Three-Level Converters – A New Approach for High Voltage and High Power DC-DC Conversions

Presented by

Xinbo Ruan

College of Electrical and Electronic Engineering

Huazhong University of Science and Technology

Aero-Power Sci-tech Center

Outlines

1. Backgrounds
2. Derivation of a Family of Three-Level Converters
3. Improved and Simplified Three-Level Converters
4. Buck TL Converter
5. ZVZCS PWM Hybrid Full-Bridge Three-Level Converter
6. Possible of Three-Level Voltage
7. Conclusions

Outlines

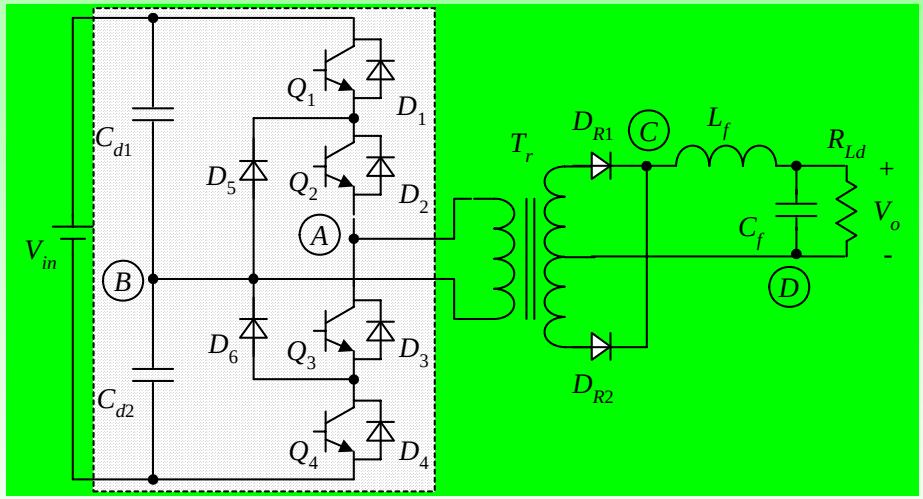
1. **Backgrounds**
2. Derivation of a Family of Three-Level Converters
3. Improved and Simplified Three-Level Converters
4. Buck TL Converter
5. ZVZCS PWM Hybrid Full-Bridge Three-Level Converter
6. Possible of Three-Level Voltage
7. Conclusions

Backgrounds

3-phase 380V±20% ac input is rectified to a dc voltage:

- w/o PFC: Vdcmax = 630V
- with PFC: Vdc = 800-1000V

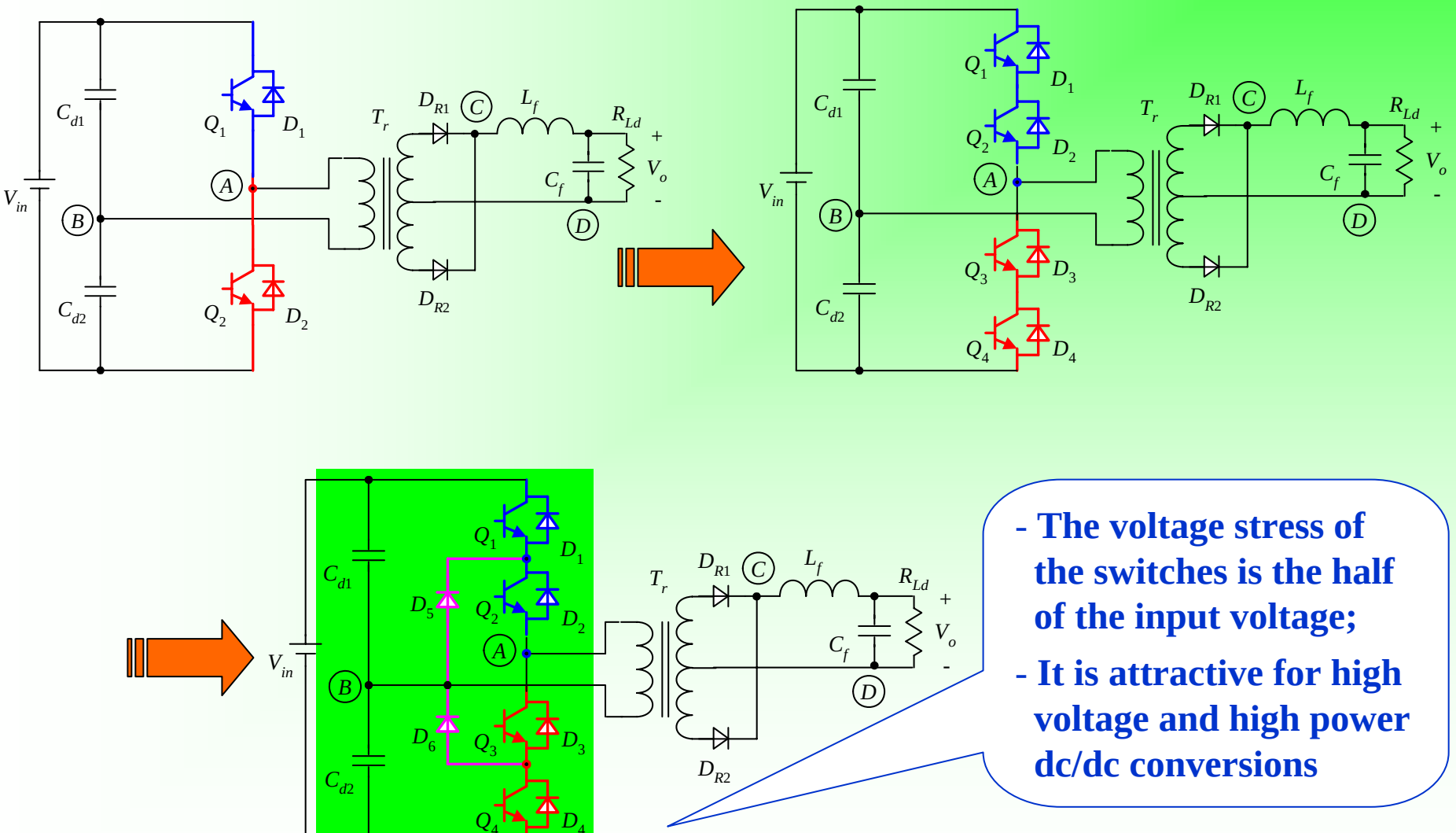
In order to reduce the voltage stress of the switches



Three-Level Converter

☺ The voltage stress of the power switch is half of the input voltage.

Derivation of Half-Bridge TL Converter



- **The voltage stress of the switches is the half of the input voltage;**
- **It is attractive for high voltage and high power dc/dc conversions**

Motivation

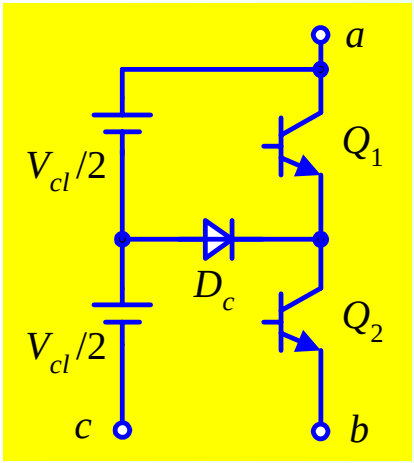
Extend the derivation of Half-Bridge Three-Level converter to all the DC-DC converters

To reduce the voltage stress of the switches.

Outlines

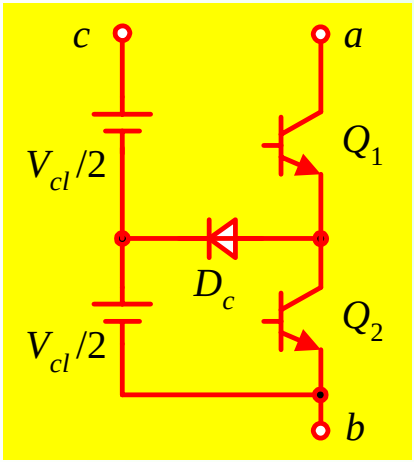
1. Backgrounds
2. **Derivation of a Family of Three-Level Converters**
3. Improved and Simplified Three-Level Converters
4. Buck TL Converter
5. ZVZCS PWM Hybrid Full-Bridge Three-Level Converter
6. Possible of Three-Level Voltage
7. Conclusions

TL Switch Cells

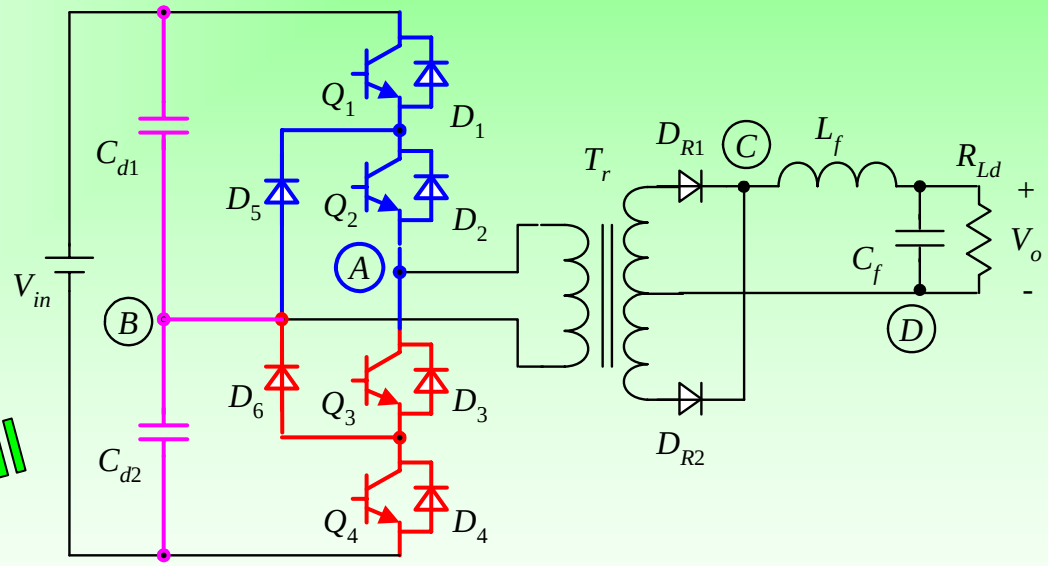


Anode Cell

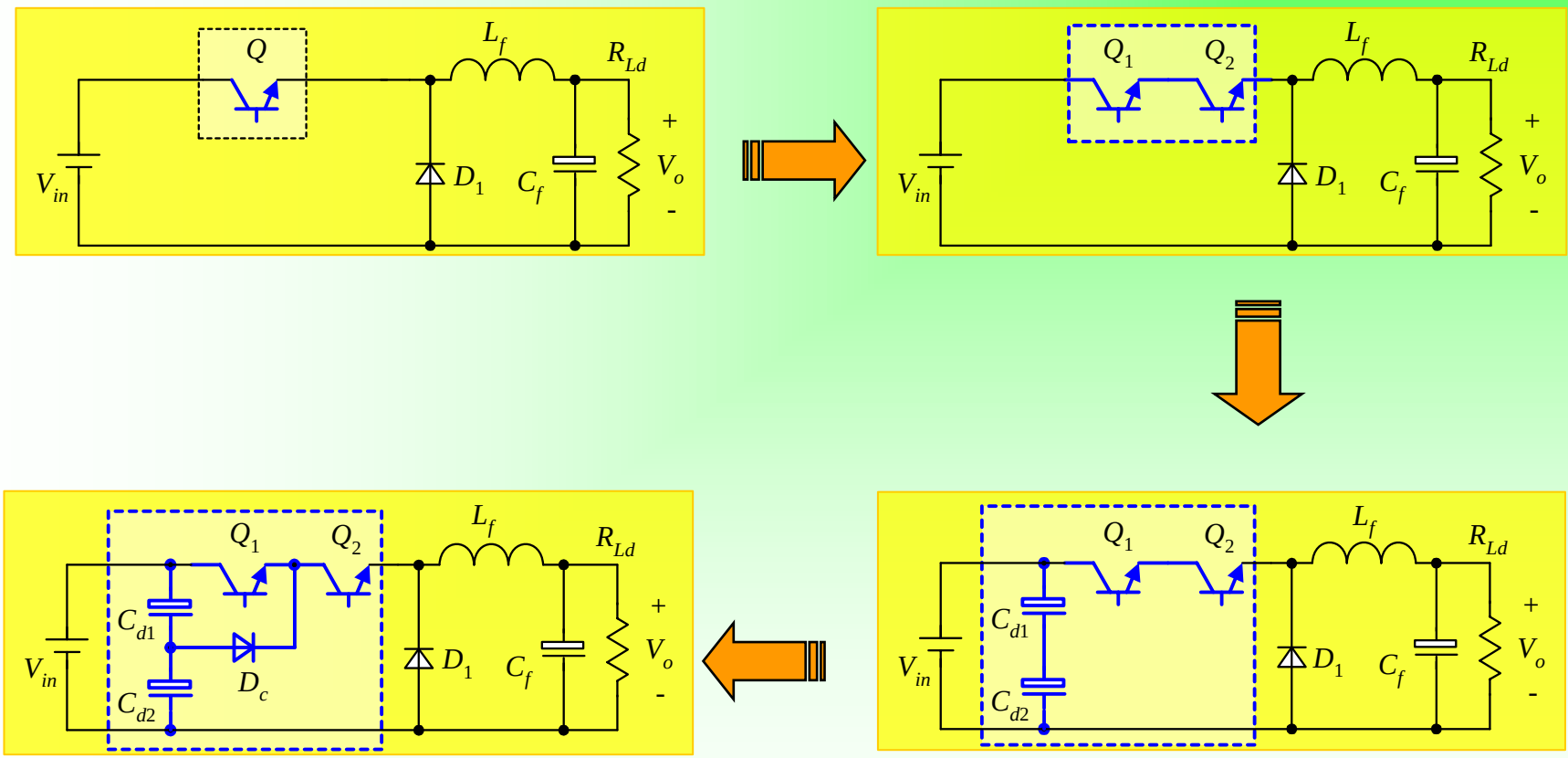
- Two series switches;
- Clamping voltage source splitting into two equally;
- Clamping diode.



Cathode Cell



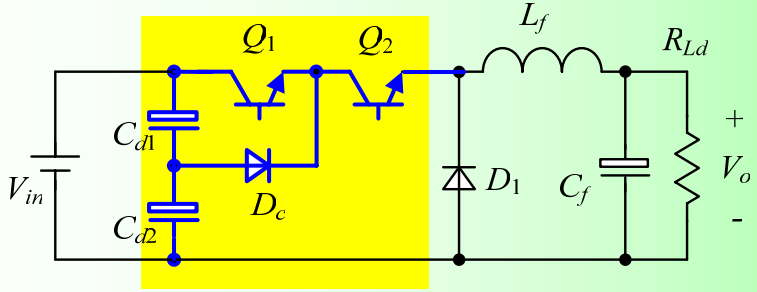
Derivation of Buck TL Converter



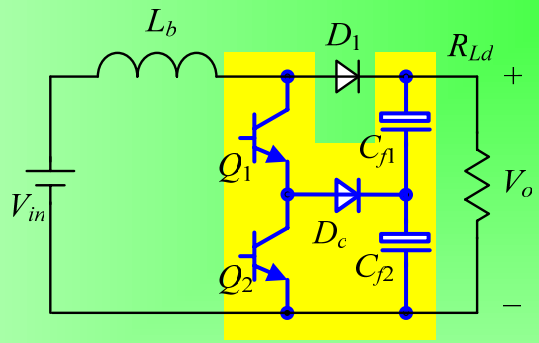
A Family of TL Converters

Aero-Power Sci-tech Center

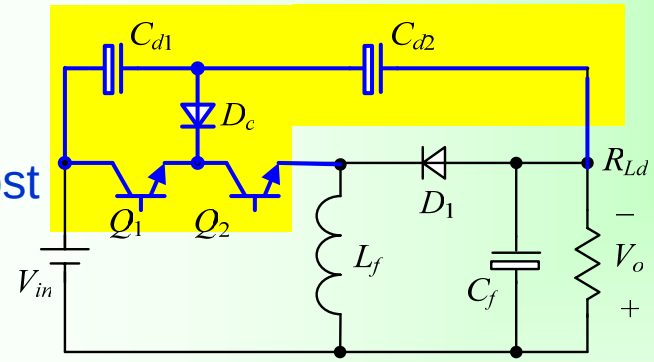
Buck



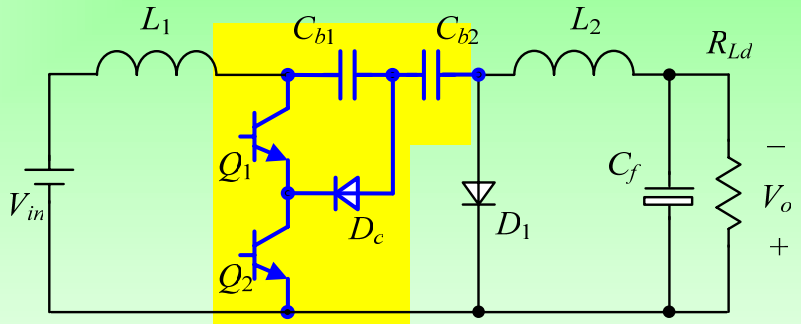
Boost



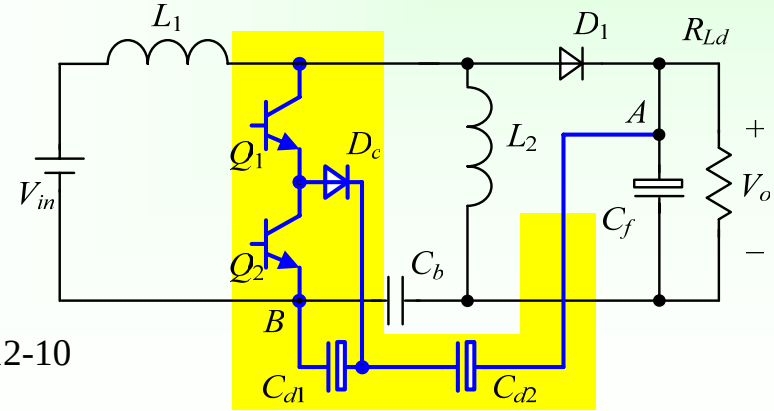
Buck/Boost



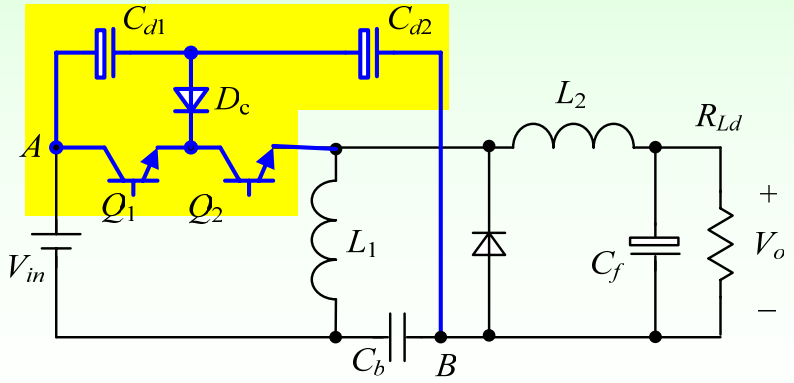
Cuk



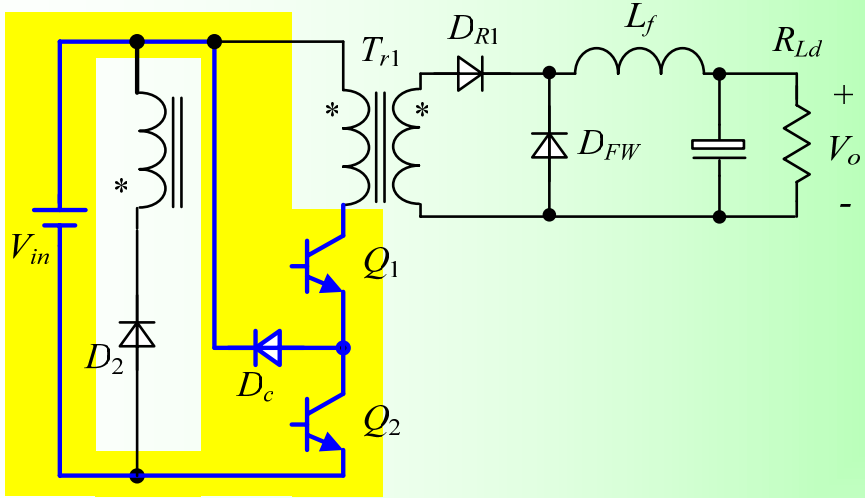
Sepic



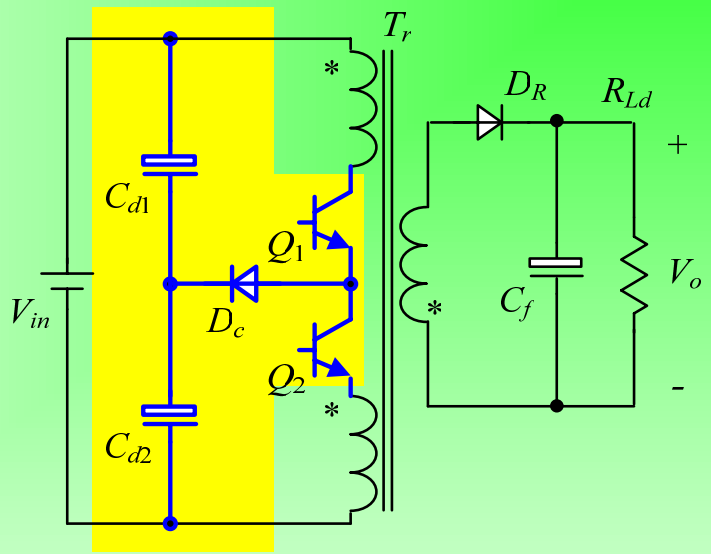
Zeta



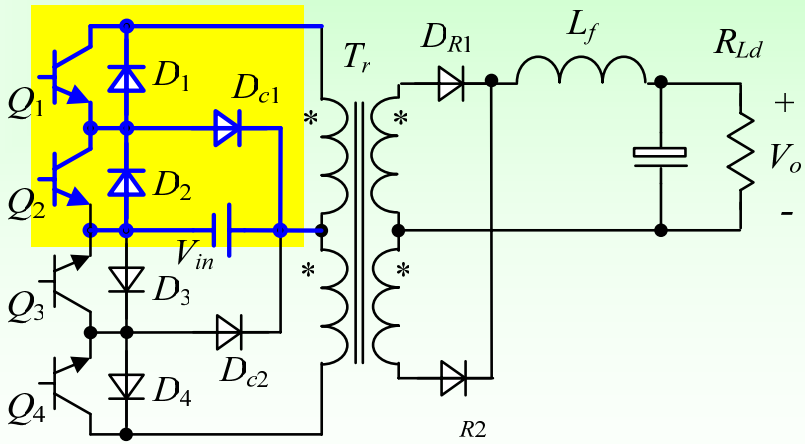
A Family of TL Converters



Forward

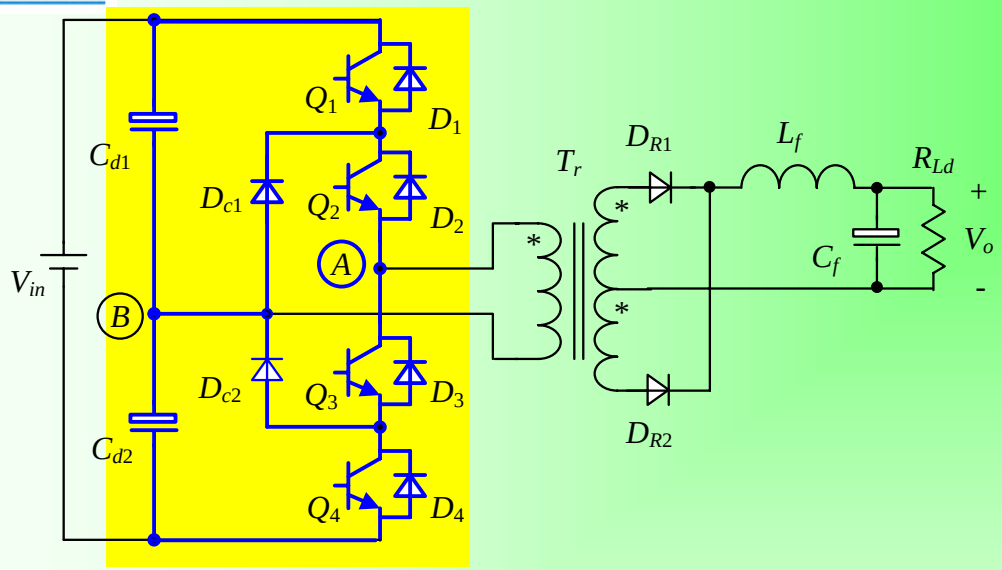


Flyback

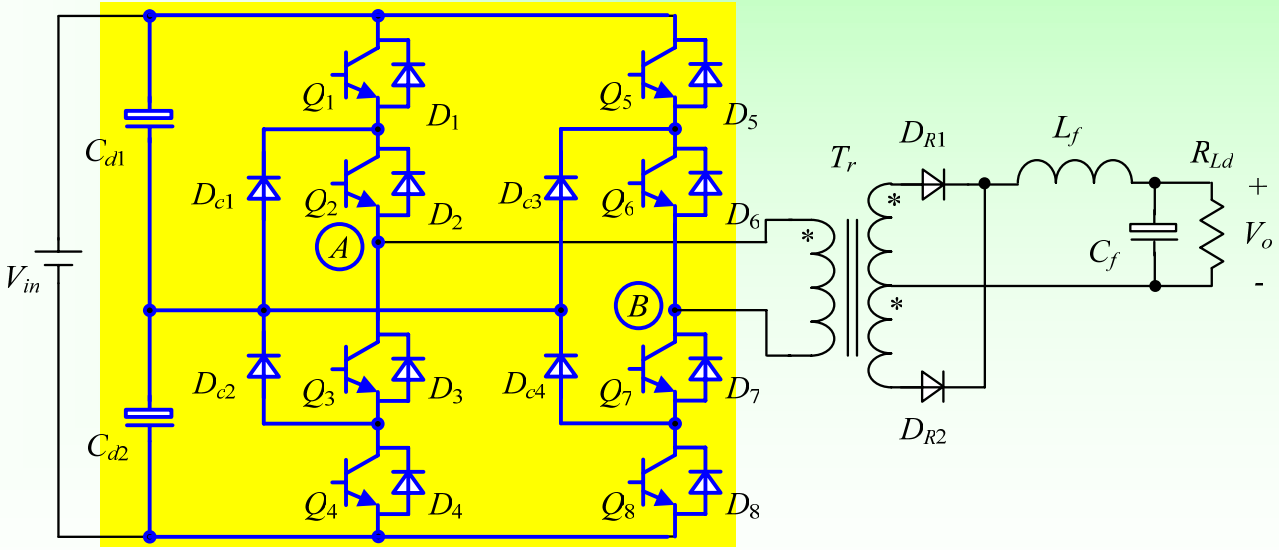


Push-Pull

A Family of TL Converters



Half-Bridge



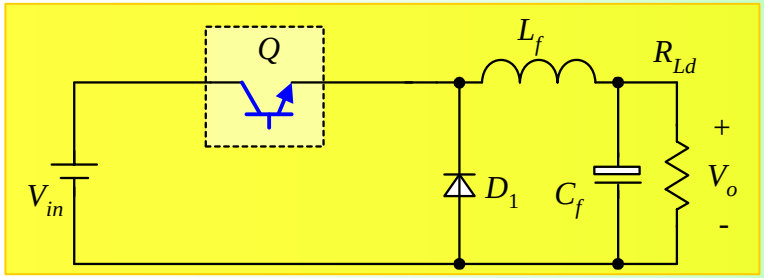
Full-Bridge

Outlines

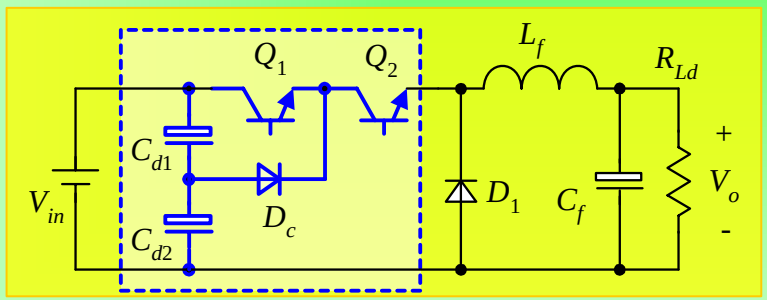
1. Backgrounds
2. Derivation of a Family of Three-Level Converters
3. **Improved and Simplified Three-Level Converters**
4. Buck TL Converter
5. ZVZCS PWM Hybrid Full-Bridge Three-Level Converter
6. Possible of Three-Level Voltage
7. Conclusions

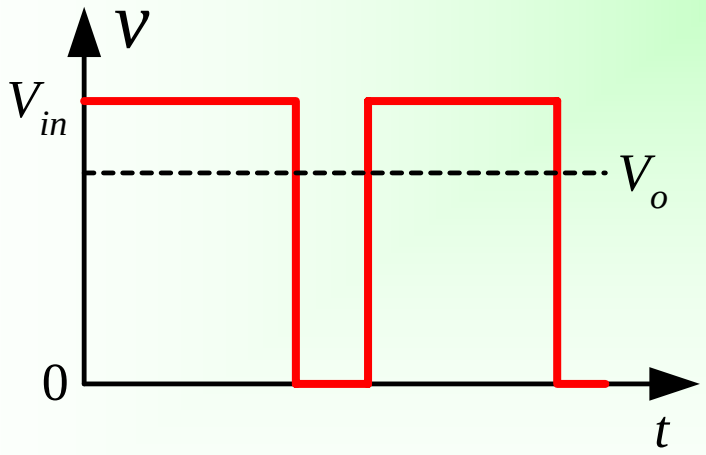
Output Waveform

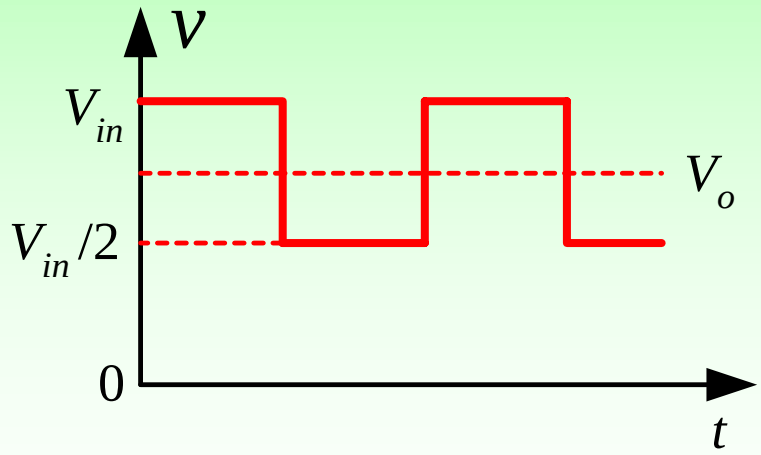
Buck Converter



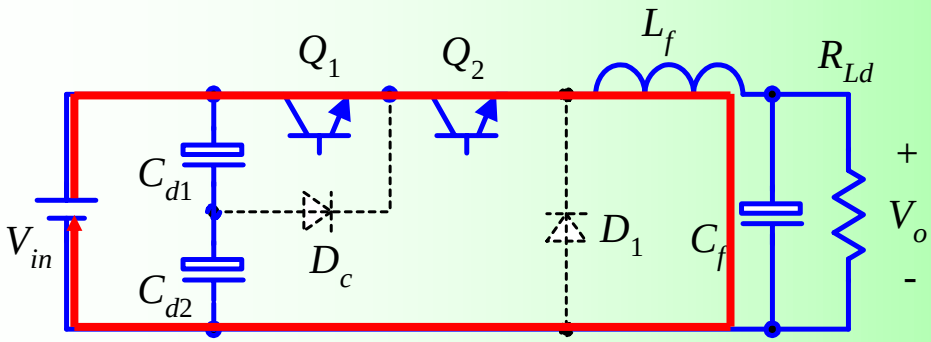
Buck TL Converter

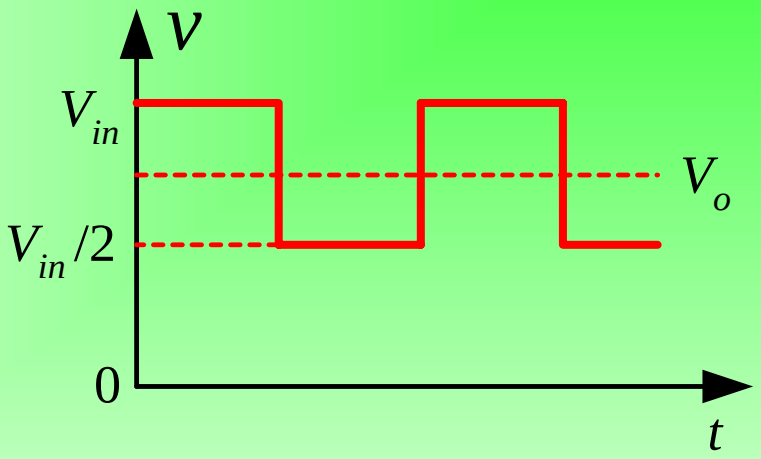


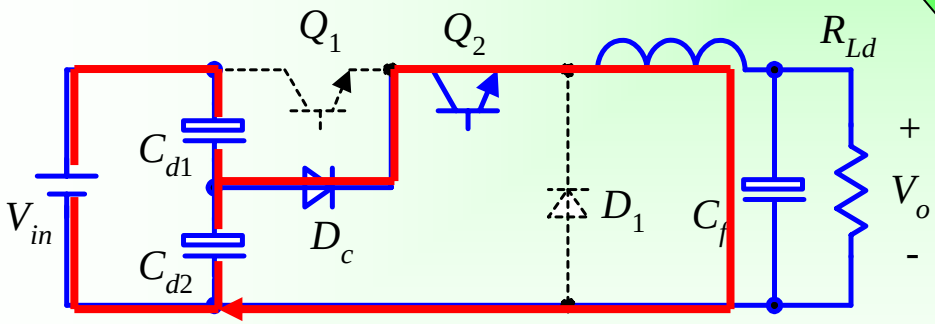




Problems of Buck TL Converter

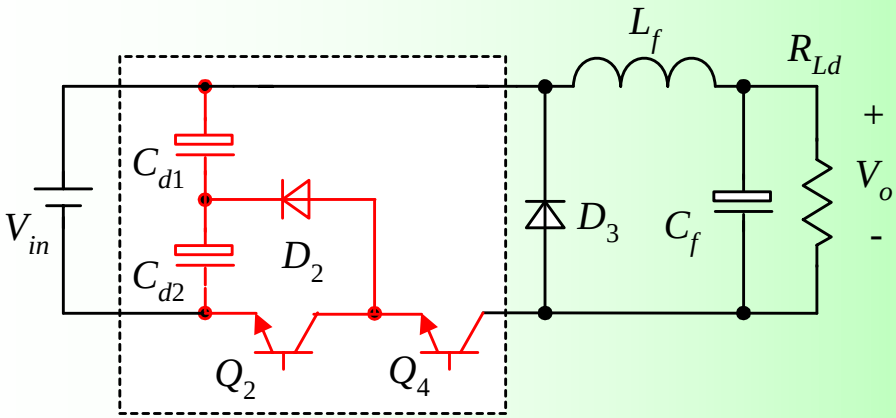


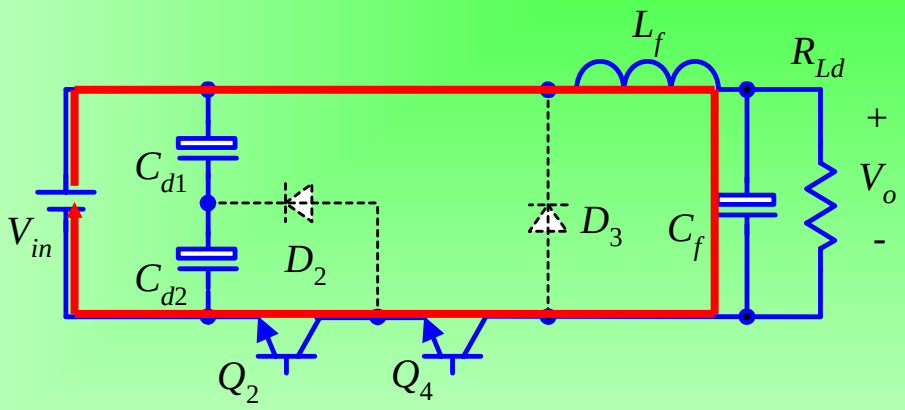




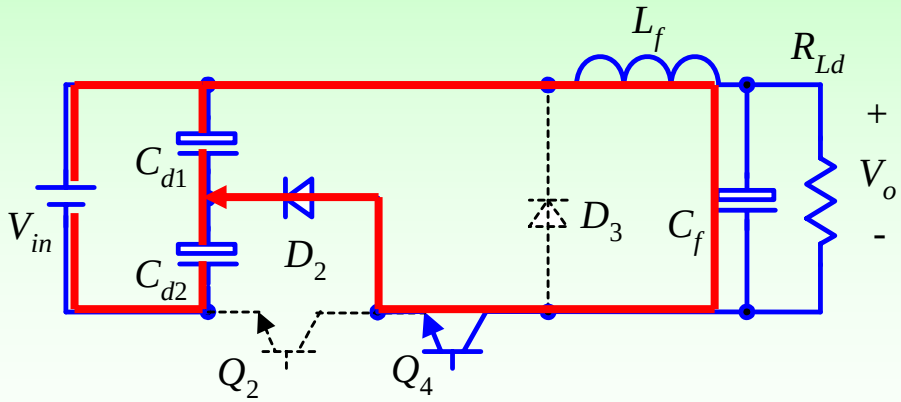
☹ C_{d2} provides more energy, which results in **unbalance of voltage of the input divided capacitors**

Problems of Buck TL Converter

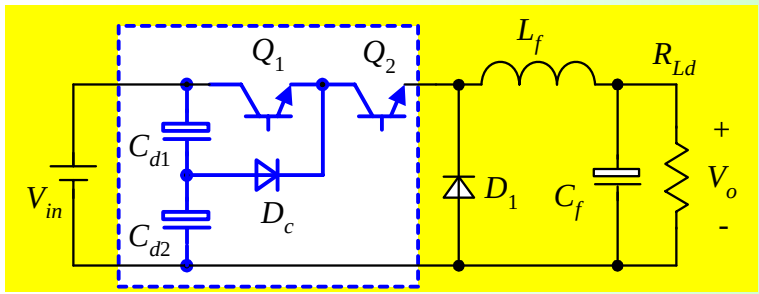


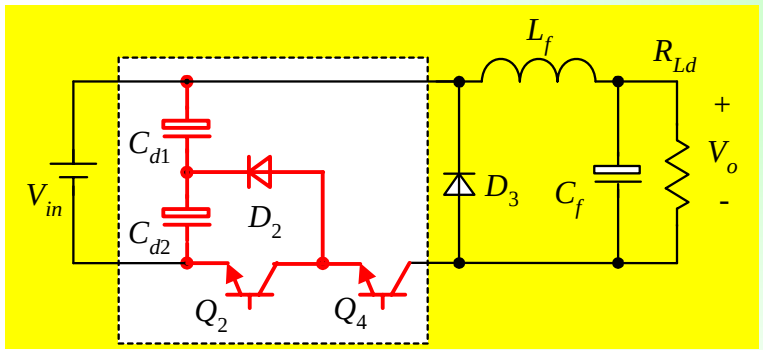


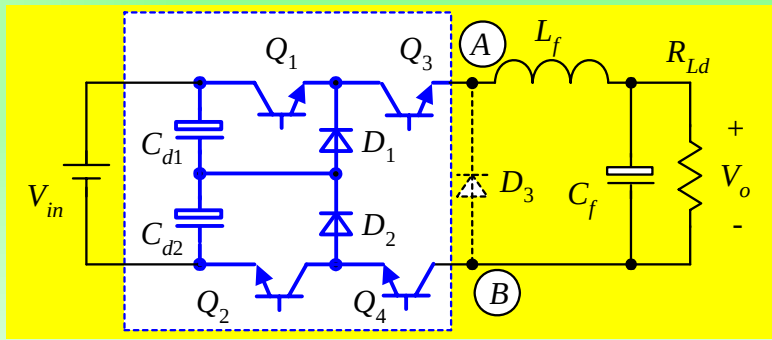
☹ C_{d1} provides more energy, which results in **unbalance of voltage of the input divided capacitors**



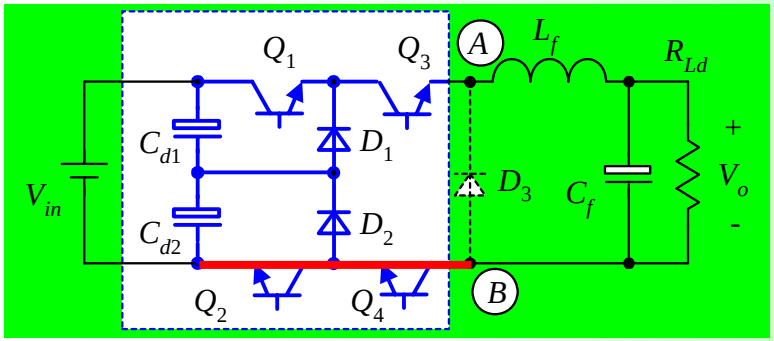
Combined Buck TL Converter

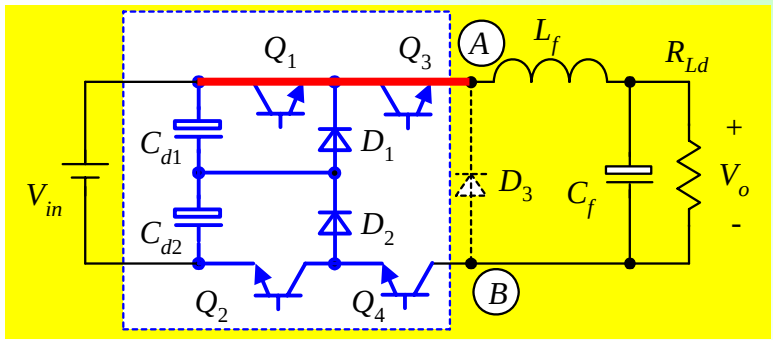


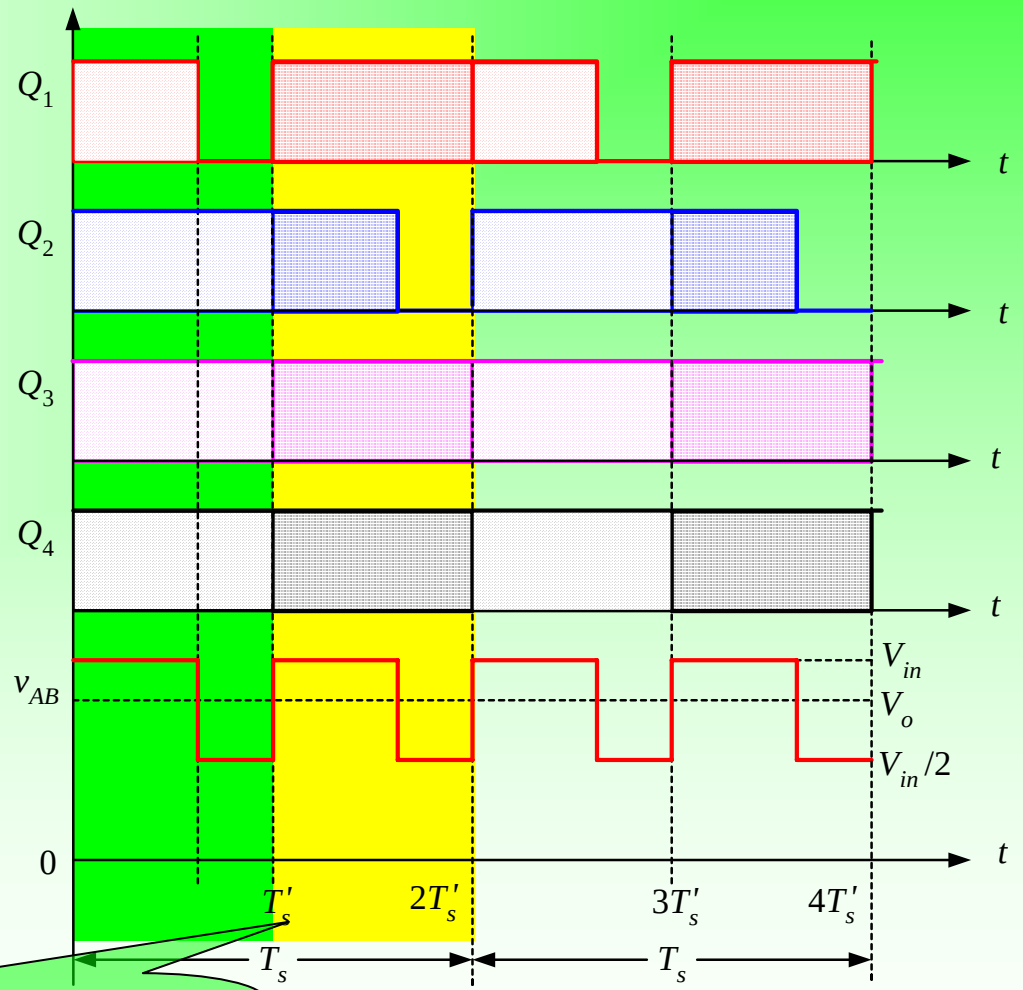




Combined Buck TL Converter

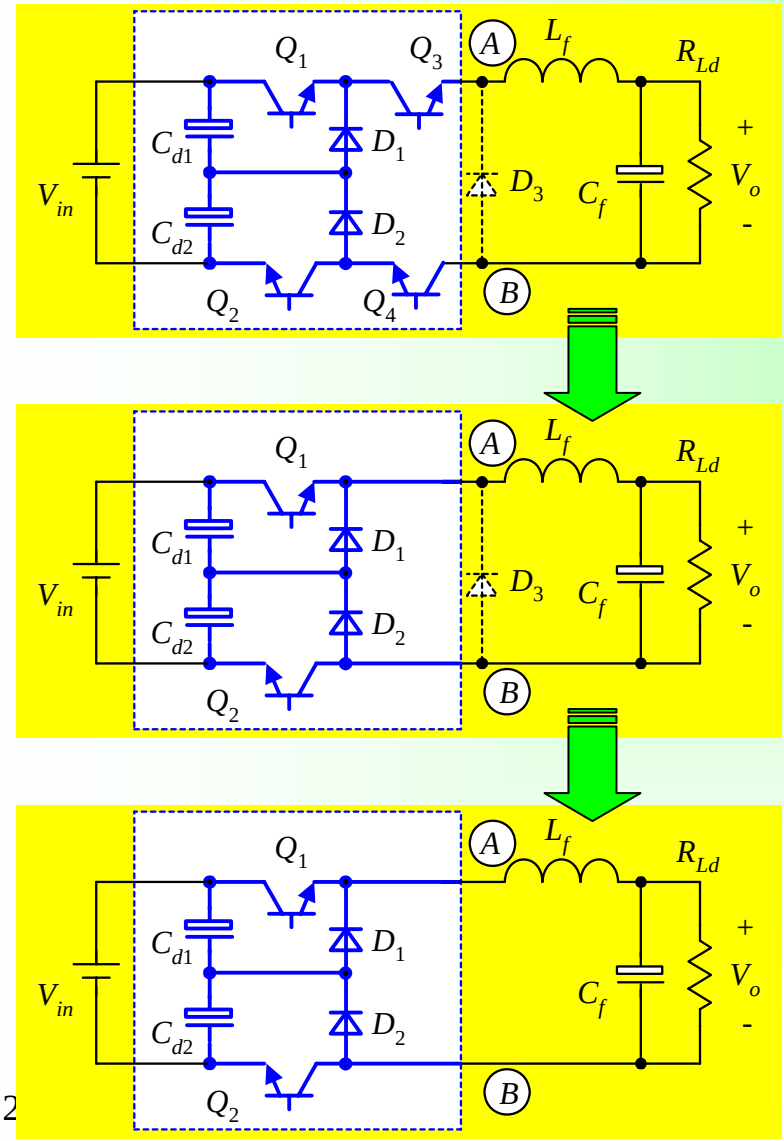


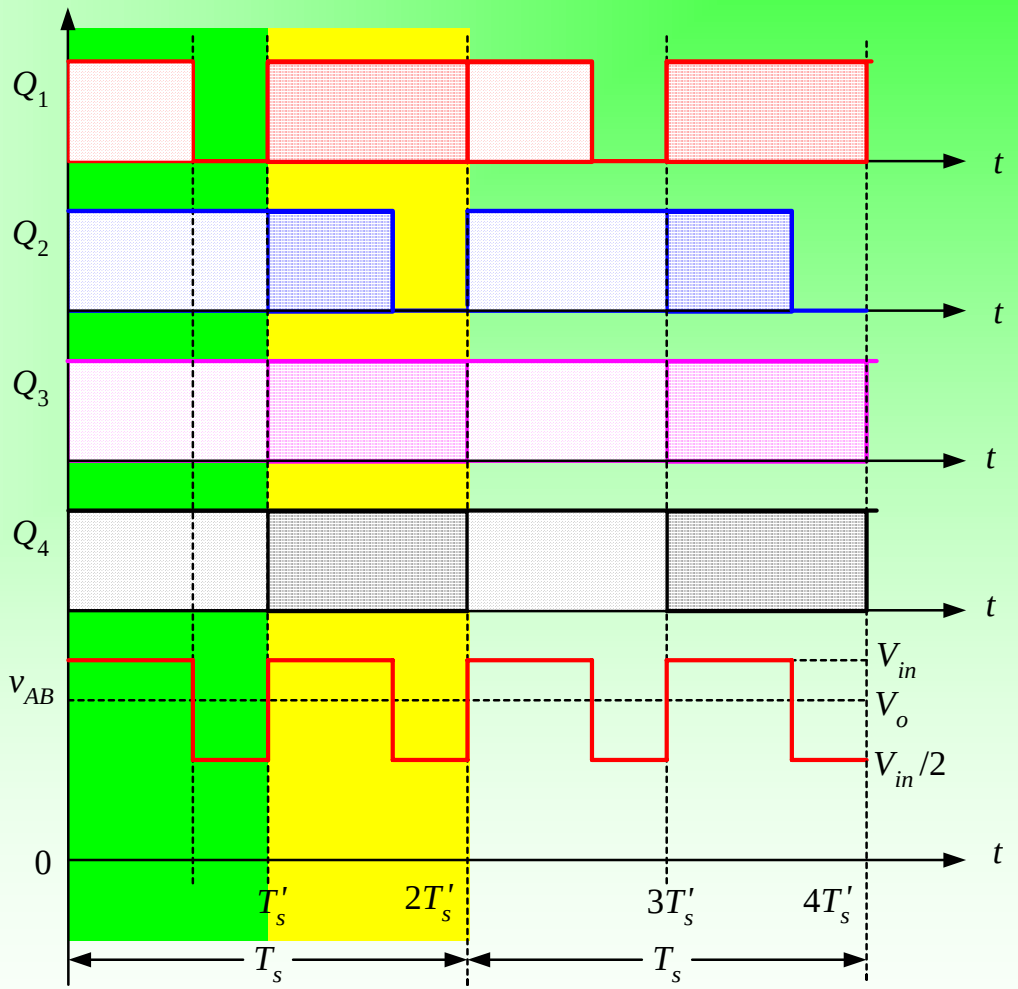




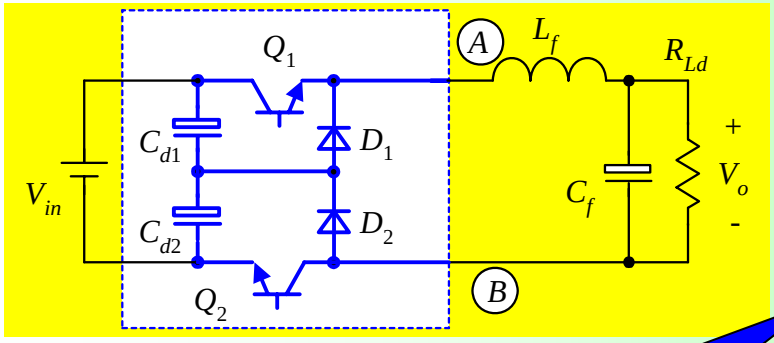
The voltage of the divided capacitors are Balanced.

Improved Buck TL Converter

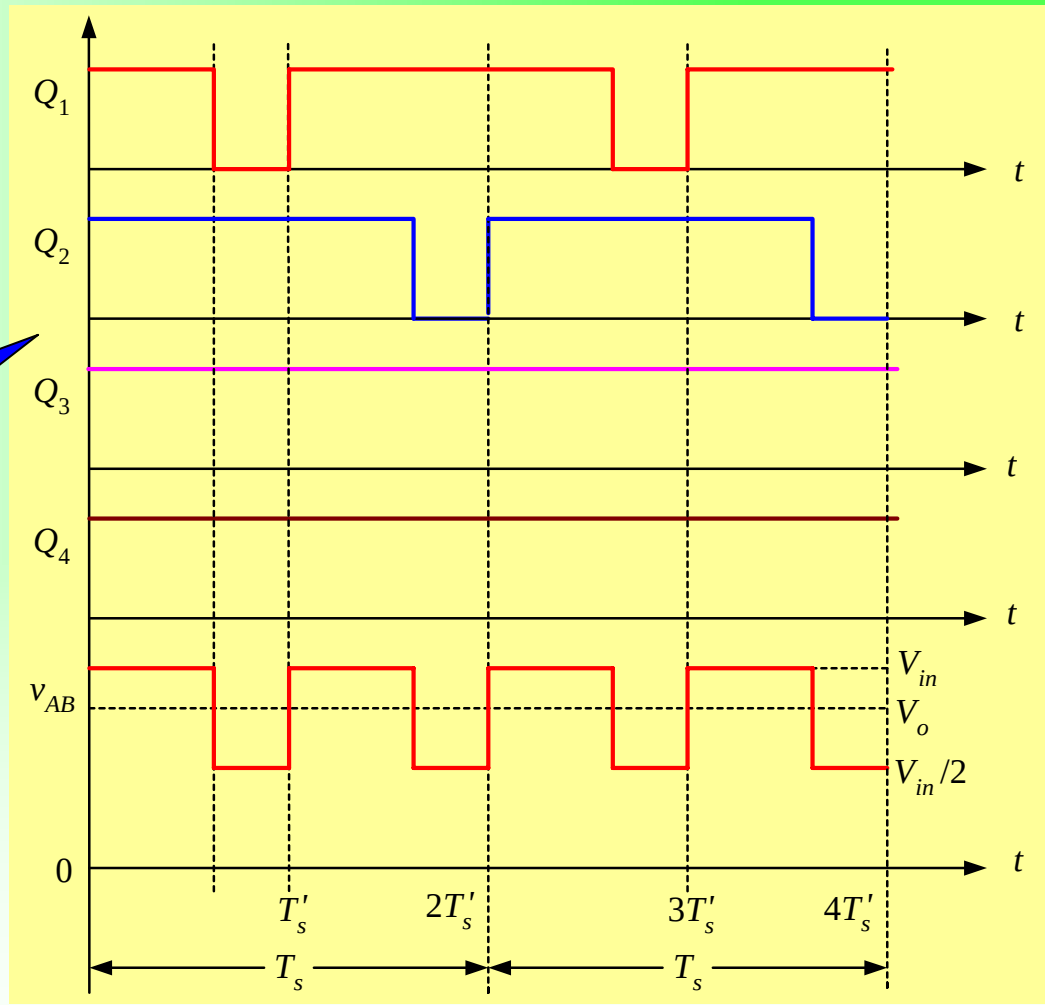




Improved Buck TL Converter



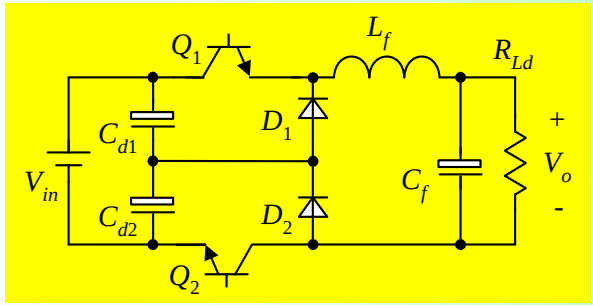
1. The voltage of the divided capacitors are **balanced**;
2. The ripple frequency of v_{AB} is twice the switching frequency;
3. Q_1 and Q_2 are interleaving switched.



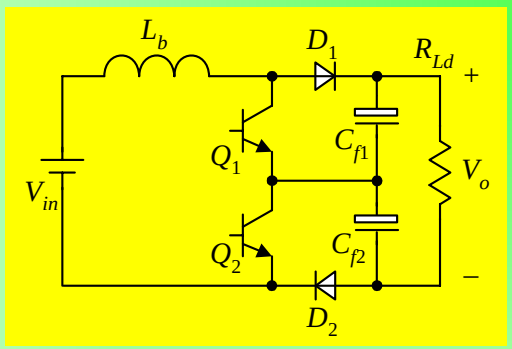
Improved TL Converters

Aero-Power Sci-tech Center

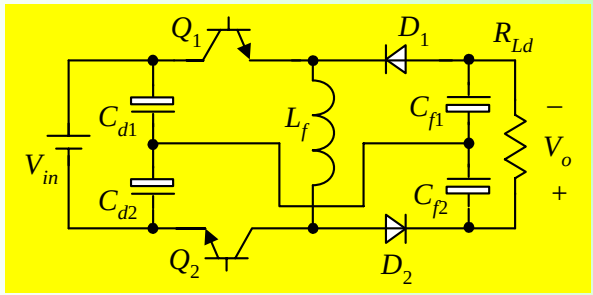
Buck



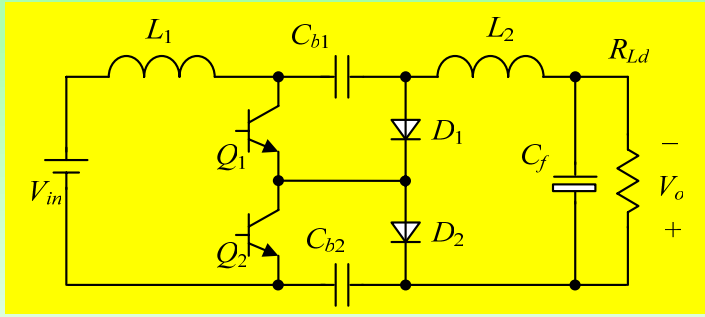
Boost



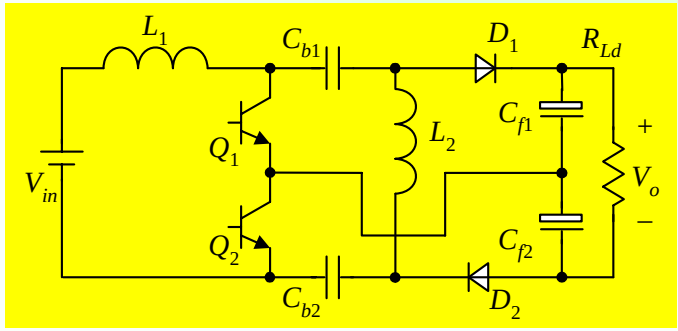
Buck/Boost



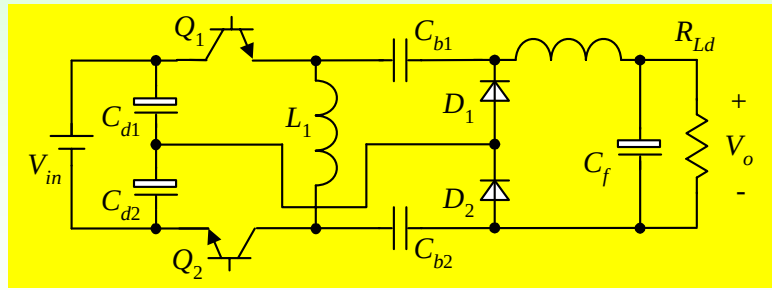
Cuk



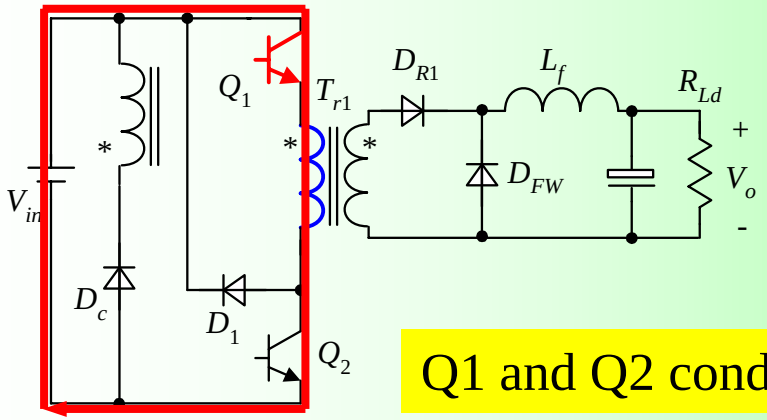
Sepic



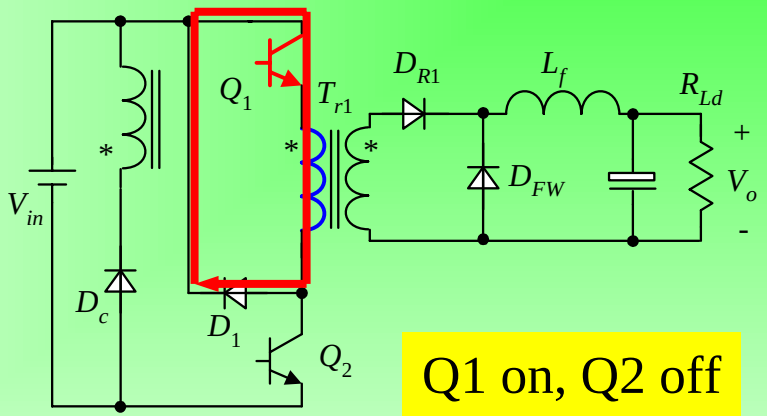
Zeta



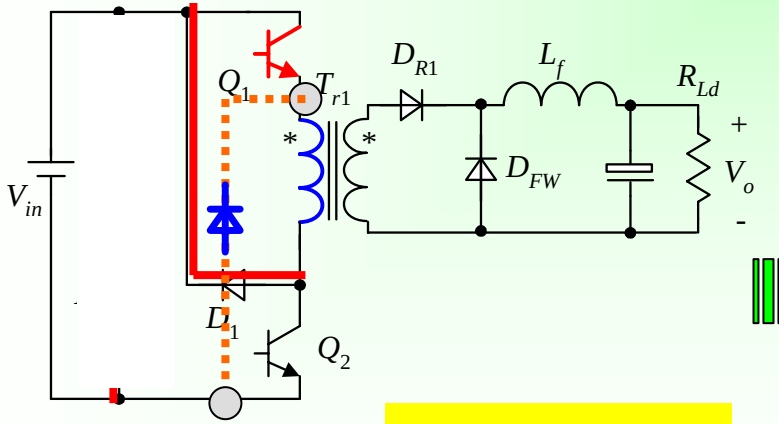
Simplified Forward TL Converter



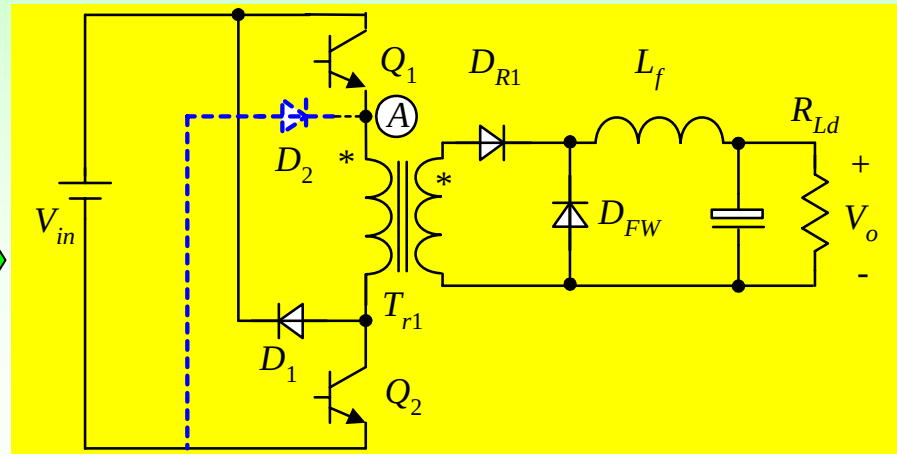
Q1 and Q2 conduct



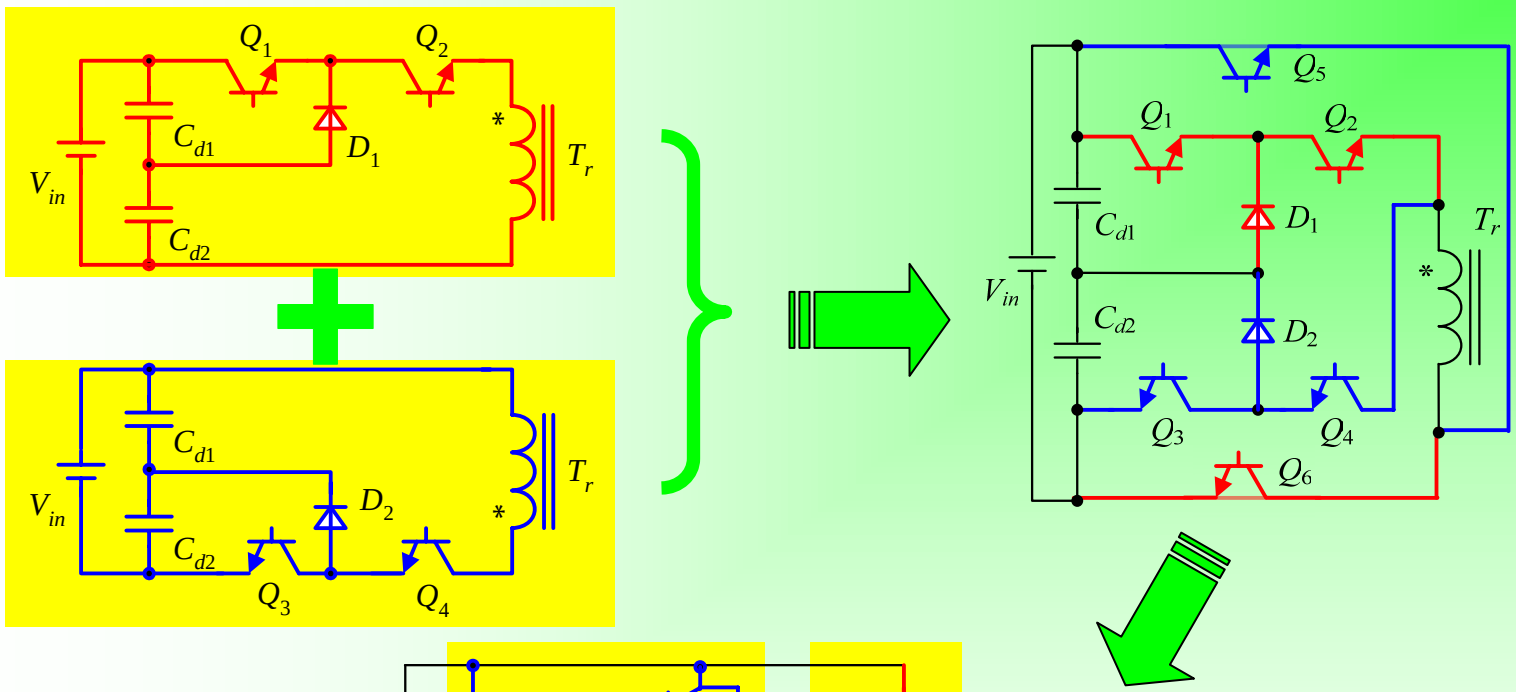
Q1 on, Q2 off

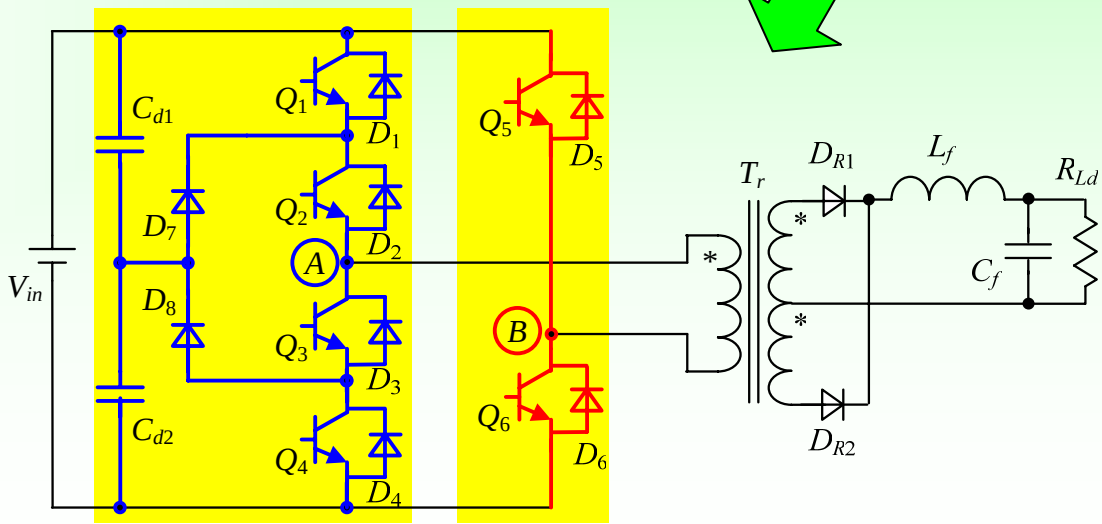


Q1 off, Q2 off



Derivation of Hybrid Full-Bridge TL Converter

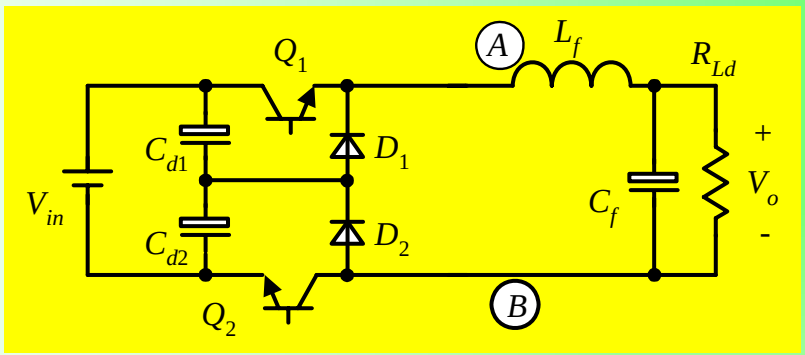


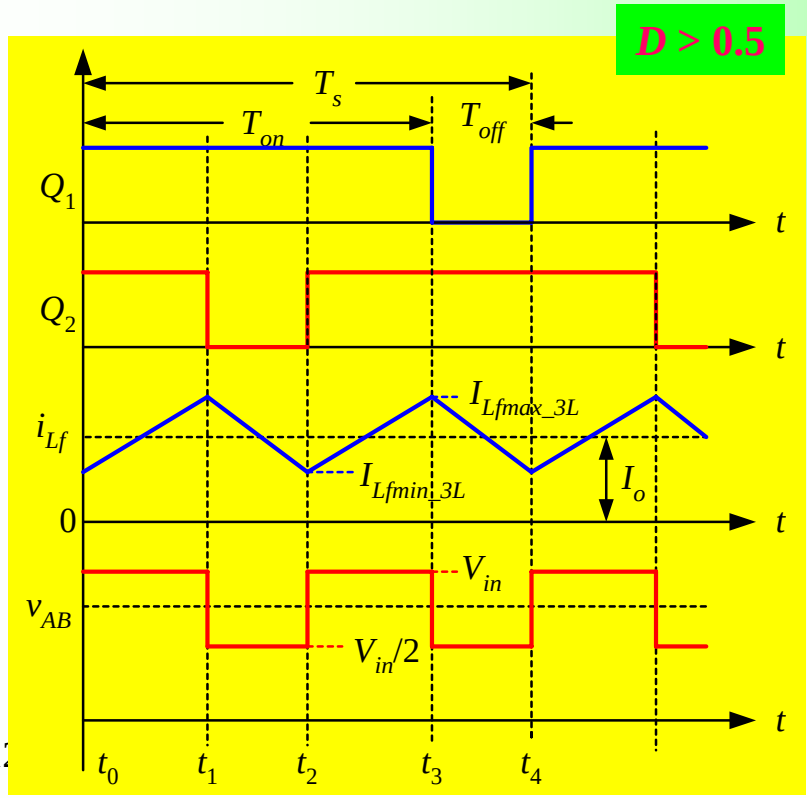


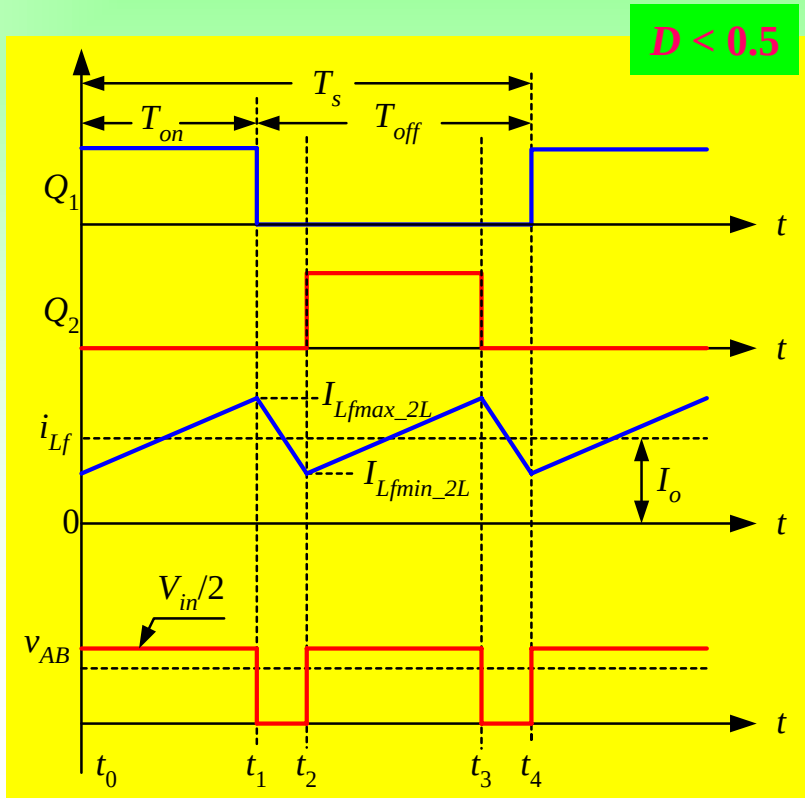
Outlines

1. Backgrounds
2. Derivation of a Family of Three-Level Converters
3. Improved and Simplified Three-Level Converters
4. **Buck TL Converter**
5. ZVZCS PWM Hybrid Full-Bridge Three-Level Converter
6. Possible of Three-Level Voltage
7. Conclusions

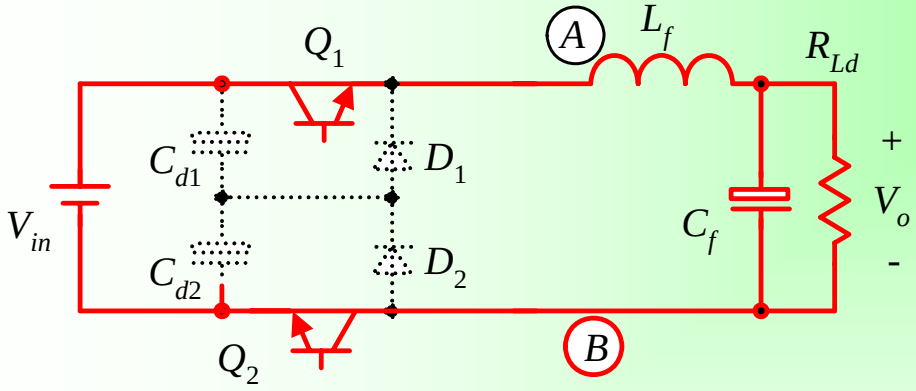
Key Waveforms



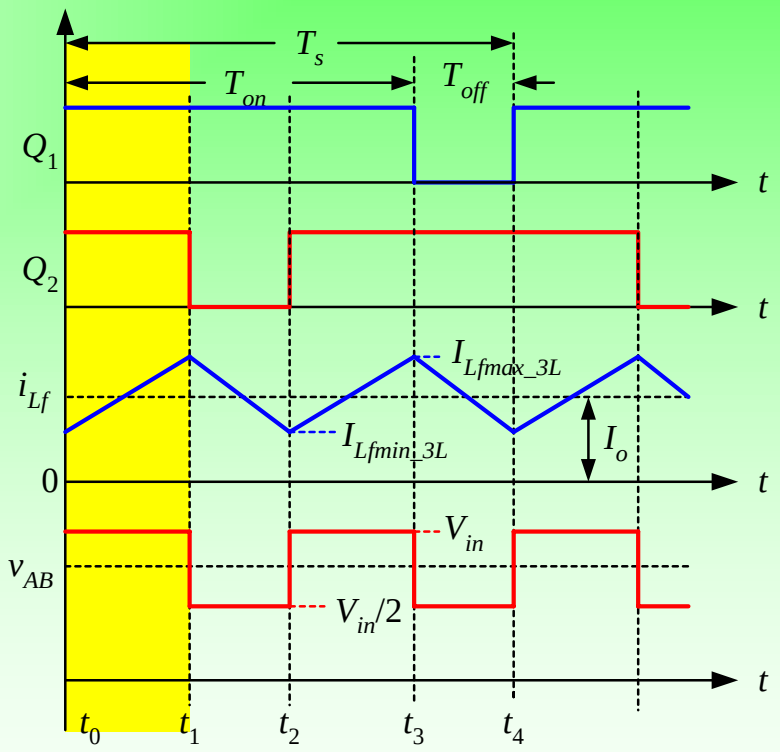




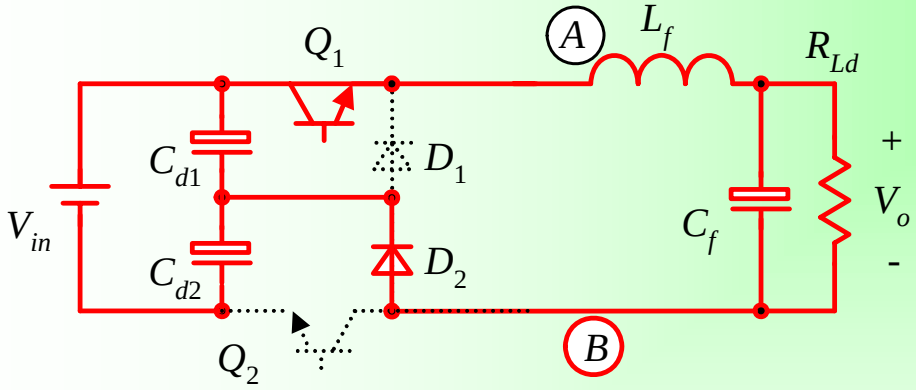
Operation of Buck TL Converter: D>0.5 (1)



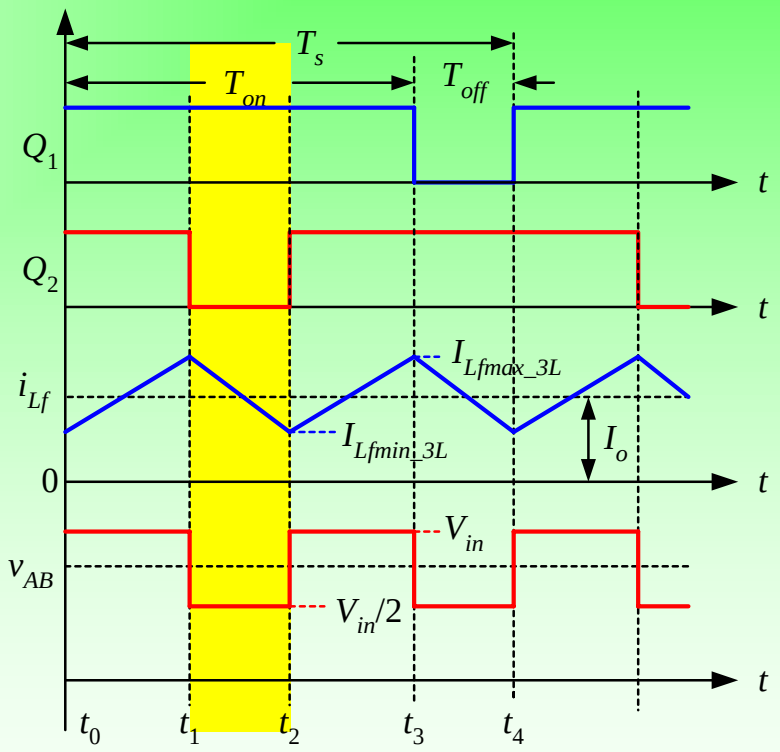
$D > 0.5$



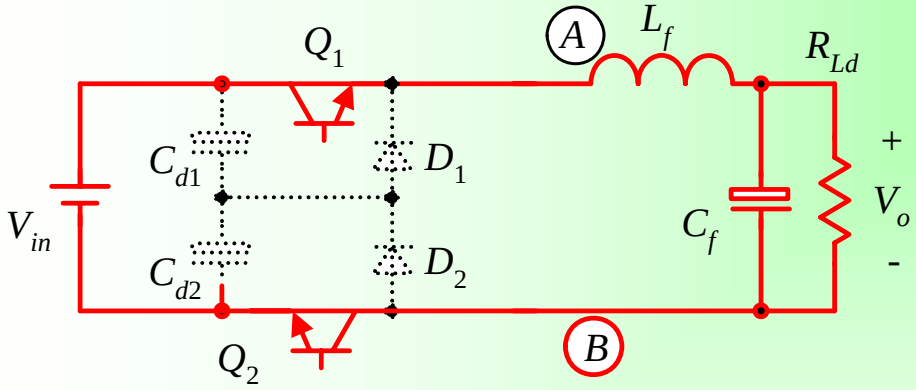
Operation of Buck TL Converter: D>0.5 (2)



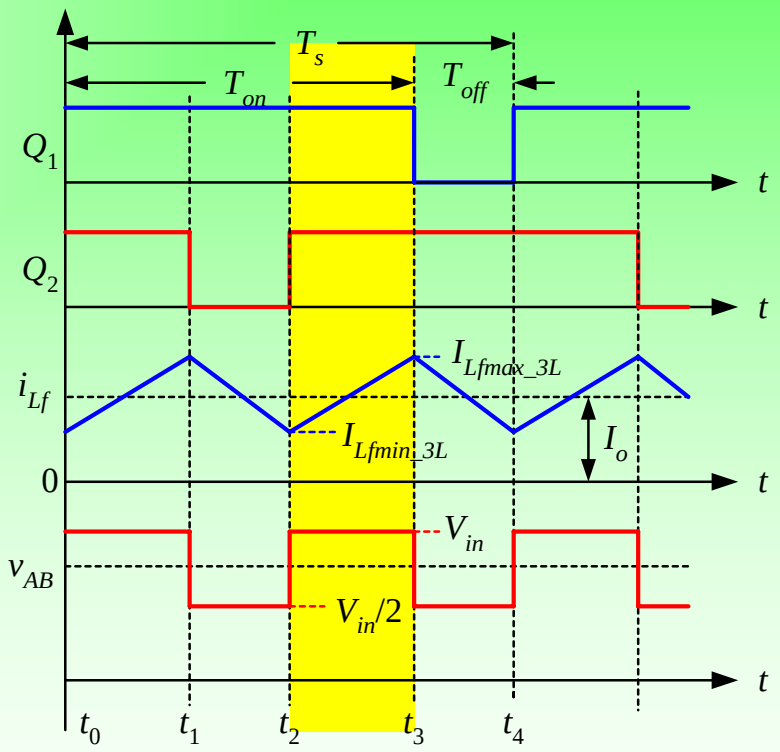
$D > 0.5$



Operation of Buck TL Converter: D>0.5 (3)

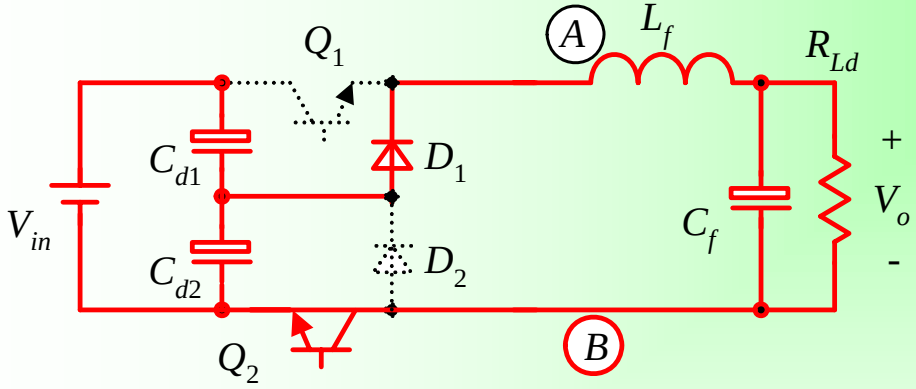


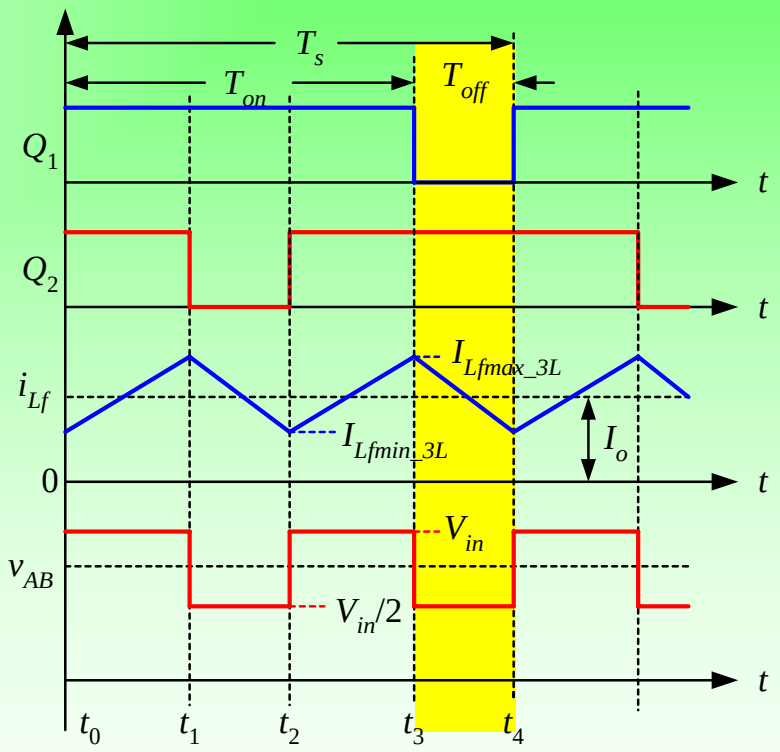
$D > 0.5$



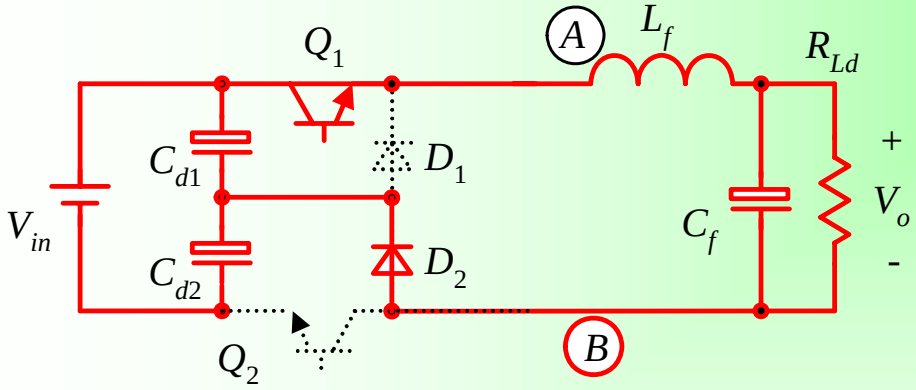
Operation of Buck TL Converter: D>0.5 (4)

D > 0.5

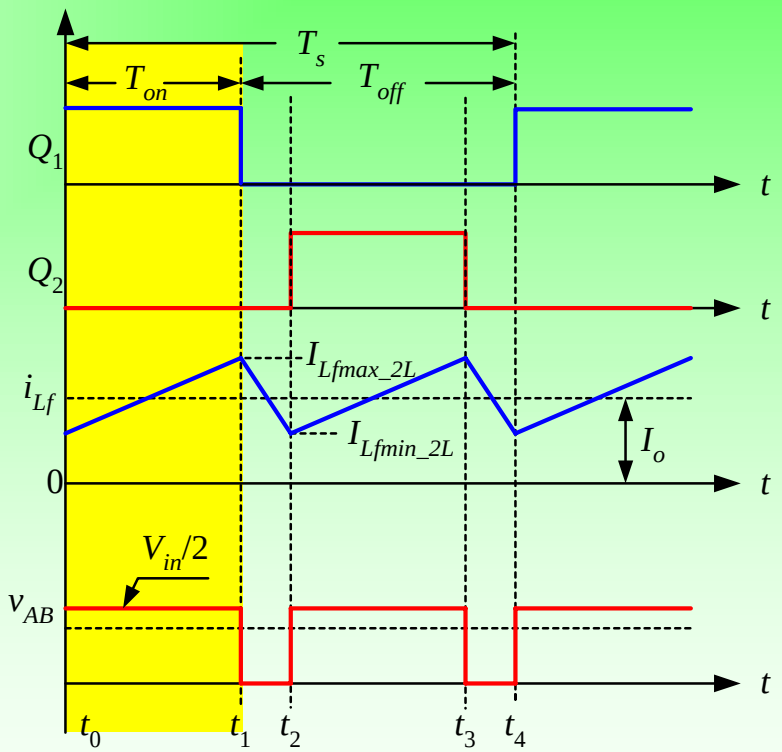




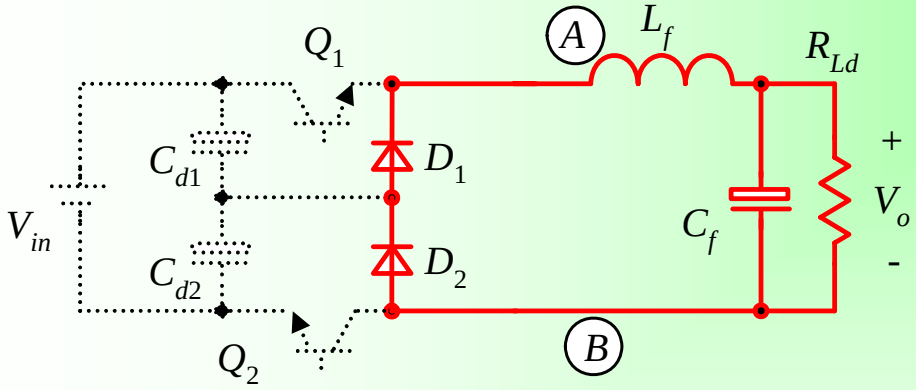
Operation of Buck TL Converter: D<0.5 (1)



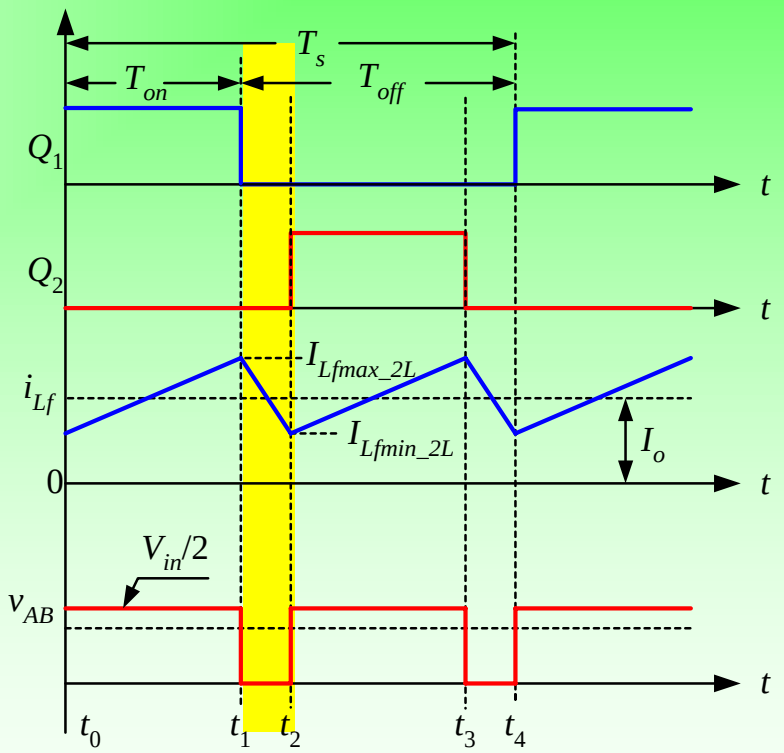
$D < 0.5$



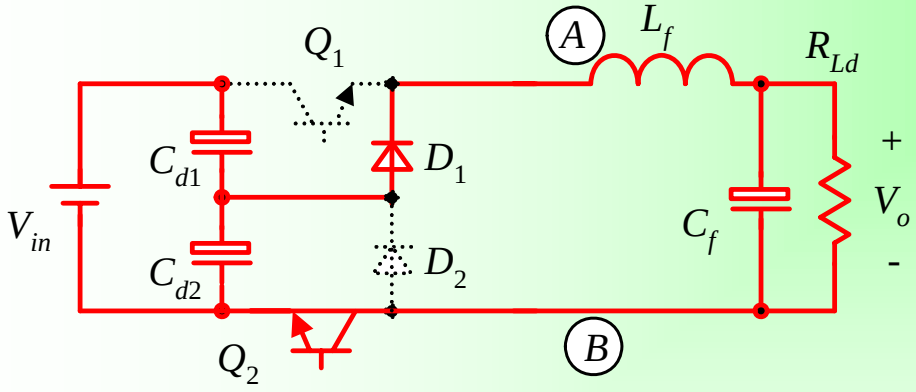
Operation of Buck TL Converter: D<0.5 (2)



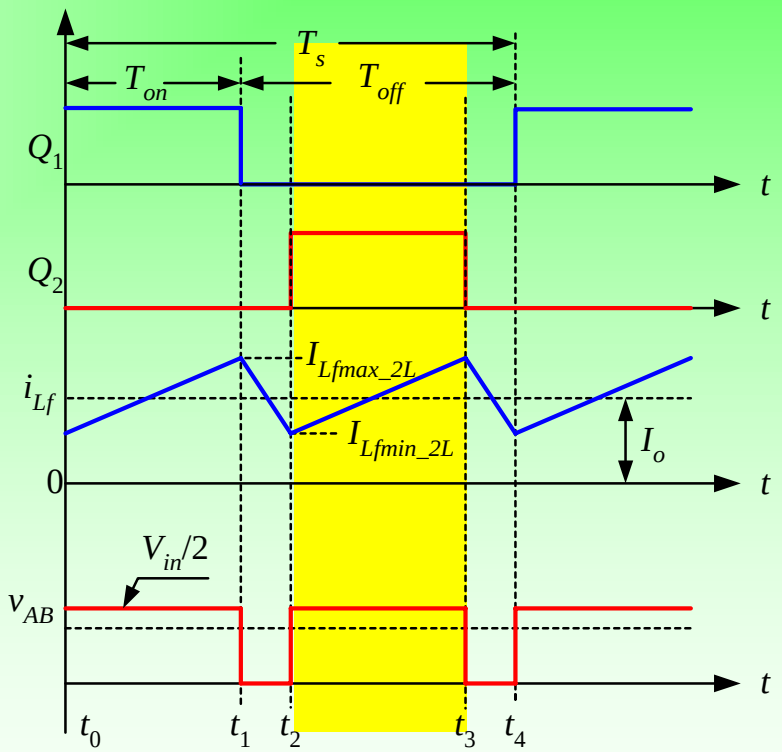
$D < 0.5$



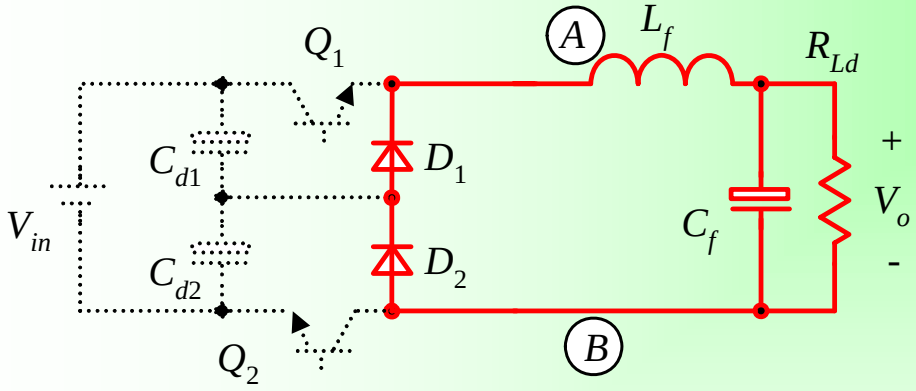
Operation of Buck TL Converter: D<0.5 (3)



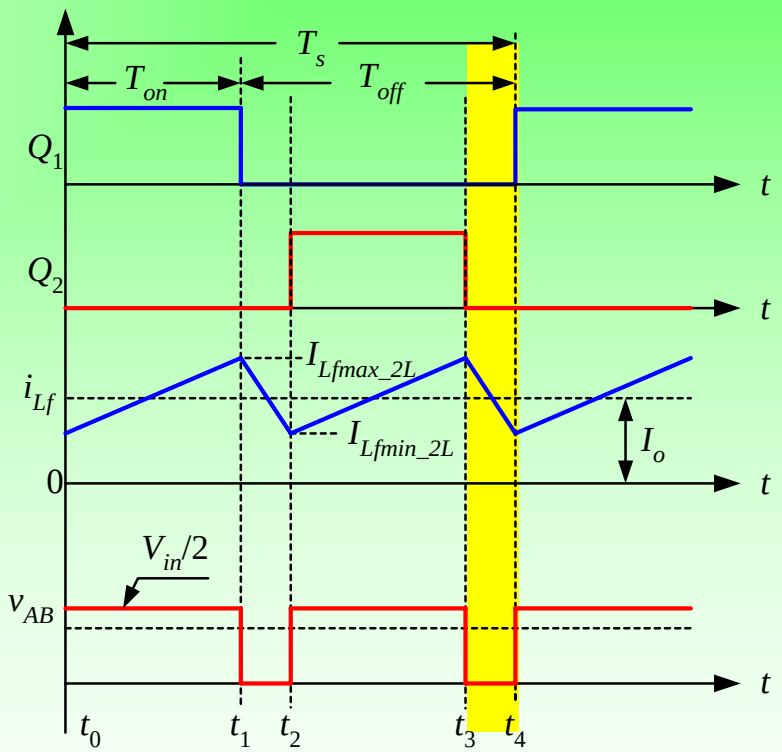
$D < 0.5$



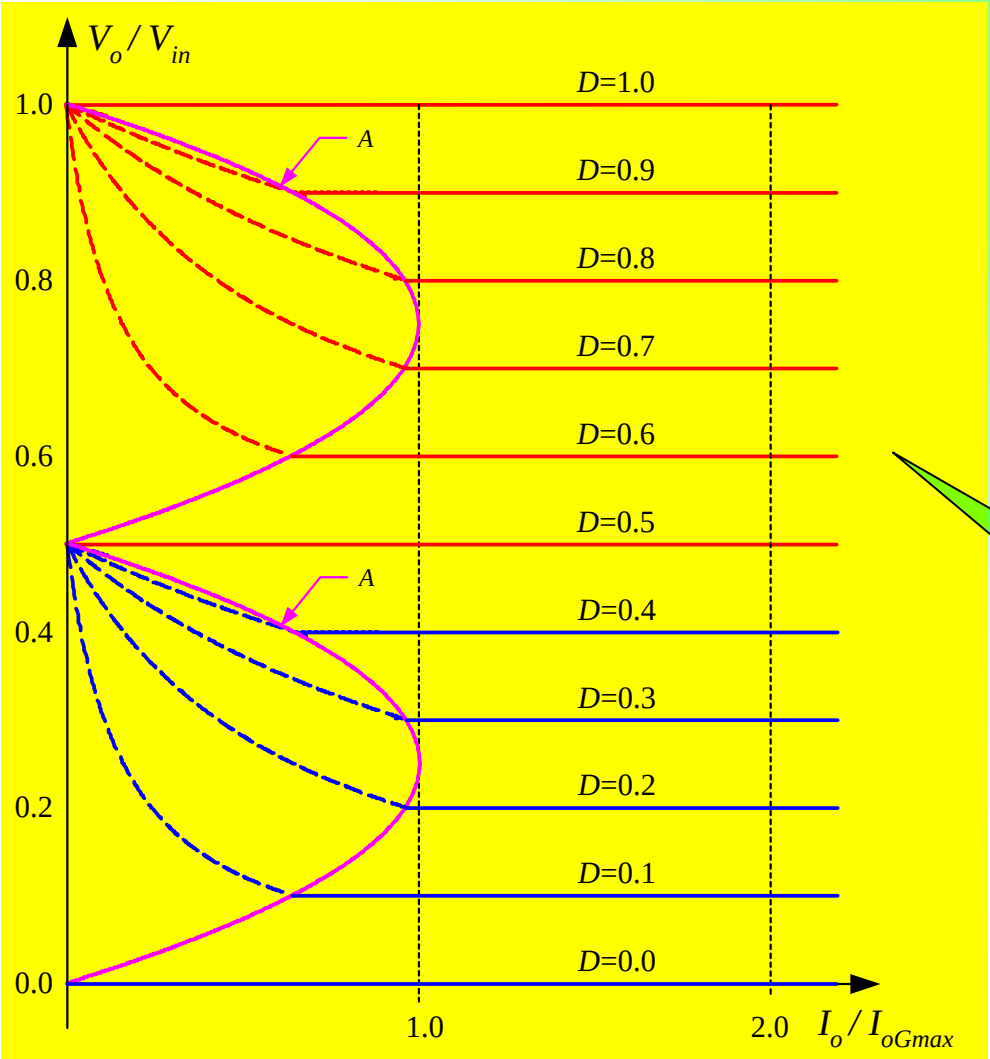
Operation of Buck TL Converter: D<0.5 (4)



$D < 0.5$

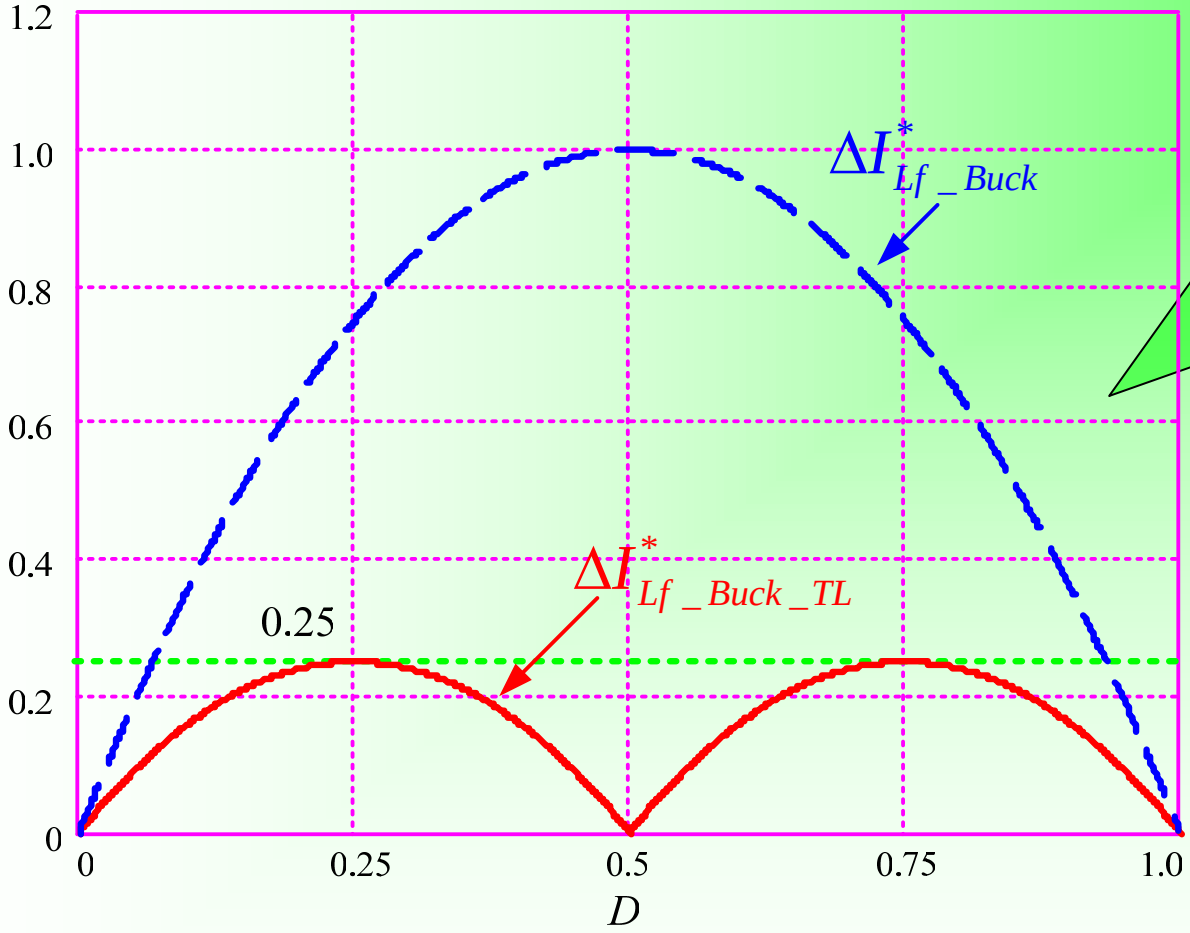


Voltage Conversion Ratio



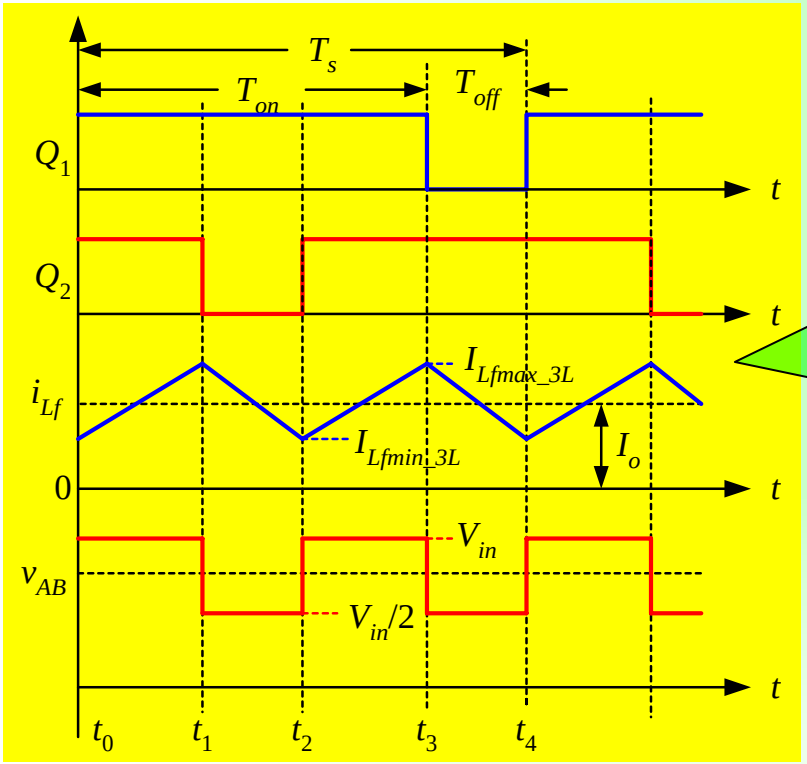
$$V_o / V_{in} = D$$

Output Filter Inductance



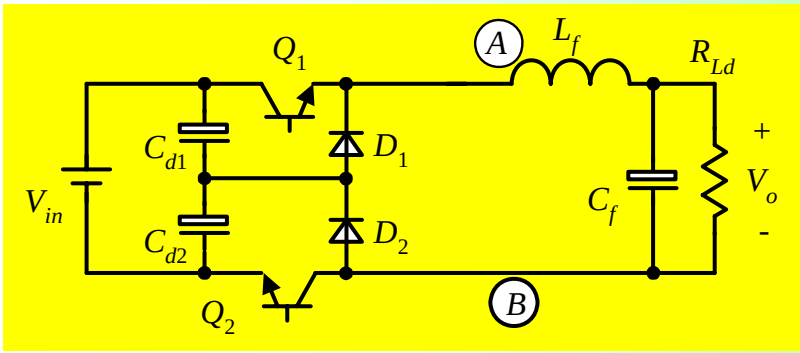
The output inductance of Buck TL converter reduces to 1/4 of that of Basic Buck converter

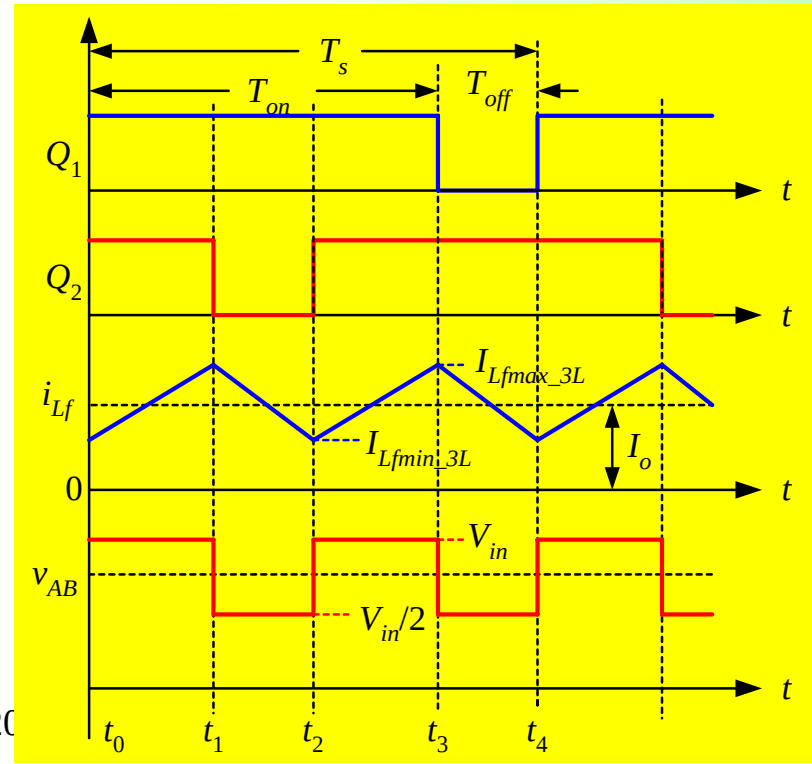
Output Filter Capacitor



The output capacitor in Buck TL converter reduces to 1/2 of that in Basic Buck converter

Unbalanced capacitor voltage



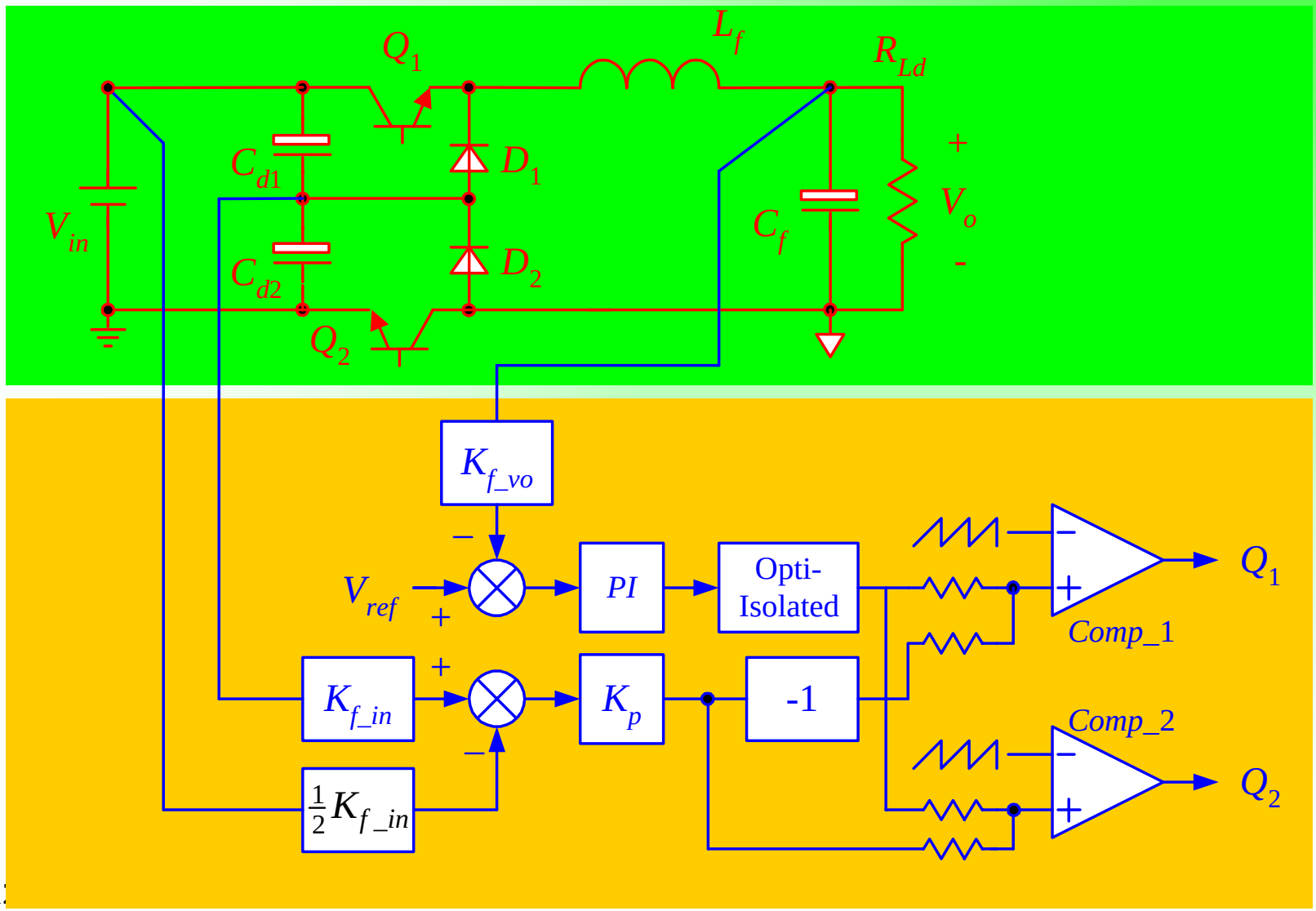


Slight difference of 1) control signal and 2) drive circuit

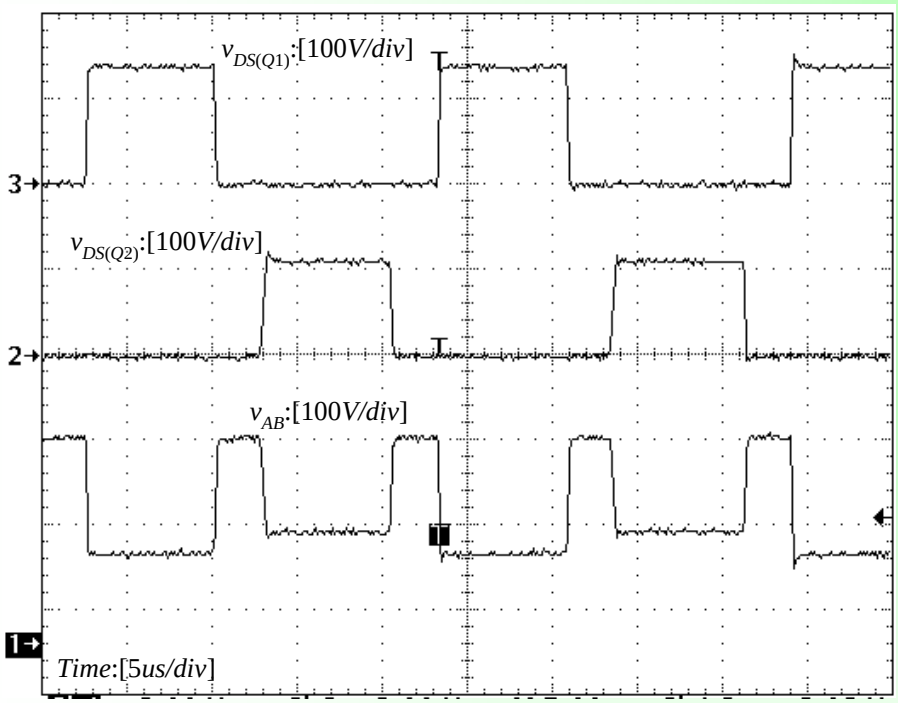
Slight difference of duty cycle of the two switches

Unbalanced voltage of the divided capacitors

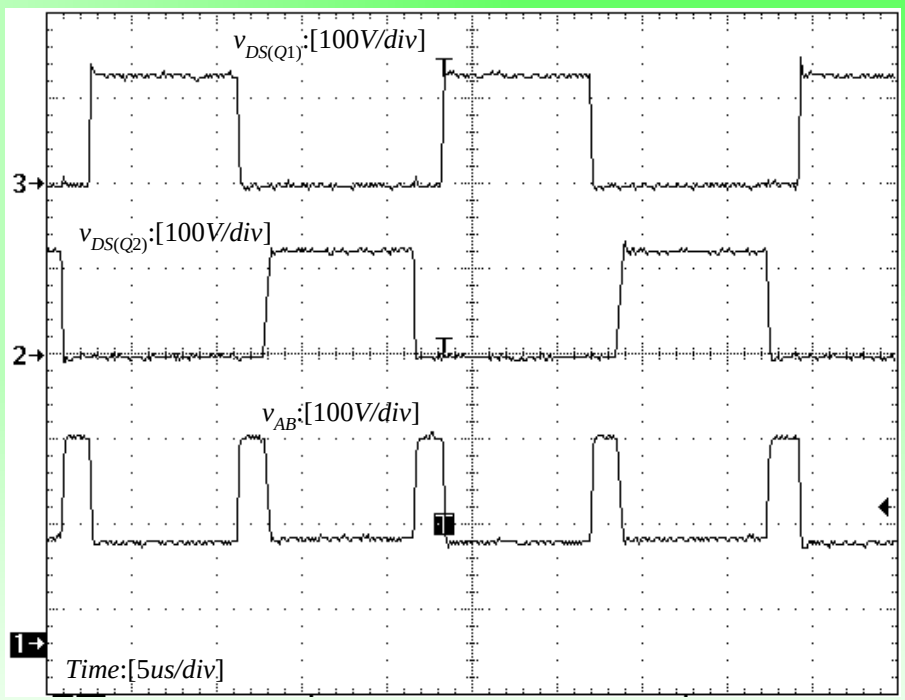
Divided Capacitor Voltage Sharing



Experimental Results



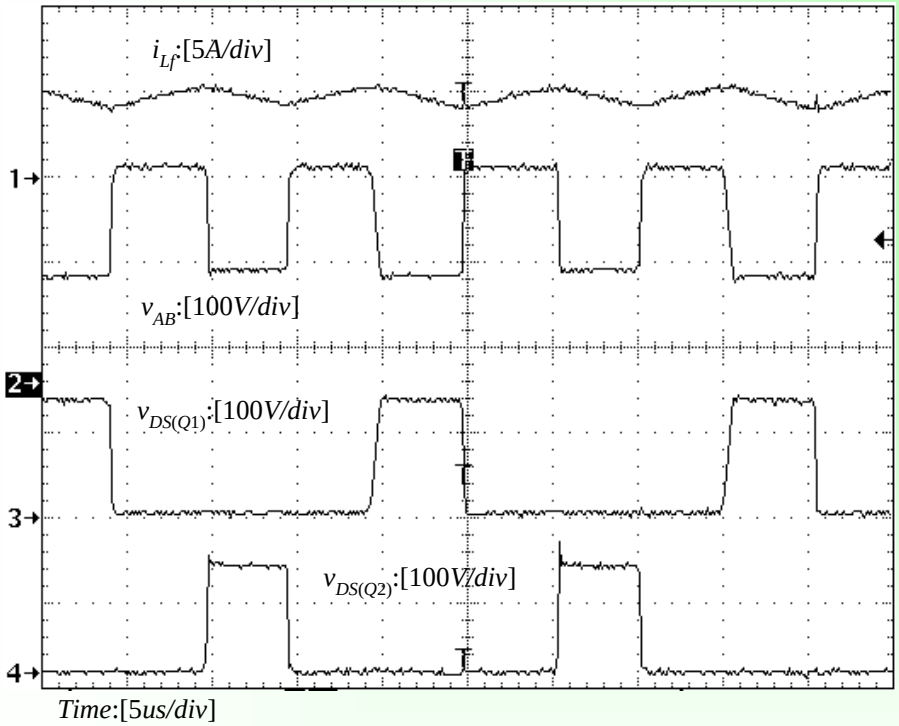
Without Feed-Forward control



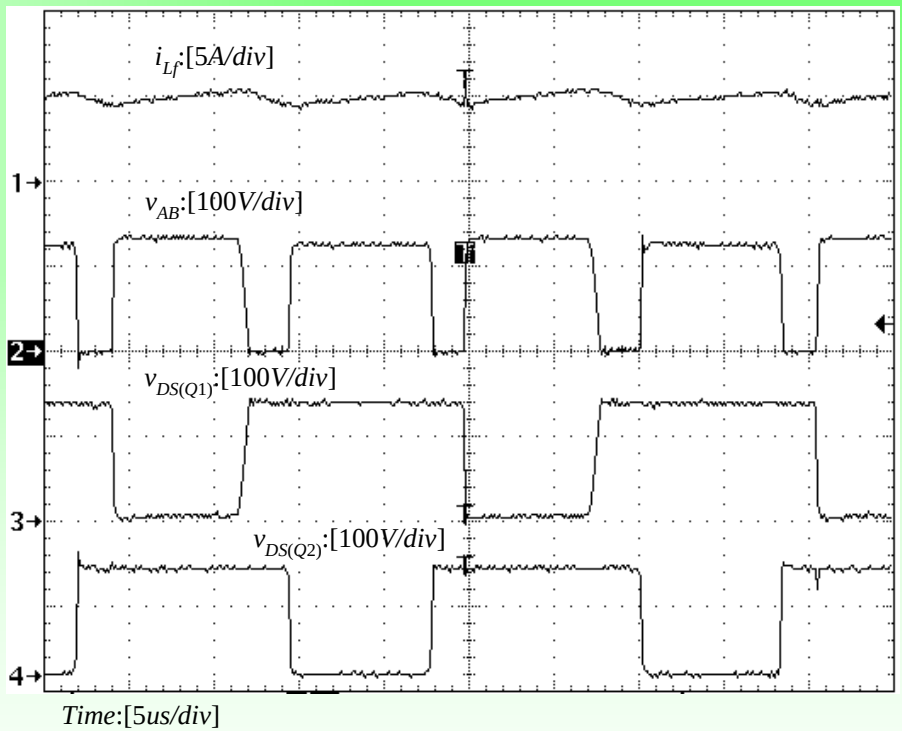
With Feed-Forward control

Experimental Results

$D > 0.5$



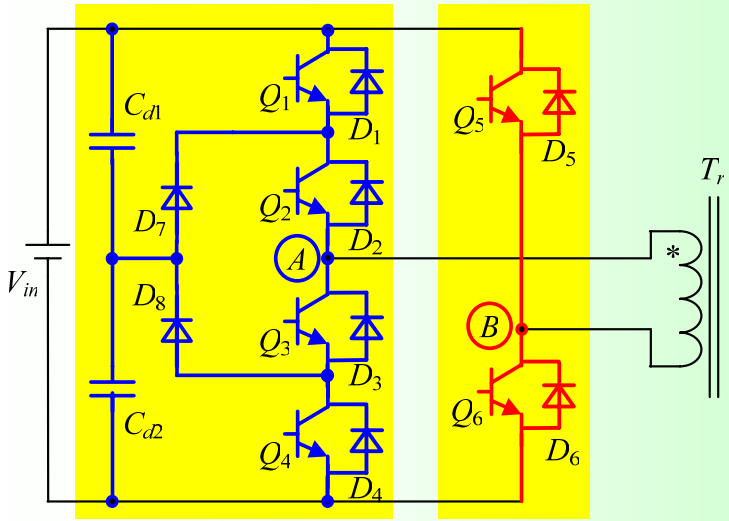
$D < 0.5$

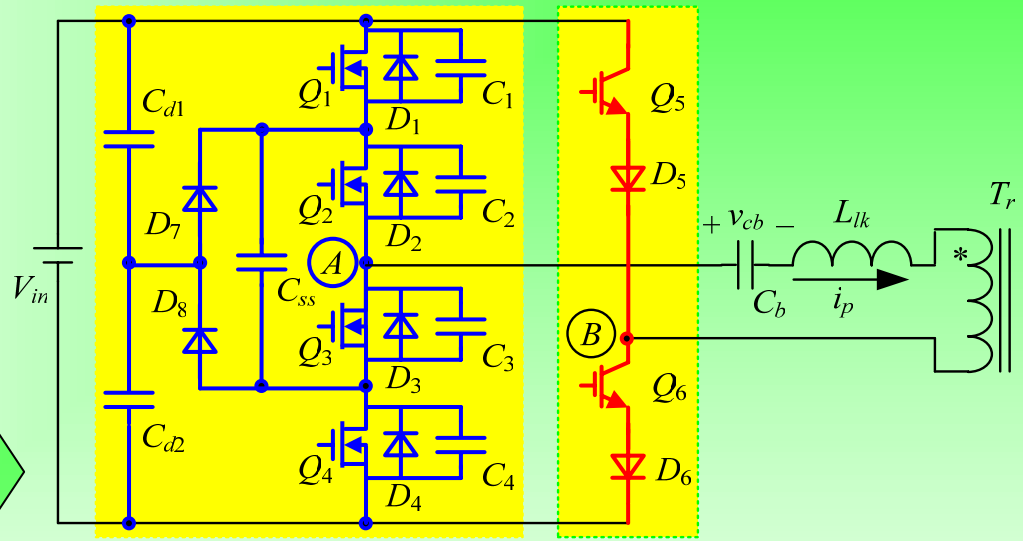


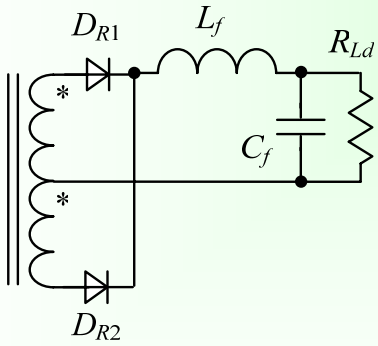
Outlines

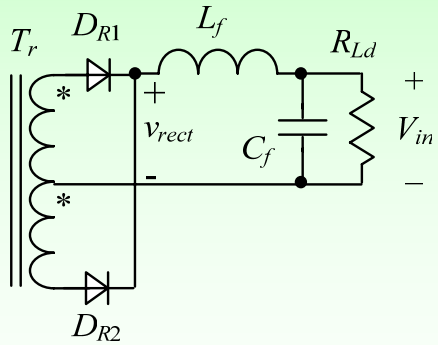
1. Backgrounds
2. Derivation of a Family of Three-Level Converters
3. Improved and Simplified Three-Level Converters
4. Buck TL Converter
5. **ZVZCS PWM Hybrid Full-Bridge Three-Level Converter**
6. Possible of Three-Level Voltage
7. Conclusions

ZVZCS PWM Hybrid Full-Bridge TL Converter

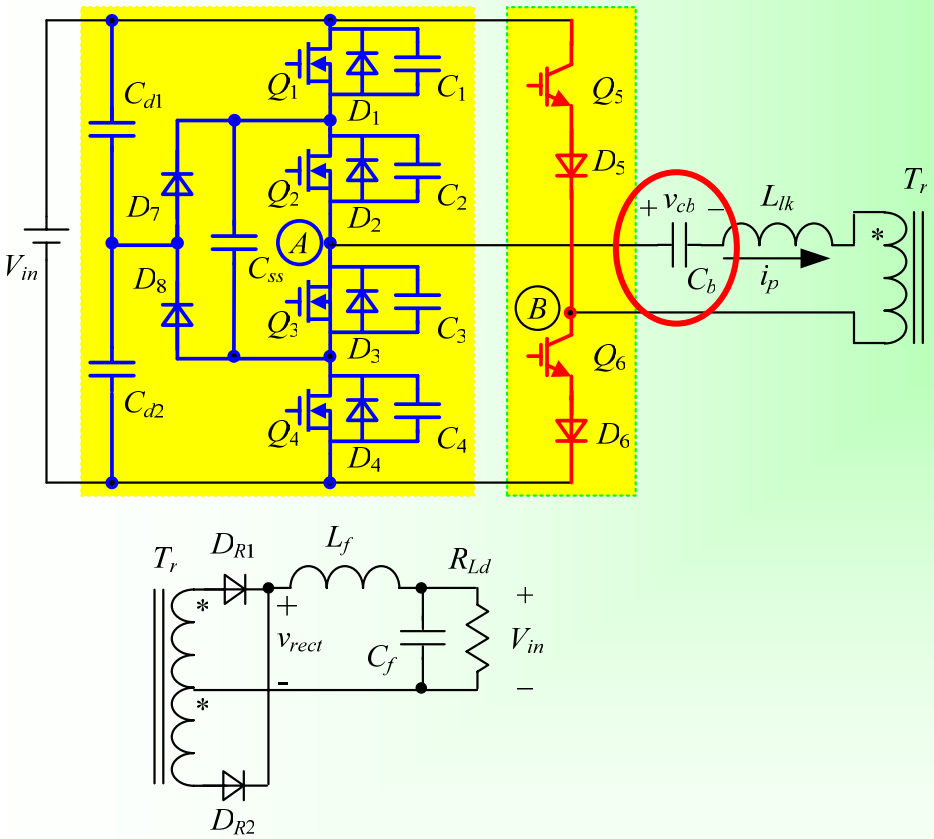


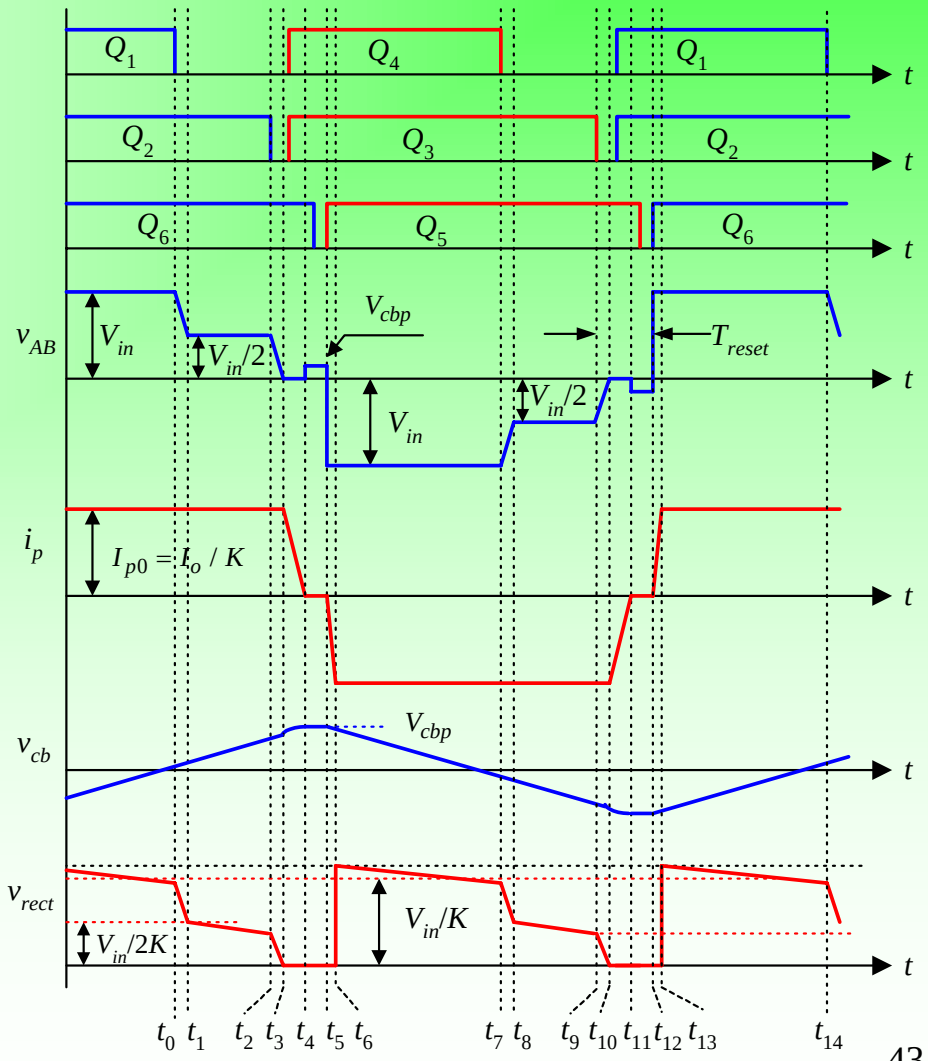




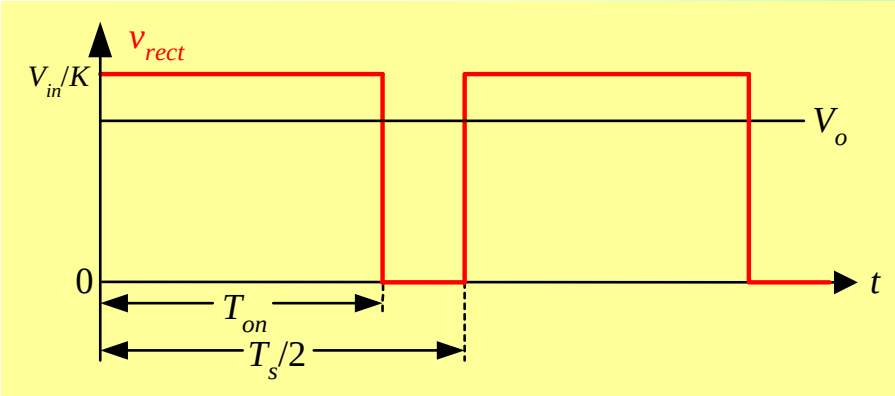


Main Circuit and Key Waveforms

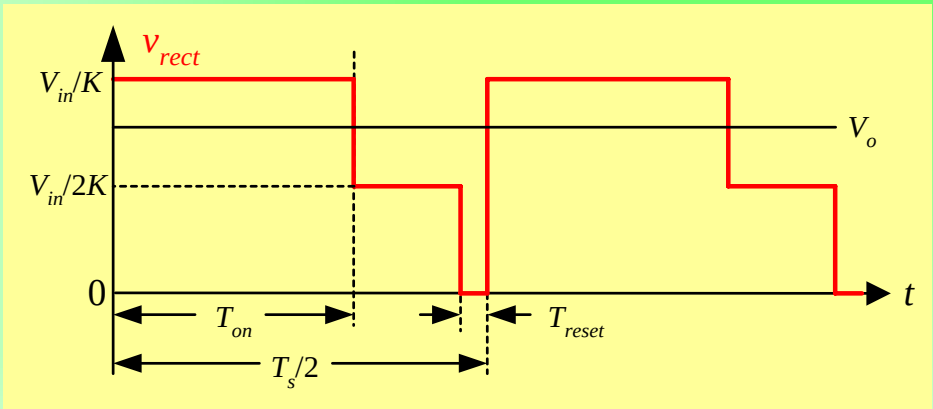




The Secondary Rectified Voltage

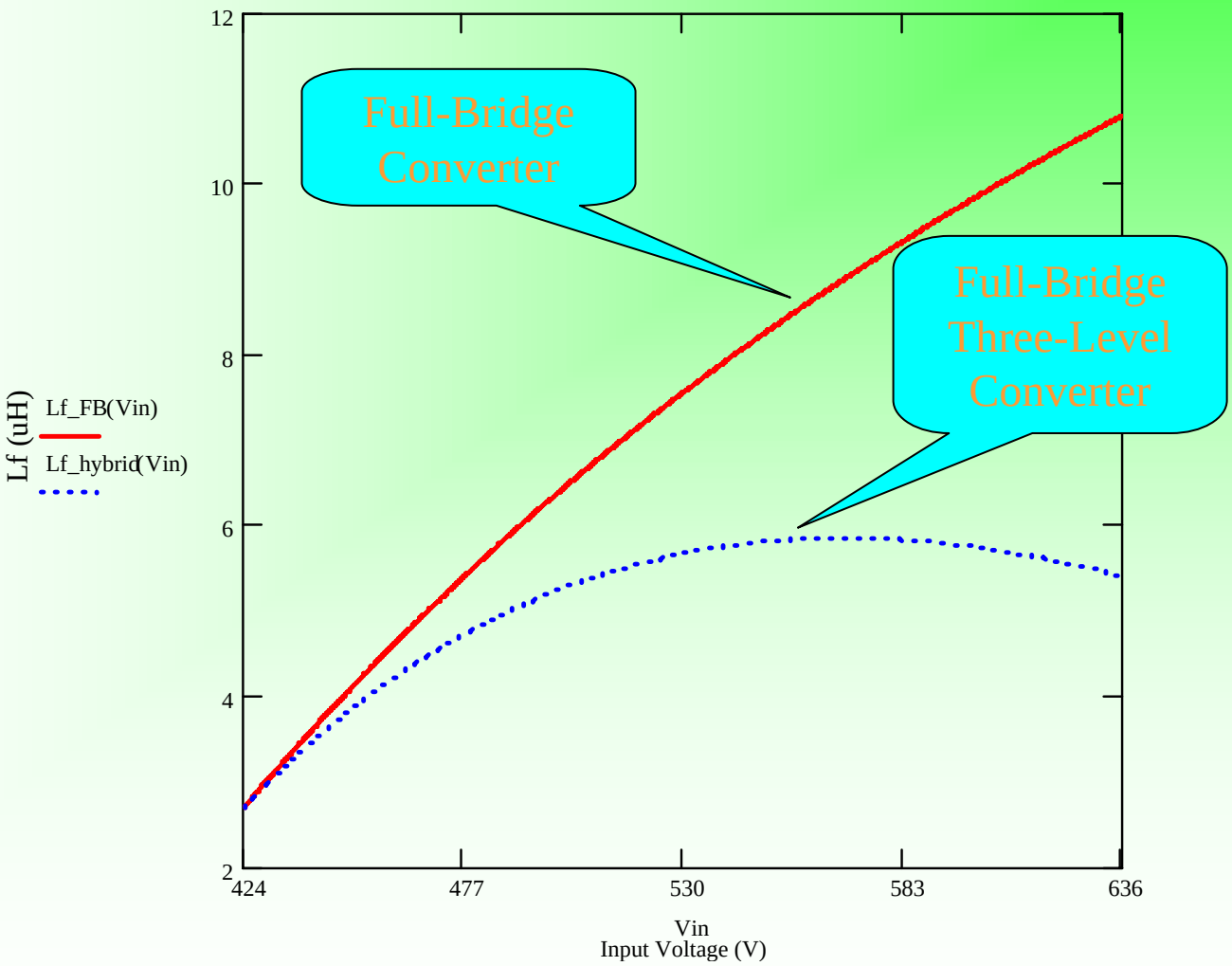


Full-Bridge Converter

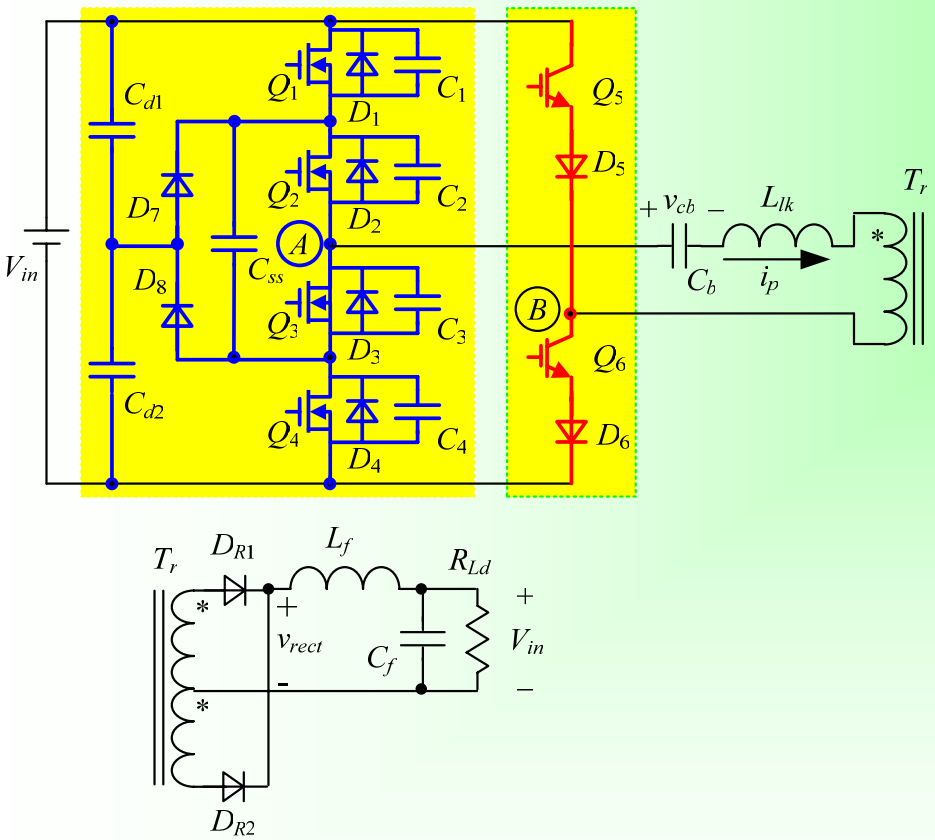


Full-Bridge Three-Level Converter

The Filter Inductance

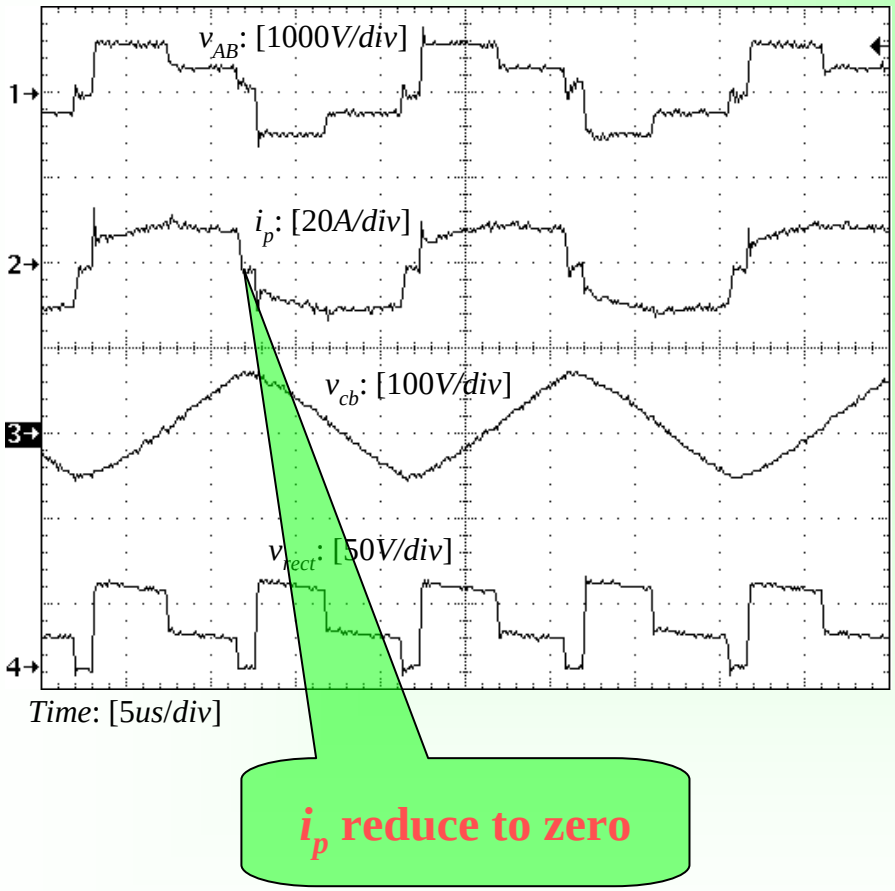


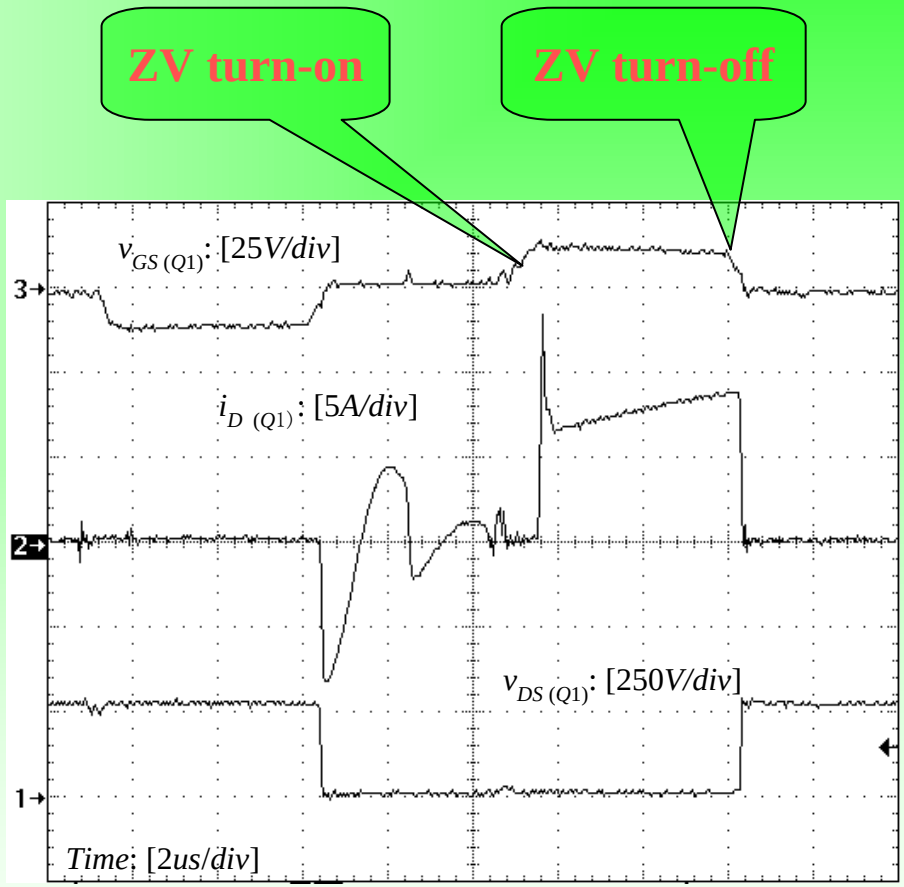
Parameters for Prototype Converter



- V_{in}=530VDC (rectified and filtered from 3 phase 380VAC/50Hz)
- V_o = 54 *VDC;*
- I_o = 50 *A;*
- $Q_1(D_1\&C_1)$ - $Q_4(D_4\&C_4)$: IRF460;
- Q_5 and Q_6: CT60AM-20;
- D_5 - D_8: DSEI30-06A;
- Rectifier diode: MEK95-06 DA;
- Ratio of windings : K=19:3;
- Leakage inductance L_{lk}=6*uH*;
- Blocking capacitor: C_b=1*uF*;
- Output filter inductance L_f=6*uH*;
- Output filter capacitor C_f=6600*uF*;
- Switching frequency: f_s=50*kHz*.

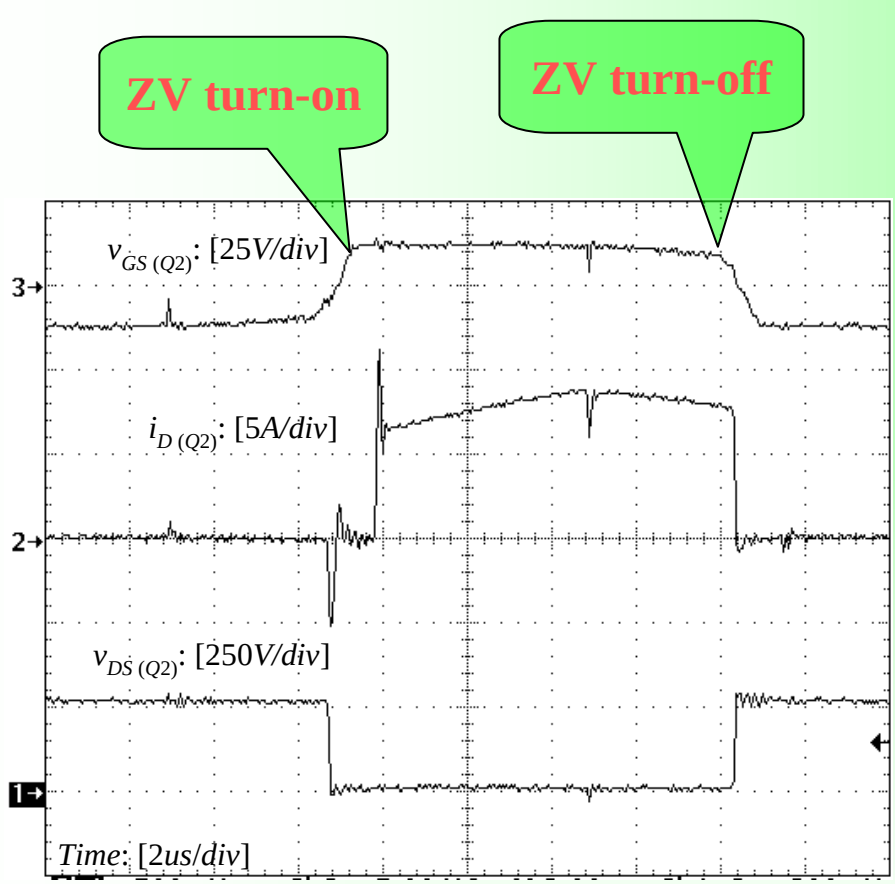
Experimental Results



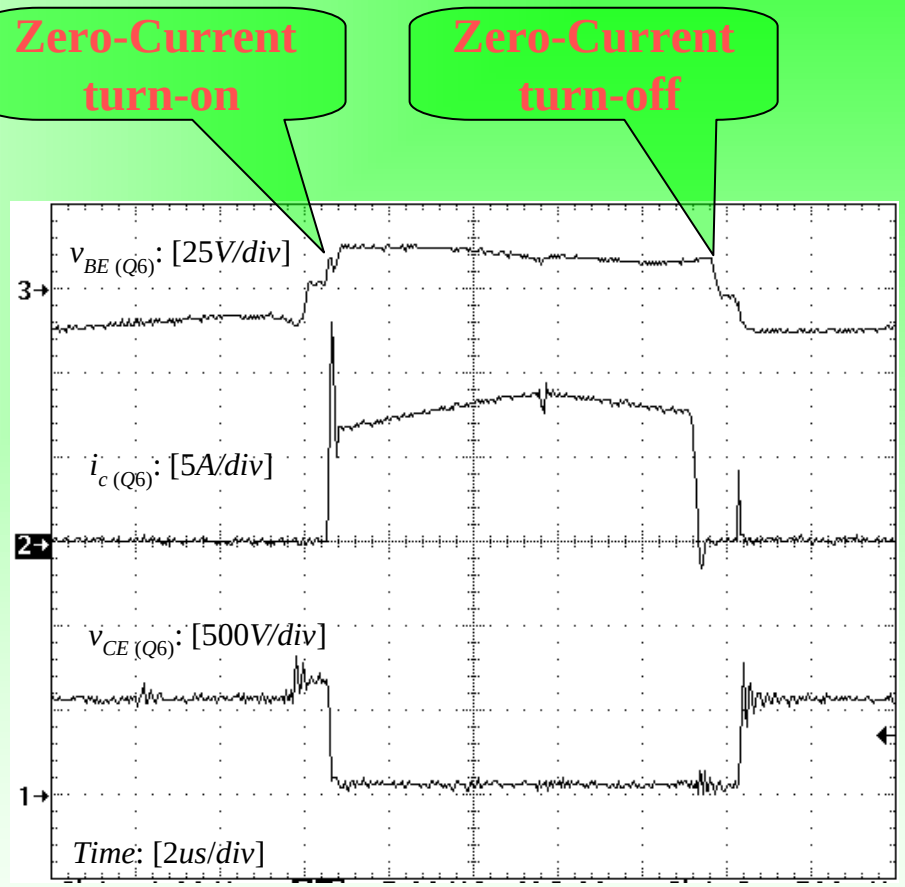


ZVS for Chopping Switches

Experimental Results

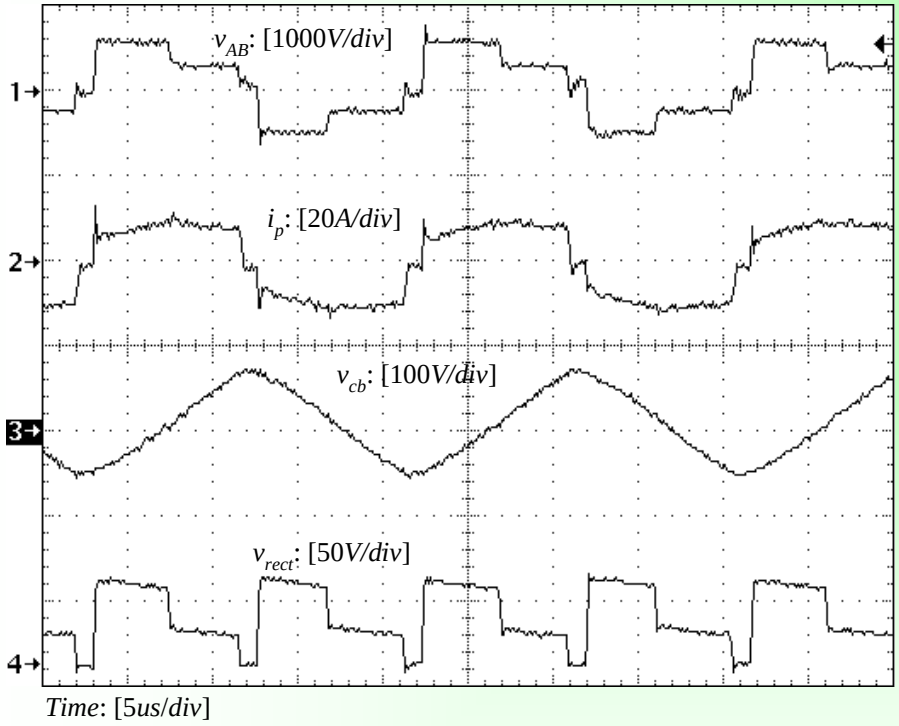


ZVS for leading Switches

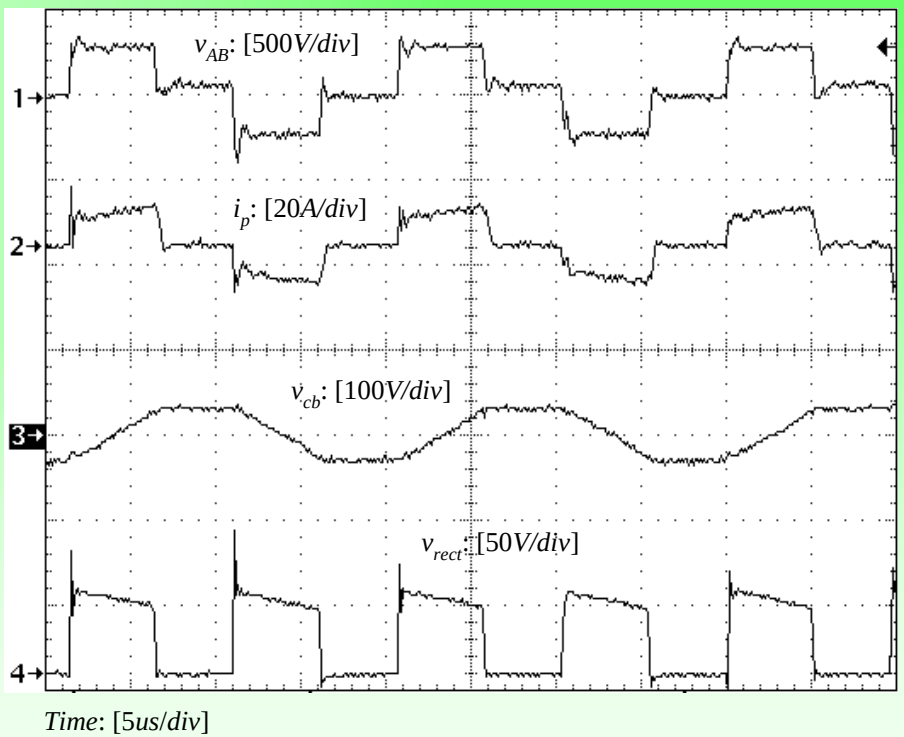


ZVS for lagging Switches

Experimental Results

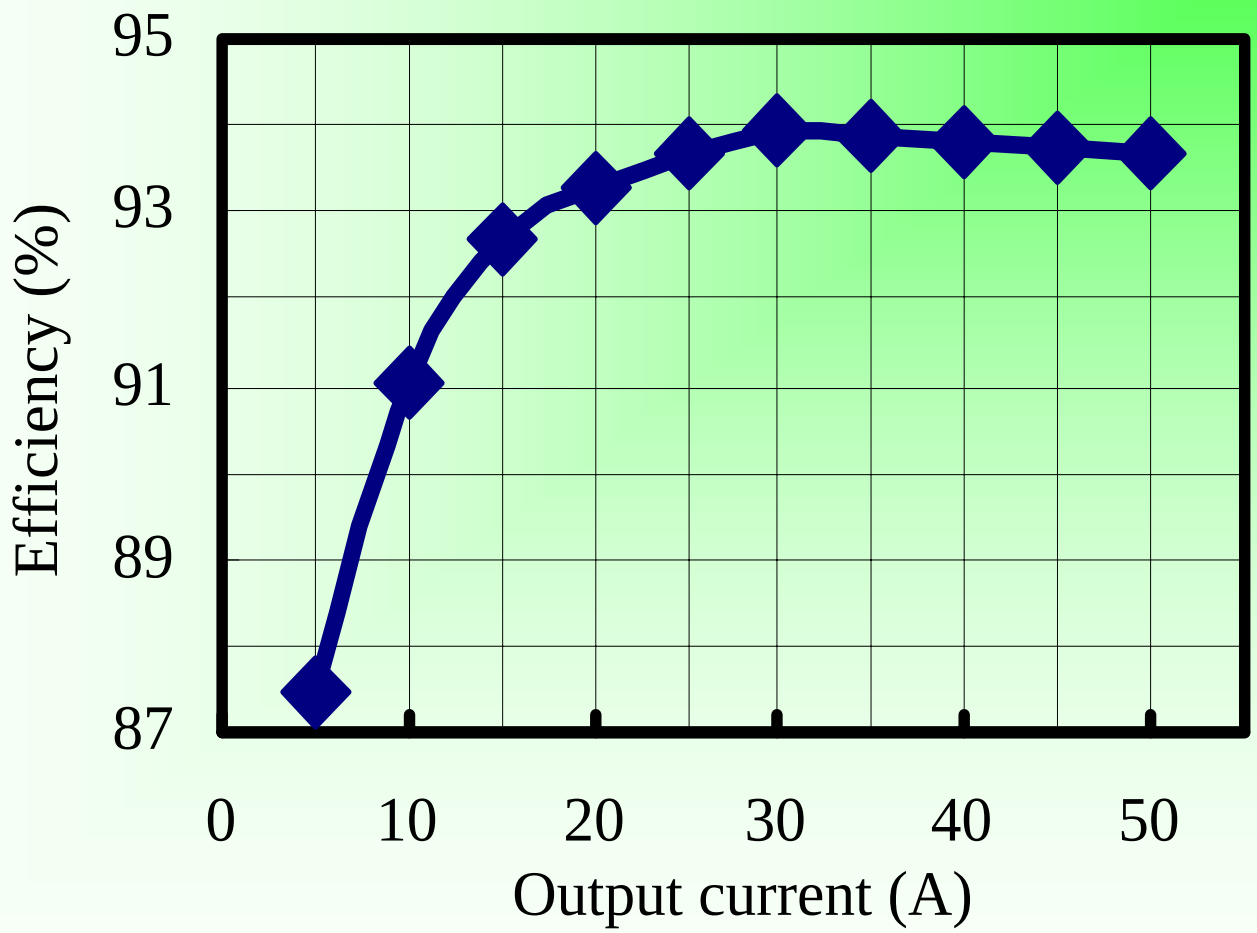


Three-Level Mode



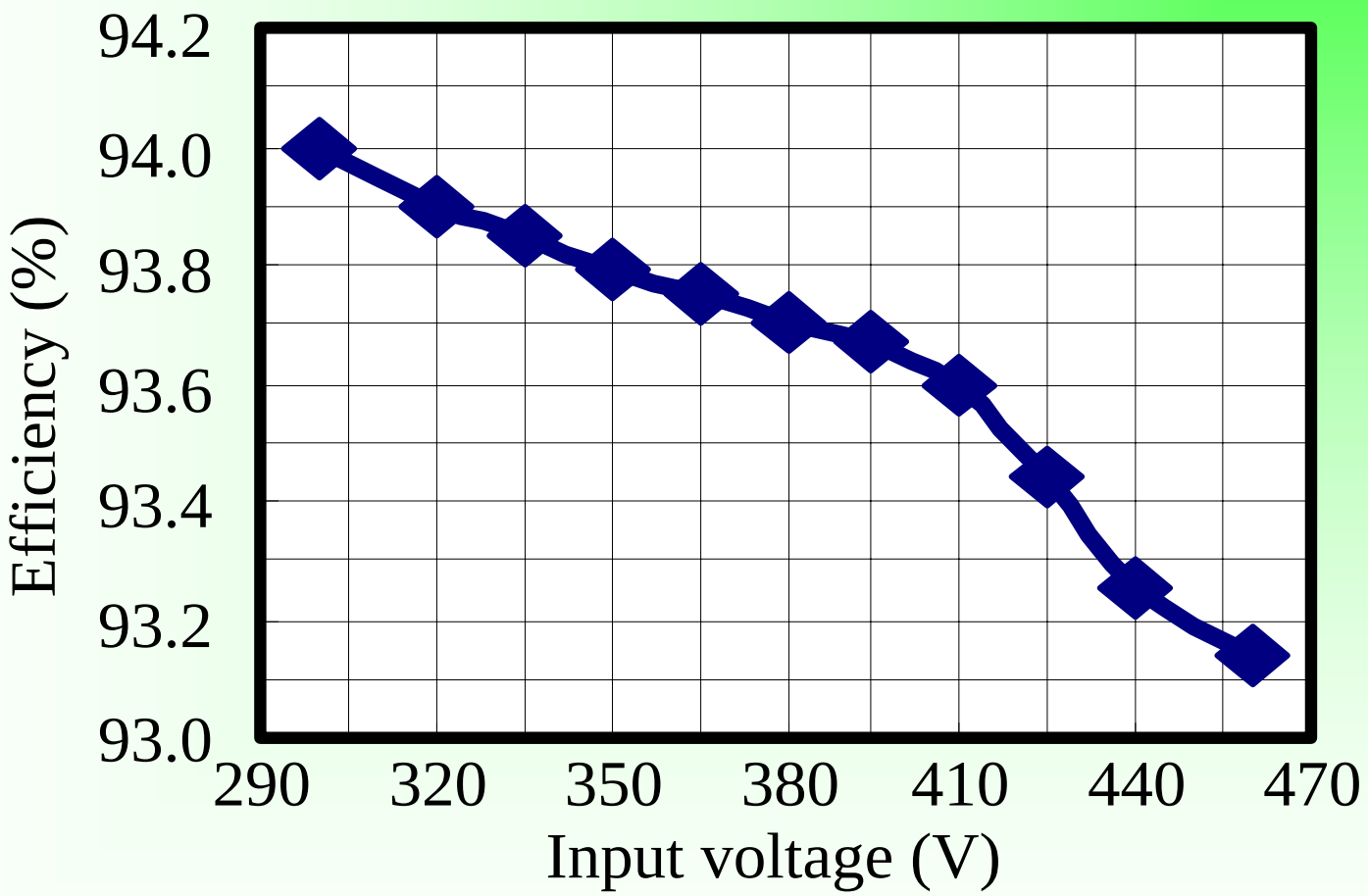
Two-Level Mode

Conversion Efficiency

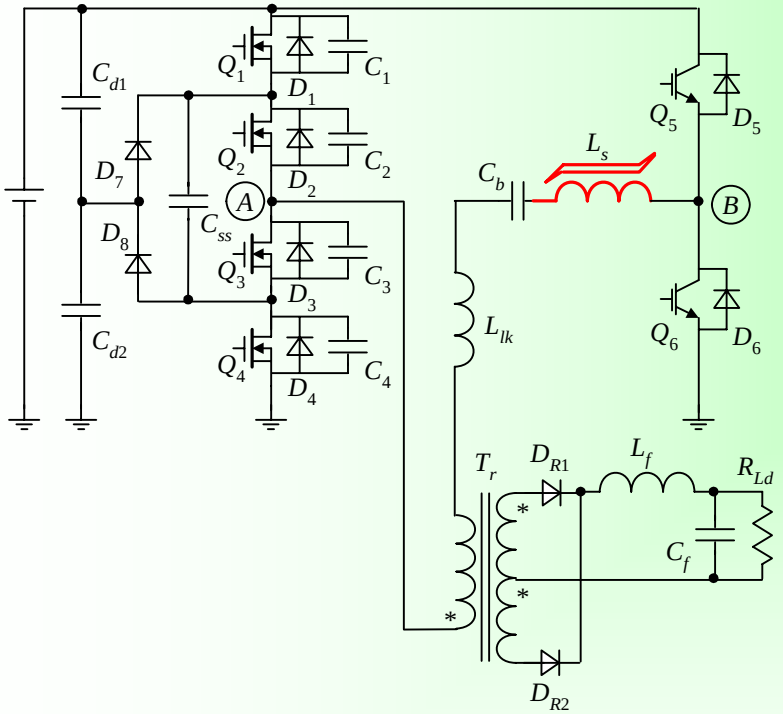


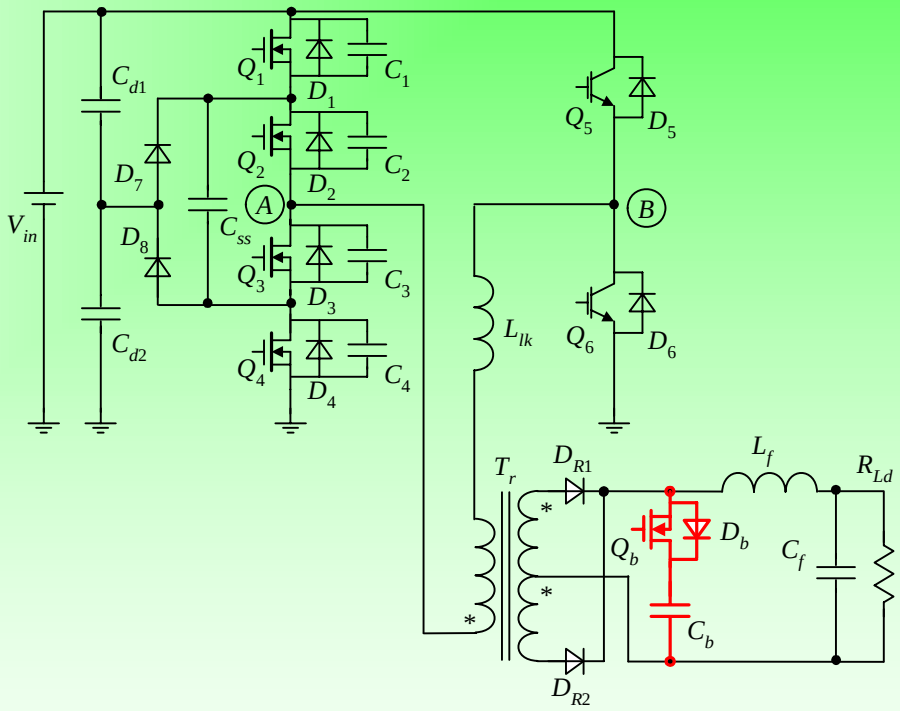
Aero-Power Sci-tech Center

Conversion Efficiency

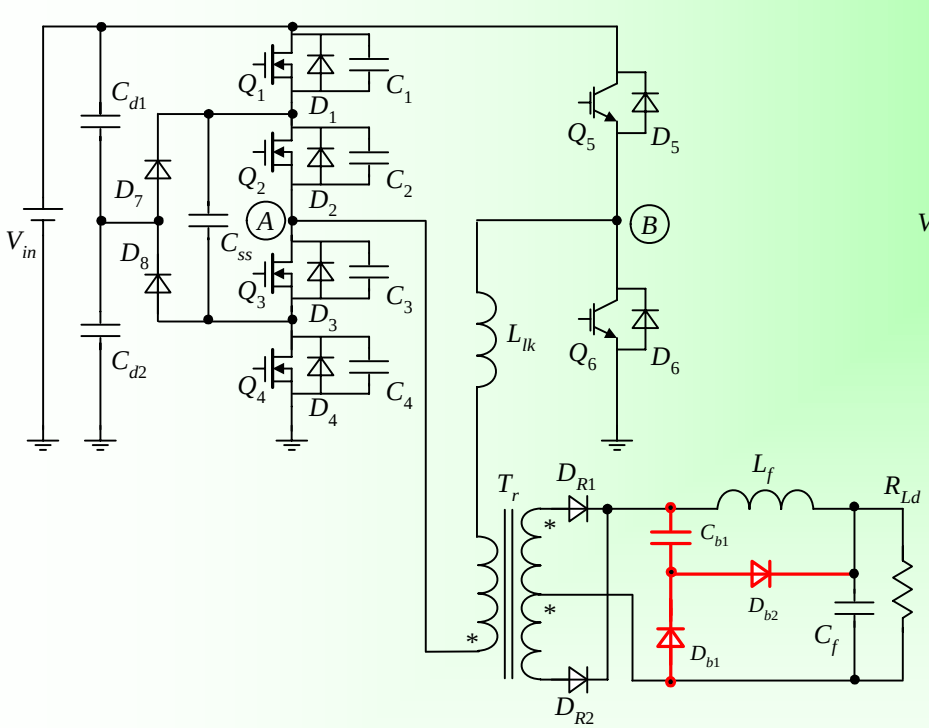


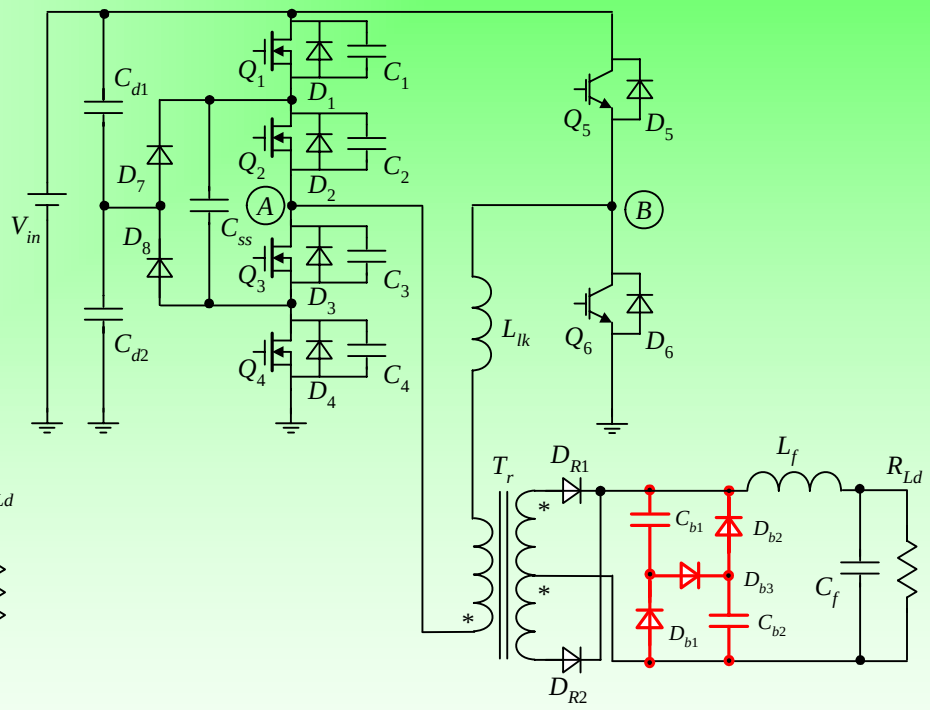
Several ZVZCS Hybrid FB TL Converters





Several ZVZCS Hybrid FB TL Converters

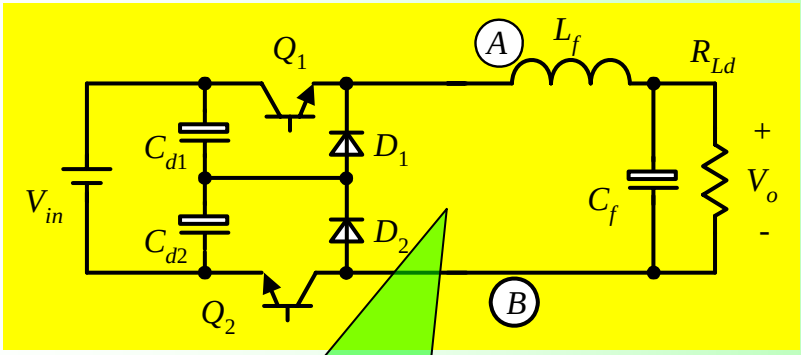




Outlines

1. Backgrounds
2. Derivation of a Family of Three-Level Converters
3. Improved and Simplified Three-Level Converters
4. Buck TL Converter
5. ZVZCS PWM Hybrid Full-Bridge Three-Level Converter
6. **Possible of Three-Level Voltage**
7. Conclusions

Availability of Three-Level Voltage Waveforms



$v_{AB} = V_{in}, V_{in}/2$ and 0

In order to achieve three-level voltage waveform,

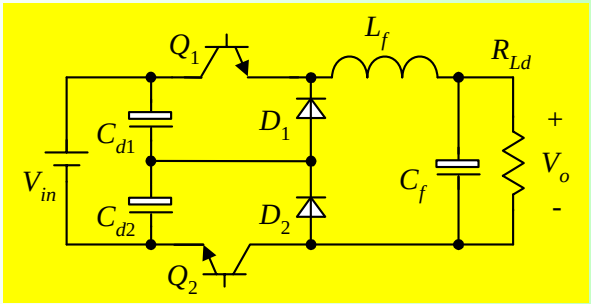
1) there should be two divided capacitors.

2) The two divided capacitors could power the load simultaneously or alternatively.

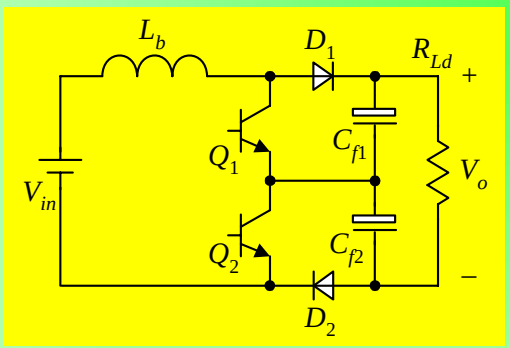
Possibility of Three-Level Voltage Waveforms

Aero-Power Sci-tech Center

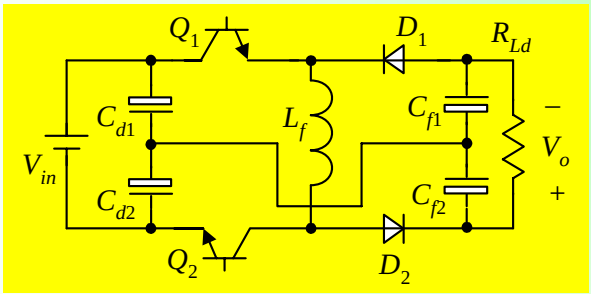
Buck



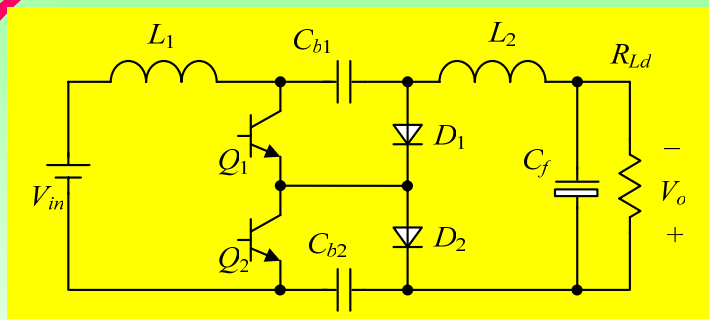
Boost



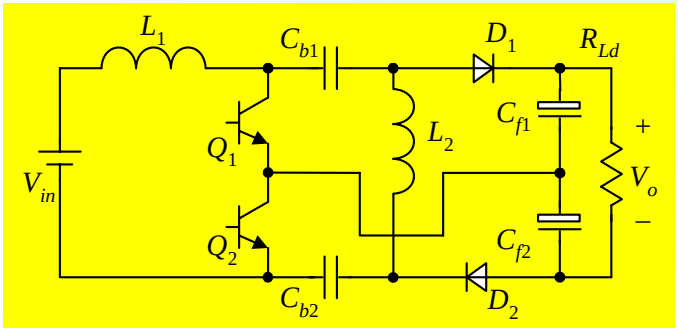
Buck/Boost



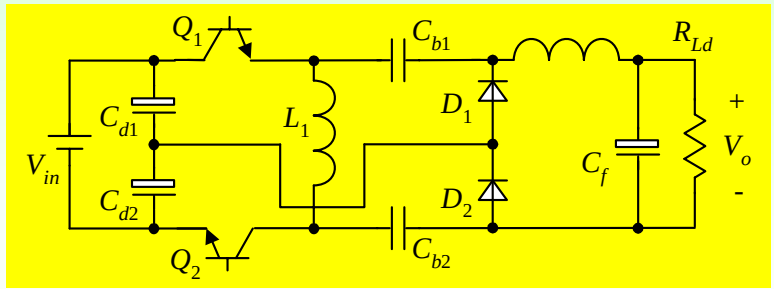
Cuk



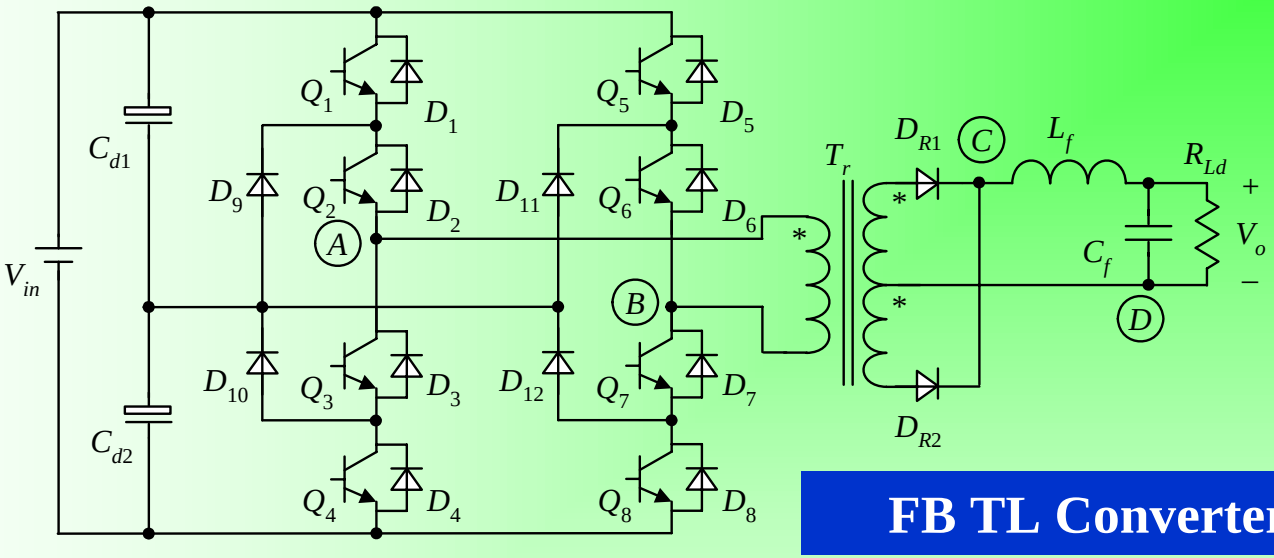
Sepic



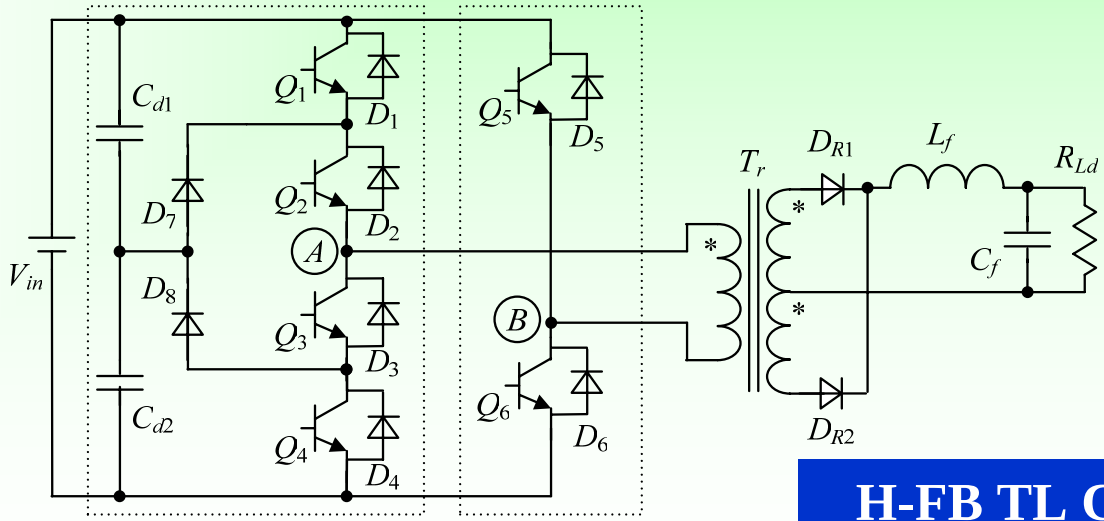
Zeta



Possibility of Three-Level Voltage Waveforms

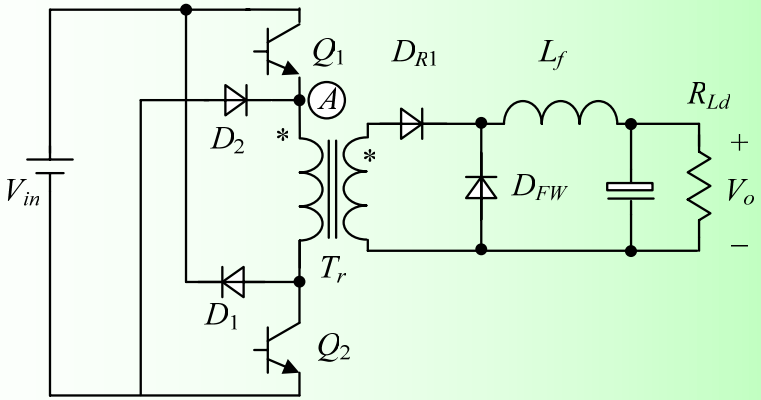


FB TL Converter

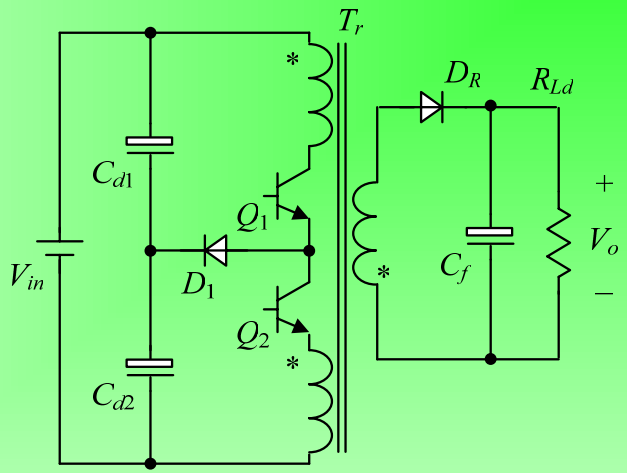


H-FB TL Converter

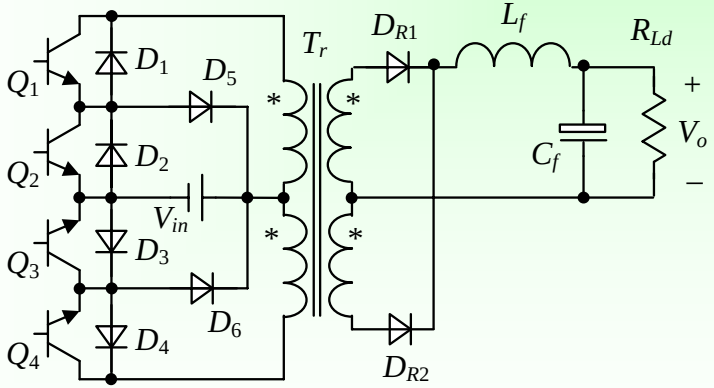
Possibility of Three-Level Voltage Waveforms



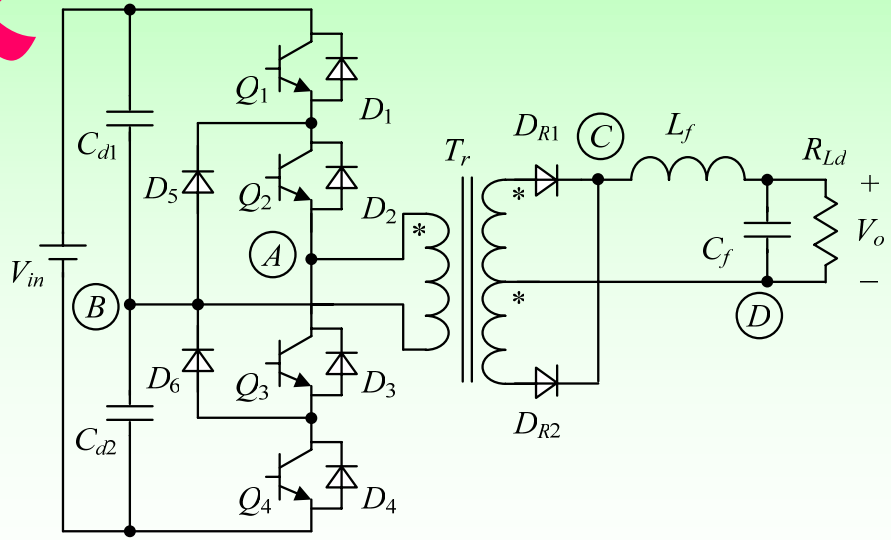
Forward TL Converter



Flyback TL Converter



Push-Pull TL Converter



HB TL Converter

Conclusions

1. Three-Level Converters

- A-TLSC and C-TLSC are extracted;
- A family of TL converters are proposed;
- The non-isolated TL converters are improved;
- Forward TL converter is further simplified;
- A hybrid FB TL converter are proposed.

2. The advantages of the TL converters

- Reduction of the voltage stress of the switches;
- some TL converters obtain TL waveform, which can significantly reduce the filter.

3. Method to ensure the voltage sharing of the divided capacitors is proposed.

APSC
Aero-Power Sci-tech Center

Thanks for your attention!

Q/A