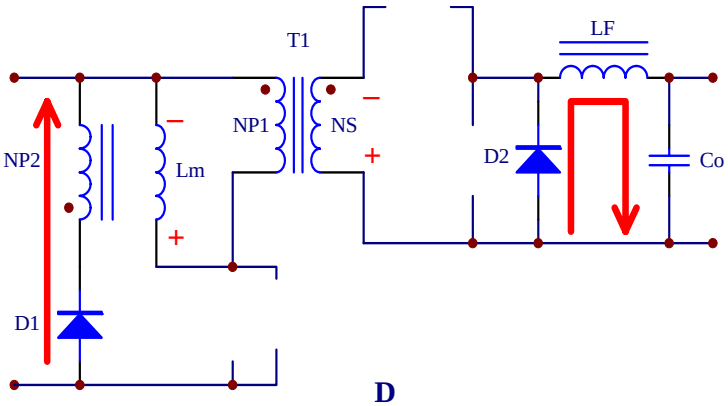
Operating Stage C



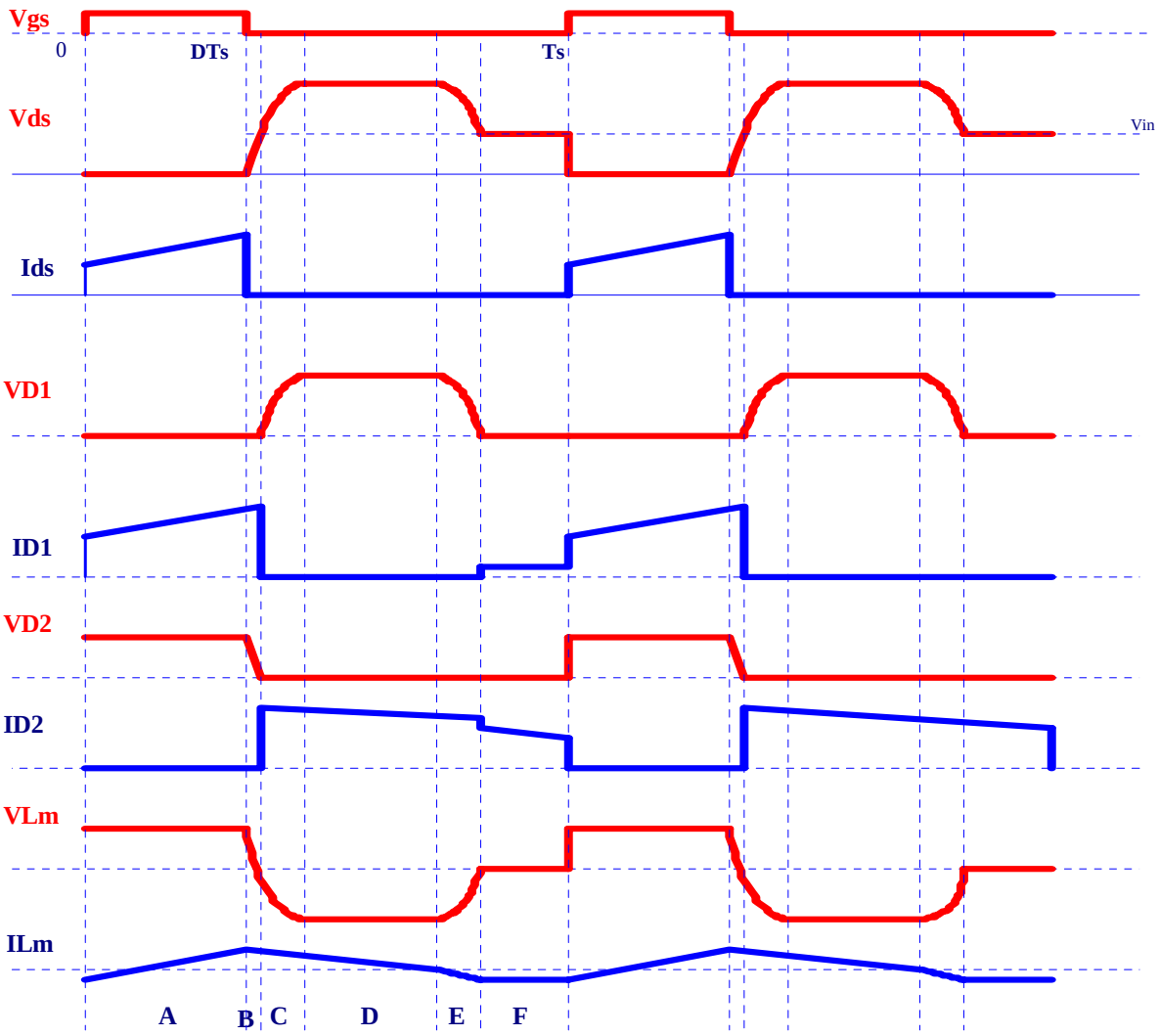
C



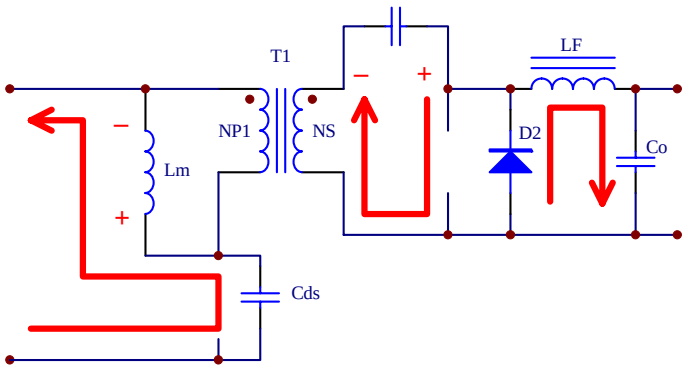
Operating Stage D



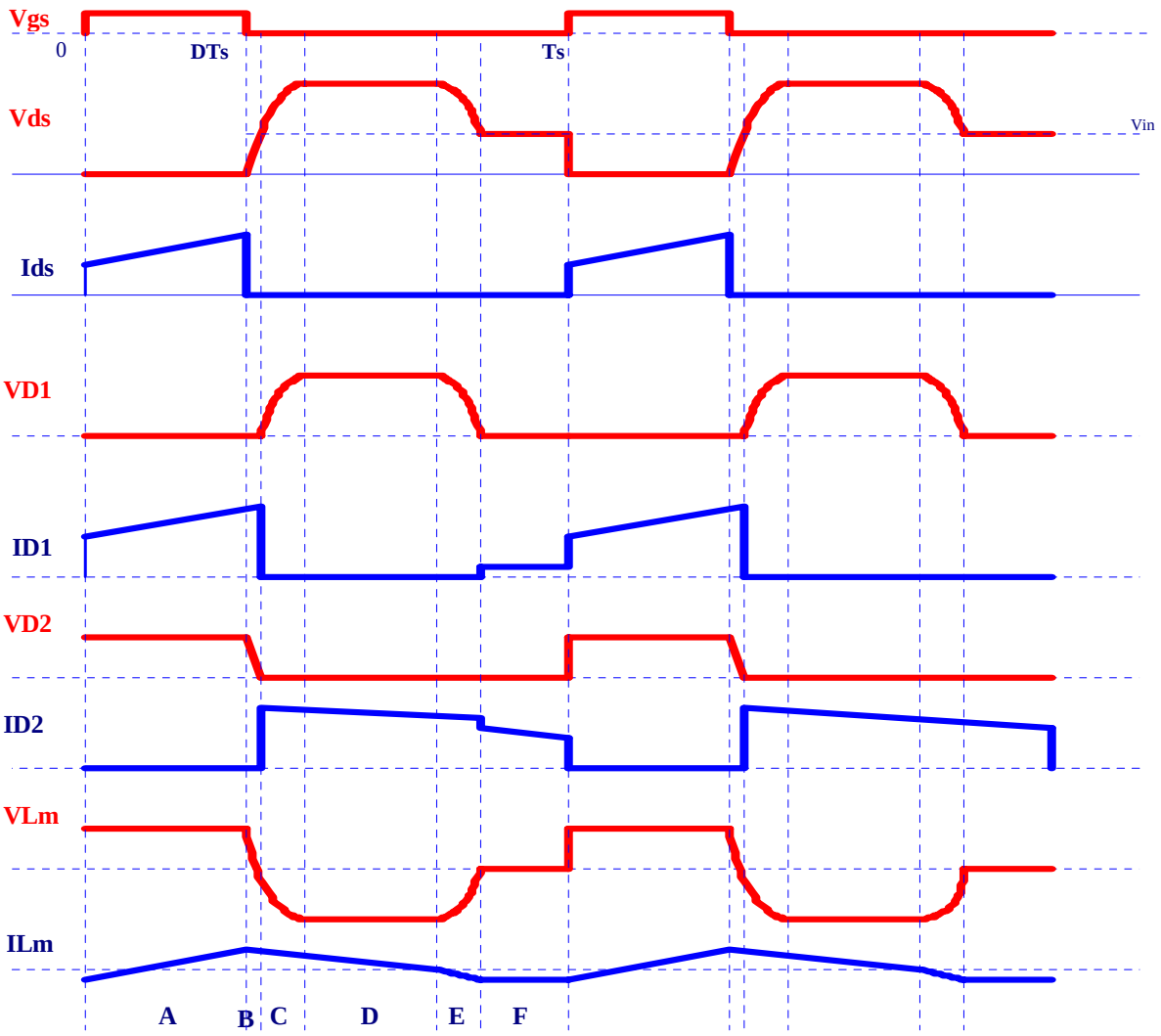
D



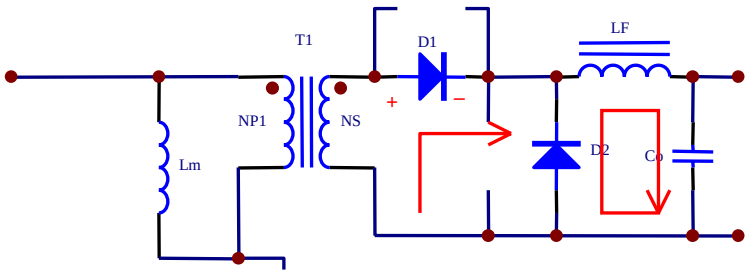
Operating Stage E



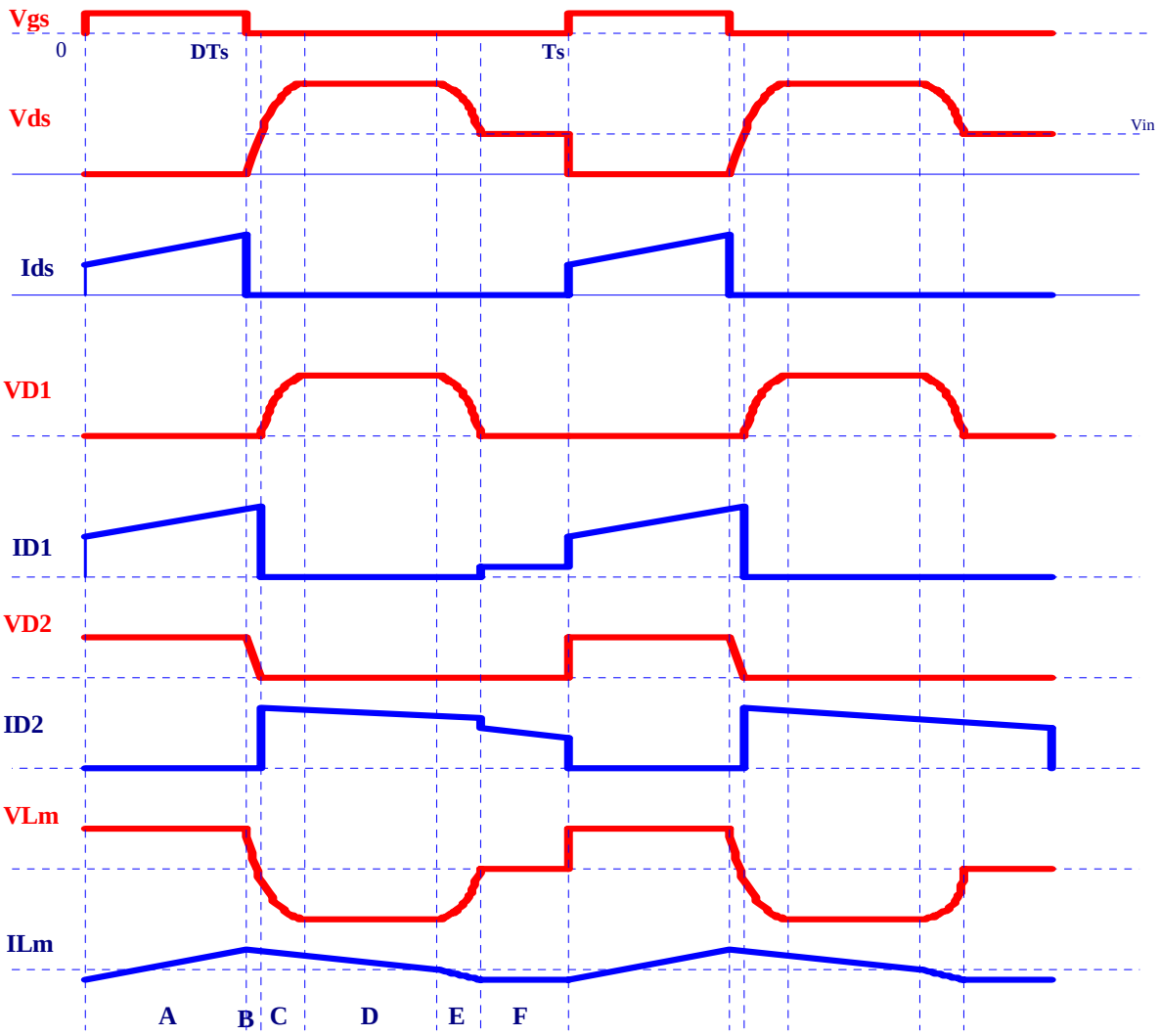
E



Operating Stage F



F



Third Winding Reset Forward

Advantages:

- Magnetizing energy recycled
- Part of TR leakage energy recycled
- Very reliable reset, no switch voltage overshoot during transient

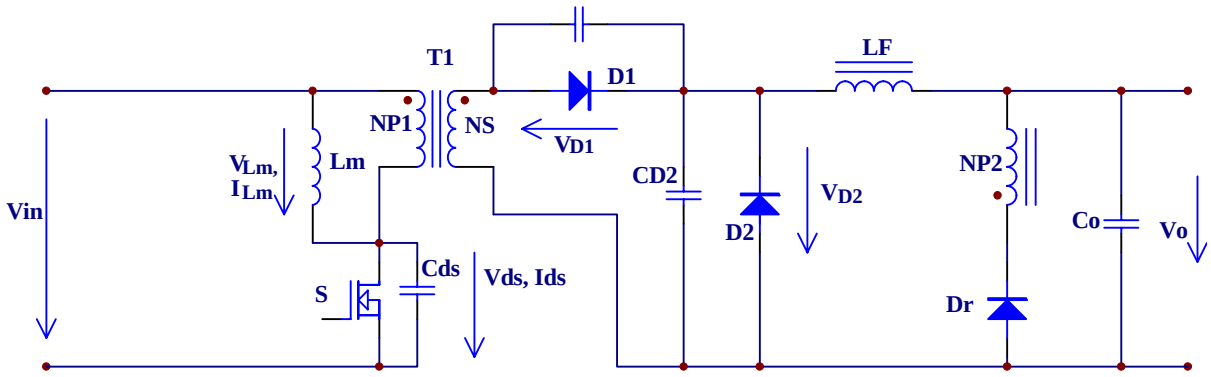
Drawbacks:

- Third winding complicates TR design
- Max Duty cycle limited to about 40% if Np2=Np1
- Clamp voltage proportional to Vin

Key Design Considerations

- **Extend maximum duty cycle to**
  - → **Reduce primary (S, TR) current stress**
  - → **Reduce D2 voltage stress**
  - → **Reduce output filter size**
  - → **Reduce input filter size**
  - → **Improve efficiency**
- **Minimize leakage inductance between Np1 and Np2**
- **CD1 does not introduce switching loss**
- **How to extend max duty cycle and what are limitations?**

Variation (1) of Third Winding Reset Forward



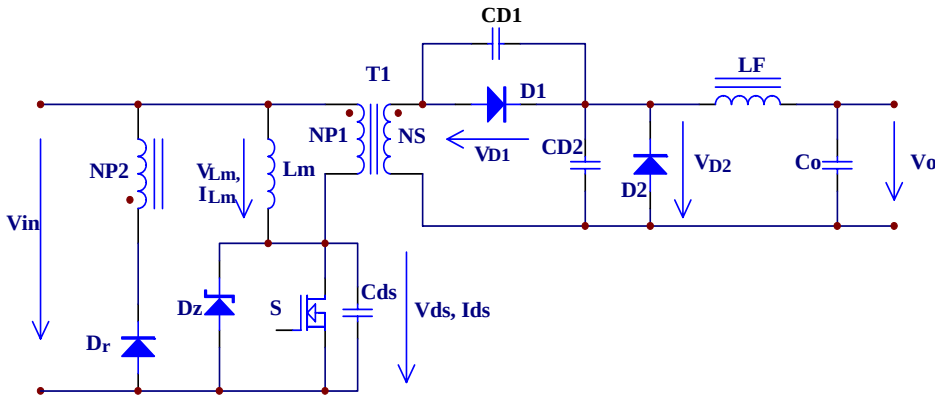
Advantages:

- Clamp voltage independent of Vin

Drawbacks:

- Introduces voltage spikes into output
- Need to be very careful about startup and transient behavior
- Not recommended

Variation (2) of Third Winding Reset Forward



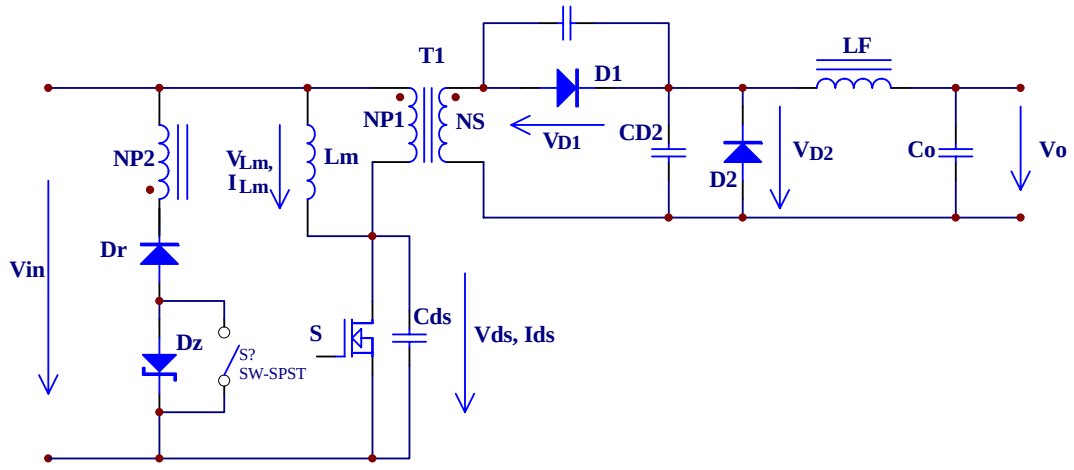
Advantages:

- Maximum switch voltage clamped by Zener diode
- Max duty cycle can be extended without increasing switch voltage stress

Drawbacks:

- Part of magnetizing energy dissipated in Dz at high line

Variation (3) of Third Winding Reset Forward



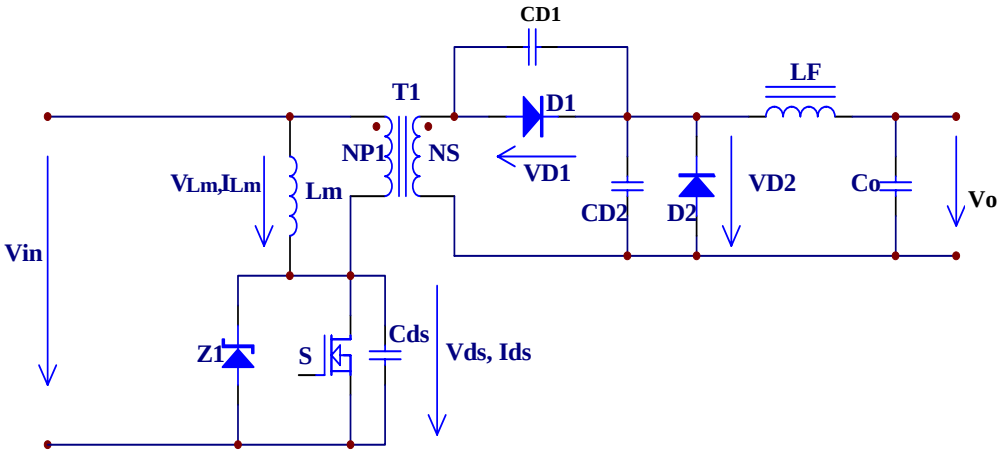
Advantages:

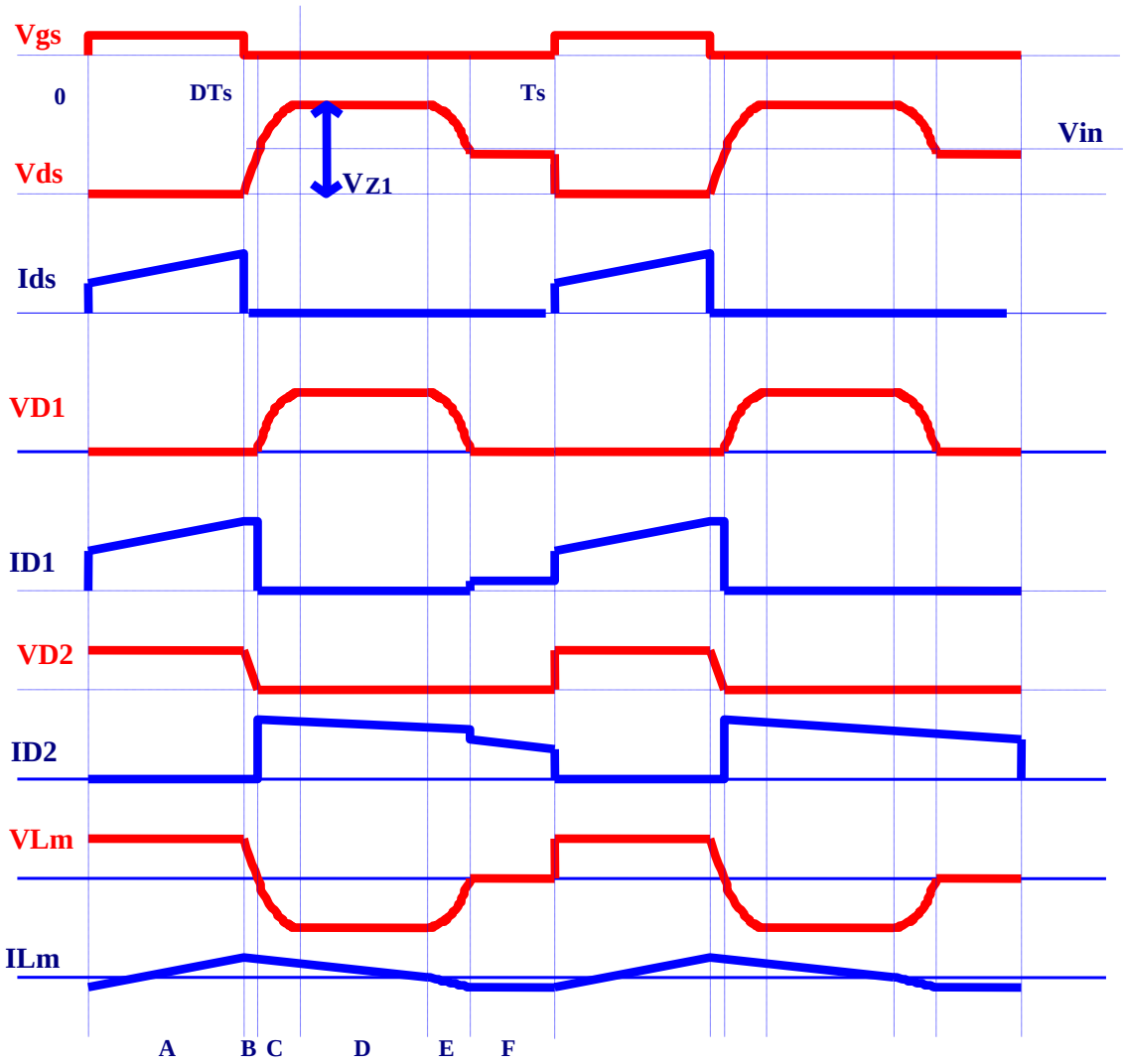
- Reset voltage increased at low line
- Max switch voltage remain unchanged

Drawbacks:

- Some magnetizing energy dissipated in Dz at low line

Zener Clamp Forward





Zener Clamp Forward

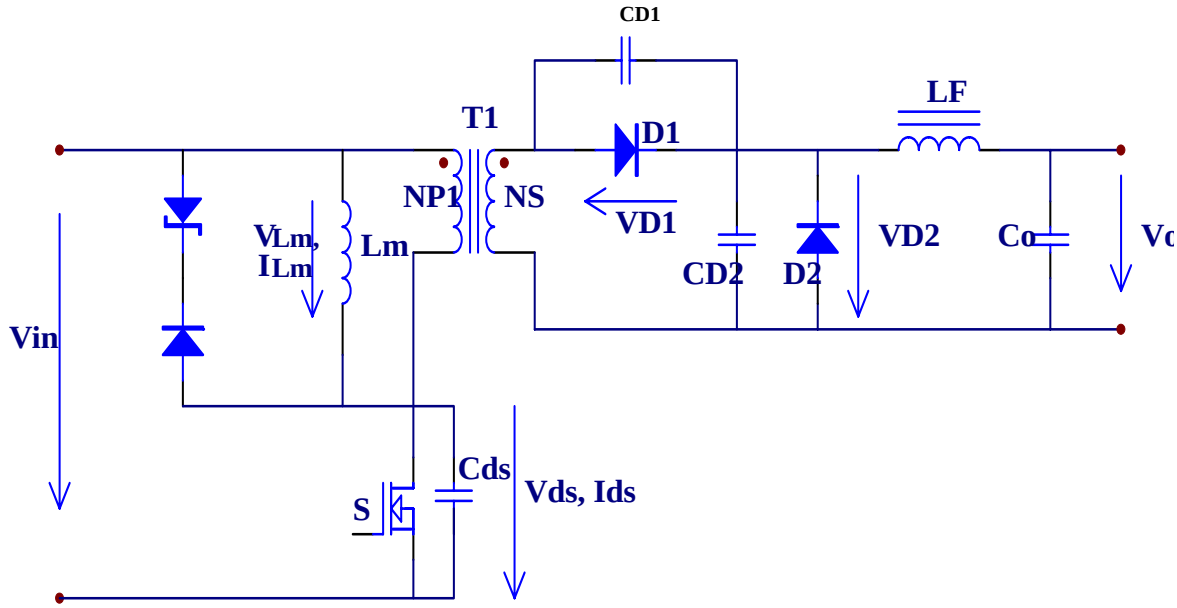
Advantages:

- Simple
- Maximum switch voltage independent of line voltage
- Max duty cycle can exceed 50%
- Reliable

Drawbacks:

- Part of magnetizing and leakage energy dissipated
- High voltage Zener diode can be expensive

Variation (1) of Zener Clamp Forward



Advantages:

- Less power dissipated in Zener diode

Drawbacks:

- Switch voltage stress dependent on Vin

Variation (2) of Zener Clamp Forward

- Place the Zener diode on the secondary

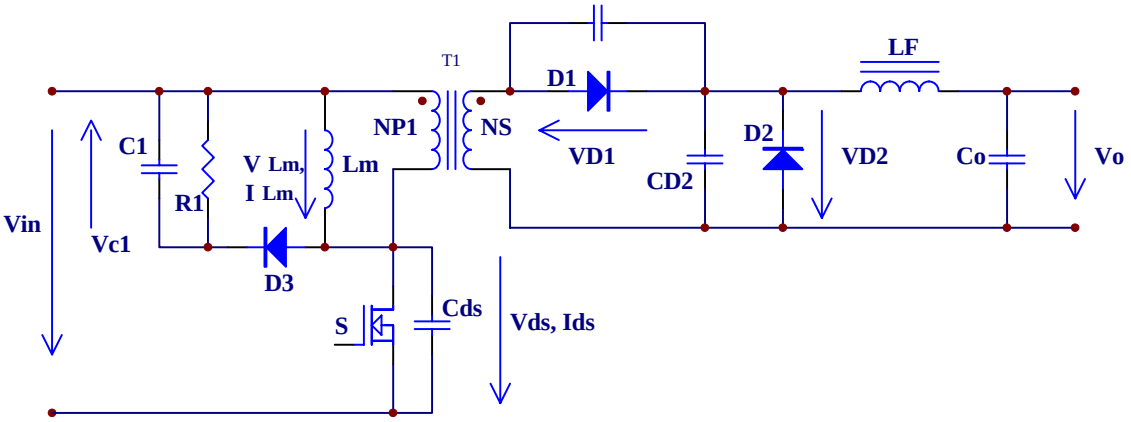
Advantages:

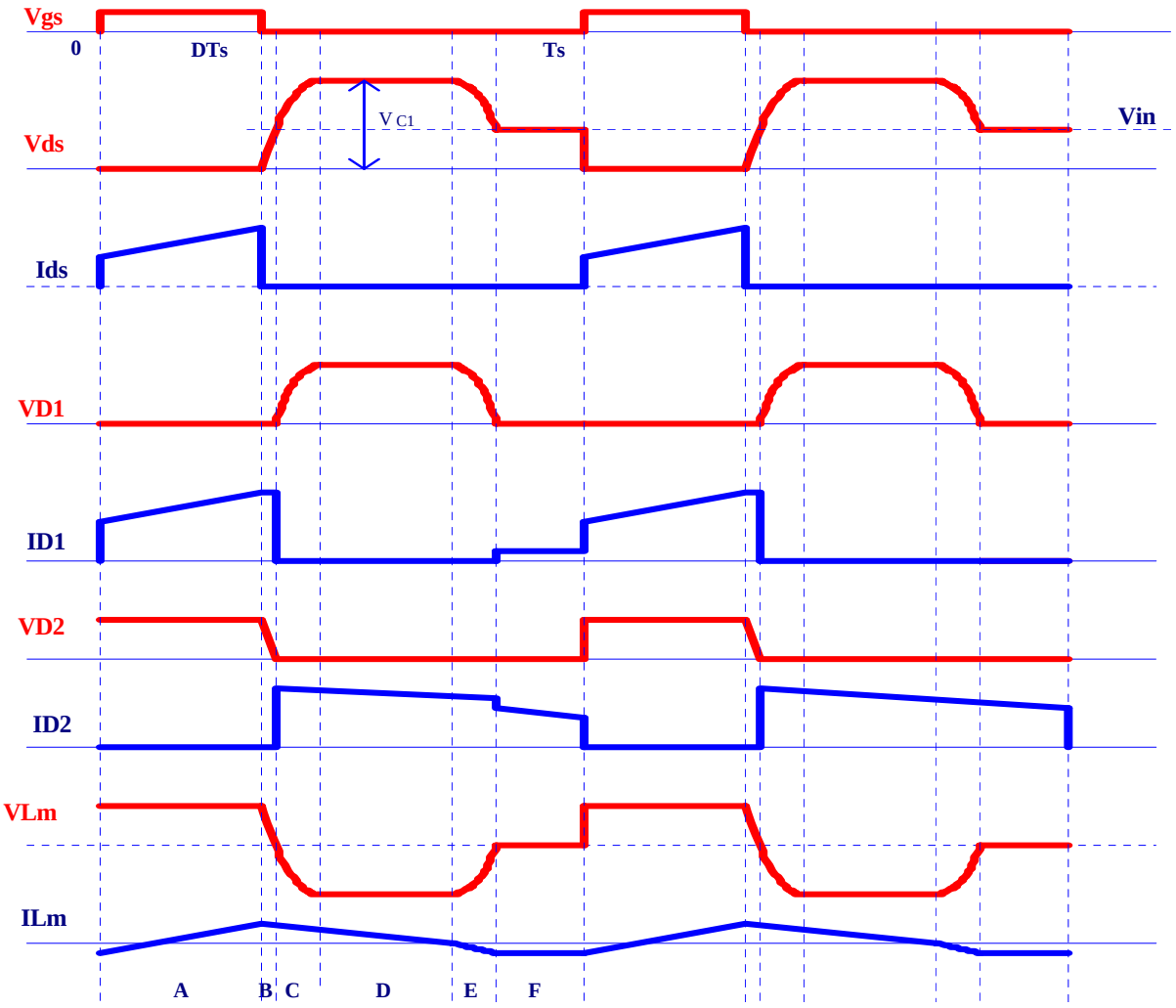
- Can use low voltage Zener diode

Drawbacks:

- Does not clamp primary switch voltage spike induced by transformer leakage

R-C-D Clamp Forward





R-C-D Clamp Forward

Advantages:

- Low cost
- Flexible in selecting clamp voltage
- Clamp voltage almost independent of Vin

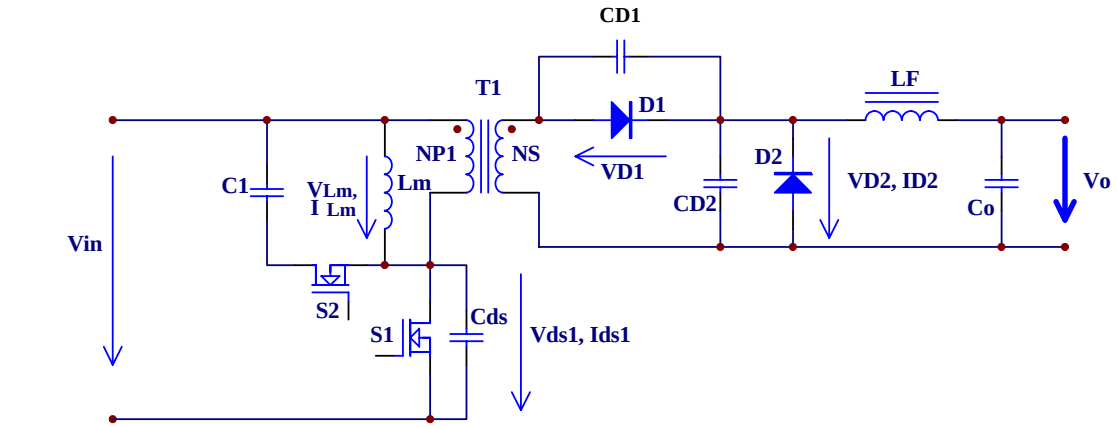
Drawbacks:

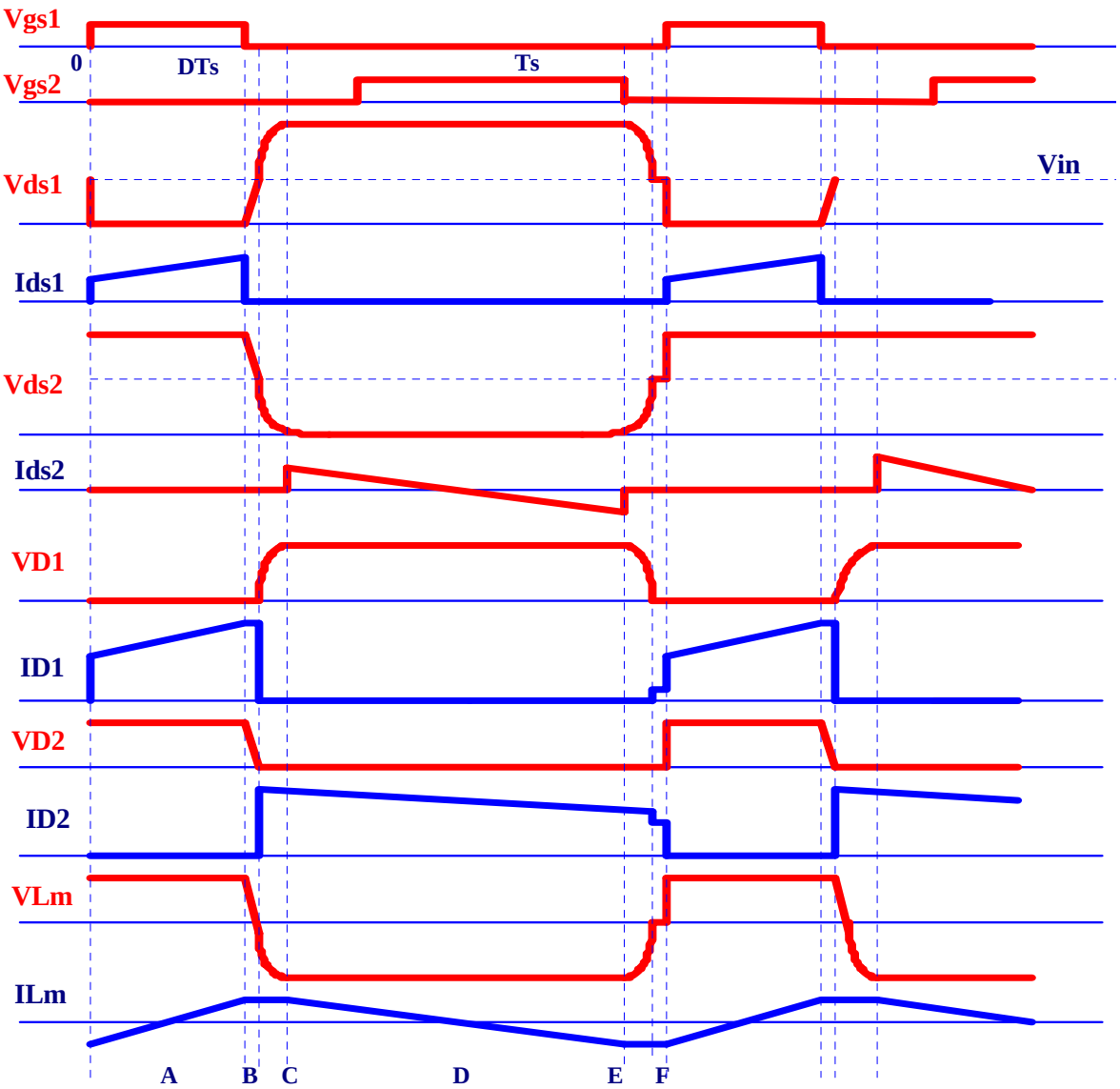
- Part of magnetizing and leakage energy dissipated

Key Design Notes

- R can be determined experimentally
- C can be connected to ground to eliminate switch voltage spike caused by parasitic inductance
- RC time constant 3-6 times bigger than switching period
- Use variable R to control switch voltage stress

Active Clamp Forward





Active Clamp Forward

Advantages:

- Magnetizing and leakage energy recycled completely
- Optimum reset scheme
- Easy to self-drive SRs (major benefit!)
- Easy to implement ZVS

Drawbacks:

- Complicated and expensive
- High switch overshoot during dynamics (startup, line or load step changes, OCP and SCP)
- Patent issue?

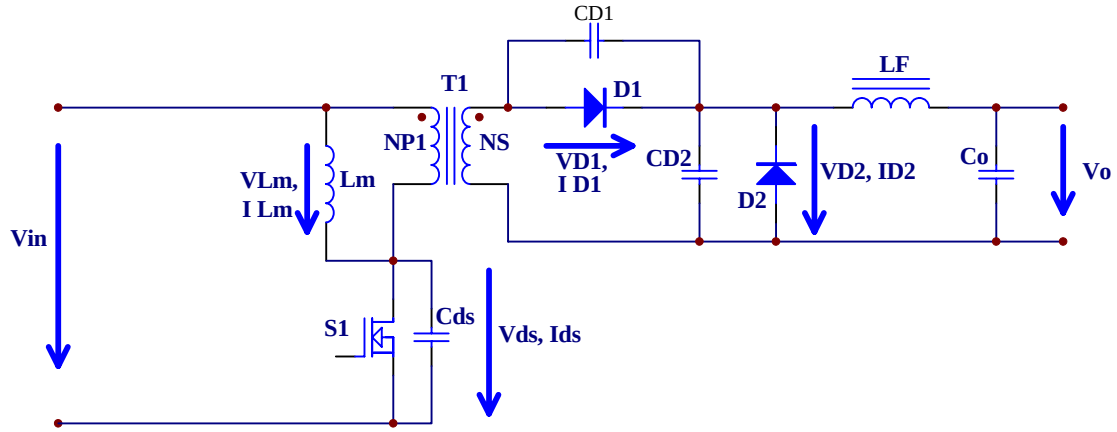
Key Design Notes

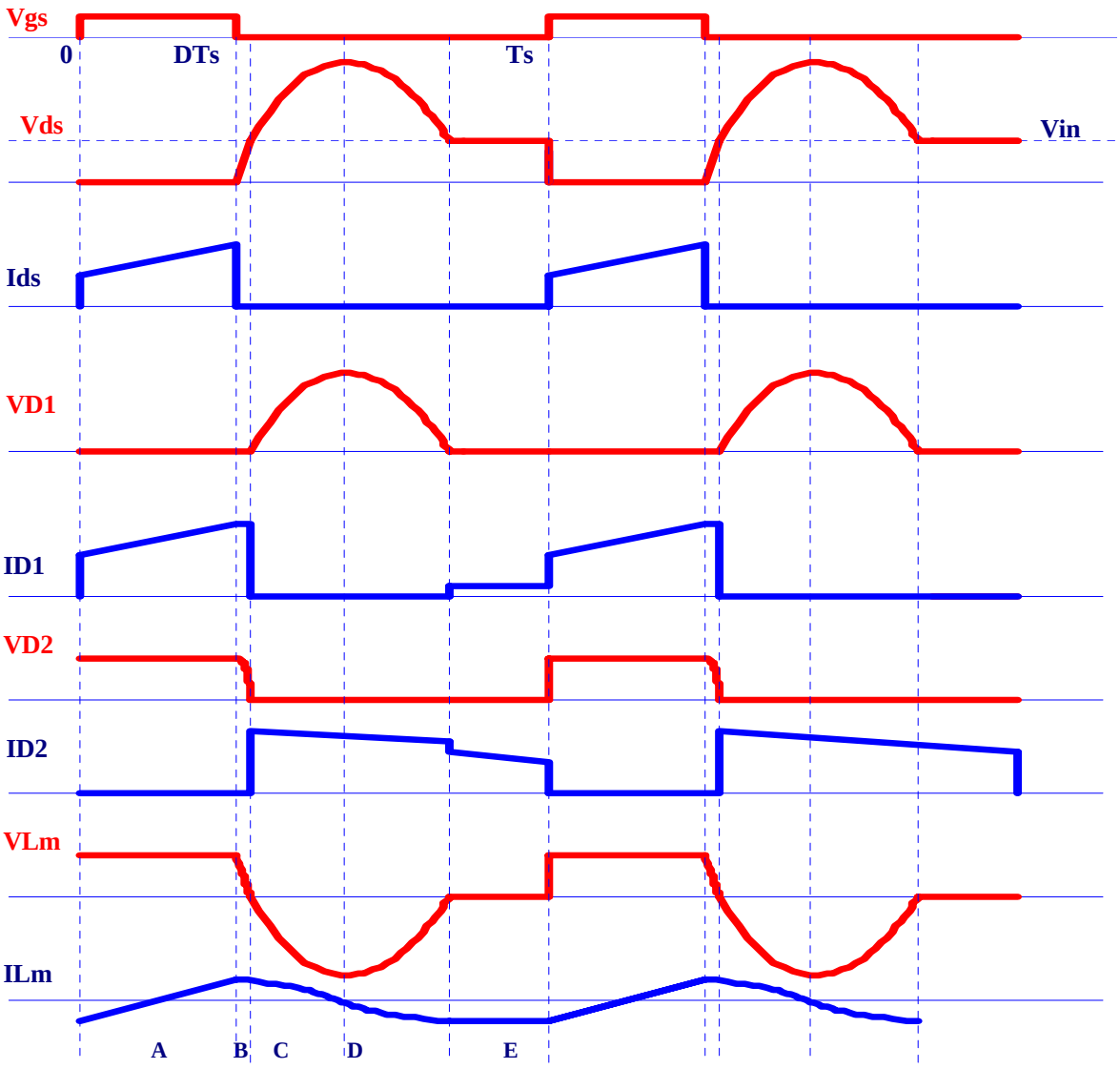
- **Magnetizing inductance is usually low**
- **C value needs to be selected carefully**
- **ZVS achieved at expense of increased conduction loss (about 30%)**
- **Need to watch dynamic behavior carefully**
- **Clamp switch slow body diode needs to be blocked for high input voltage applications**

Variations of
Active Clamp Forward

1. **Use P-channel FET**
2. **Clamp on secondary side**
3. **Third winding reset**

Resonant Reset Forward





Resonant Reset Forward

Advantages:

- Simple and low cost
- Magnetizing and leakage energy fully recycled
- Easy to extend max duty cycle
- Widely used in wide input range (such as military) applications

Drawbacks:

- Sinusoidal reset waveform has higher peak than square like waveform

Key Design Notes

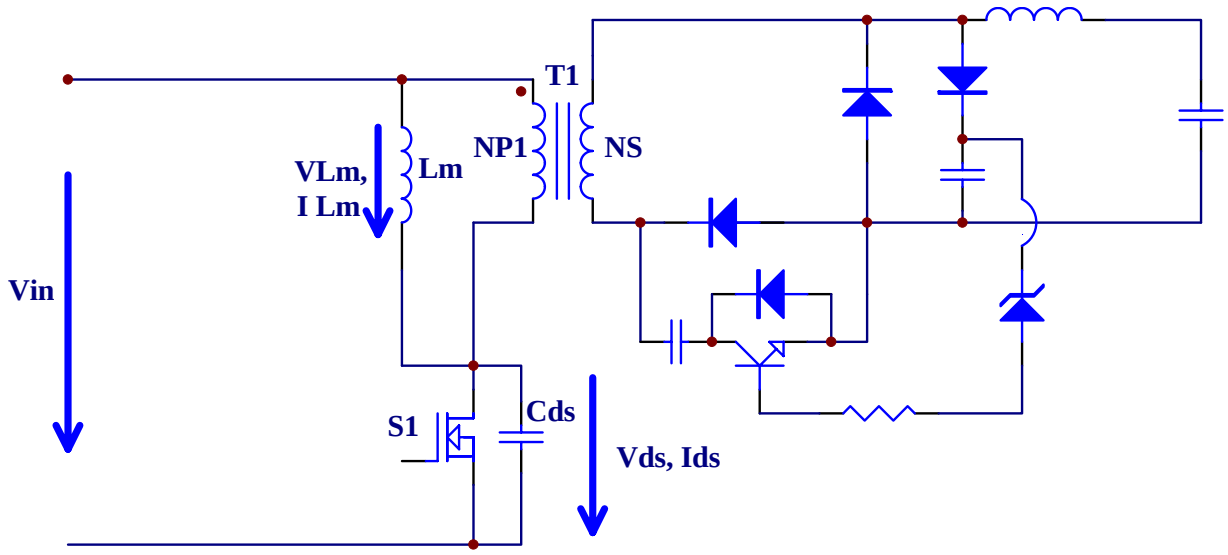
- External resonant cap is often needed to reduce peak switch voltage
- C can be placed across D1 to avoid excessive capacitive turn on loss
- Power switch can be turned on before completion of resonance
- How to reduce max switch voltage stress?

Reducing Switch Voltage Stress (1)

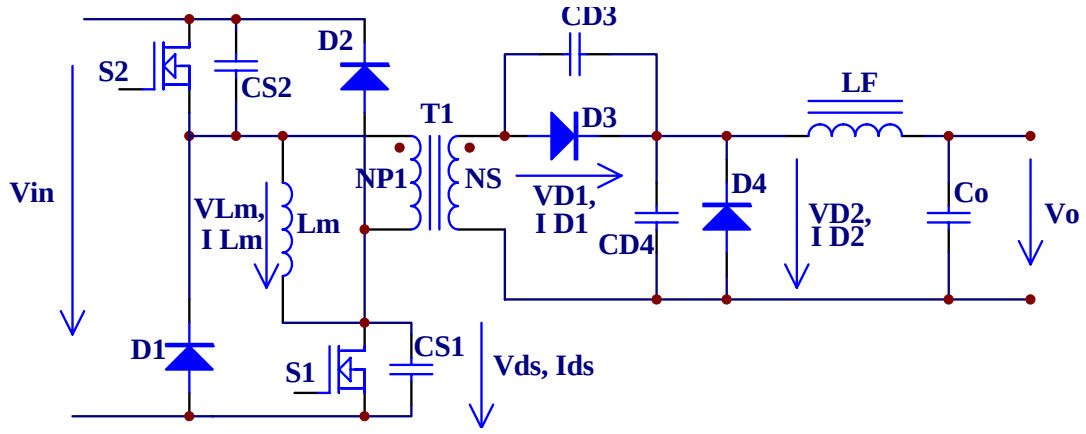
- **Add a zener across power switch (not the transformer)**

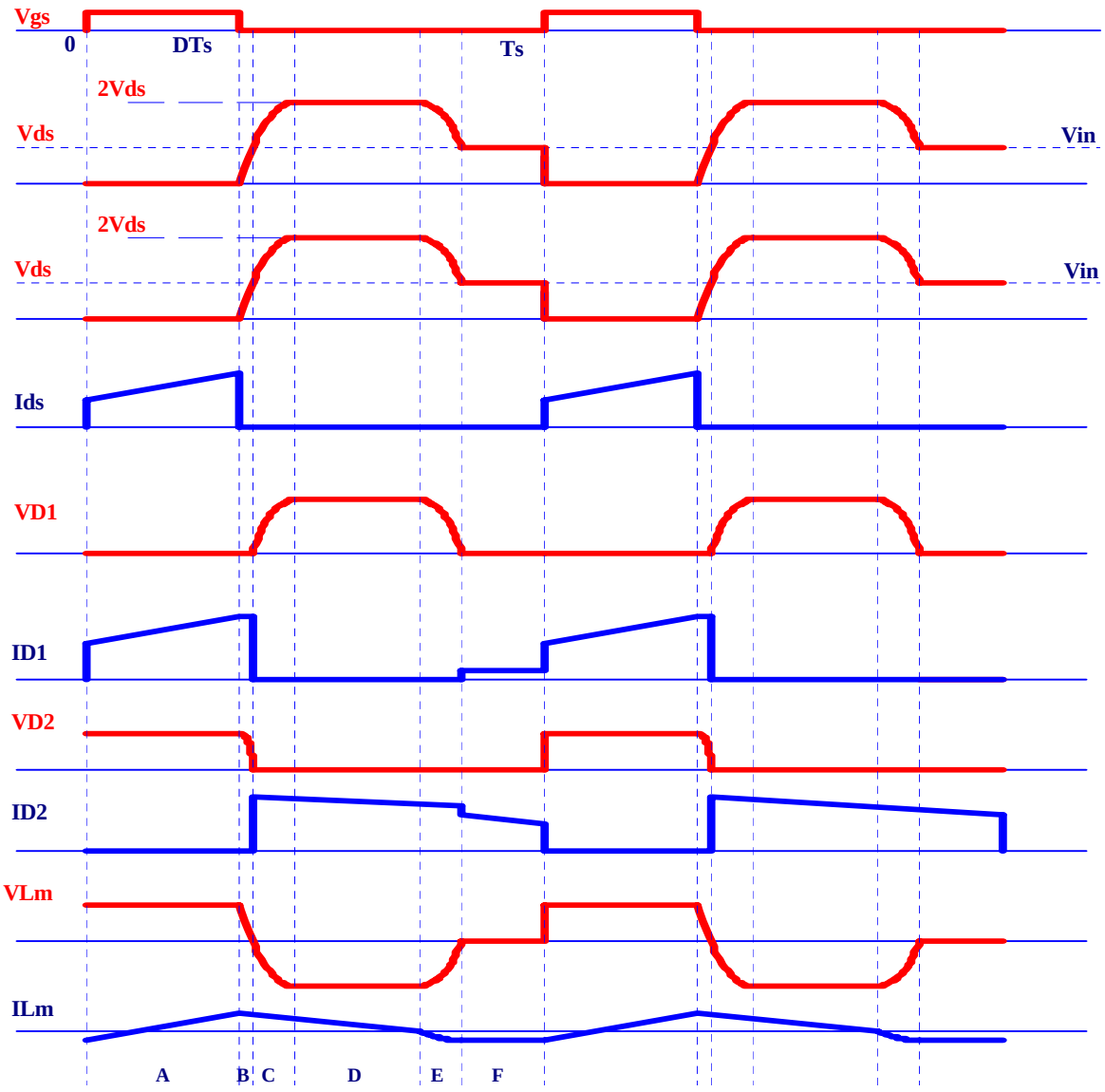
Reducing Switch Voltage Stress (2)

- **Add an external cap and a switch on secondary**



Two Switch Forward





Two Switch Forward

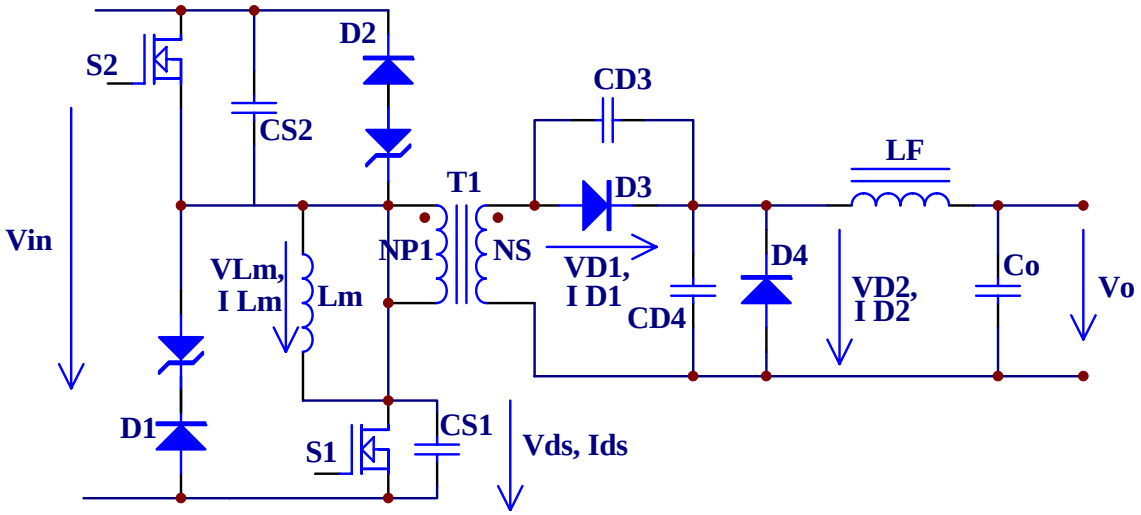
Advantages:

- Low switch voltage stress
- Suited for high power applications
- Very reliable reset
- Magnetizing and leakage energy recycled completely

Drawbacks:

- Needs a second switch with float driving
- Duty cycle limited to about 40%
- How to extend duty cycle?

Variation (1) of 2-Switch Forward



Advantages:

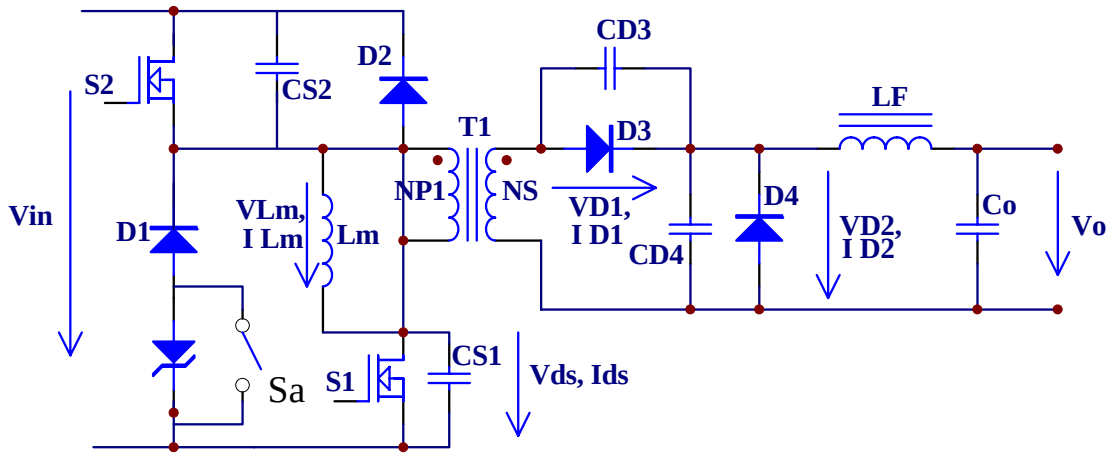
- Duty cycle can exceed 50%
- Simple and low cost

Drawbacks:

- Increases max. switch voltage stress

(which may not be a problem)

Variation (2) of 2-Switch Forward



Advantages:

- Max switch voltage stress does not increase
- Magnetizing energy completely recycled at high line