

# **An Overview of Forward Converter with Various Reset Schemes**

**By**

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**9/20/07**

## 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?

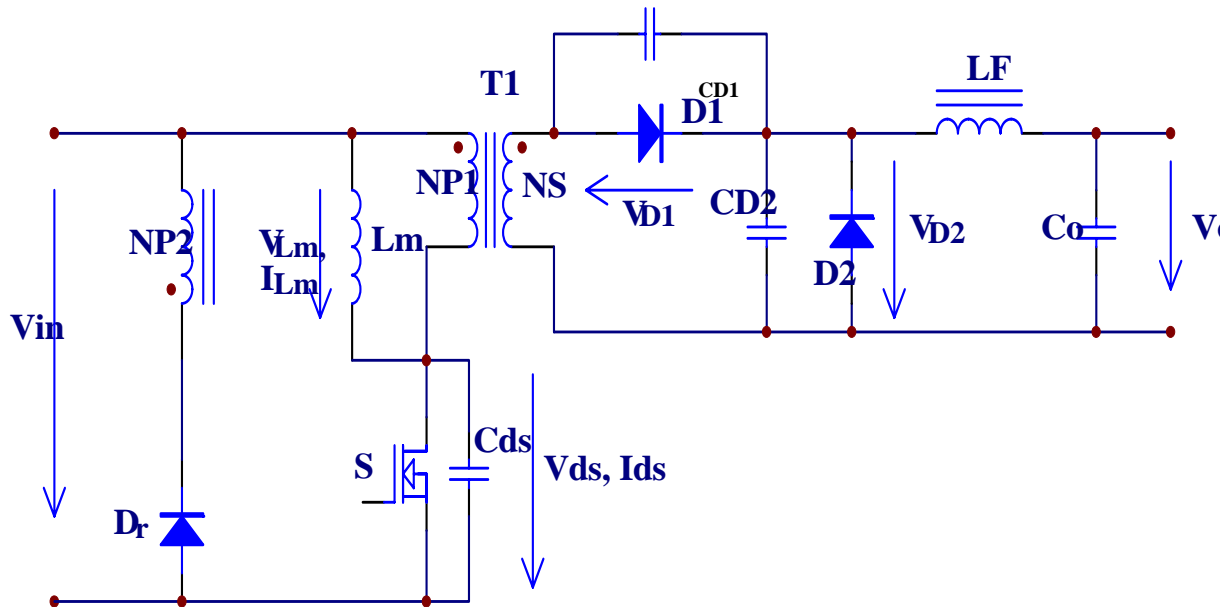
## Test

- 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

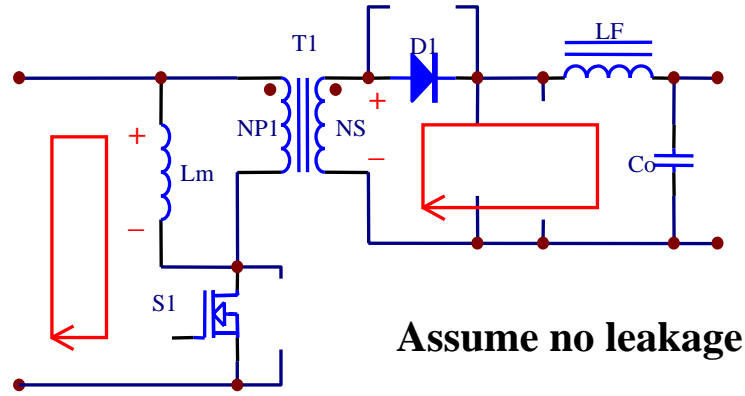
- **Third Winding Reset Forward**
- **Zener Clamp Forward**
- **R-C-D Clamp Forward**
- **Active Clamp Forward**
- **Resonant Reset Forward**
- **Two Switch Forward**
- **ZCS Quasi-Resonant Forward**
- **ZVS Quasi-Resonant Forward**
- **ZVS Multi-Resonant Forward**
- **ZVT Forward**
- **.....**

# Third Winding Reset Forward

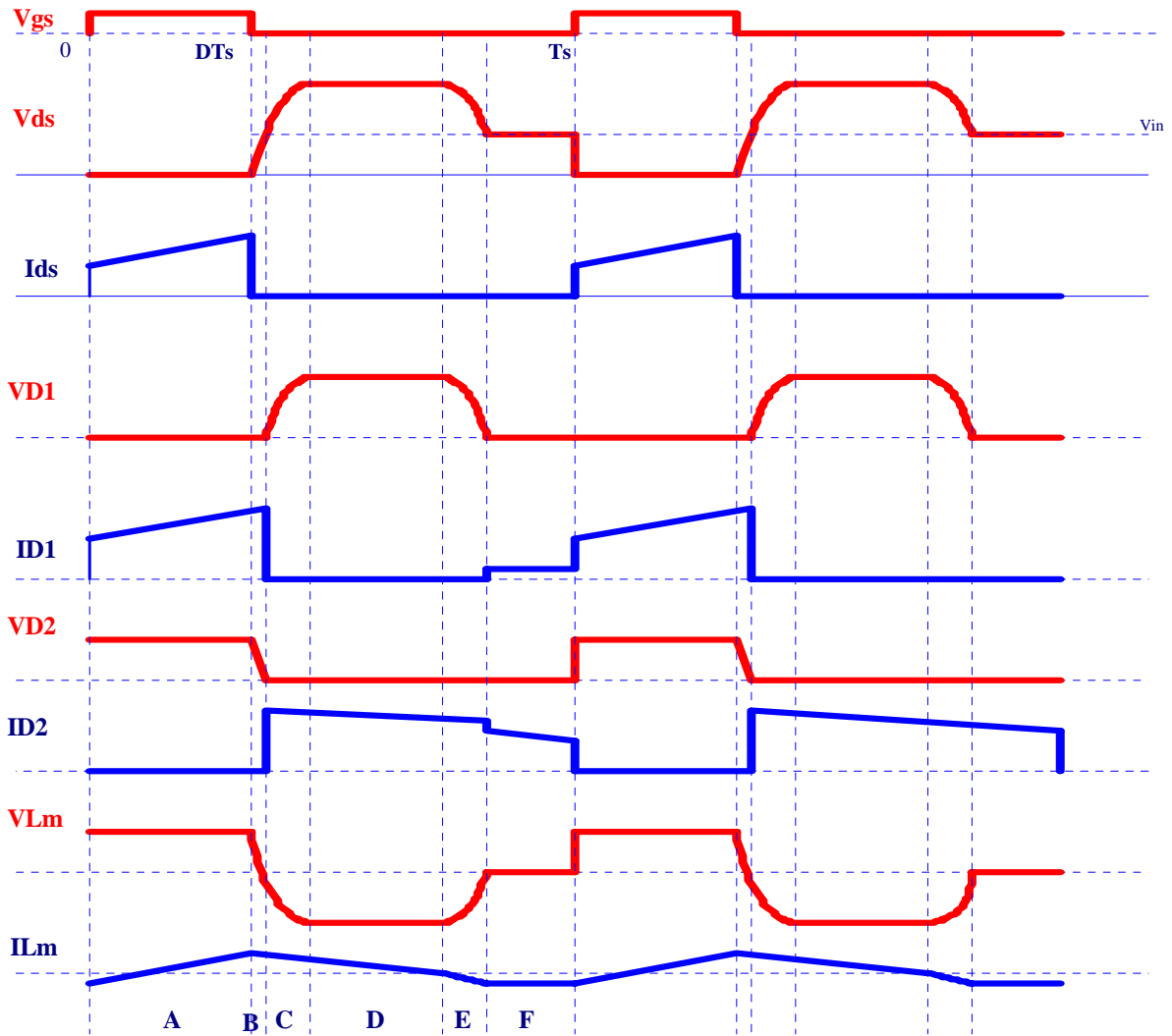


- How does B-H curve look?

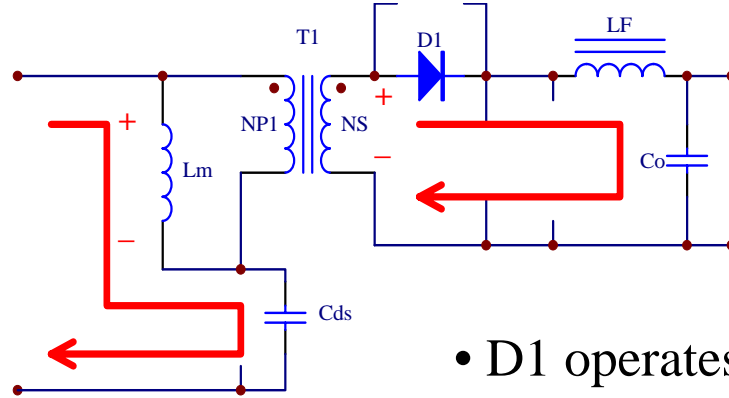
# Operating Stage A



A

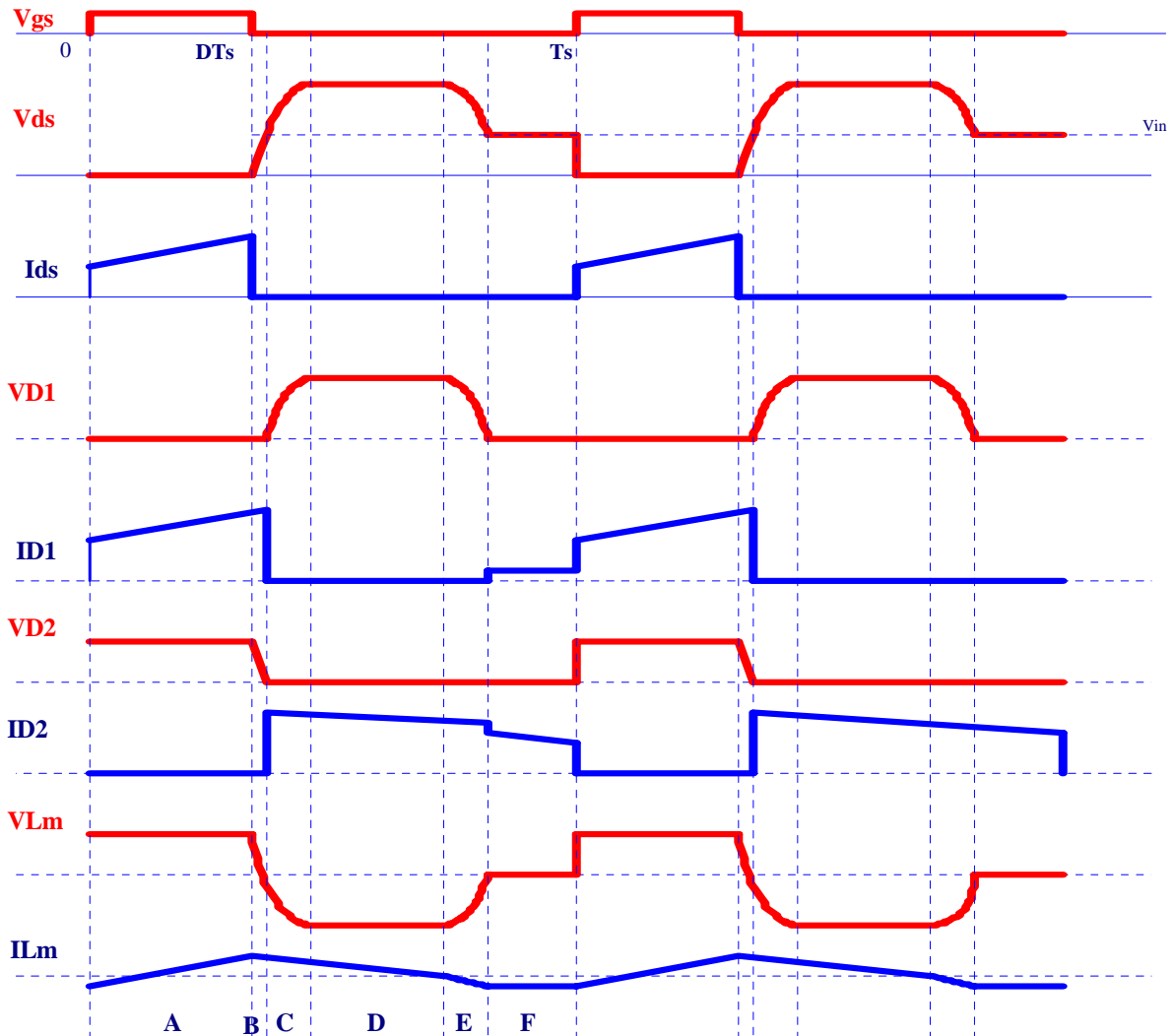


# Operating Stage B

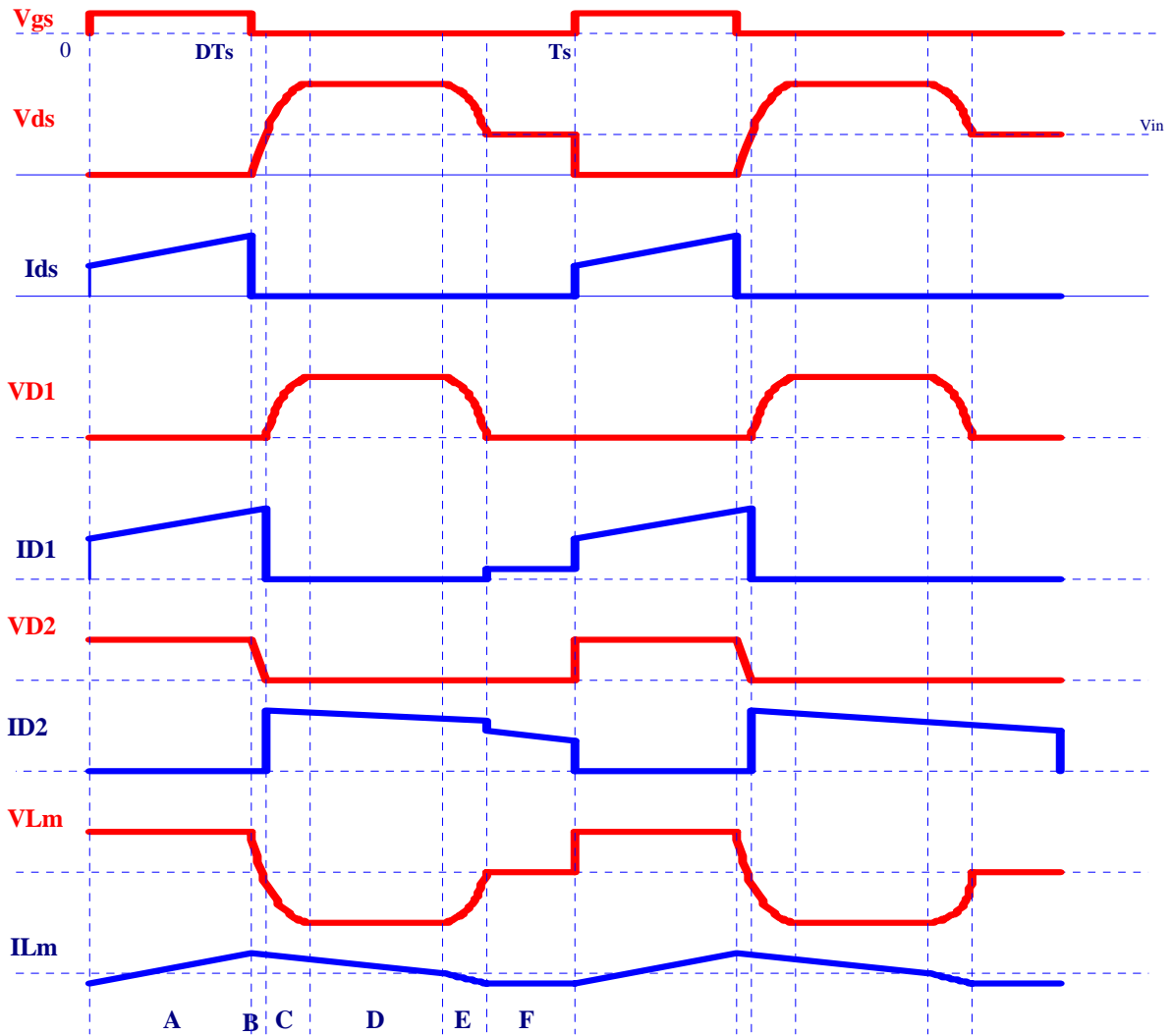
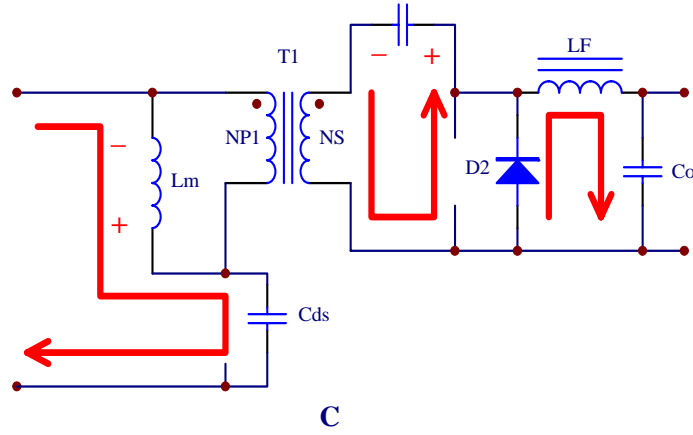


- D1 operates with ZVS

**B**

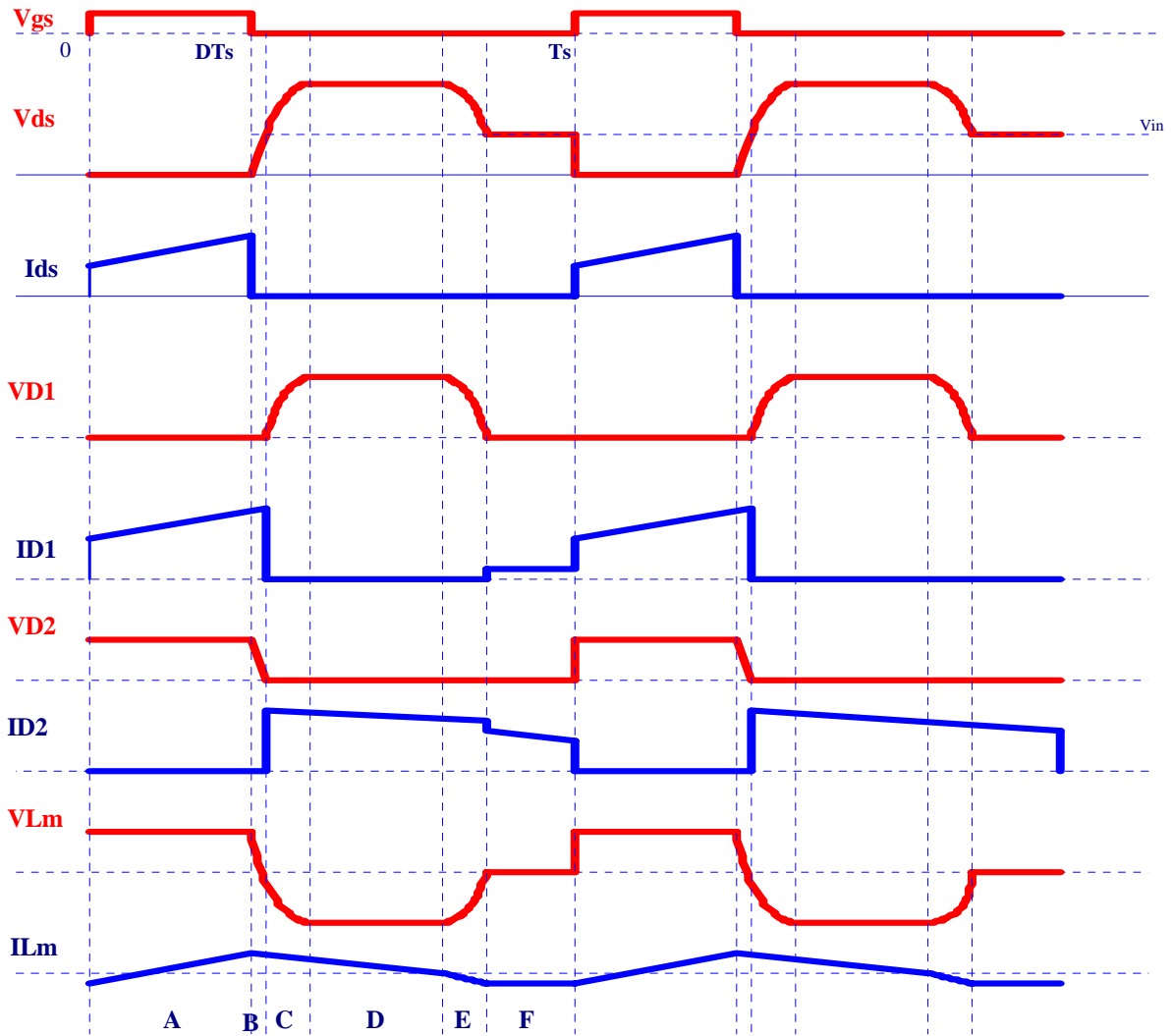
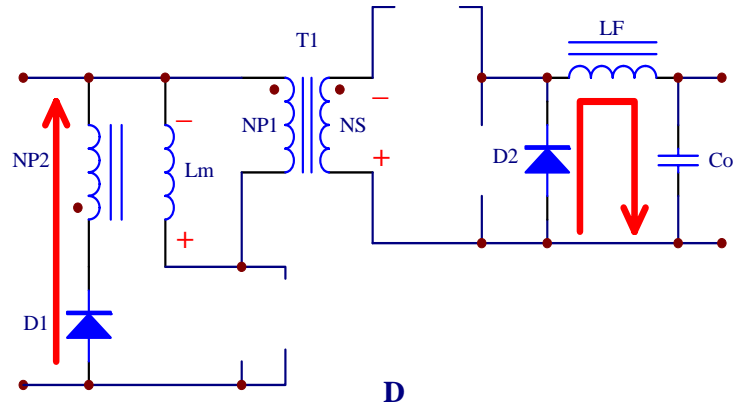


# Operating Stage C

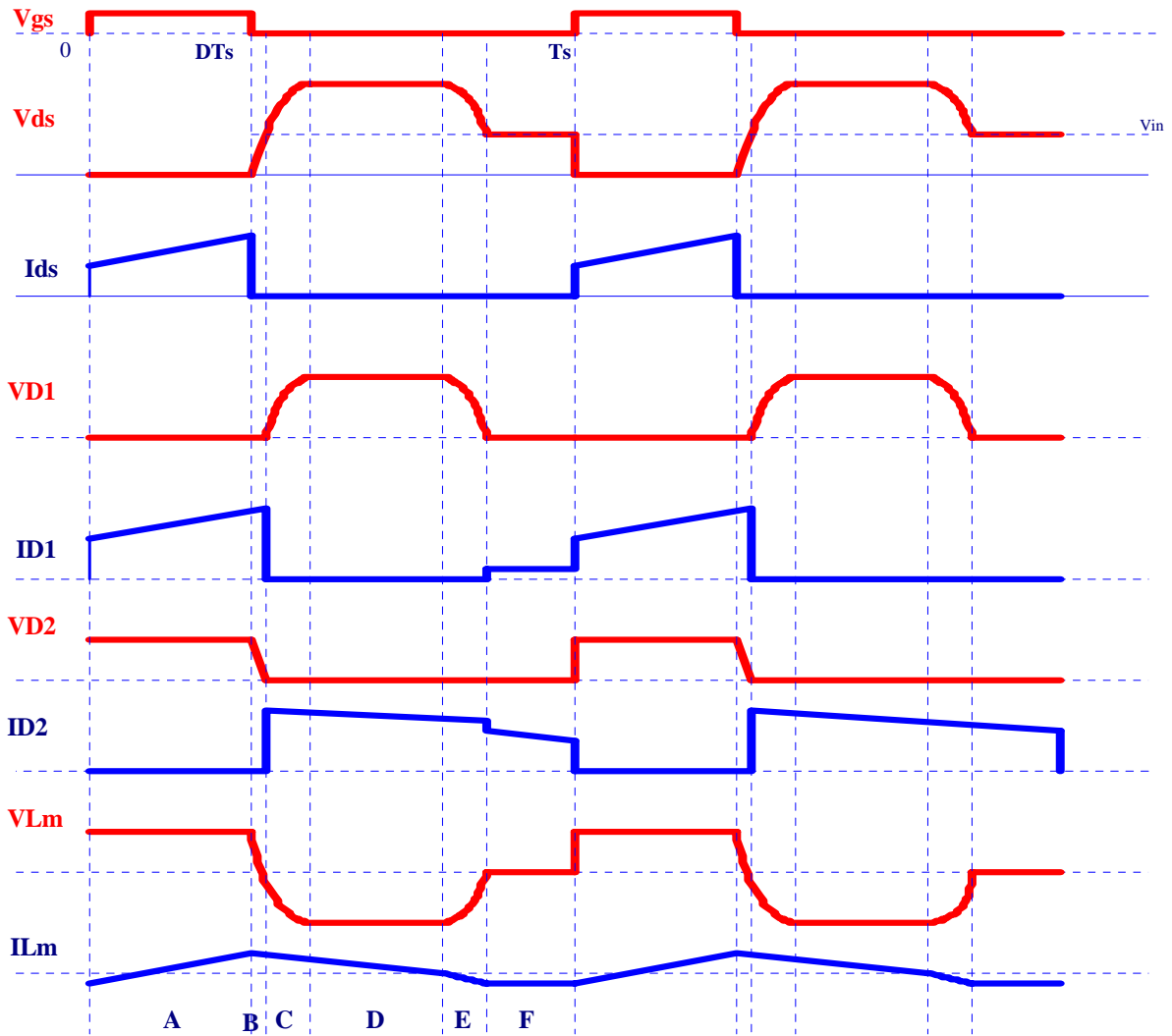
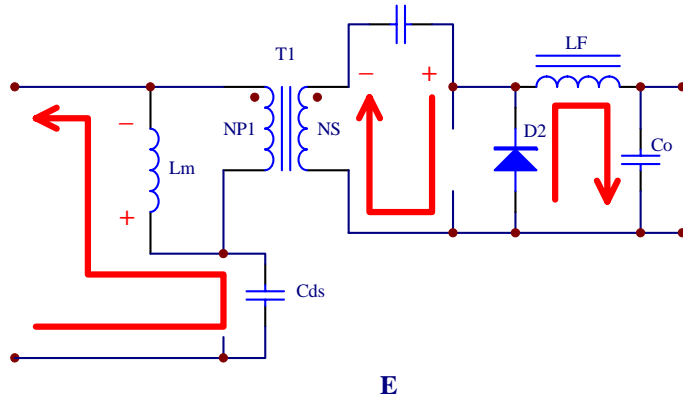




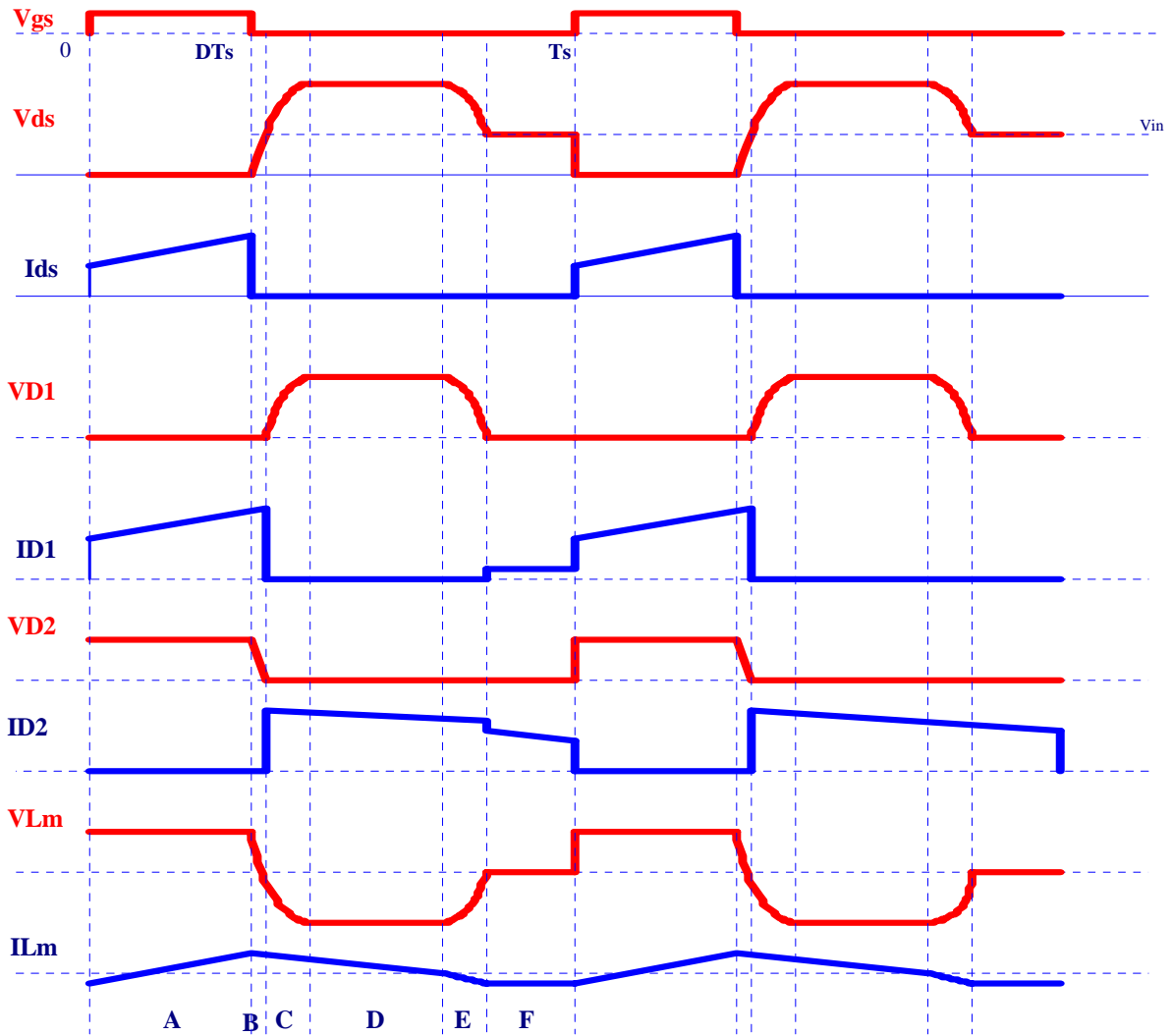
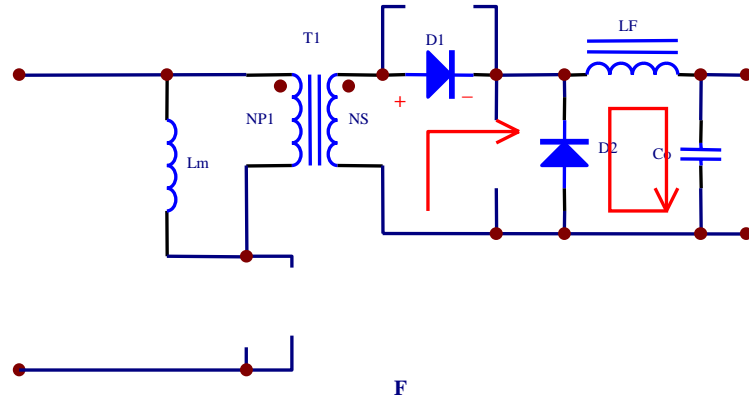
# Operating Stage D



# Operating Stage E



# Operating Stage F



## Third Winding Reset Forward

### Advantages:

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

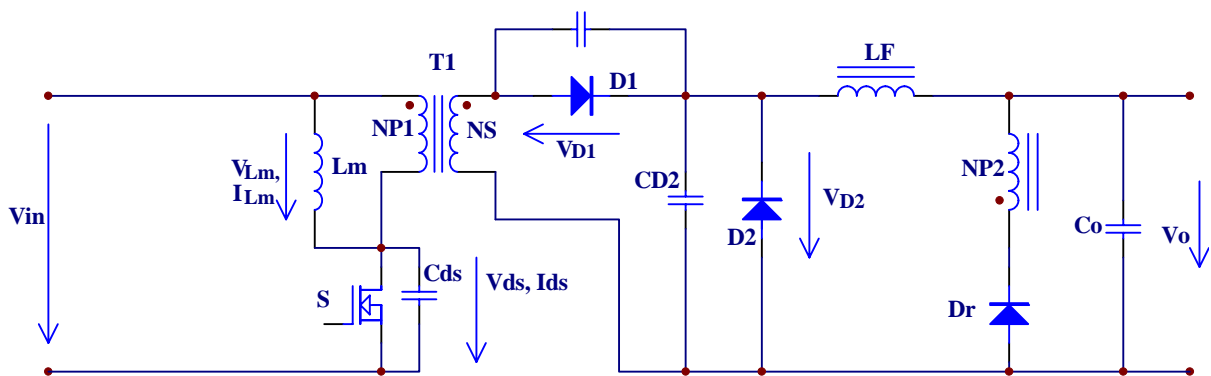
### Drawbacks:

- Third winding complicates TR design
- Max Duty cycle limited to about 40%  
if  $N_{p2}=N_{p1}$
- Clamp voltage proportional to  $V_{in}$

## 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



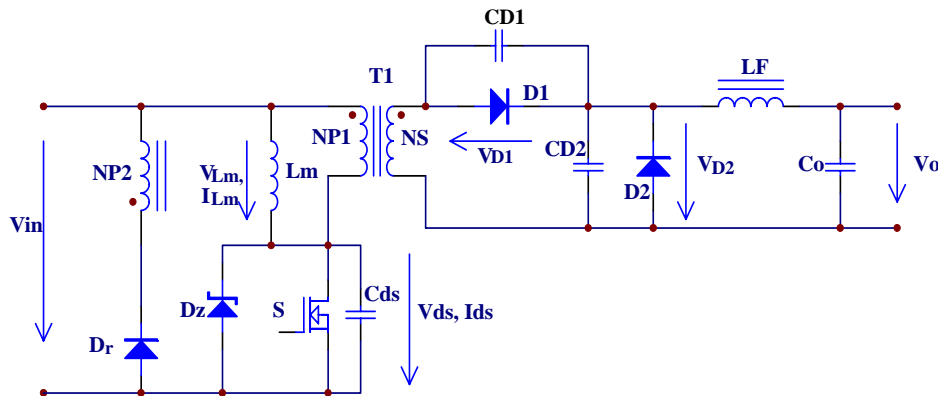
## Advantages:

- Clamp voltage independent of  $V_{in}$

## 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



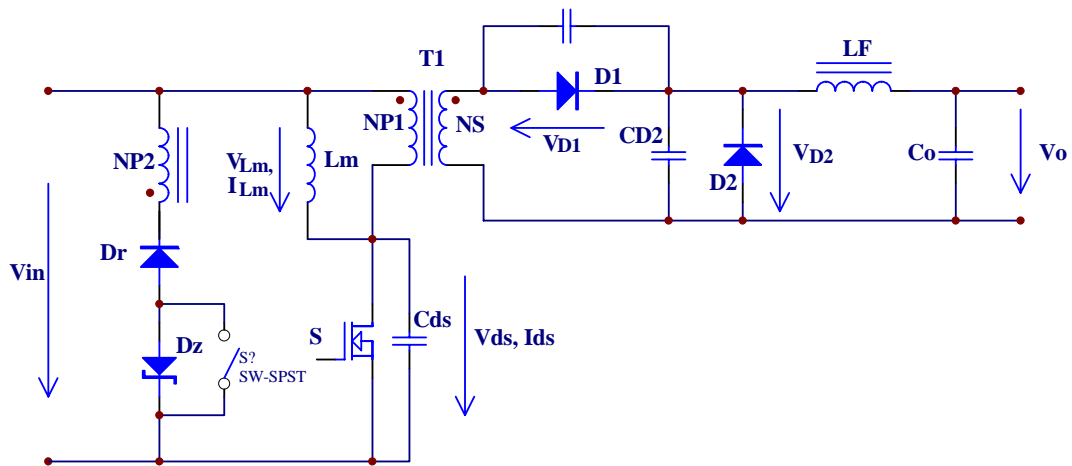
### Advantages:

- 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  $D_z$  at high line

## Variation (3) of Third Winding Reset Forward



### Advantages:

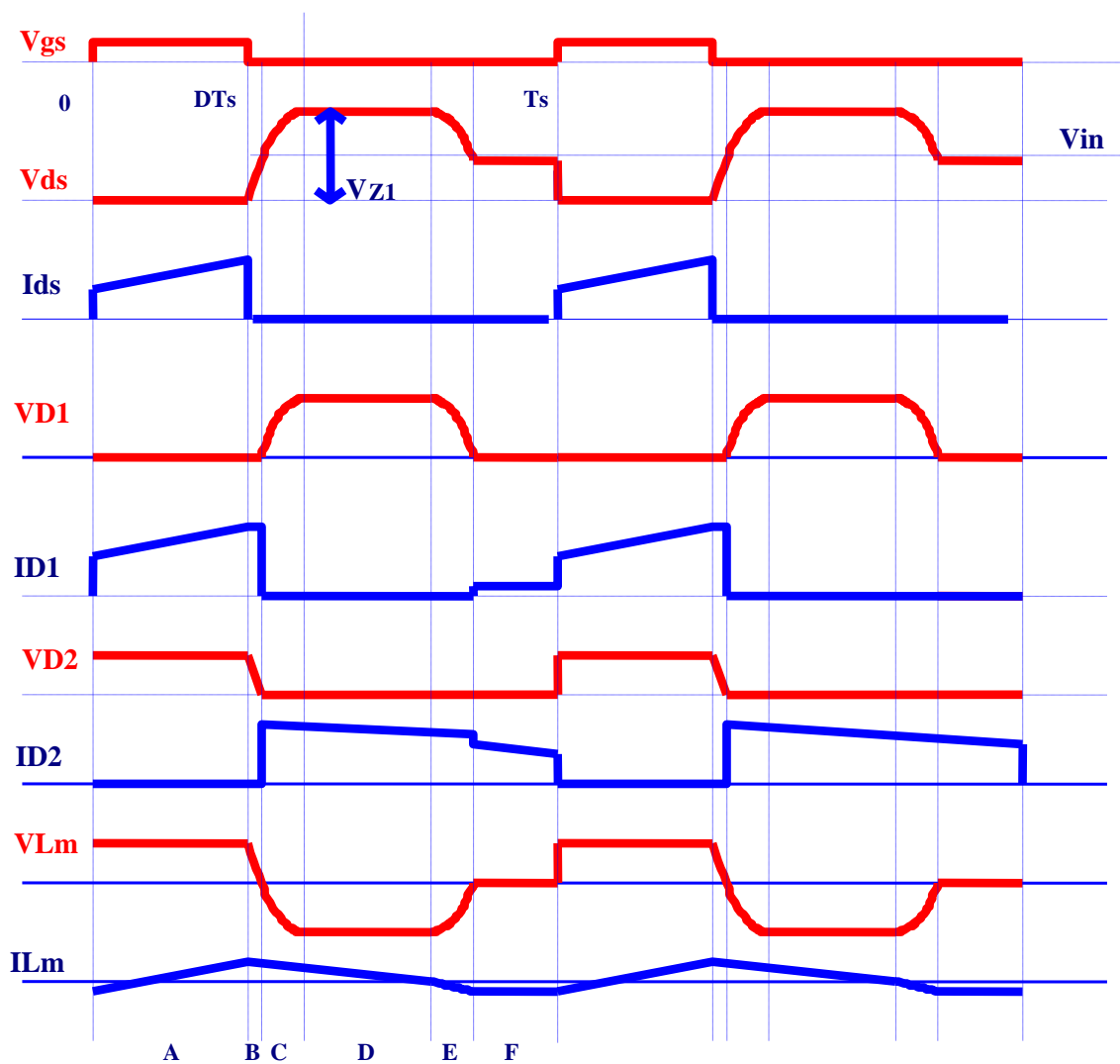
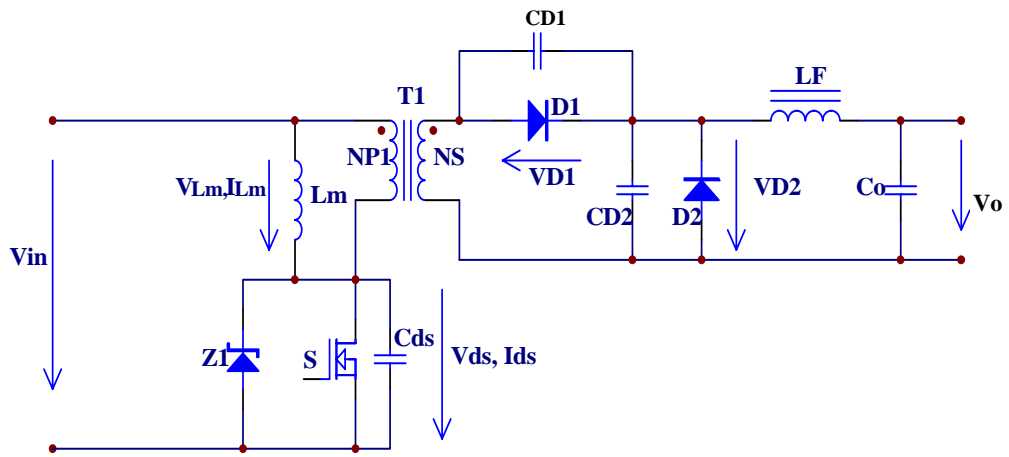
- Reset voltage increased at low line
- Max switch voltage remain unchanged

### Drawbacks:

- Some magnetizing energy dissipated in  $D_z$  at low line



# Zener Clamp Forward



## Zener Clamp Forward

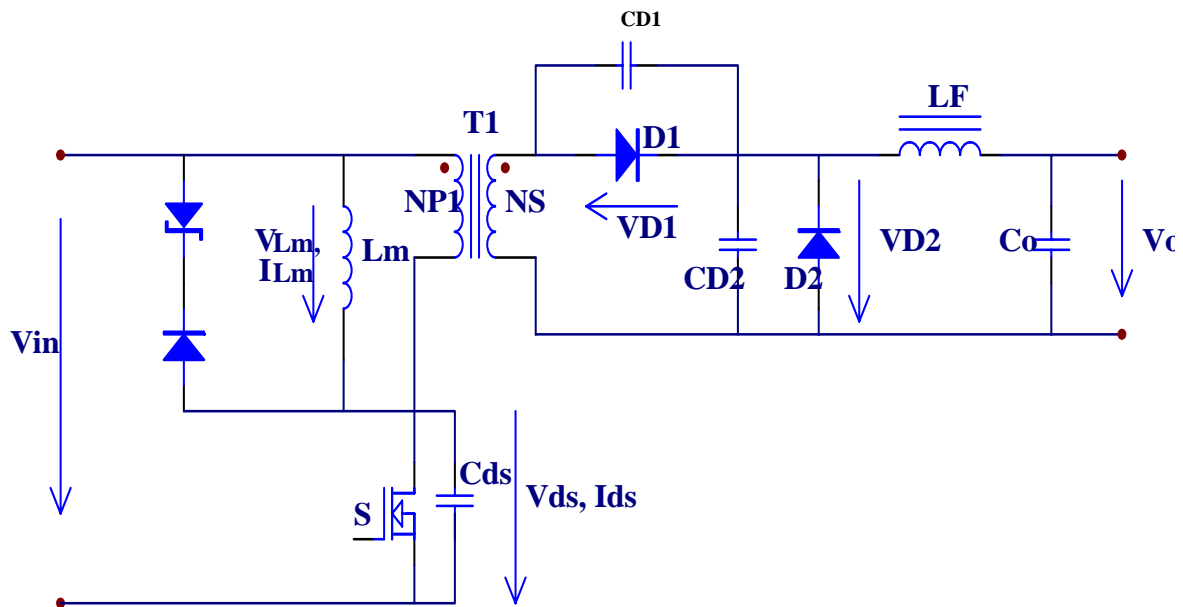
### Advantages:

- 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  $V_{in}$

## Variation (2) of Zener Clamp Forward

- Place the Zener diode on the secondary

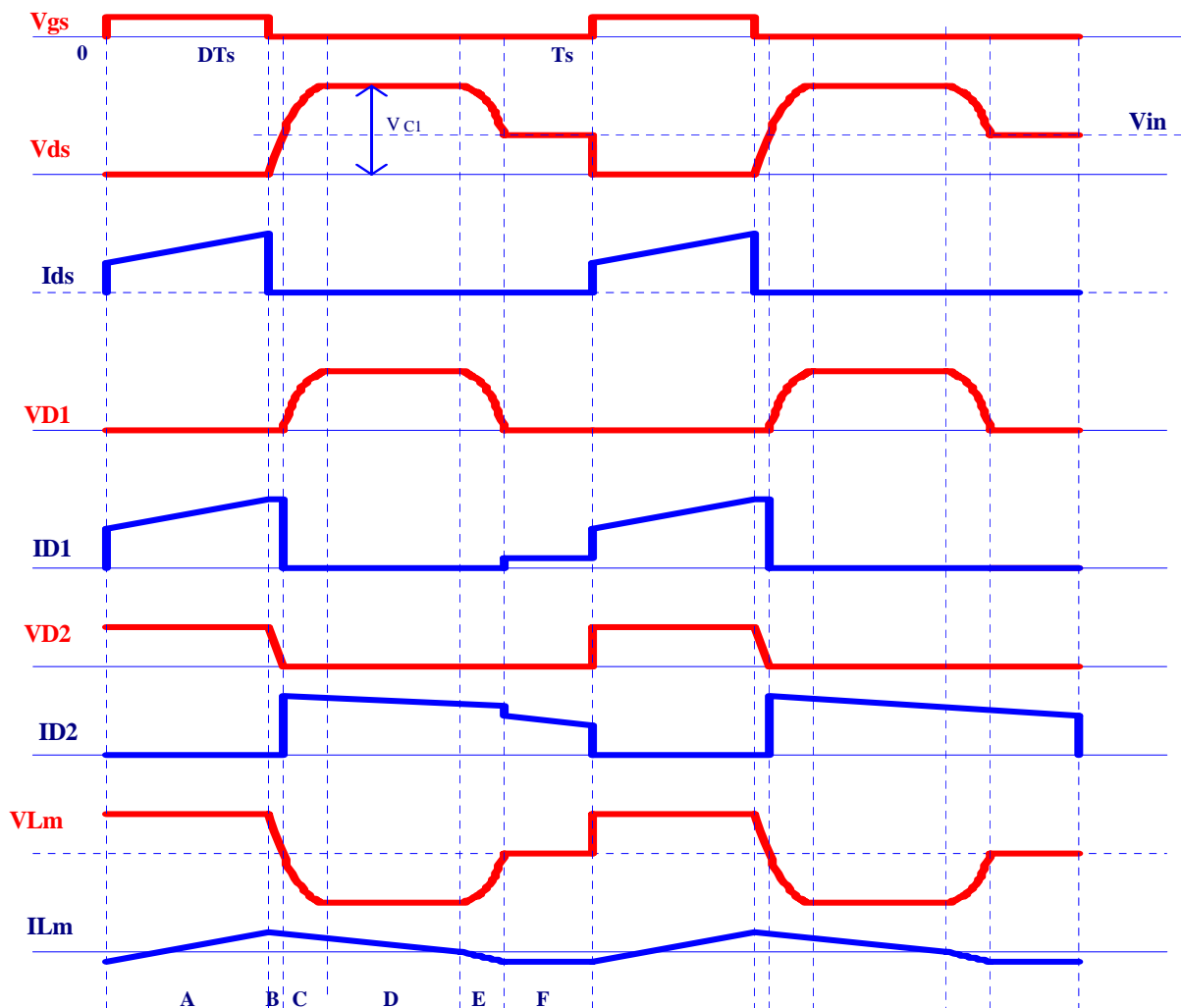
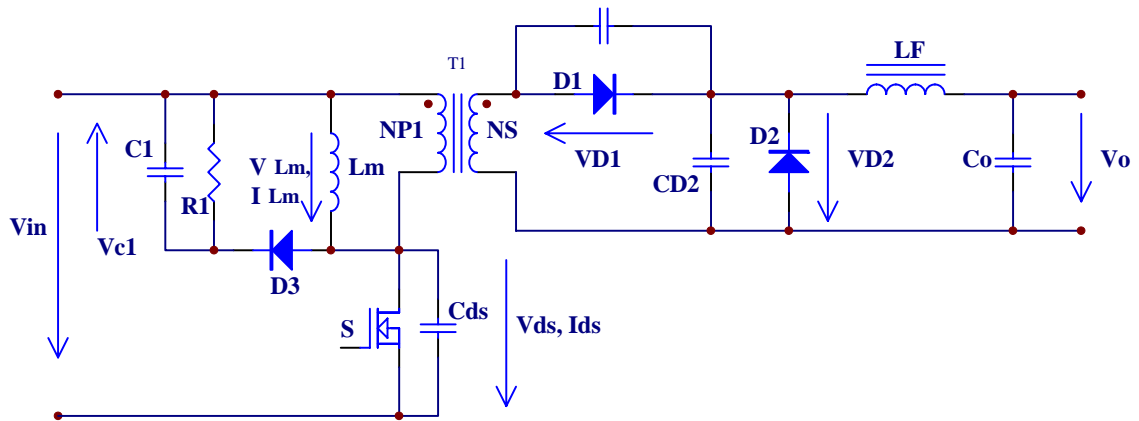
### Advantages:

- 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  $V_{in}$

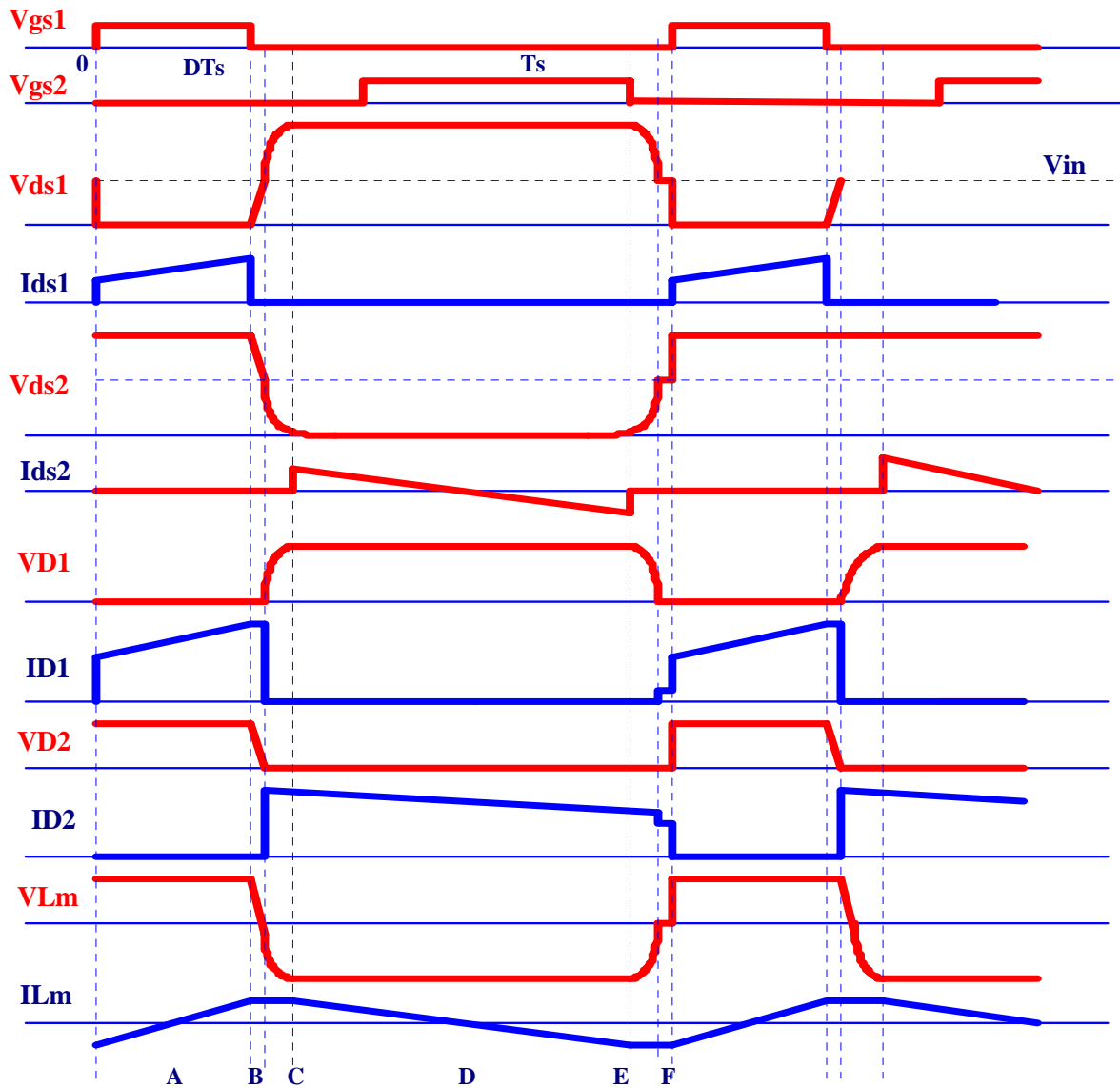
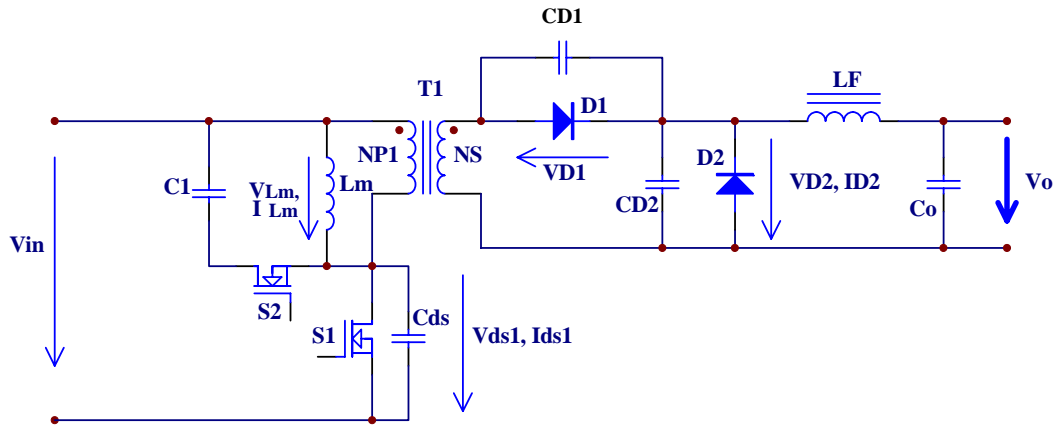
### Drawbacks:

- 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?

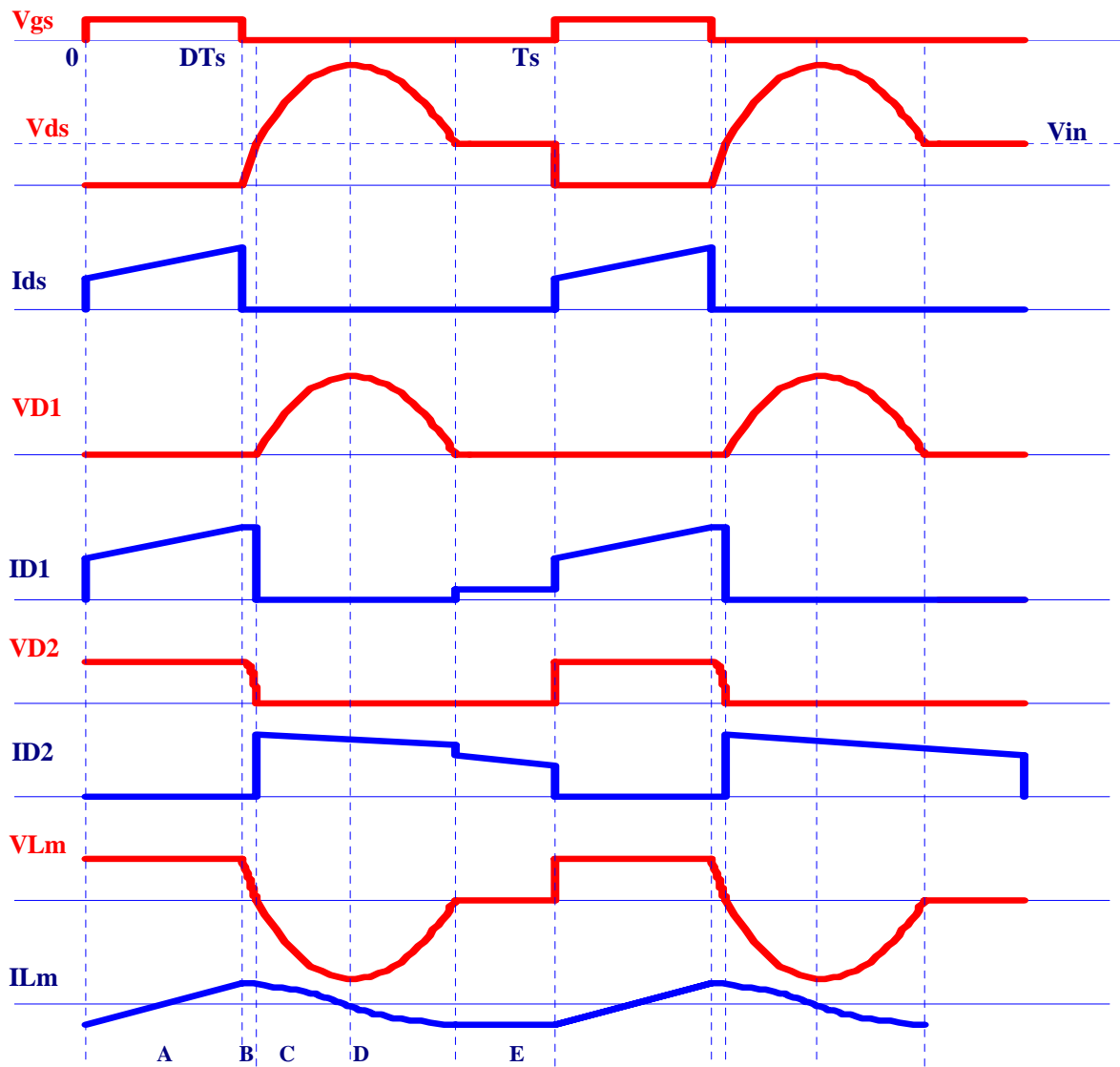
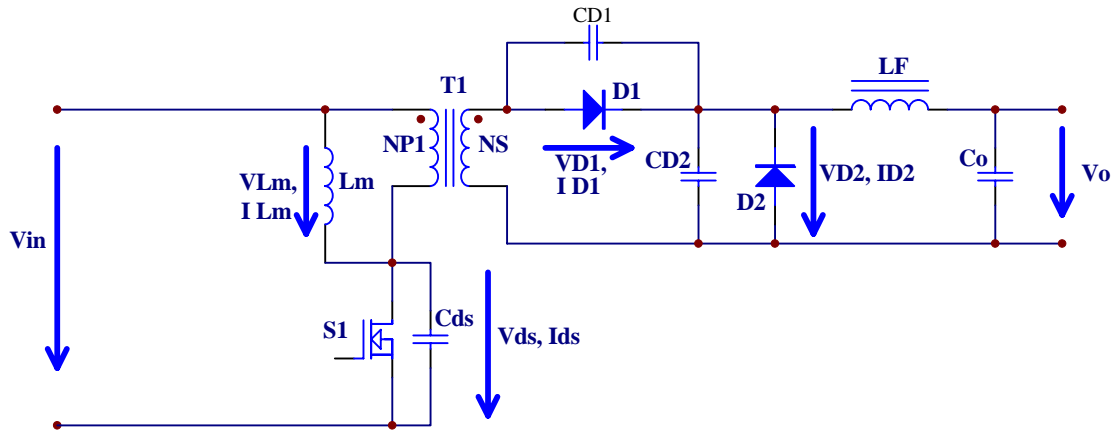
## Key Design Notes

- 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

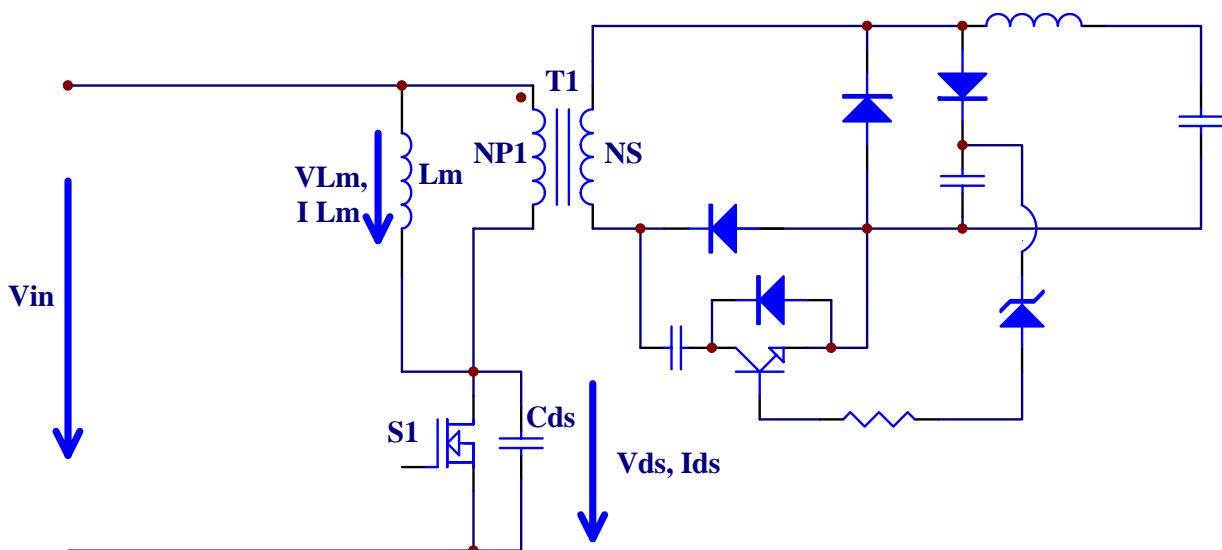
- **External resonant cap is often needed to reduce peak switch voltage**
- **C can be placed across D1 to avoid excessive capacitive turn on loss**
- **Power switch can be turned on before completion of resonance**
- **How to reduce max switch voltage stress?**

# Reducing Switch Voltage Stress (1)

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

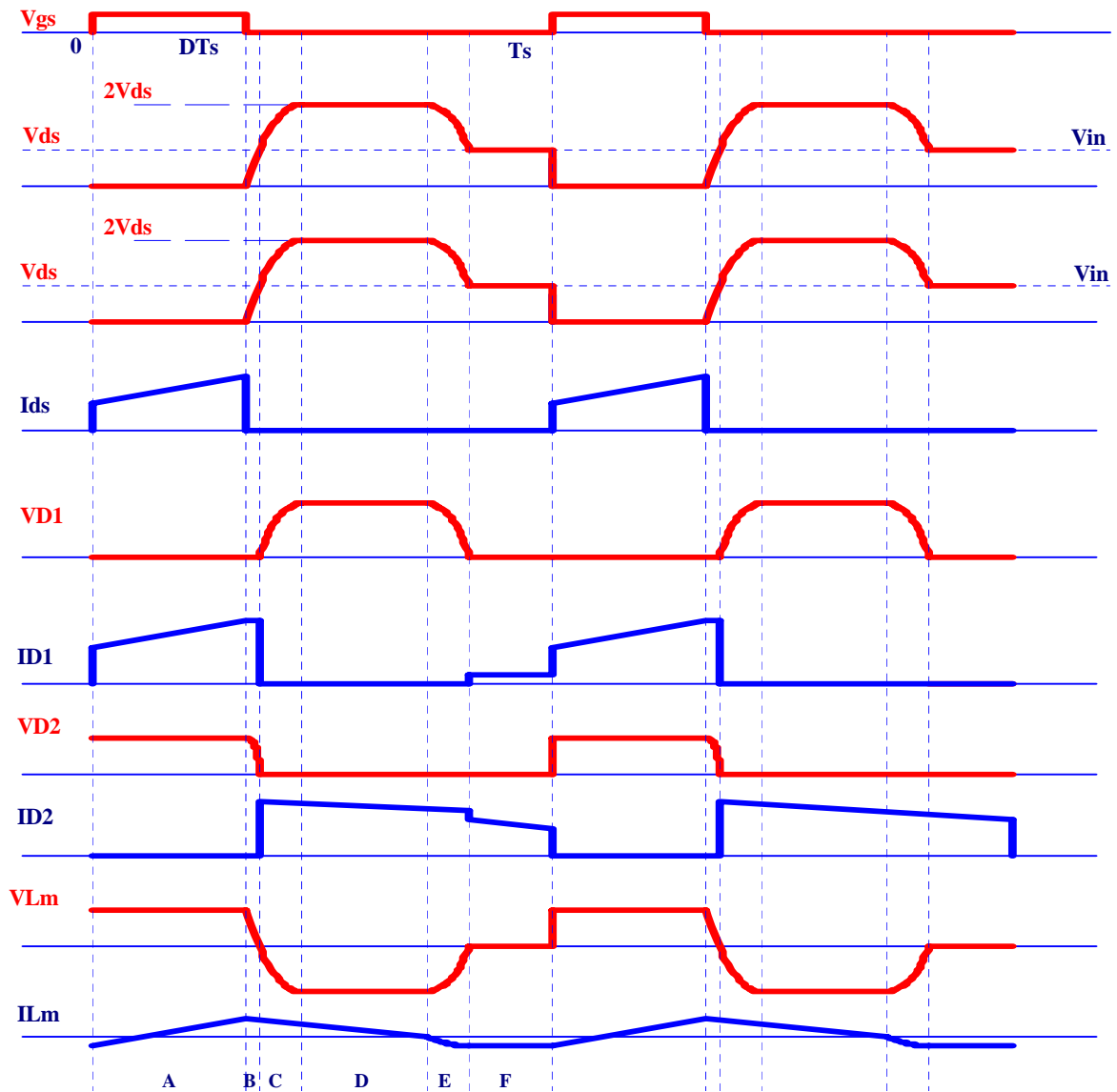
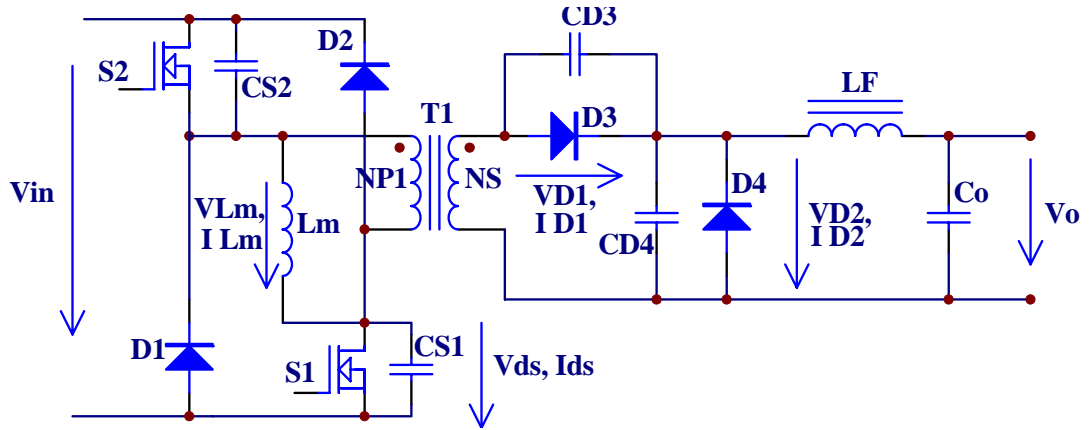
# Reducing Switch Voltage Stress (2)

- Add an external cap and a switch on secondary





# Two Switch Forward



## Two Switch Forward

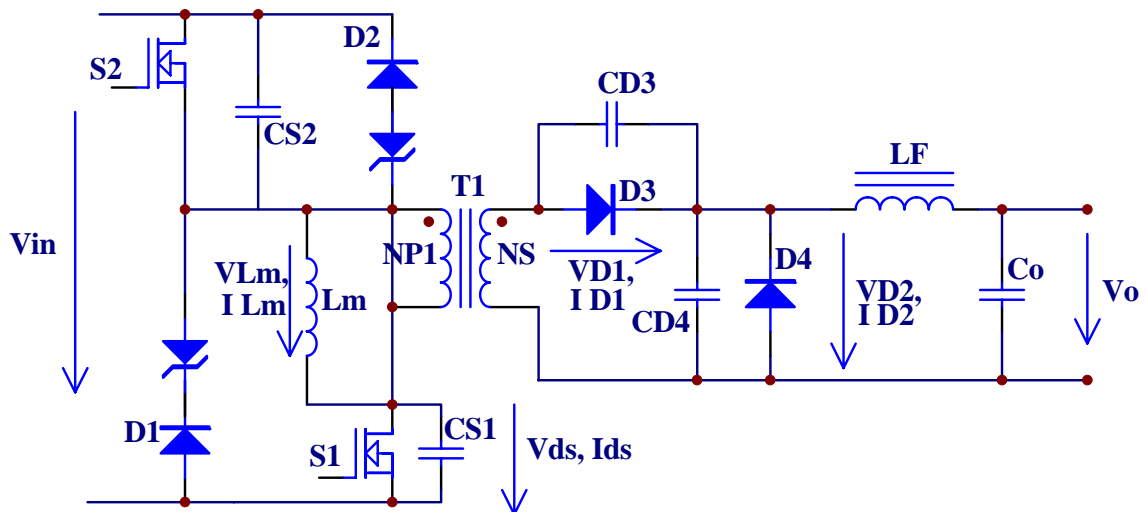
### Advantages:

- 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



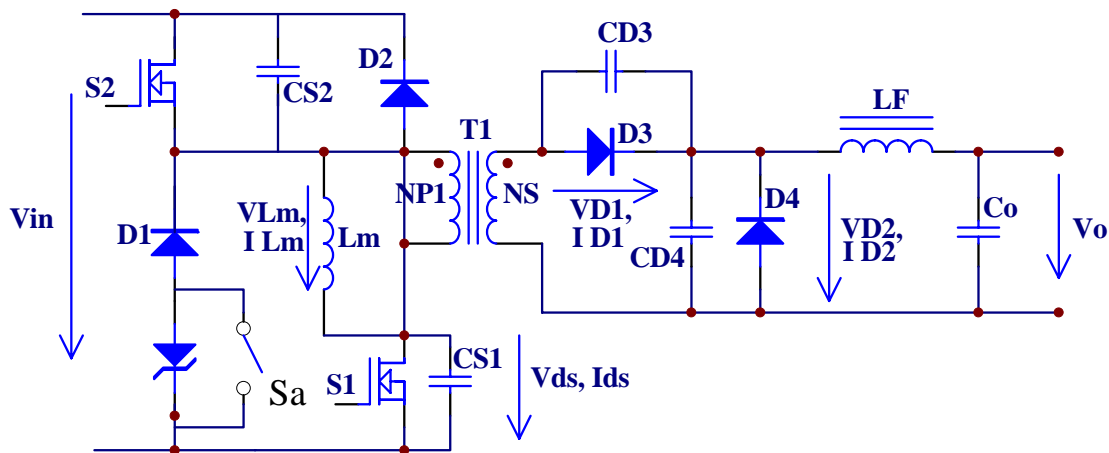
### Advantages:

- 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