Soft-Switching PWM Full-Bridge Converters

Presented by

Xinbo Ruan

Aero-Power Sci-tech Center
Nanjing University of Aeronautics and Astronautics

Outlines

- Backgrounds
- PWM Strategies for Soft-Switching Full-Bridge Converters
- ZVS PWM Full-Bridge Converters
- ZVZCS PWM Full-Bridge Converters
- Conclusion

- **Backgrounds**
- PWM Strategies for Soft-Switching Full-Bridge Converters
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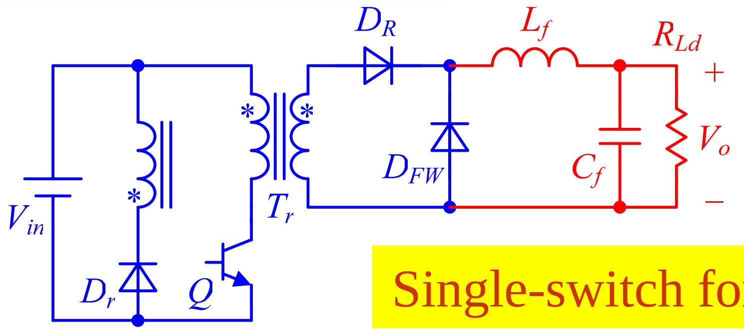
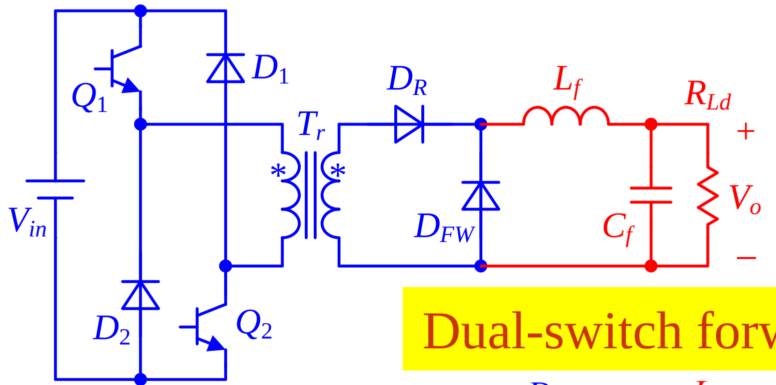
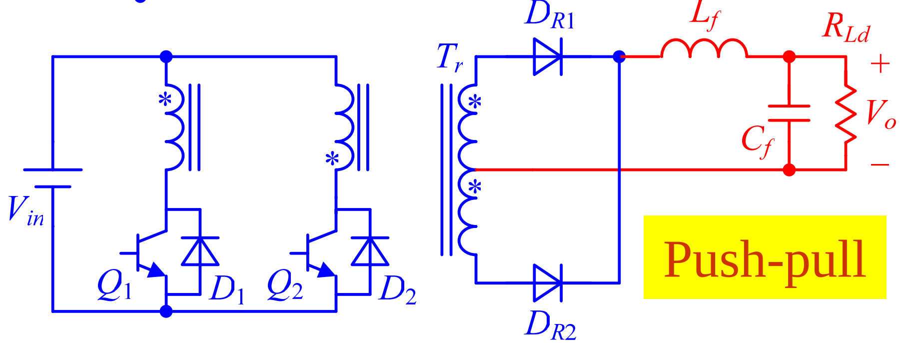
Buck-Derived Converters



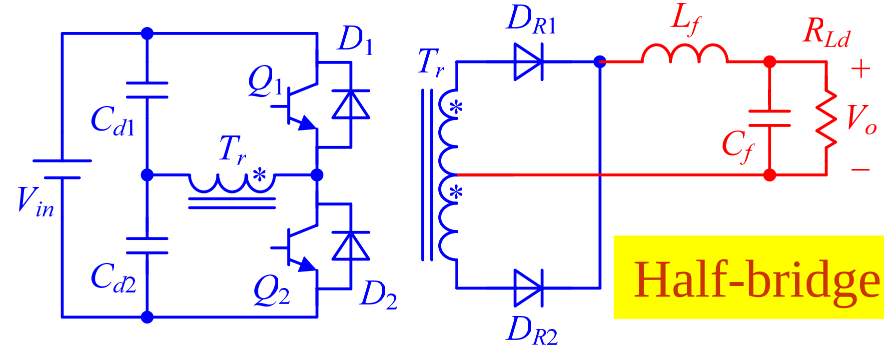
Single-switch forward



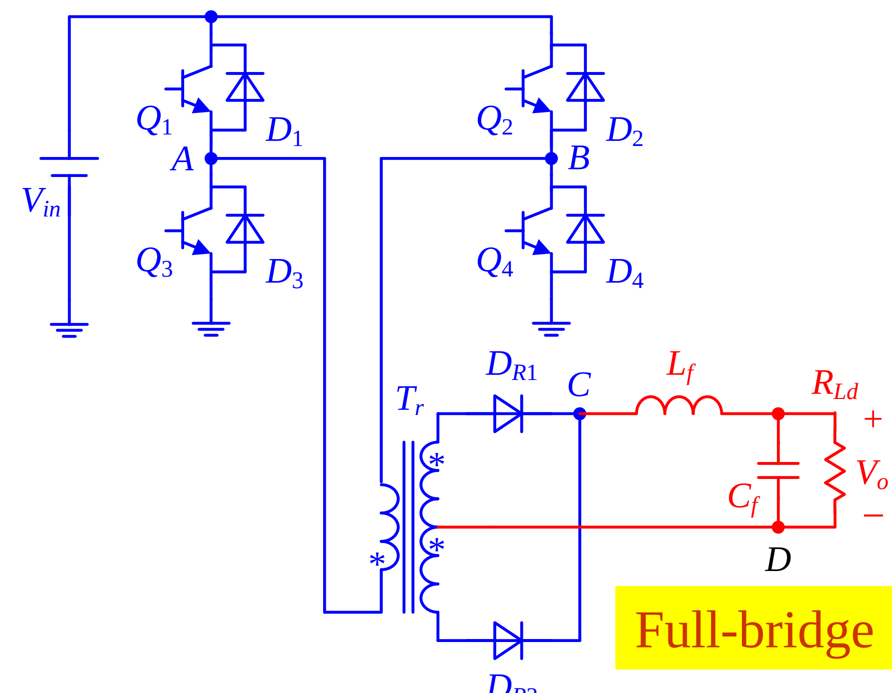
Dual-switch forward



Push-pull



Half-bridge



Full-bridge

Among the buck-derived converters, the **full-bridge** converter can output **maximum power**, given that the power switches have the **same voltage and current ratings**.

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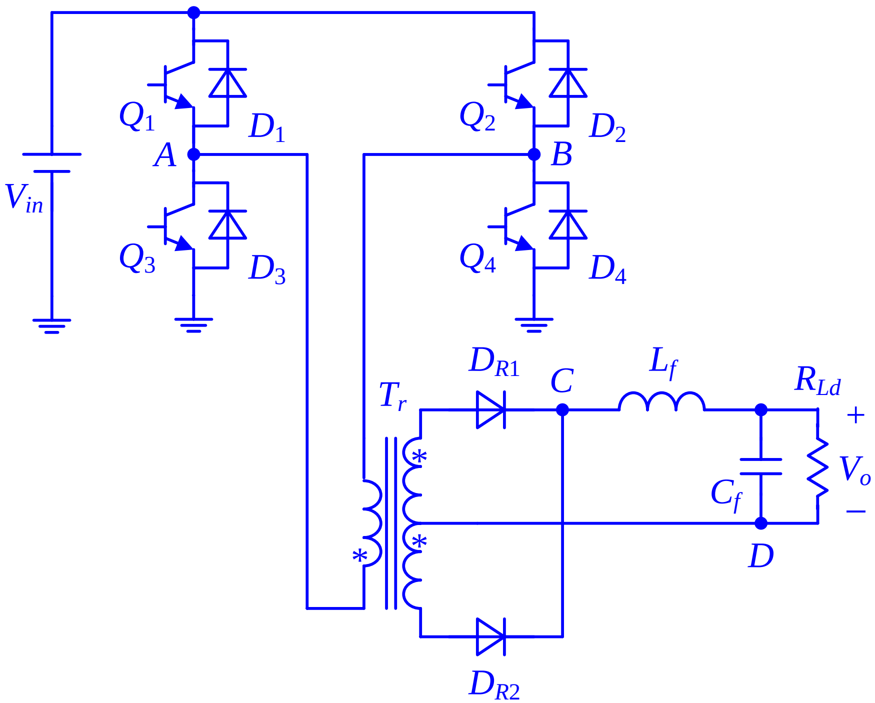
Applications of Full-Bridge Converters

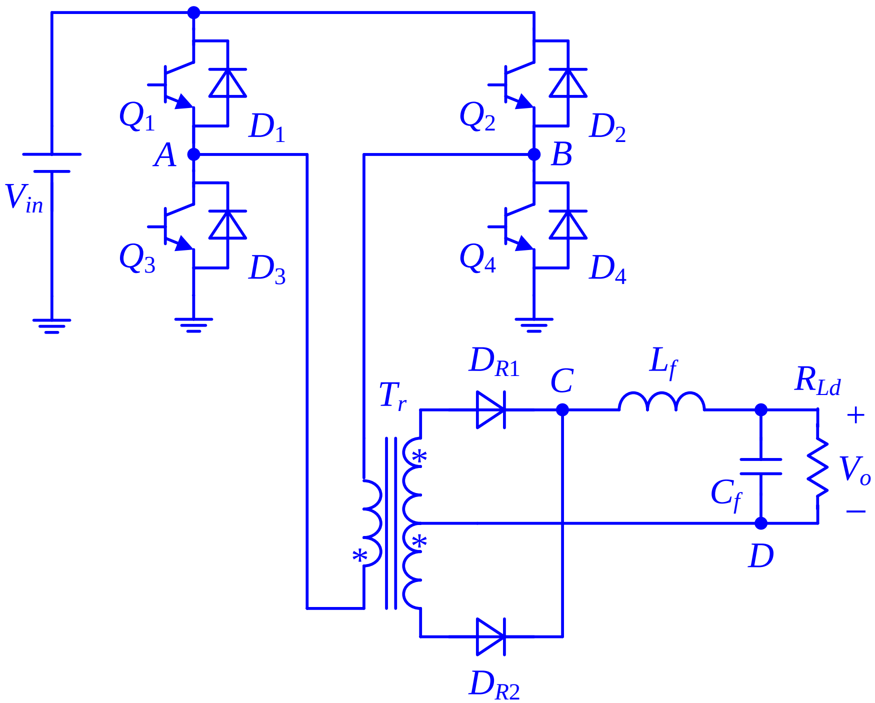


The full-bridge converter have widely used in medium-to-high power dc-dc conversions:

- Switching-mode rectifier for telecommunications, power system, etc.;
- electroplating power supply;
- dc-dc converters for electrical-powered vehicles.
- dc-dc converters for aircraft, ship and satellites.

⋮

Objectives of This Presentation



Soft-switching techniques

Various control strategies

Various topologies

Reveal the relationship among the existing modulation strategies

Reveal the relationship among the existing topologies

Propose other modulation strategies and topologies

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- **PWM Strategies for Soft-Switching Full-Bridge Converters**
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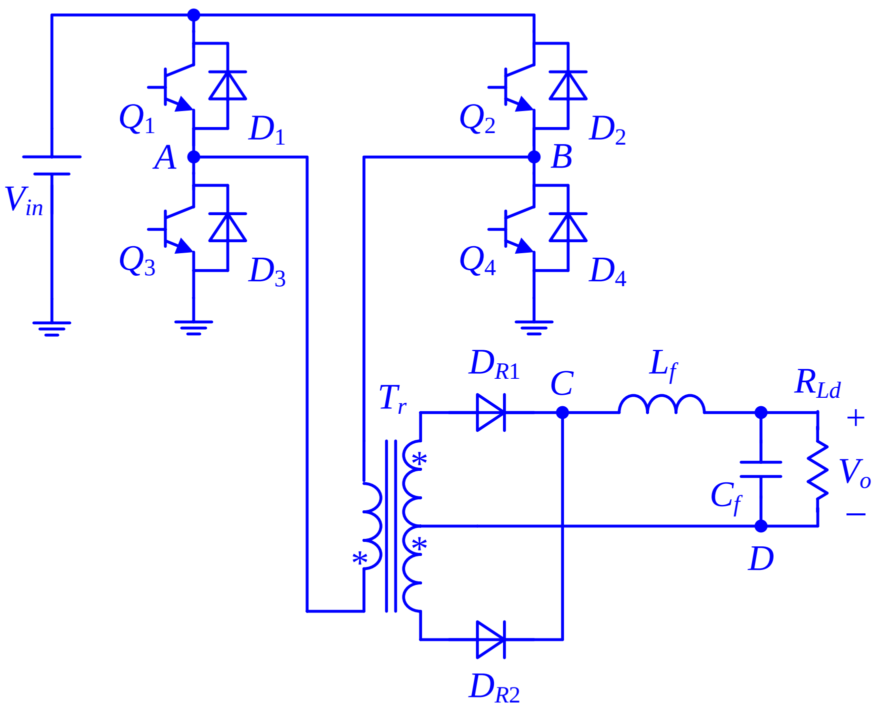
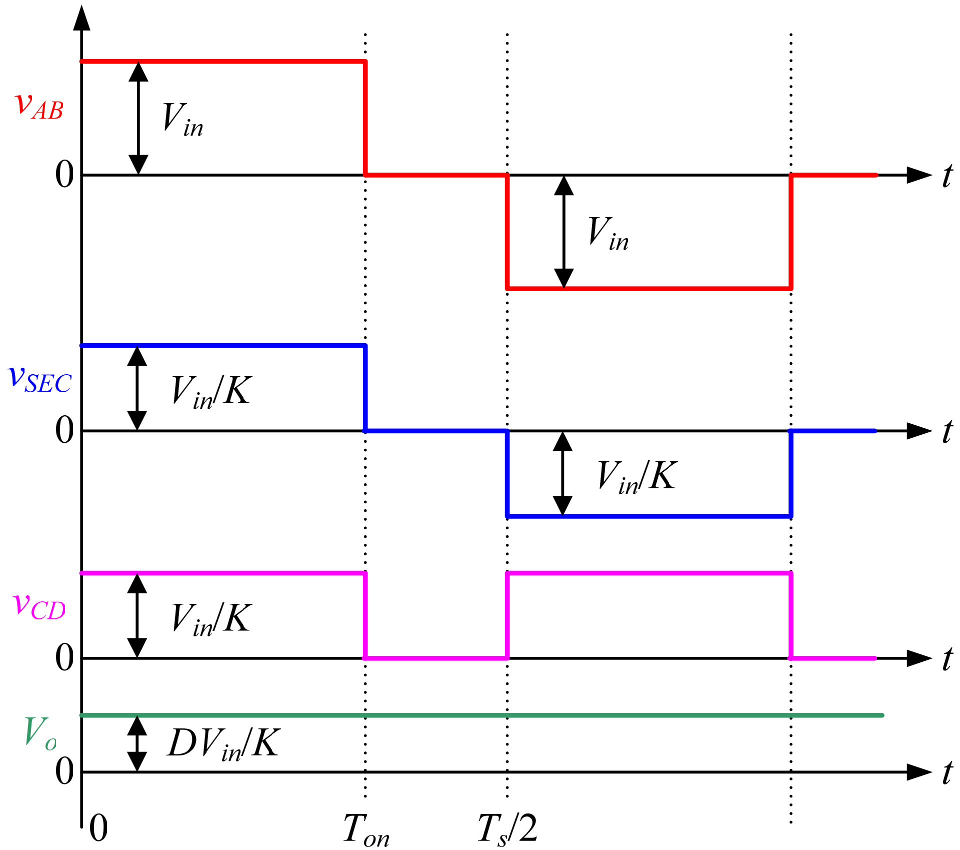
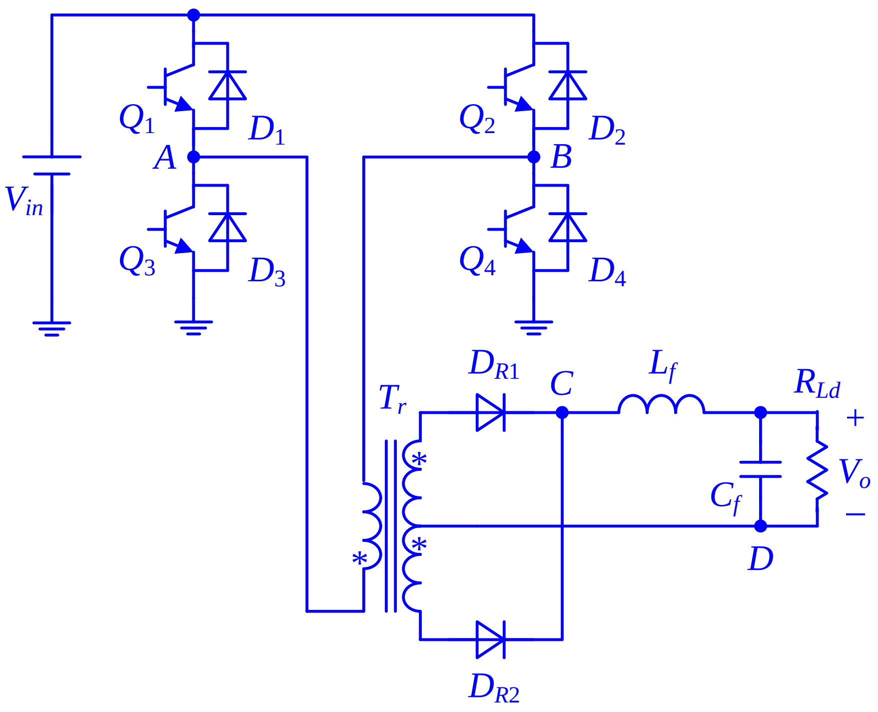
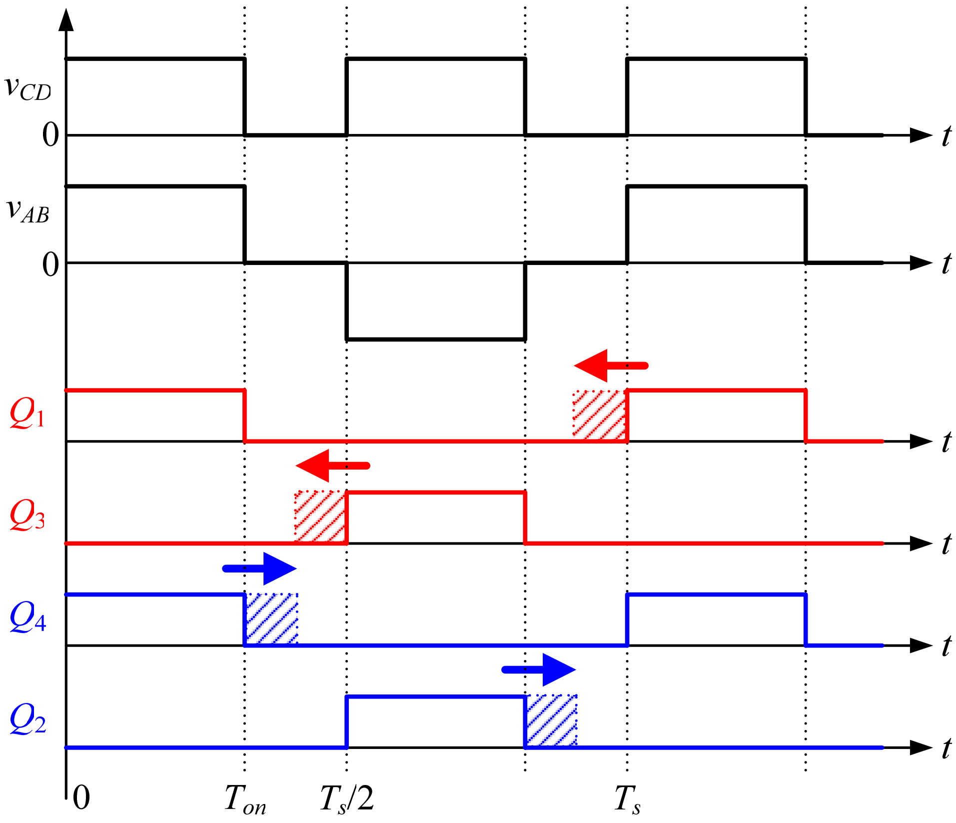
Basic Operating Principle of Full-Bridge Converter





PWM Strategies for Full-Bridge Converter





A Family of PWM Strategies for FB Converter

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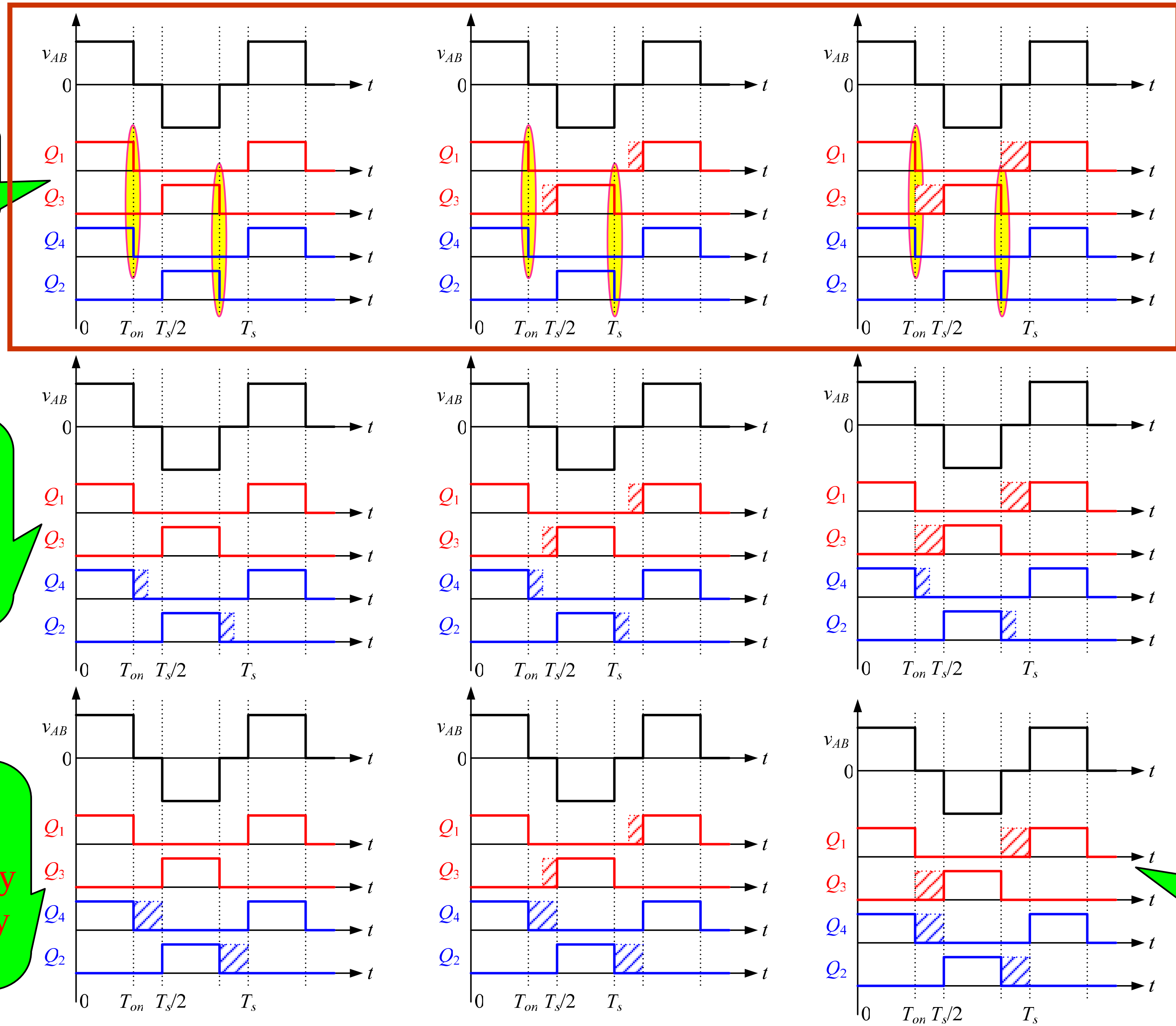


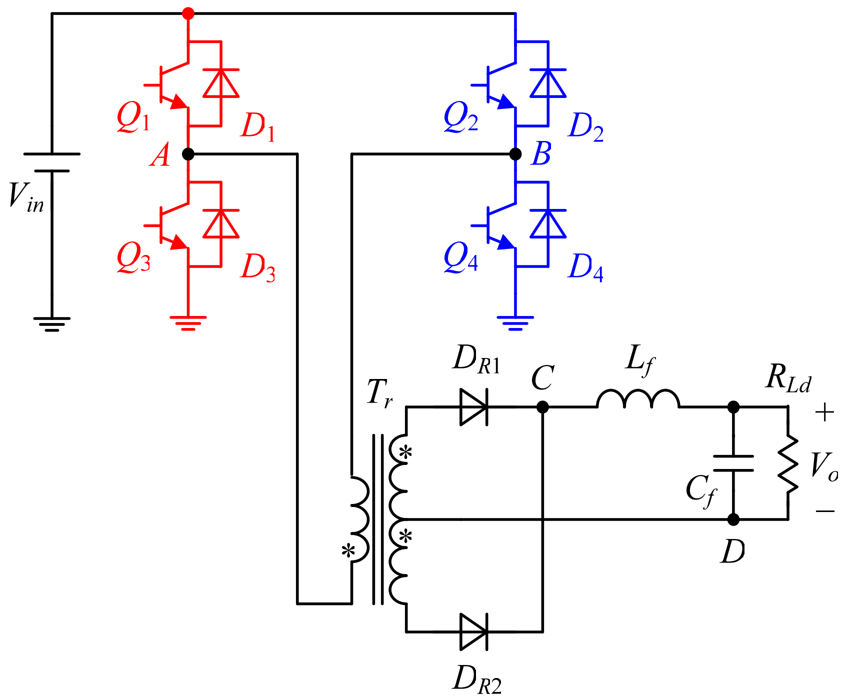
Basic PWM

This strategy has been successfully used in a power supply

One leg operates in complementary with 50% duty cycle

Phase-Shifted Control

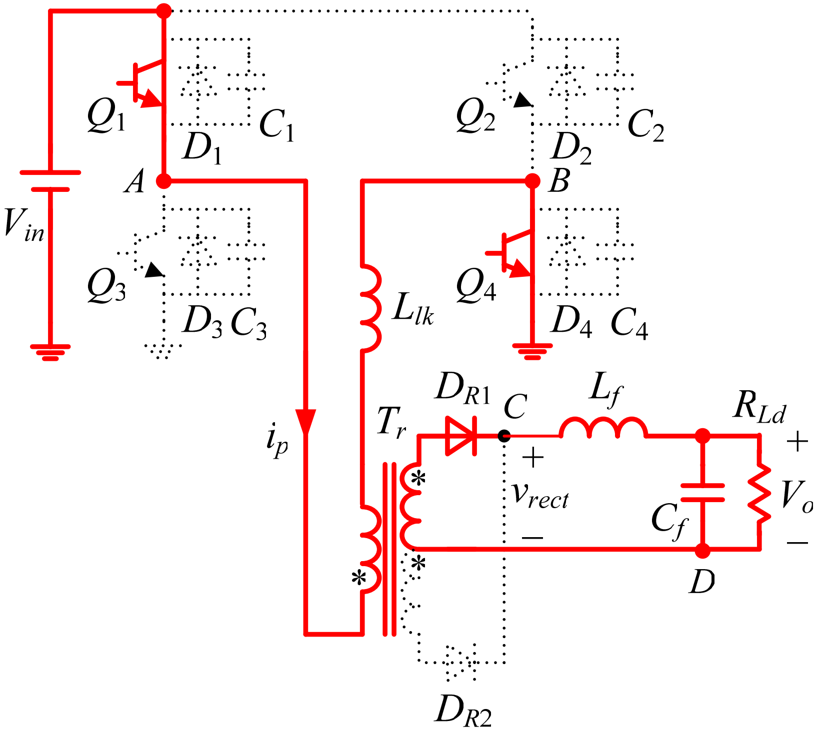
Categorization of the PWM Strategies

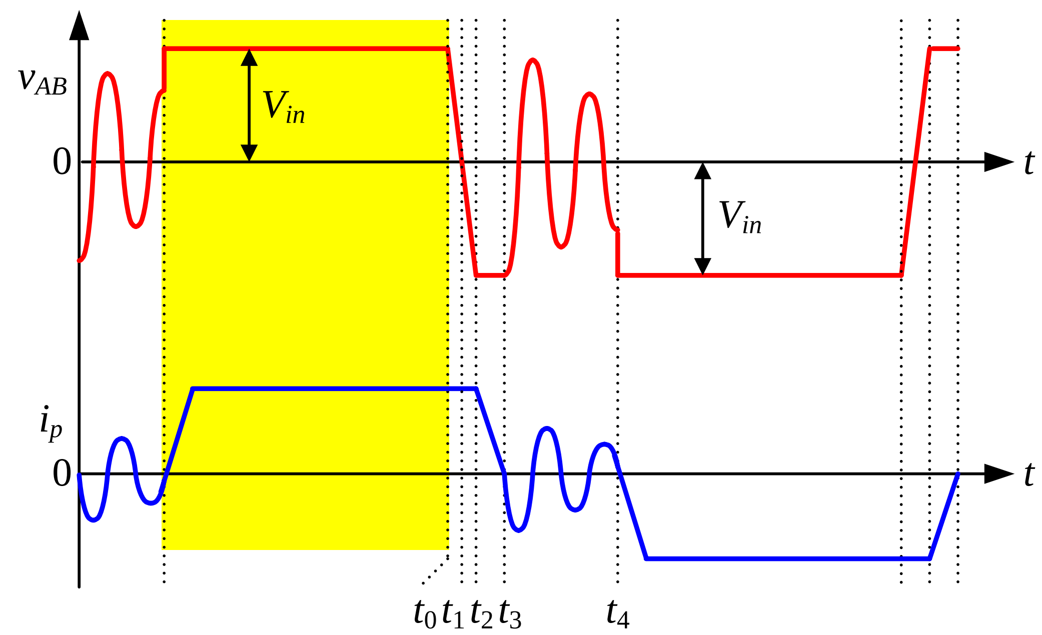


According to the **turn-off sequence** of the **diagonal switches**, the family of PWM strategies can be divided into two categories:

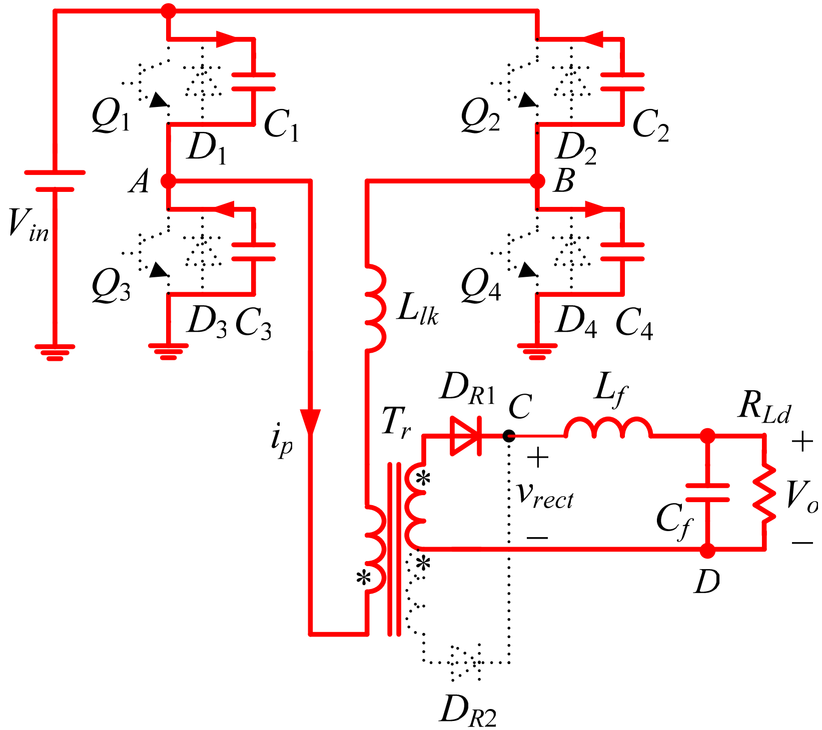
1. the diagonal switches turn off simultaneously;
2. the turn-off instances of the diagonal switches are staggered. One turns off before the other.

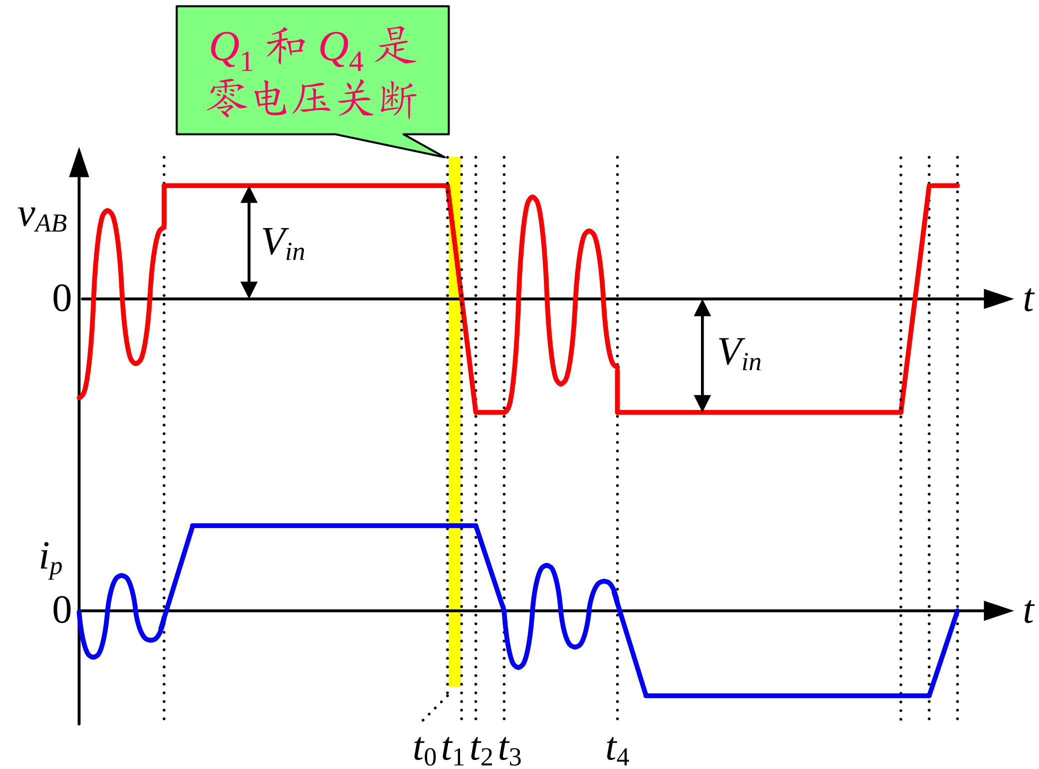
The Diagonal Switches Turn Off Simultaneously





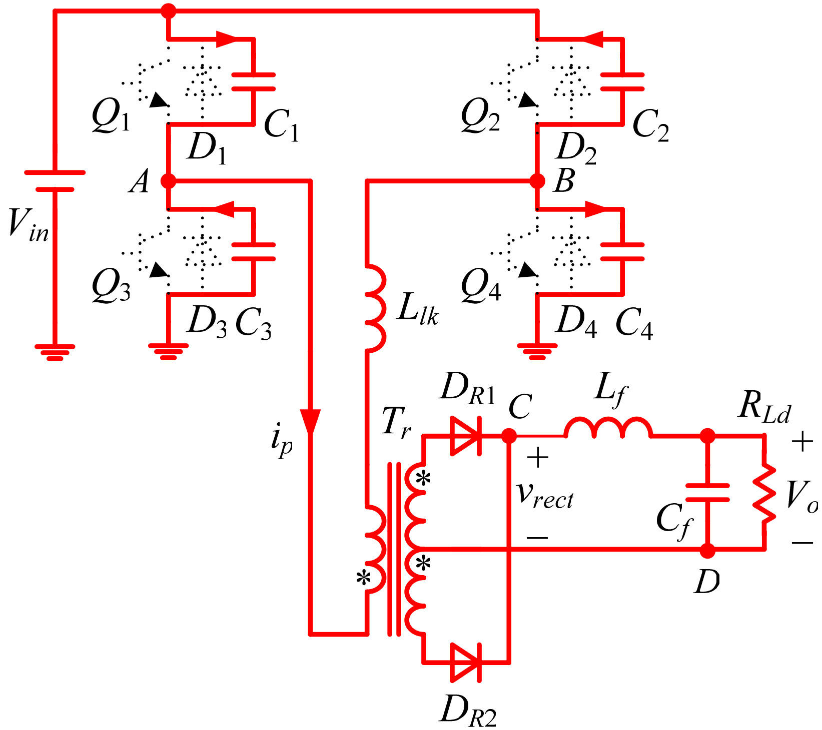
The Diagonal Switches Turn Off Simultaneously

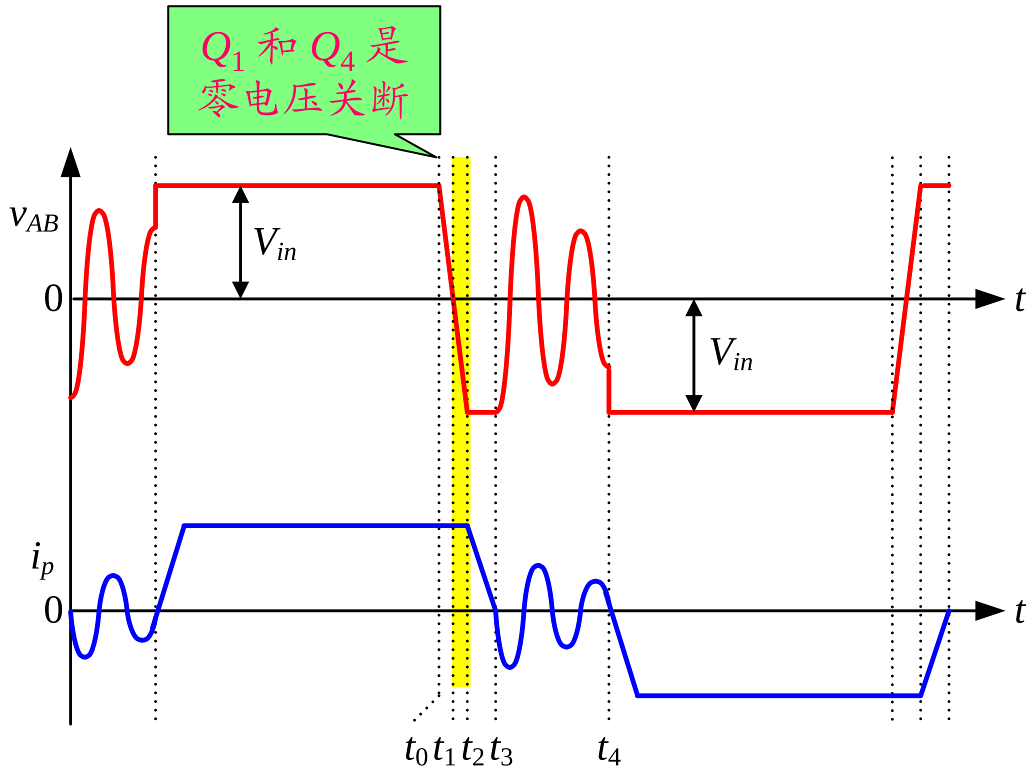




$v_A>v_B$

The Diagonal Switches Turn Off Simultaneously

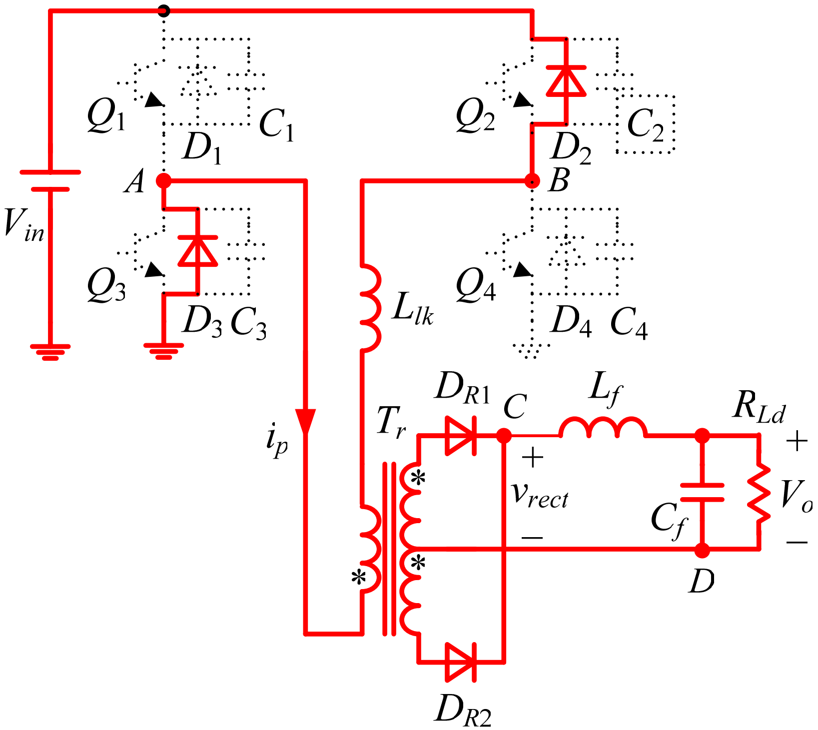


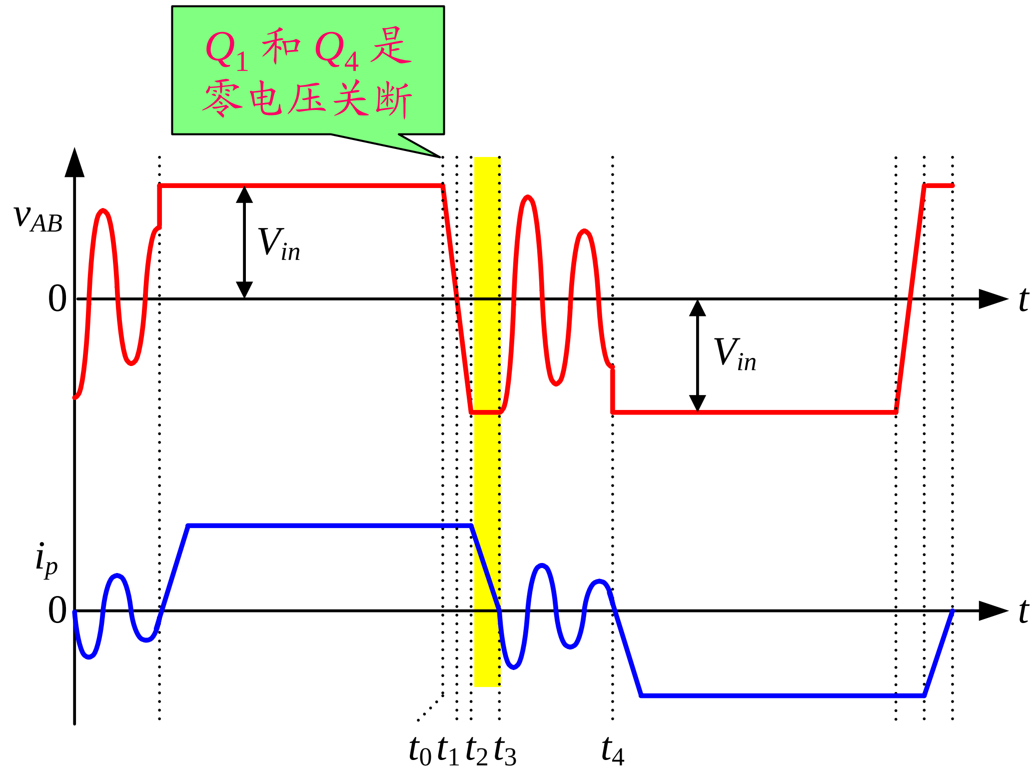


$v_A > v_B$

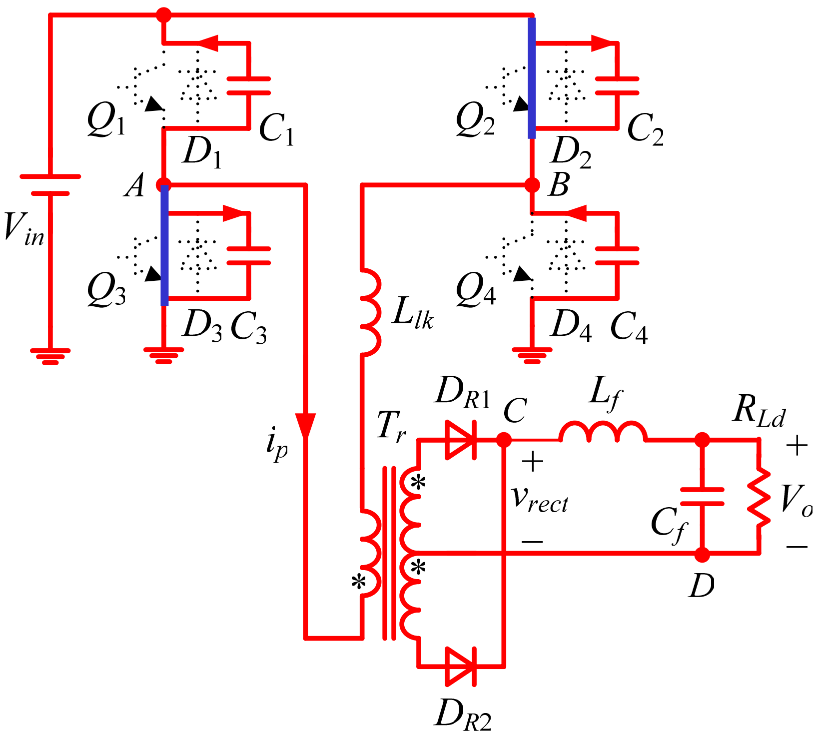
both the two rectifier diode conduct

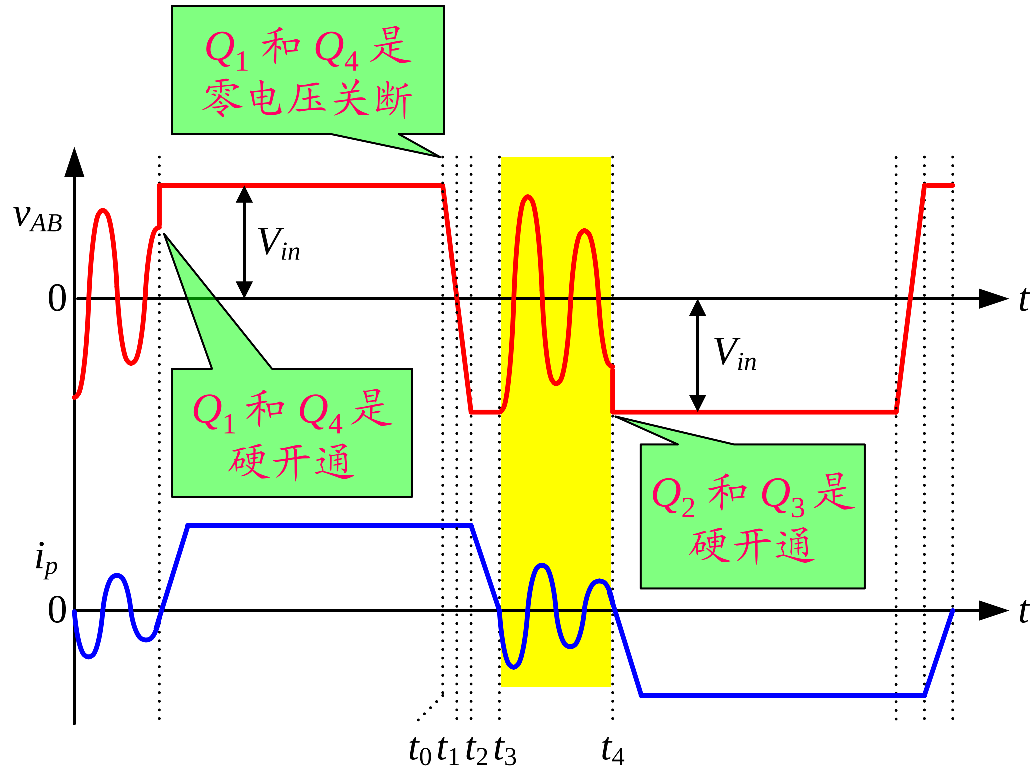
The Diagonal Switches Turn Off Simultaneously





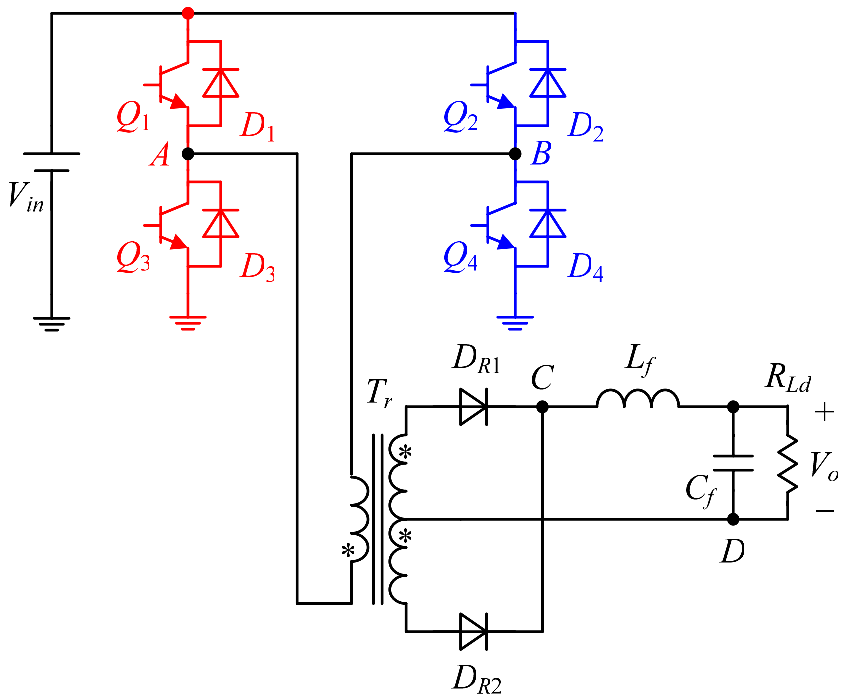
The Diagonal Switches Turn Off Simultaneously





☹ **If the diagonal switches turn off simultaneously, the power switches CAN NOT realize soft-switching.**

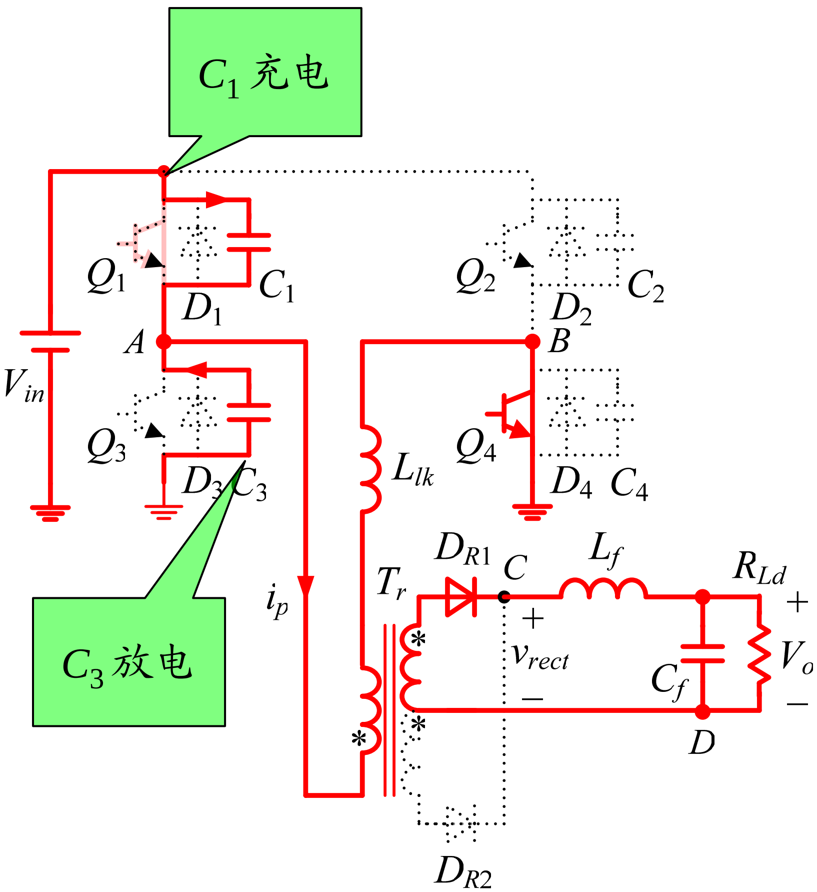
Turn-Off Instances of Diagonal Switches Staggered



If the **turn-off instances** of the **diagonal switches is staggered**, the switching transition will be improved.

1. the switches turning off firstly constitute the LEADING LEG;
2. the switches turning off lately constitute the LAGGING LEG.

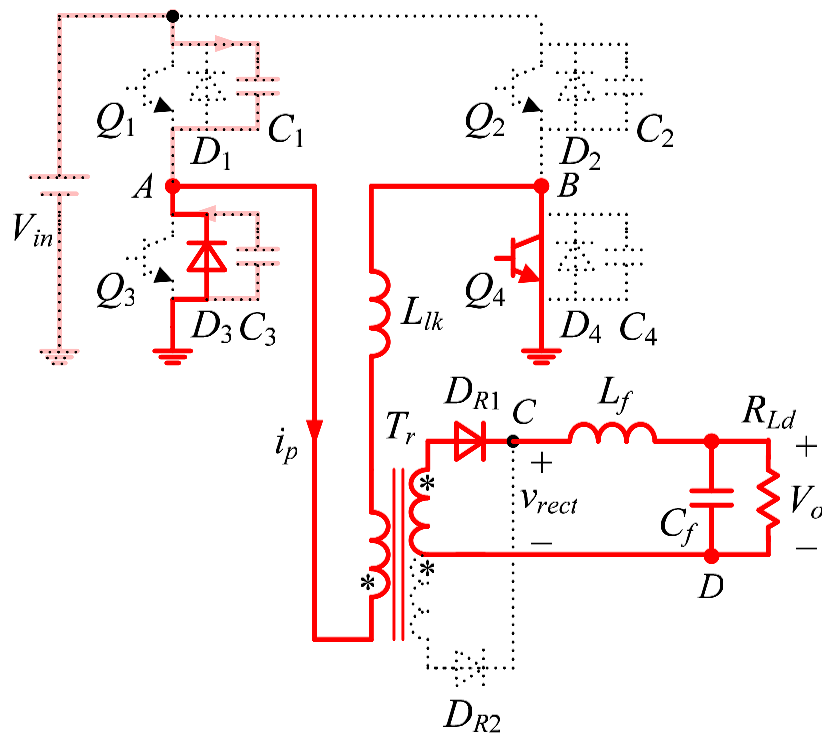
Soft-Switching for the Leading Leg



When the leading switch turns off, the current flowing out/into point A is the reflected output filter inductor current, a nearly constant current source.

- ☞ the leading leg CAN ONLY realize zero-voltage-switching (ZVS), and CANNOT realize zero-current-switching (ZCS);
- ☺ the leading leg is easier to realize ZVS.

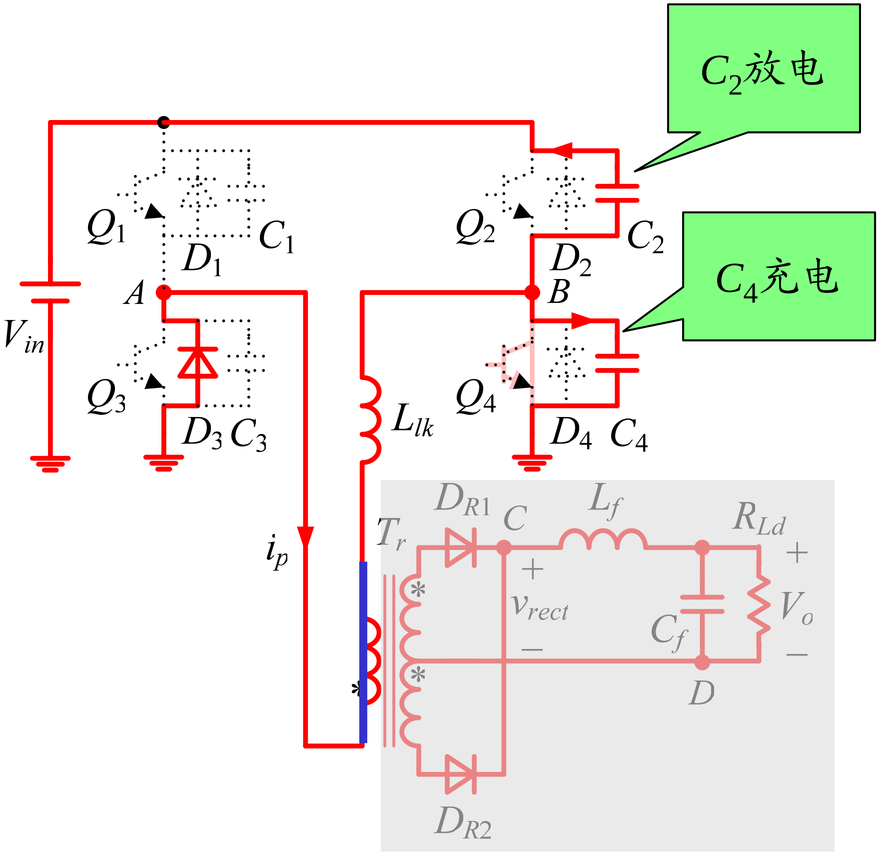
Zero State



Zero state

- **Constant current mode:** i_p keep nearly constant → Lagging leg realize ZVS
- **Current reset mode:** i_p decays to zero → Lagging leg realize ZCS

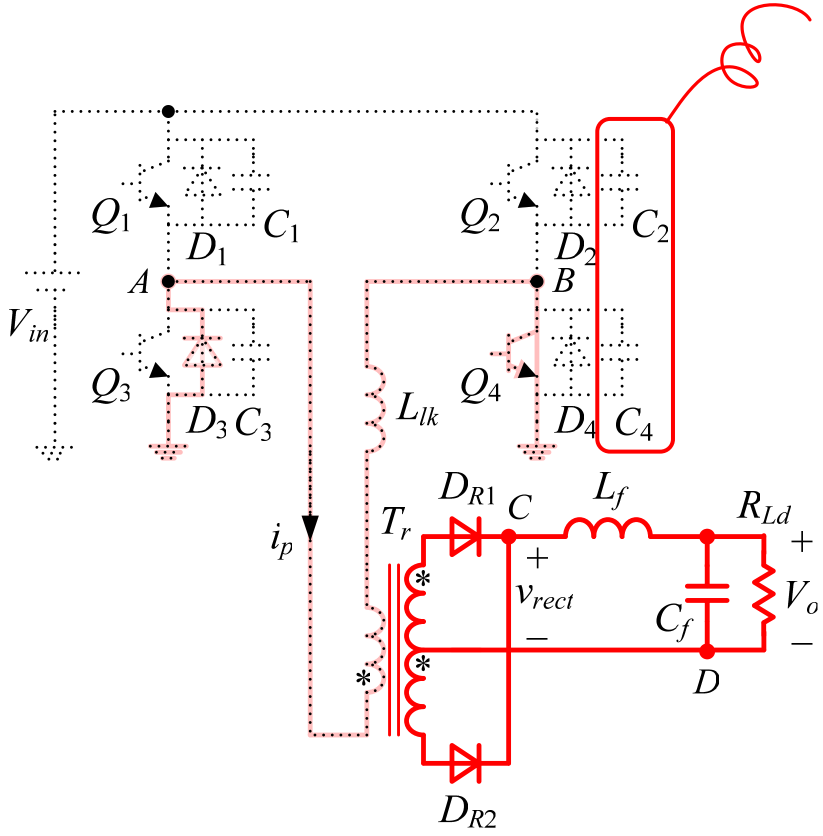
The Lagging Leg Realizes ZVS



☞ the lagging switches should have capacitors in parallel with them, so that they can realize ZVS;

☹ ONLY the leakage inductor provides energy for achieving ZVS for the lagging leg, so the lagging leg is difficult to realize ZVS than the leading leg.

The Lagging Leg Realizes ZCS



- the lagging switches can realize ZCS if zero state operating in current reset mode.;
- The lagging switches should have No capacitor in parallel with them.
- At zero state, when the primary current i_p decays to zero, it should keep at zero.

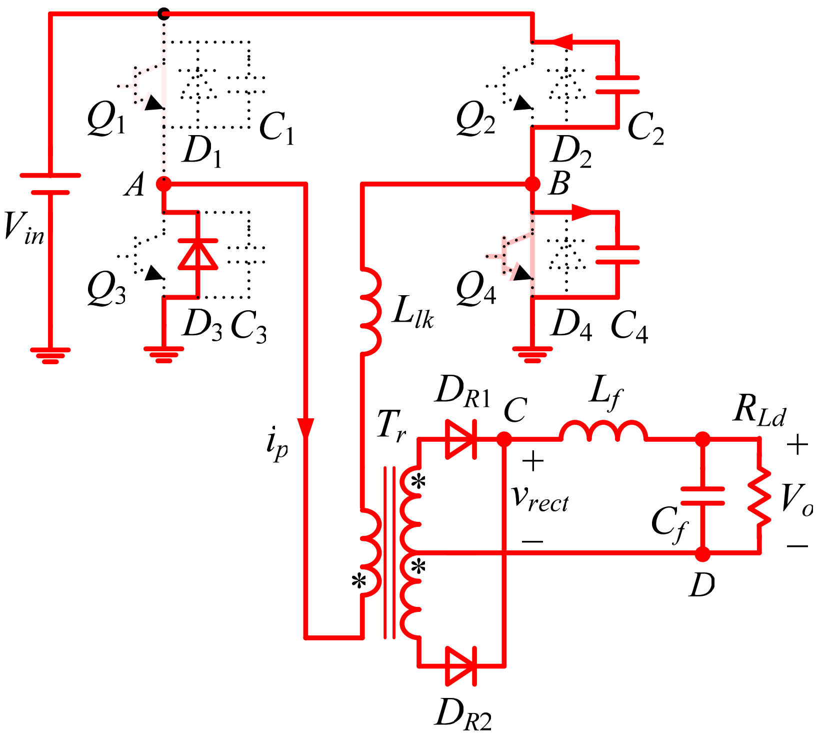
Soft-Switching Types of PWM FB Converter

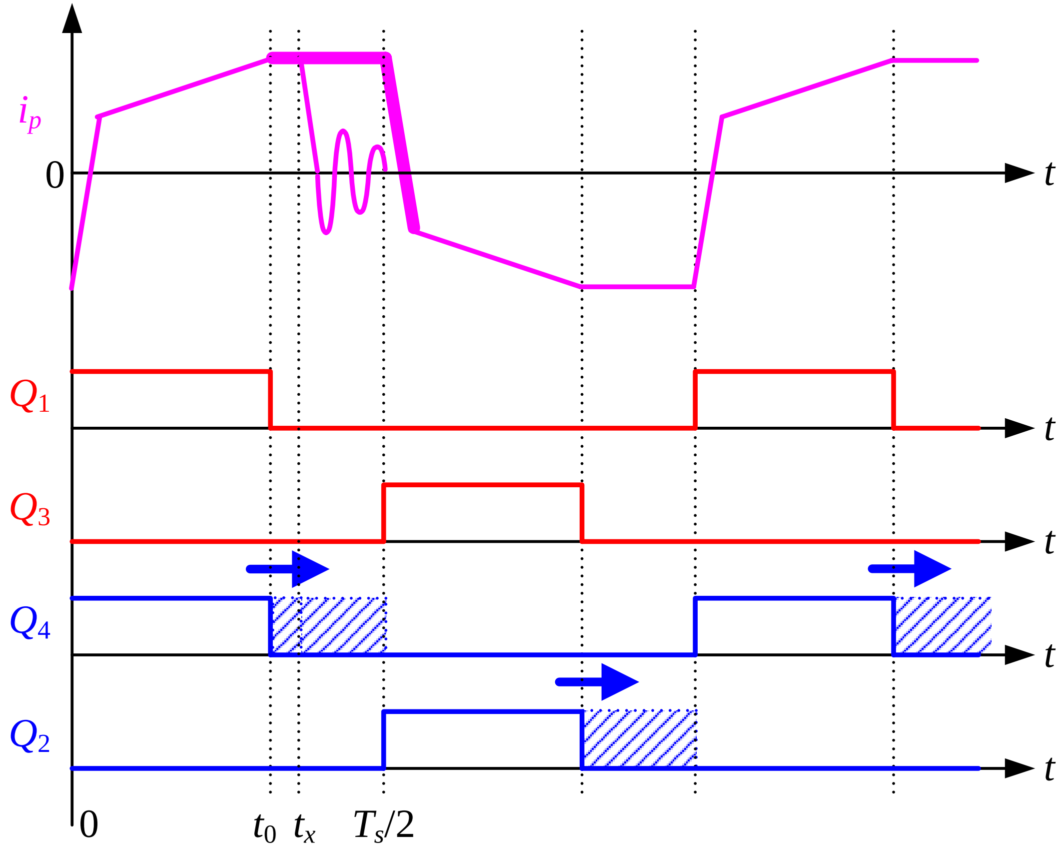
Soft-switching PWM full-bridge converter

ZVS type	ZVZCS type
Both the leading leg and lagging leg realize ZVS.	The leading leg realizes ZVS, while the lagging leg realizes ZCS.

The realization of soft-switching for the power switches **DOES NOT** require any auxiliary power switch, it utilizes **appropriate switching mechanism** of the four power switches.

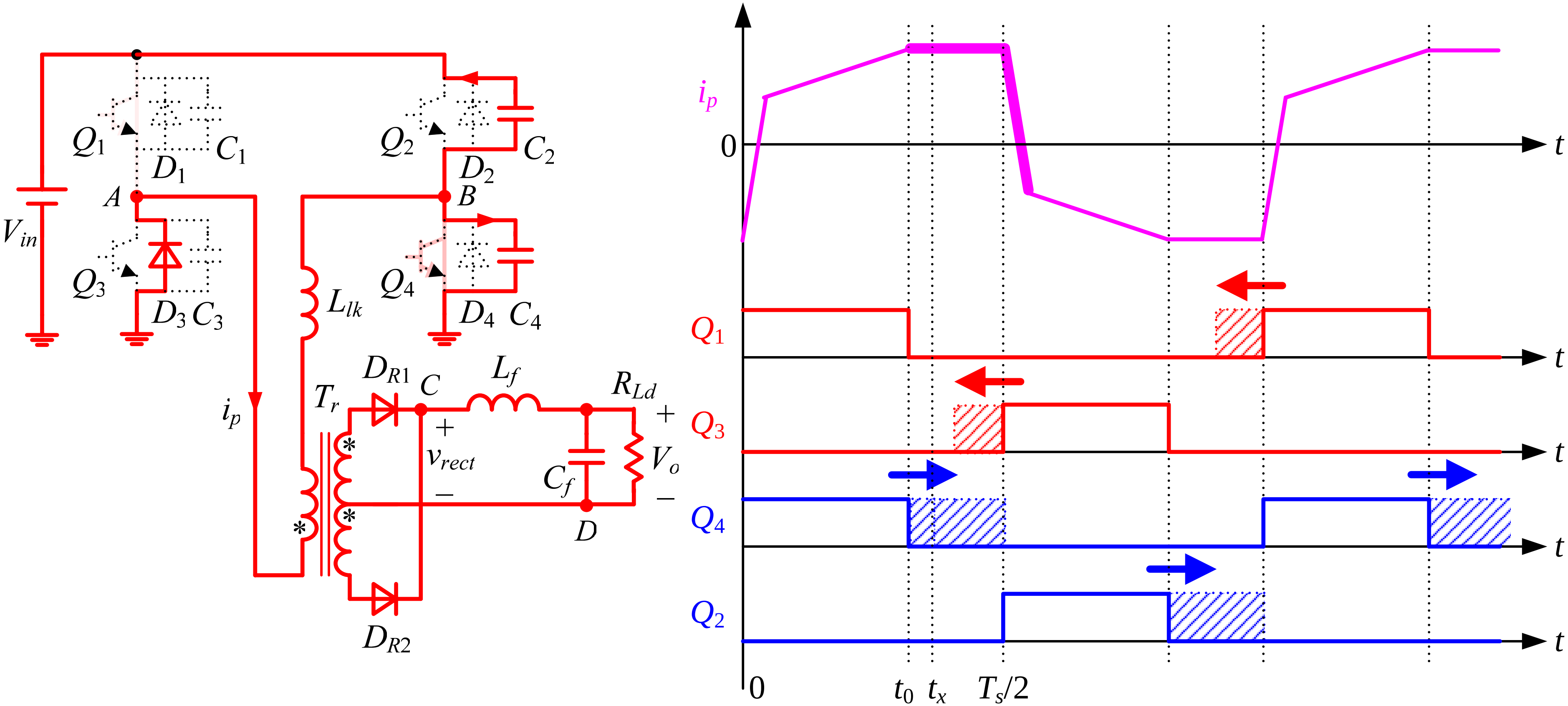
ZVS Type: The Switching of Lagging Switches





☞ In order to ensure ZVS for the lagging switches, the turn-off time instant of the lagging switches should be delayed to $T_s/2$, i.e., the conducting time of the lagging switches should be $T_s/2$.

ZVS Type: The Switching of Leading Switches



☞ Since i_p flowing through the anti-paralleled diode of Q_3 at zero state, the turn-on instant can be at any time, so the conduction time of the leading switches can be three kinds.

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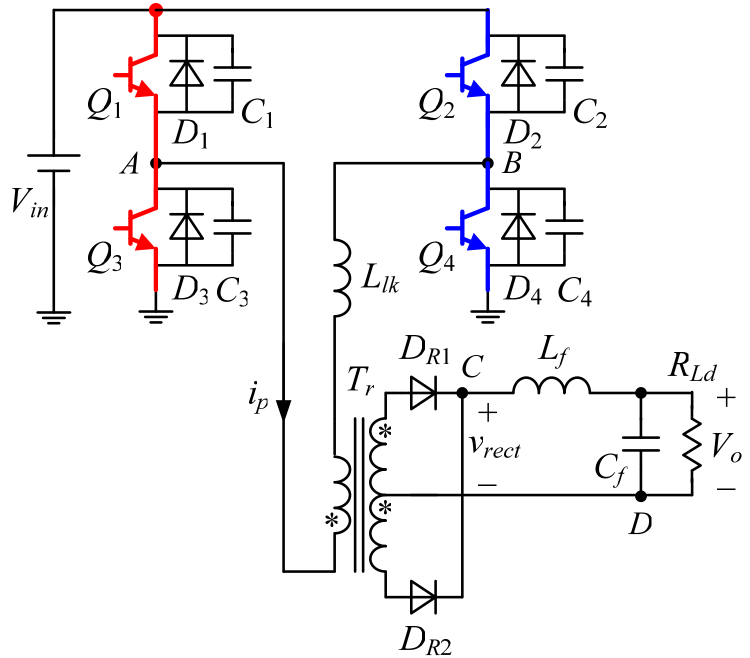
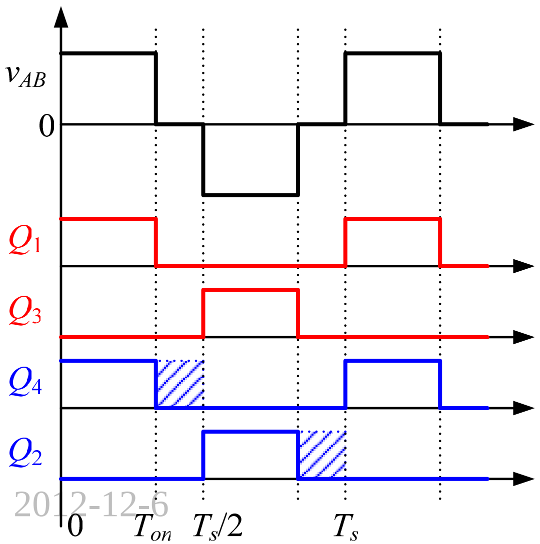
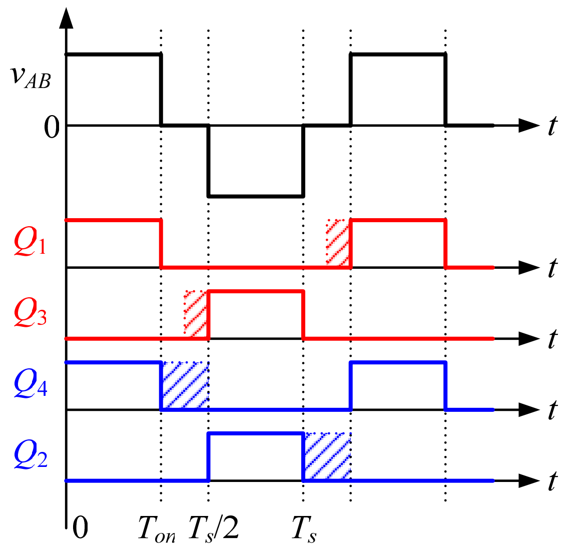
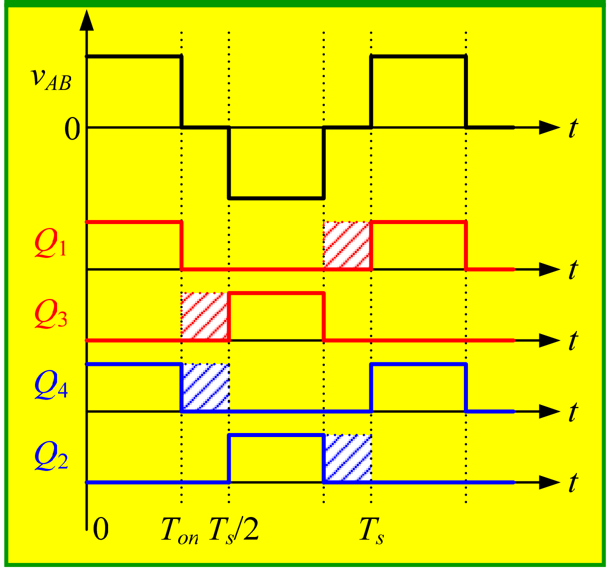
ZVS Type: PWM Strategies



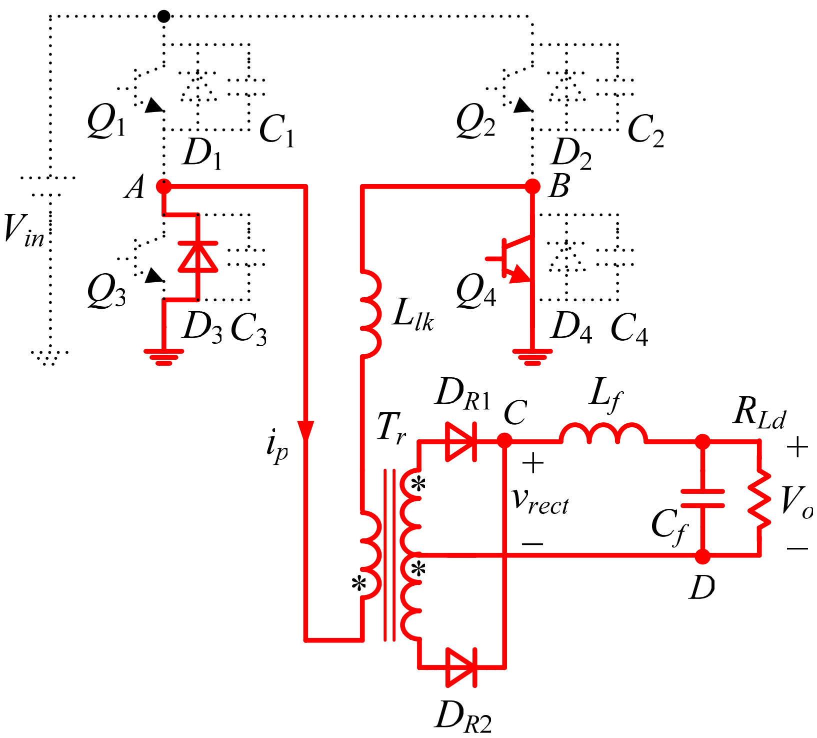


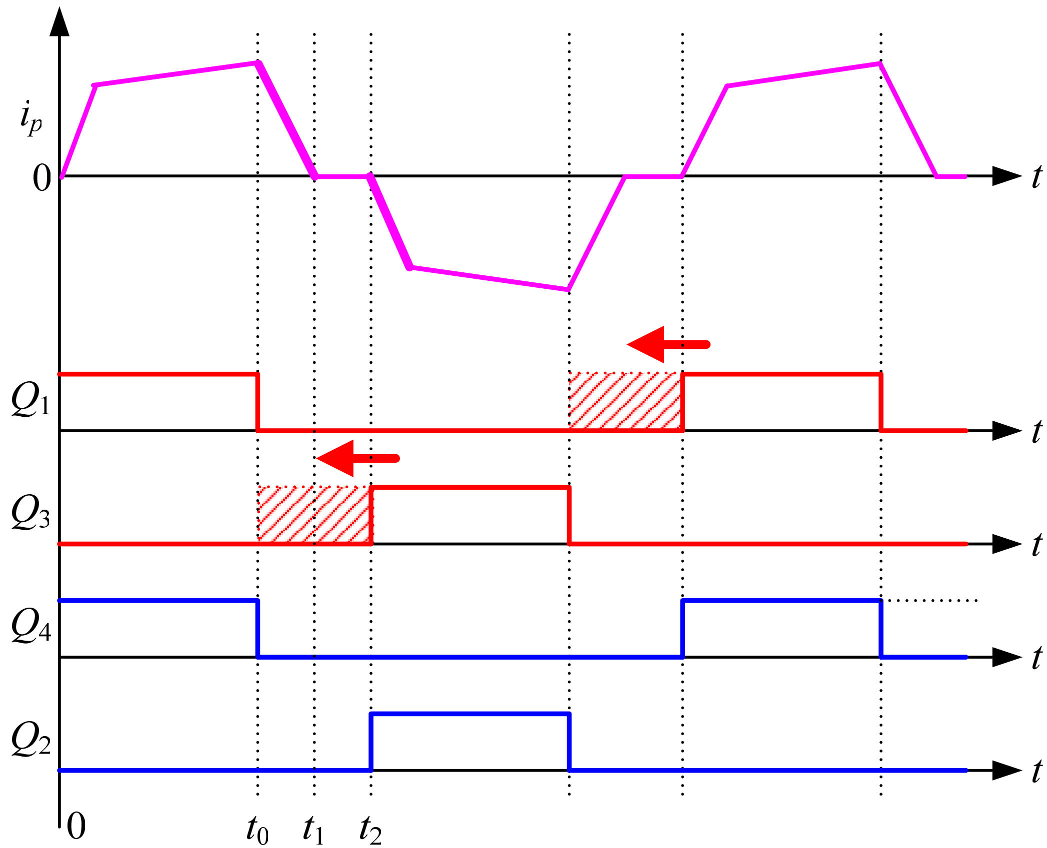


Phase-Shifted Control



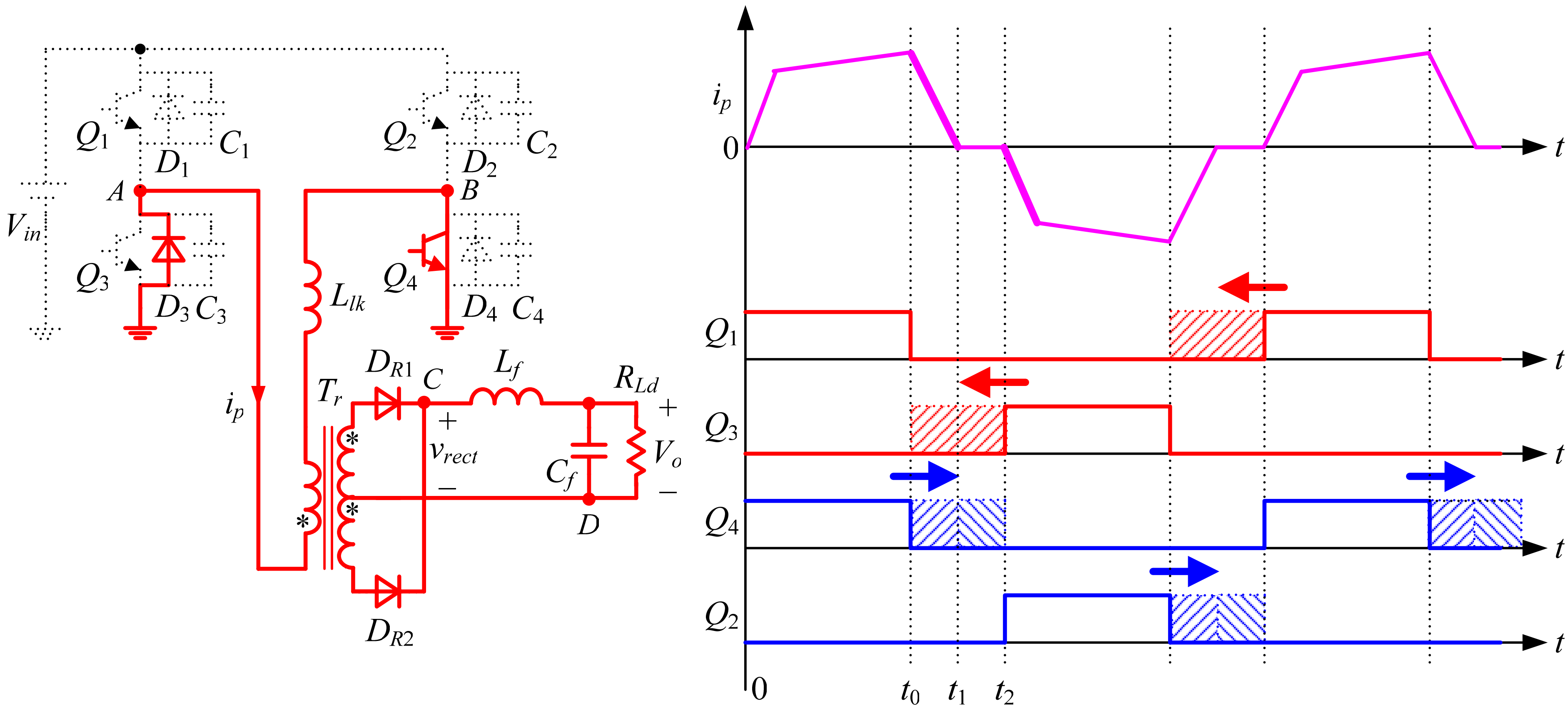
ZVZCS Type: The Switching of Leading Switches





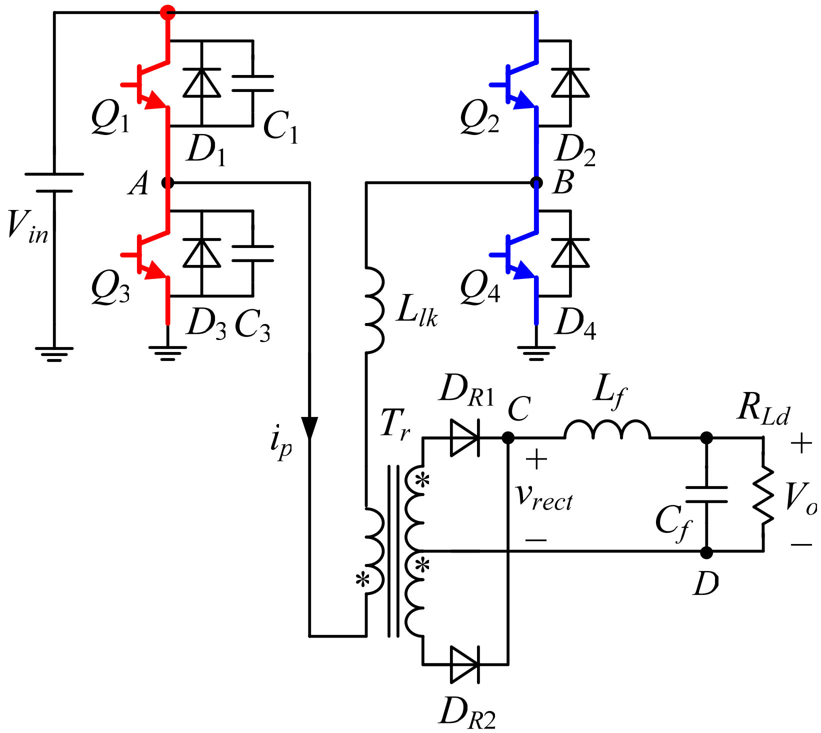
☞ In order to ensure zero-voltage turn-on of the leading switches, the turn-on time instant should be moved forward and let the conducting time to be $T_s/2$.

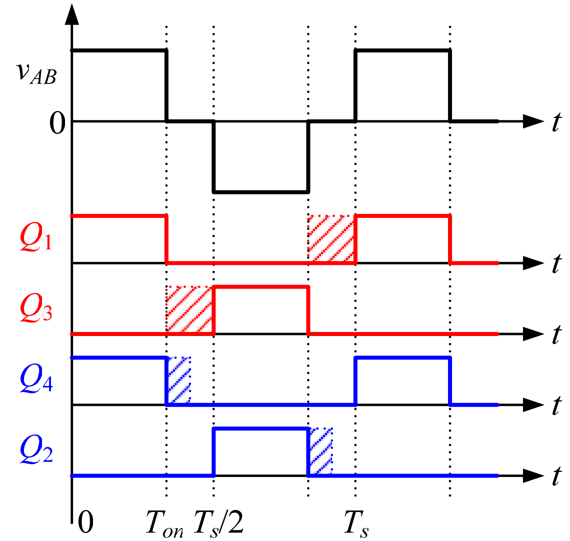
ZVZCS Type: The Switching of Lagging Switches



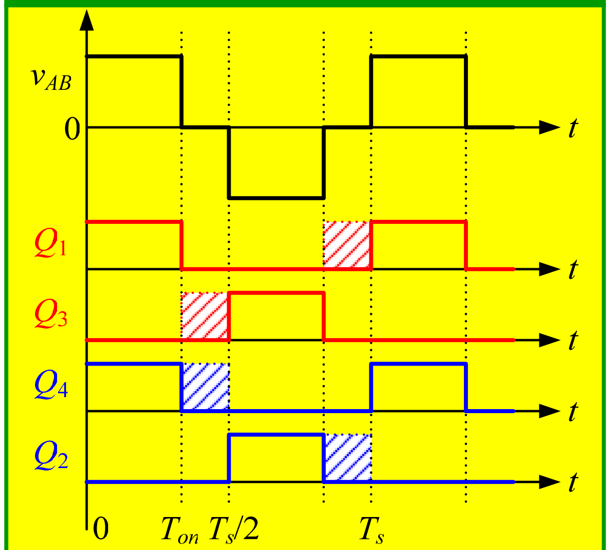
☞ In order to ensure zero-current turn-off of the lagging switches, the turn-off time instant should be delayed to the time when i_p is reset or even to let the conducting time to be $T_s/2$.

ZVZCS Type: PWM Strategies





Phase-Shifted Control



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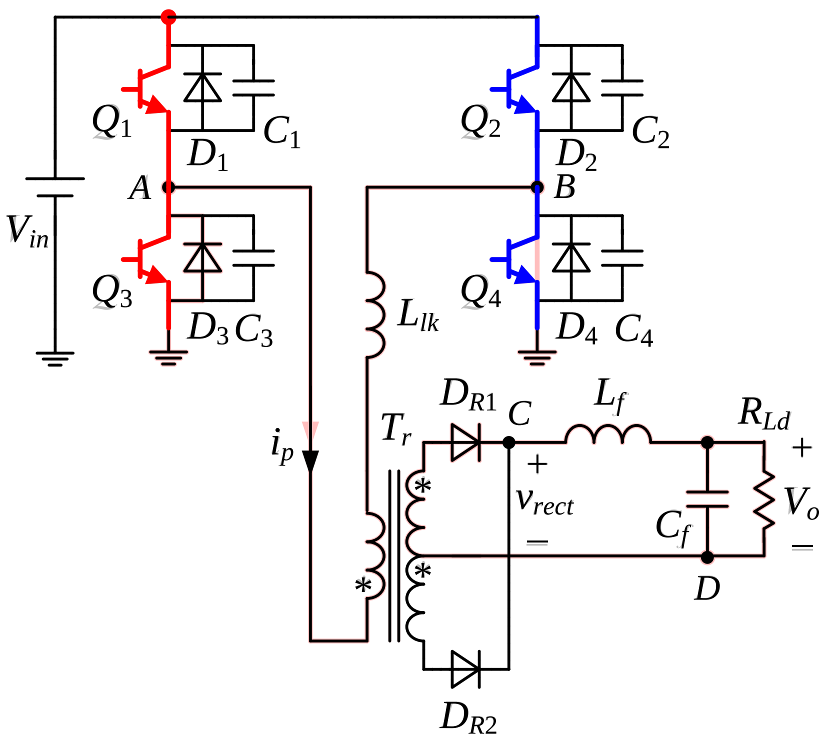
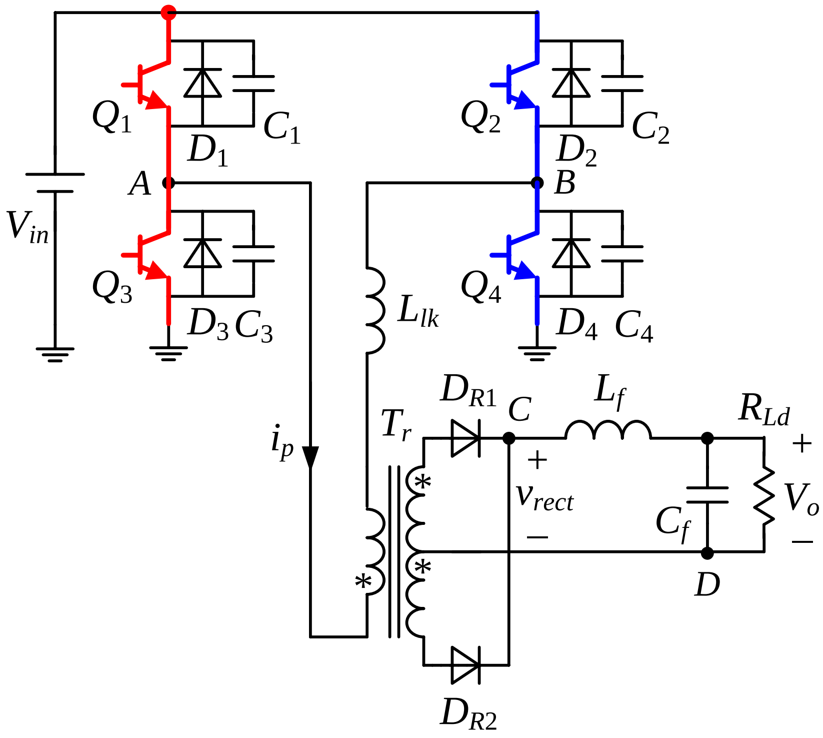
Basic ZVS PWM Full-Bridge Converter



Advantages

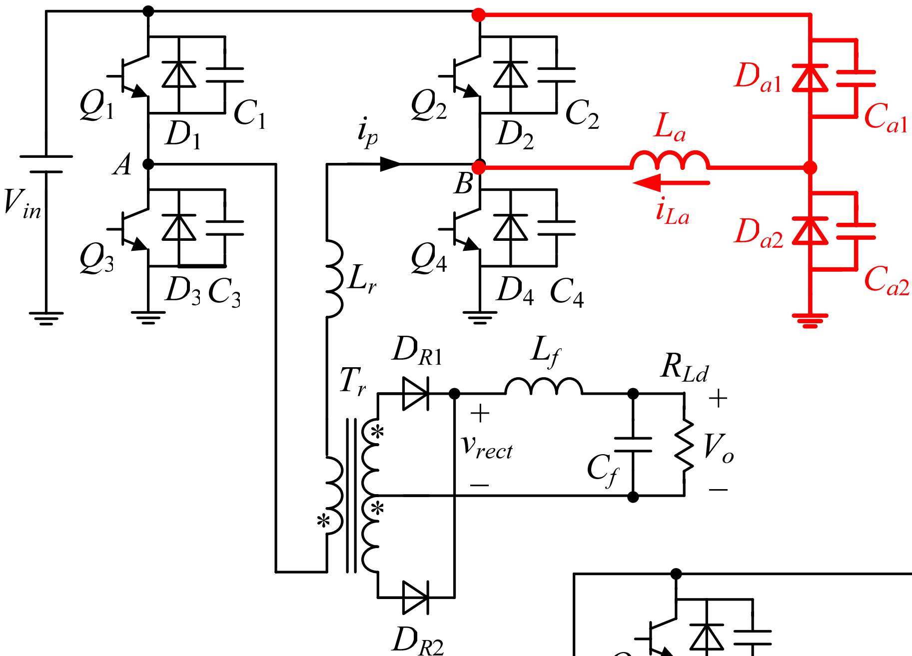
- ☺ The junction capacitors of the power switches and the leakage inductor of the transformer are **fully** used to achieve ZVS for the power switches.
- ☺ No auxiliary power switches and element is required. This leads to **simple topology**.
- ☺ It operates with **constant frequency**, leading to easy optimization of the transformer and input and output filter.
- ☺ Various commercial controller IC are available, leading to **simple implementation** of control circuit.

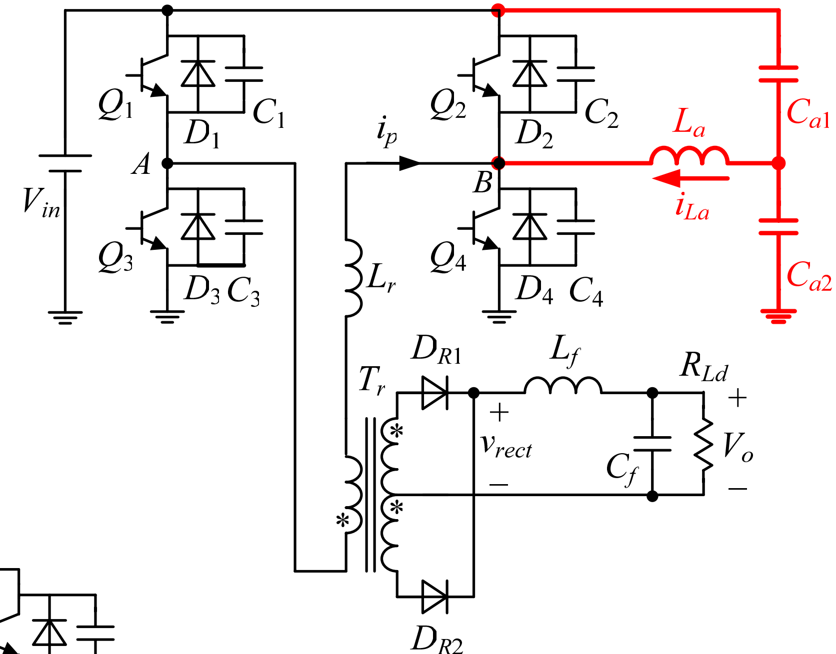
Basic ZVS PWM Full-Bridge Converter

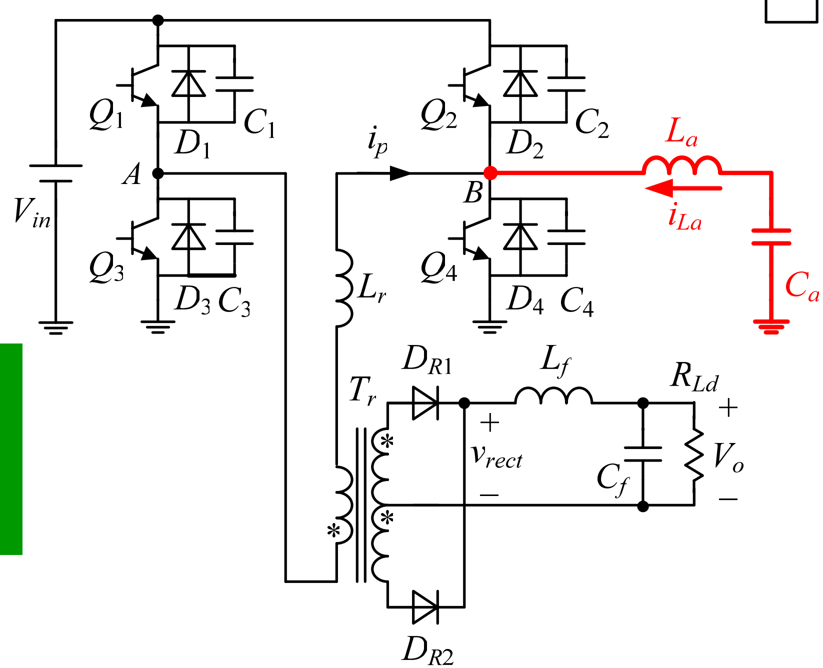


Characteristics	
☺	The leading leg can realize ZVS in a **wide** load range because both the energy stored in the filter inductor and leakage inductor are utilized.
☹	The lagging leg is relatively **difficult** to realize ZVS since only the energy stored in the leakage inductor is used.
☹	The leakage inductor or external resonant inductor results in **duty cycle loss**, thus the primary-to-secondary turns ratio of the transformer should be reduced, which leading to high voltage stress of the rectifier diodes and primary current stress..

Increase Load-Range of ZVS for Lagging Switches

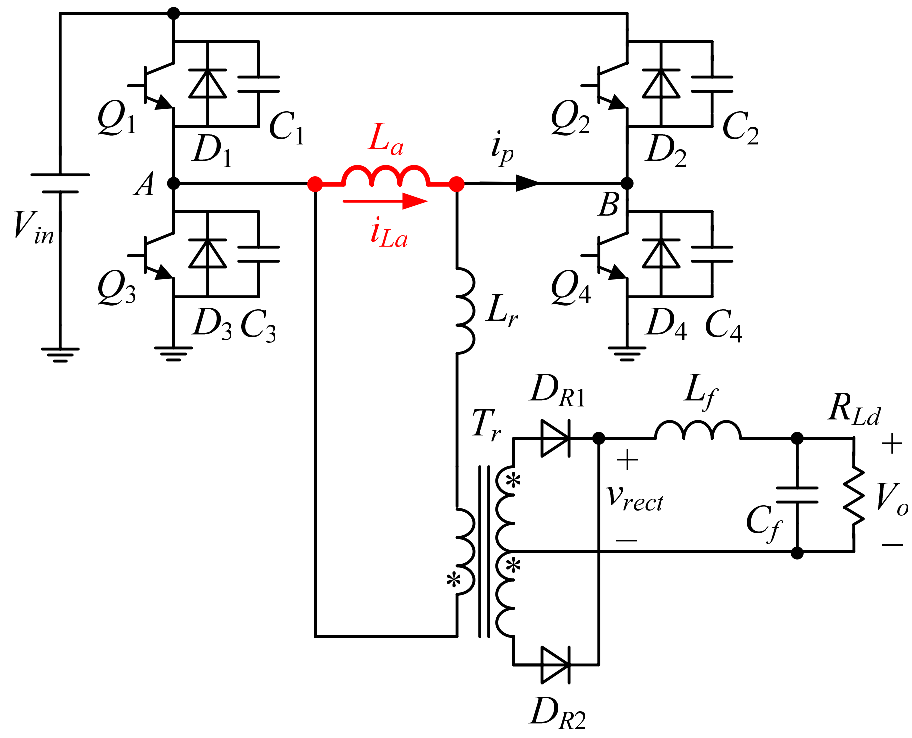






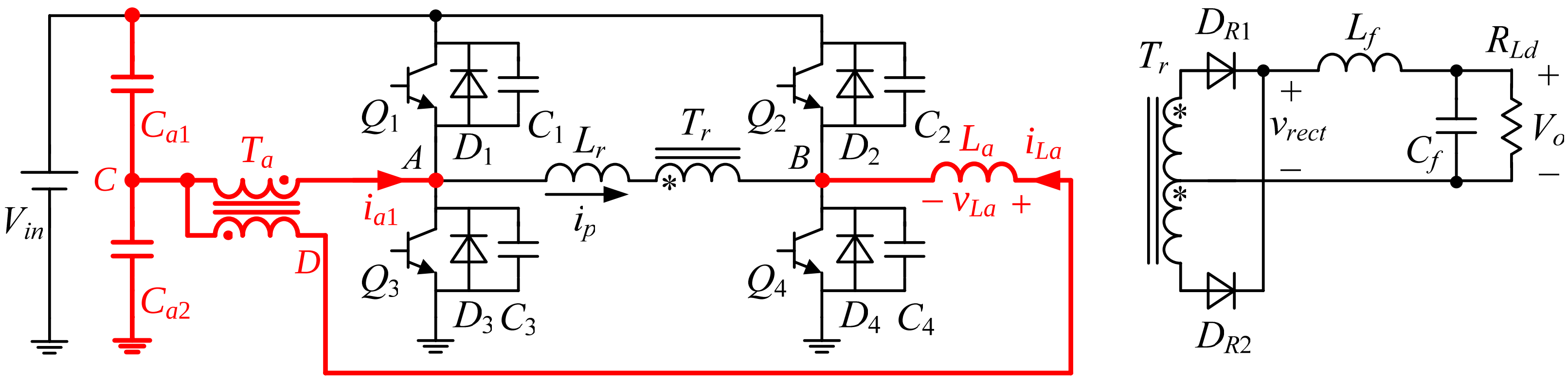
The auxiliary inductor current is independent with the load current

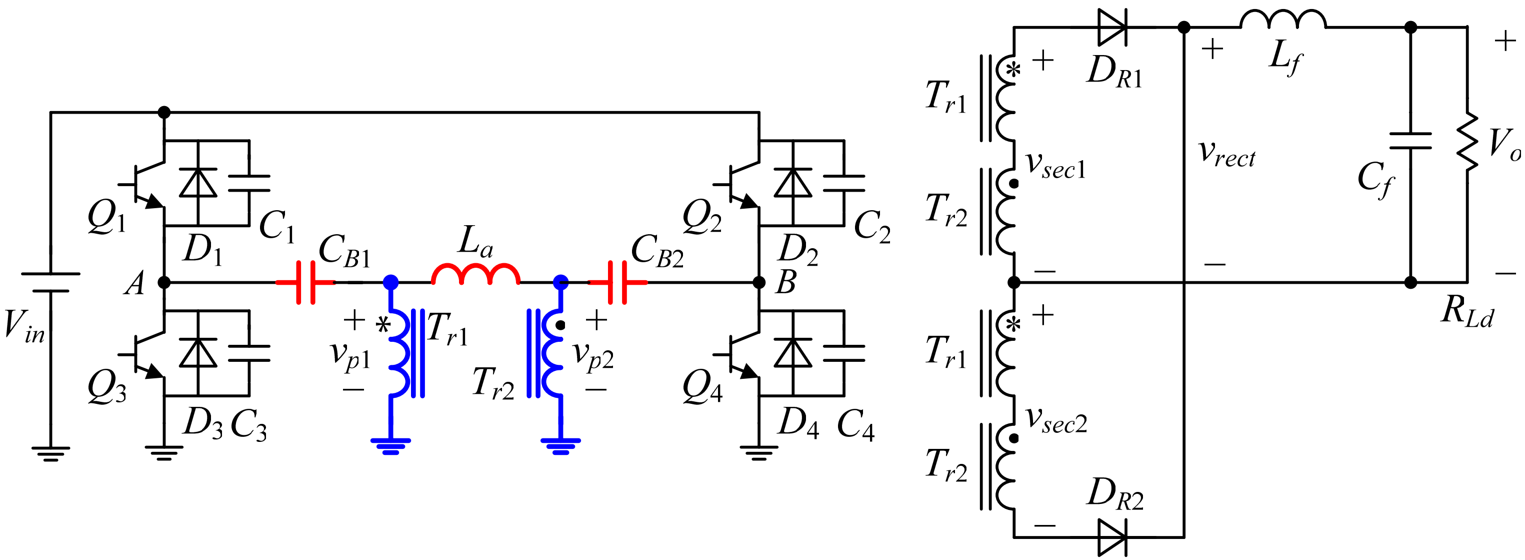
Increase Load-Range of ZVS for Lagging Switches



The auxiliary inductor current increases with the load current

Increase Load-Range of ZVS for Lagging Switches





The auxiliary inductor current is adaptive with the load current, i.e., it is reduced as the load current increases.

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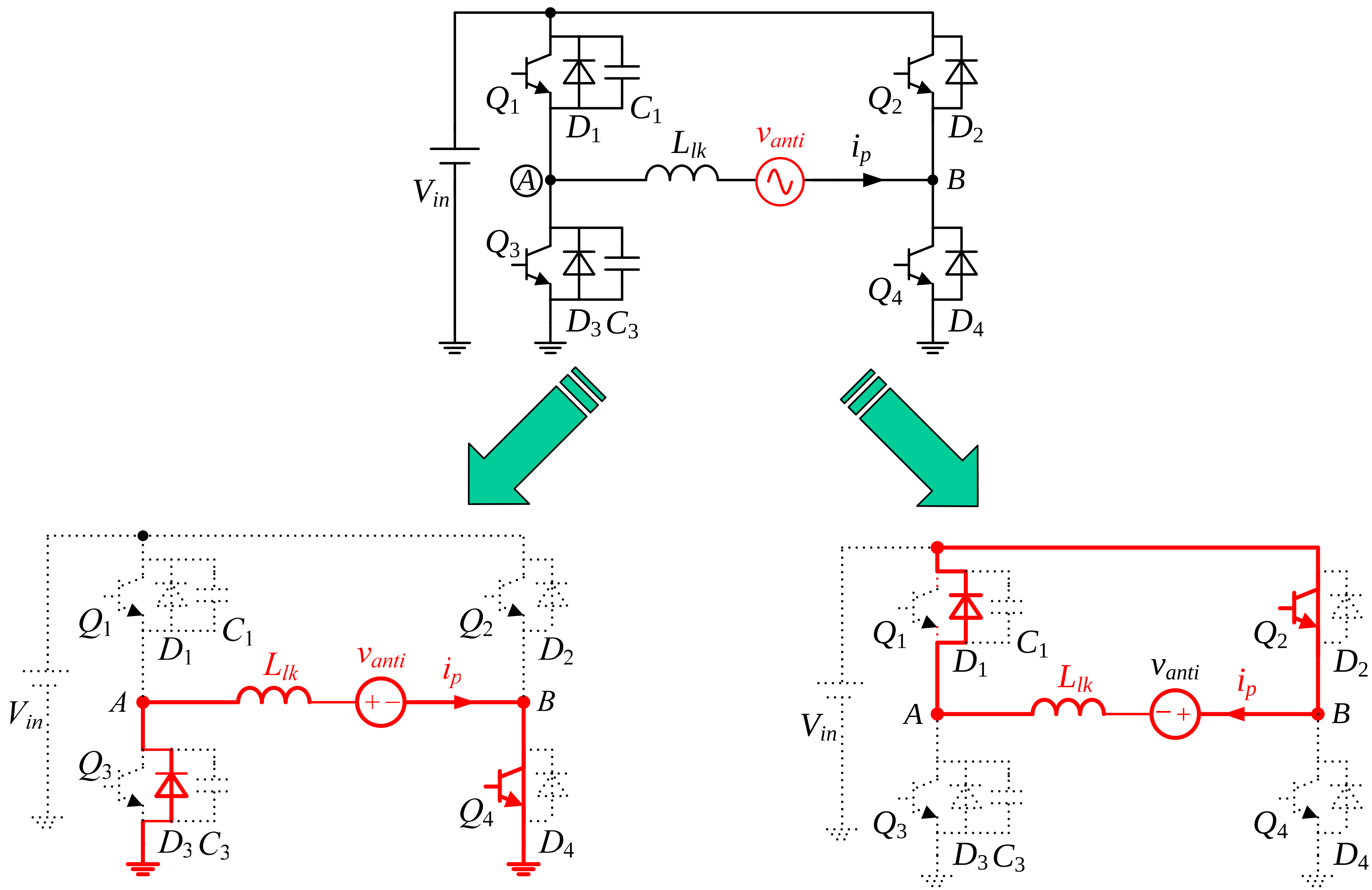
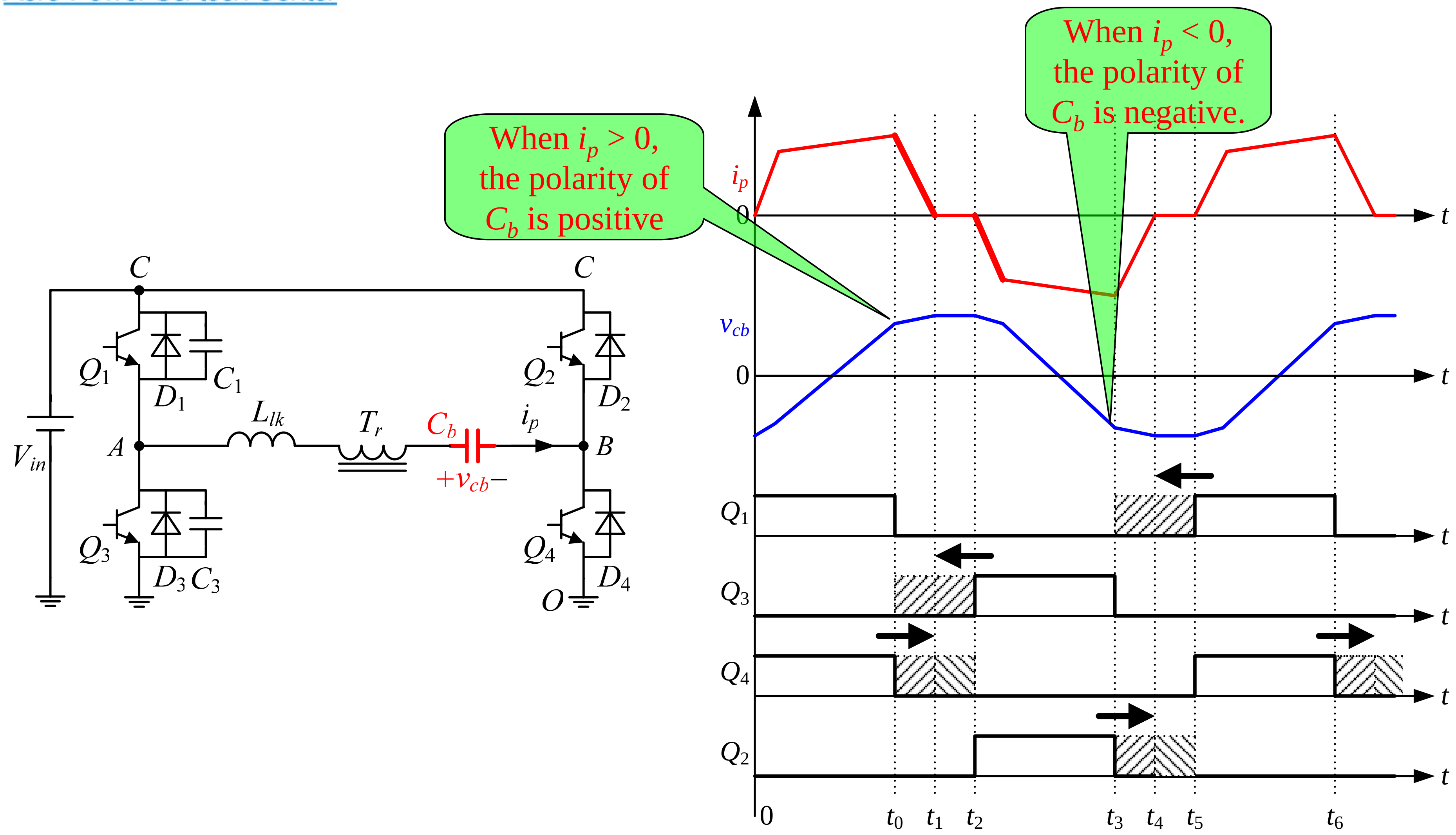
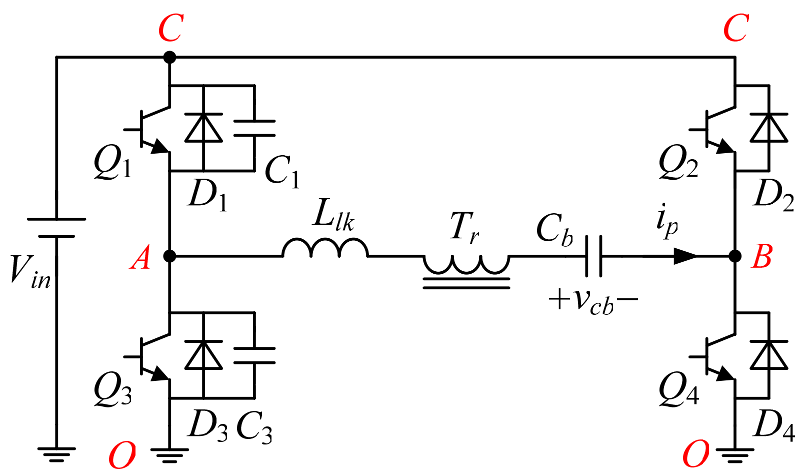
Block Voltage Source for Resetting Primary Current



Implementation of Block Voltage Source



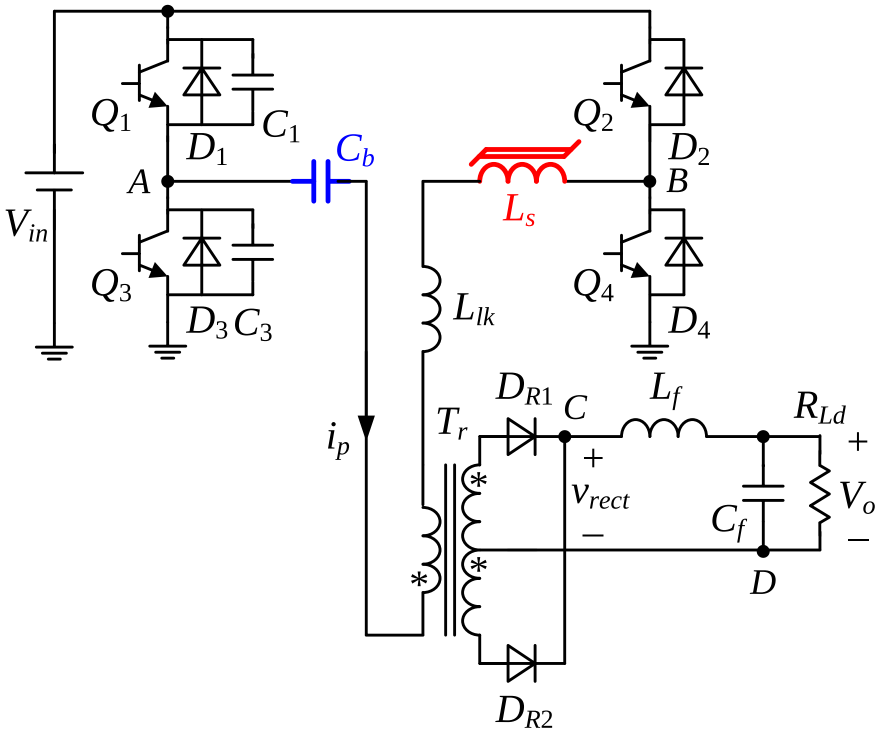
Blocking Reverse Flowing Path of i_p at Zero State

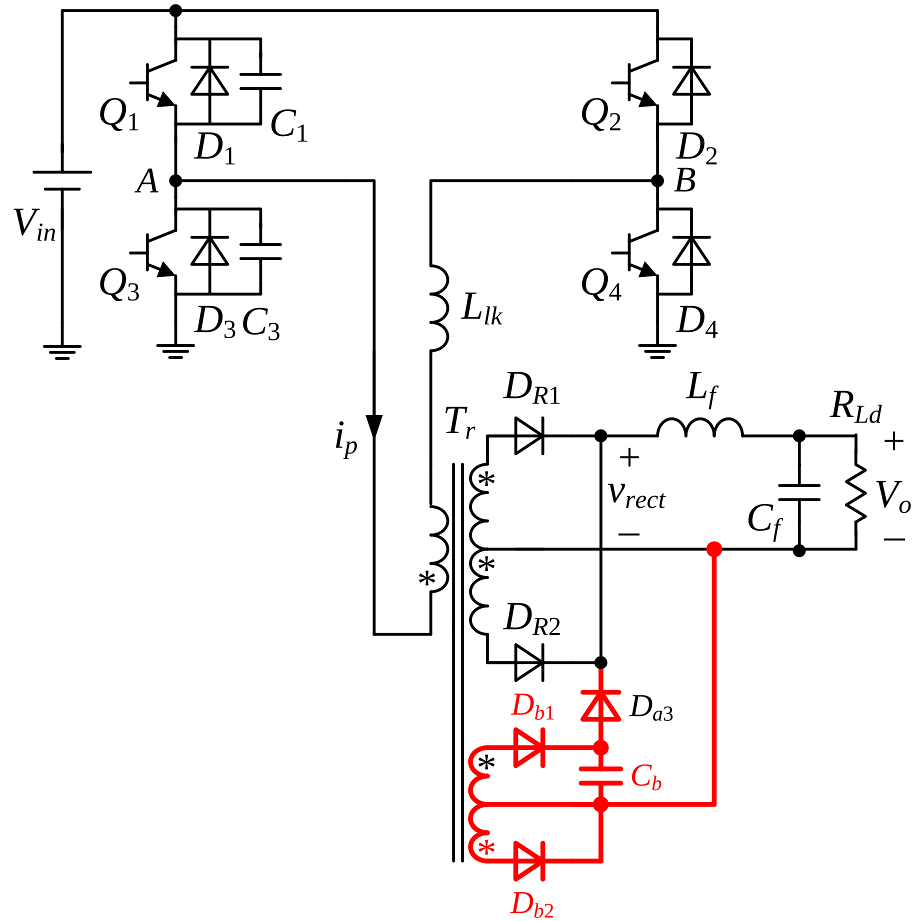


Possible places to block the reverse flowing path of i_p

- AC/AO segment; ✘
- AB segment;
- BC/BO segment.

Blocking Reverse Flowing Path of i_p at Zero State





AB segment to block the reverse flowing path of i_p

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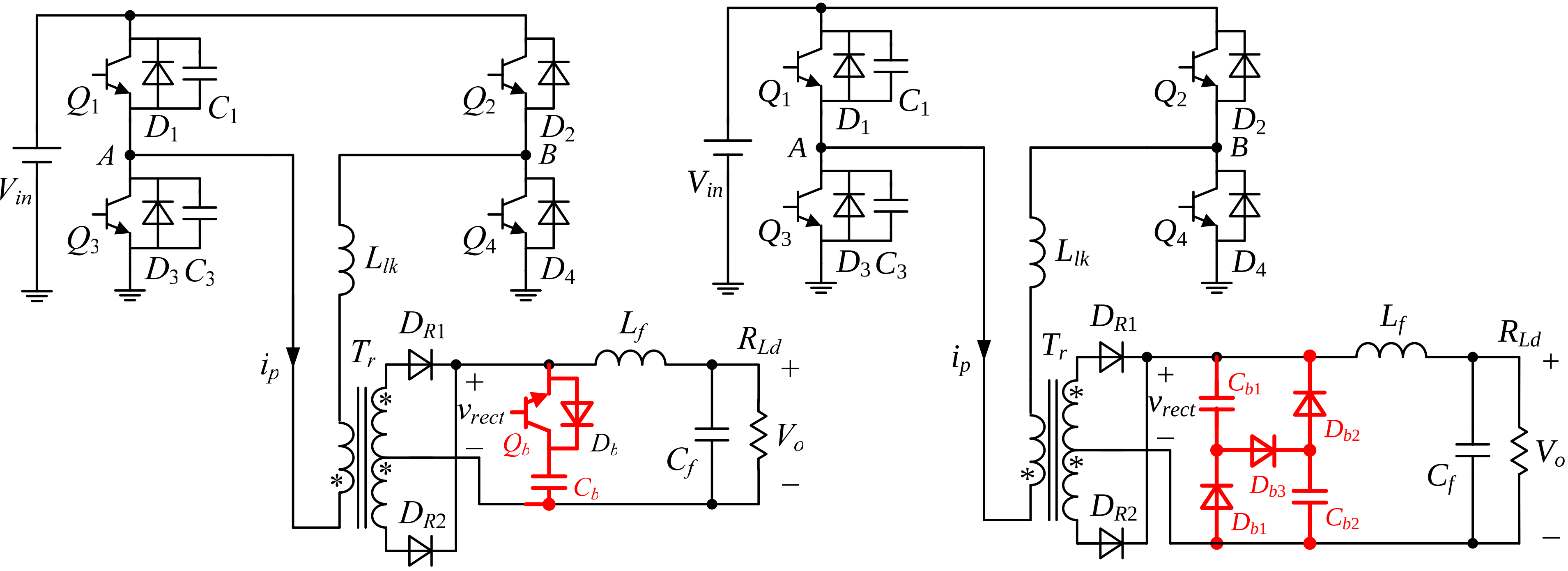

AB segment to block the reverse flowing path of i_p

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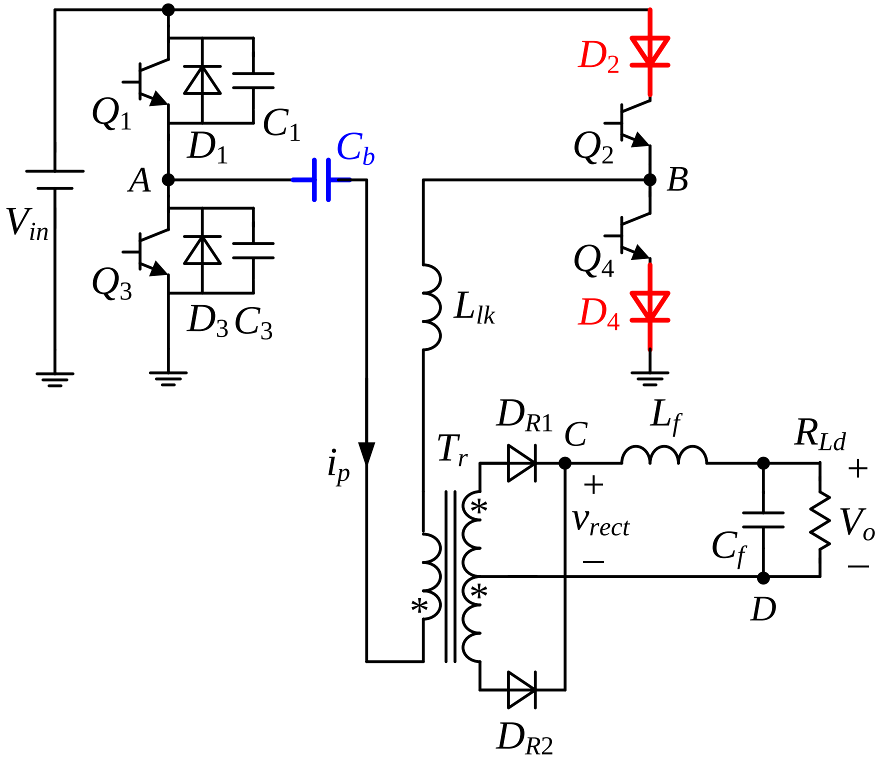

<u>BC/BO segment to block the reverse flowing path of i_p</u>

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Conclusion

- ☞ A family of PWM strategies are proposed for full-bridge converter, which can be divided into two categories: one is that the diagonal switches turn off simultaneously, and the other is that the diagonal switches turn off at different time instance. The form one cannot achieve soft-switching for the power switches, and the latter one provides the possibility of achieve soft-switching, thus the concept of **LEADING LEG and LAGGING LEG** is introduced.

- ☞ The leading leg **CAN ONLY** and is **EASY** to realize ZVS, and the lagging leg can realize ZVS or ZCS, thus the soft-switching PWM full-bridge converter can be categorized into two kinds: One is **ZVS type**, for which both the leading leg and lagging leg realize ZVS; and the other one is **ZVZCS type**, for which the leading leg realize ZVS, and the lagging leg realize ZCS. The suitable PWM strategies for ZVS type and ZVZCS type full-bridge converter are pointed out.

Conclusion

- ☞ For ZVS PWM full-bridge converter, the leading leg is easier to realize ZVS than the lagging leg. Some auxiliary circuits to help the lagging leg to realize ZVS are presented.

- ☞ For ZVZCS PWM full-bridge converter, the method of resetting the primary current at zero state are proposed, and the relationship of the several existing topologies are revealed. Furthermore, a new topology is proposed.

Thanks for your attention !

Questions? / Answer!