

Aula 10 – Inversores de pulso ressonante

Parte 1 – Introdução, Princípio de operação e Tipos de conversores



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heverton.pereira@ufv.br

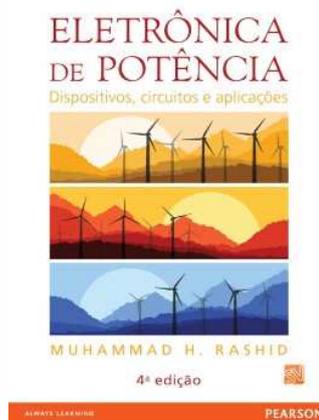


Introdução

		Tópicos
01	-	Introdução
02	-	Diodos de potência e circuitos RLC chaveados
03	-	Retificadores com diodos
04	-	Transistores de potência
05		Conversores CC-CC
06		Tiristores
07		Retificadores controlados
08	-	Conversores CC-CA
09	-	Controladores de tensão CA
10	-	Inversores de pulso ressonante

Capítulo 7 do Livro

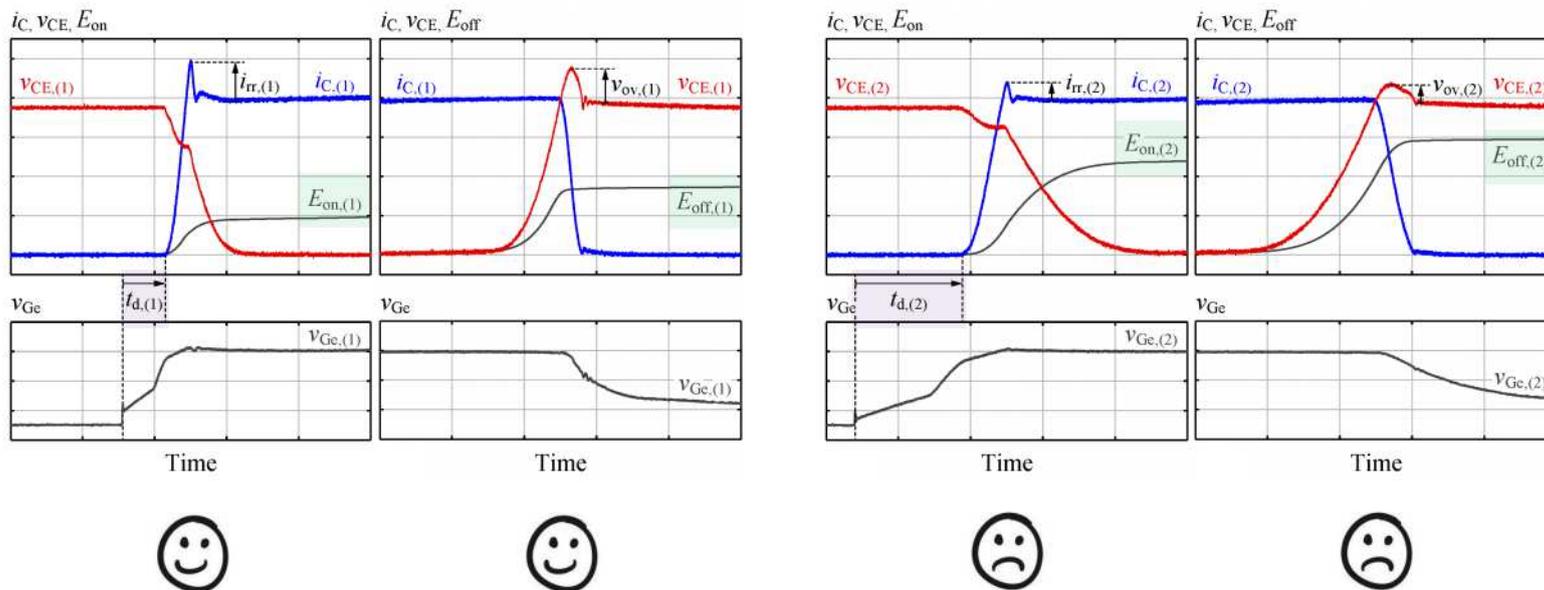
M. H. Rashid: Eletrônica de Potência: Dispositivos, circuitos e aplicações. 4ª. Edição, Pearson, 2014



Introdução

Modulação PWM tem como consequência:

- ✓ Alto valor di/dt
- ✓ Perdas proporcionais a frequência de chaveamento



Introdução

Modulação PWM tem como consequência interferência eletromagnética devido a di/dt e dv/dt

Two major sources of EMI in power electronics are dv/dt and di/dt during switching times. In fact, a DC voltage of few hundred volts is chopped by a power switch in a fraction of microsecond. Thus, conducted emission is a major issue in most power electronic systems due to significant over voltage and leakage current generated by fast switching and stray components of the system.

- High di/dt may create significant over voltage in power converters due to stray inductance of current loops
- High dv/dt may create significant leakage current in magnetic elements and electric motors due to stray capacitive coupling between windings and a frame

How to reduce EMI noise?

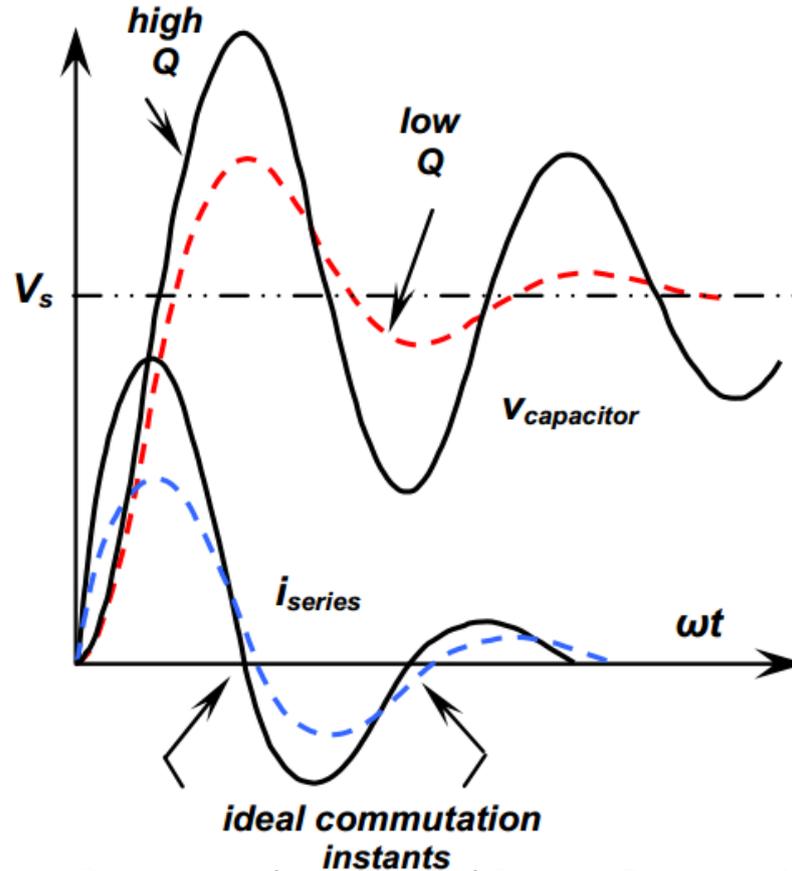
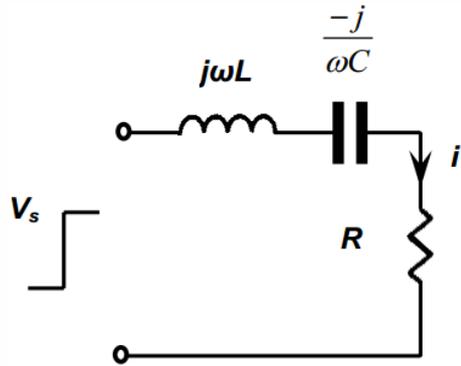
As discussed in the above section, decreasing dv/dt and di/dt means increasing the switching time which increases losses. Thus, it is a trade off between losses and EMI to determine the switching time. The other alternative is to reduce stray inductance and capacitance of a power electronic system using a better layout, interconnection and configuration.

Introdução

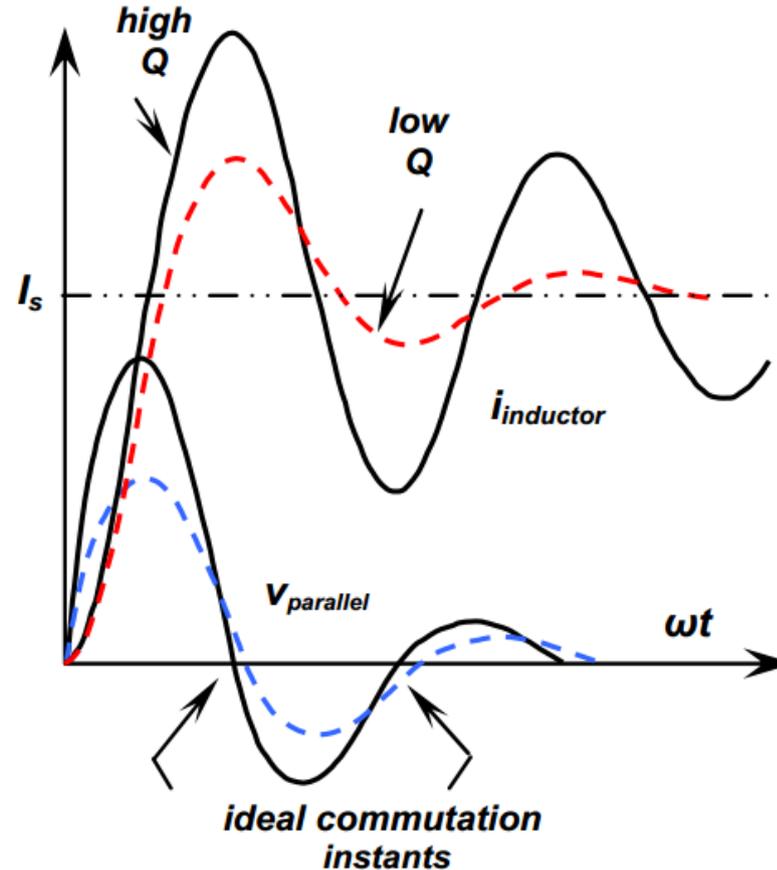
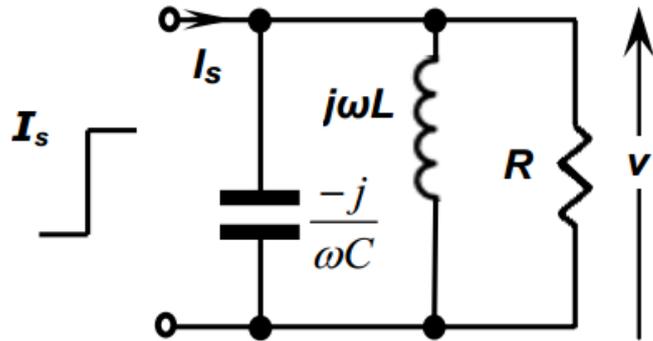
Como resolver o problema?

- ✓ Comutar (ligar e desligar) a chave quando a tensão ou a corrente for zero.
- ✓ Para forçar a corrente/tensão passar por zero é possível utilizar um circuito LC. Esse circuito é chamado de conversor ressonante.

Introdução



Introdução



Aplicações

- ✓ Lâmpadas fluorescentes
- ✓ Aquecimento por indução



Fontes: <https://dmohankumar.wordpress.com/2011/08/28/compact-fluorescent-lamp/>
<http://www.motherearthnews.com/renewable-energy/induction-cooking-zbcz1403>

Classificação dos conversores ressonantes

1. Inversores ressonantes série
2. Inversores ressonantes paralelo
3. Inversores ressonantes classe E
4. Retificadores ressonantes classe E
5. Conversores ressonantes com comutação com tensão zero
(zero-voltage-switching — ZVS)
6. Conversores ressonantes com comutação com corrente zero
(zero-current-switching — ZCS)
7. Conversores ressonantes ZVS de dois quadrantes
8. Inversores com barramento CC ressonante

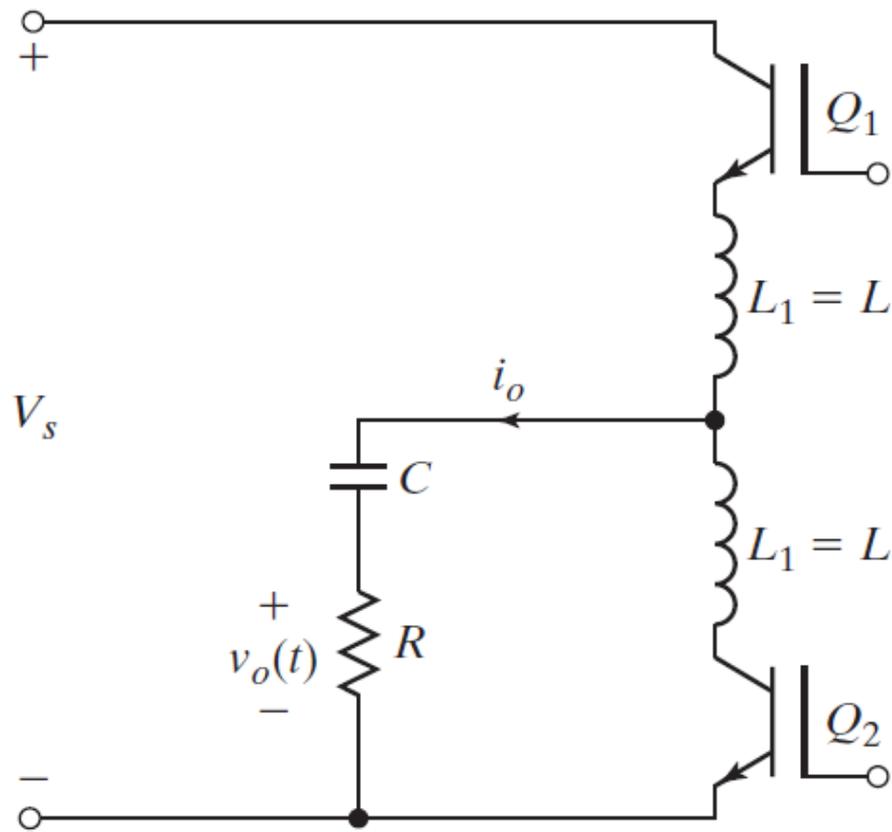
Inversores ressonantes série

- Os inversores ressonantes série são baseados na oscilação ressonante da corrente.

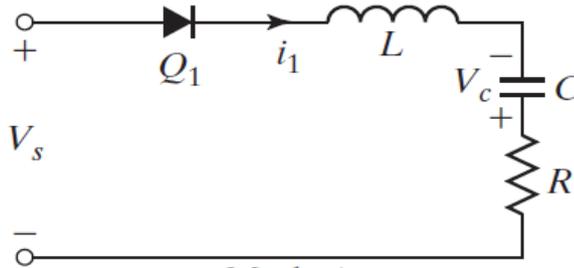
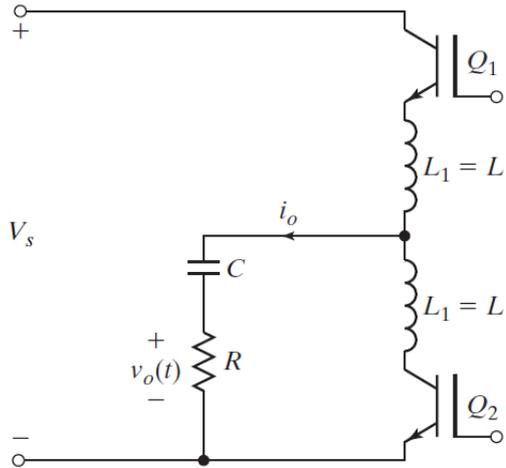
- Os inversores série podem ser classificados em duas categorias:
 1. Inversores ressonantes série com chaves unidirecionais.
 2. Inversores ressonantes série com chaves bidirecionais.

- Há três tipos de inversor ressonante série:
 1. Básico,
 2. Meia ponte
 3. Ponte completa.

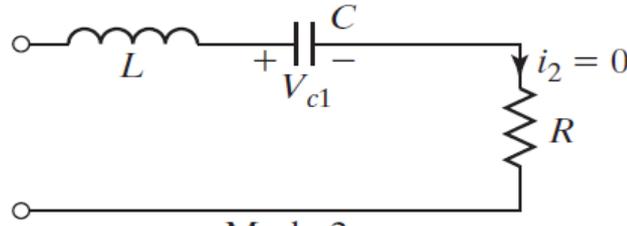
Inversores ressonantes série básico



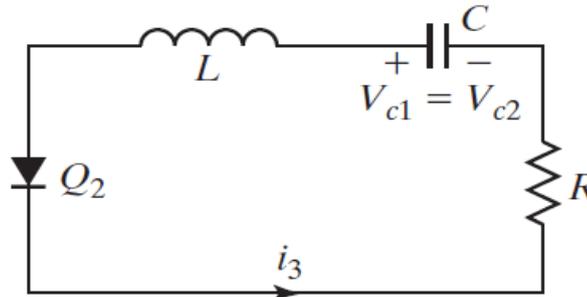
Inversores ressonantes série básico



Modo 1

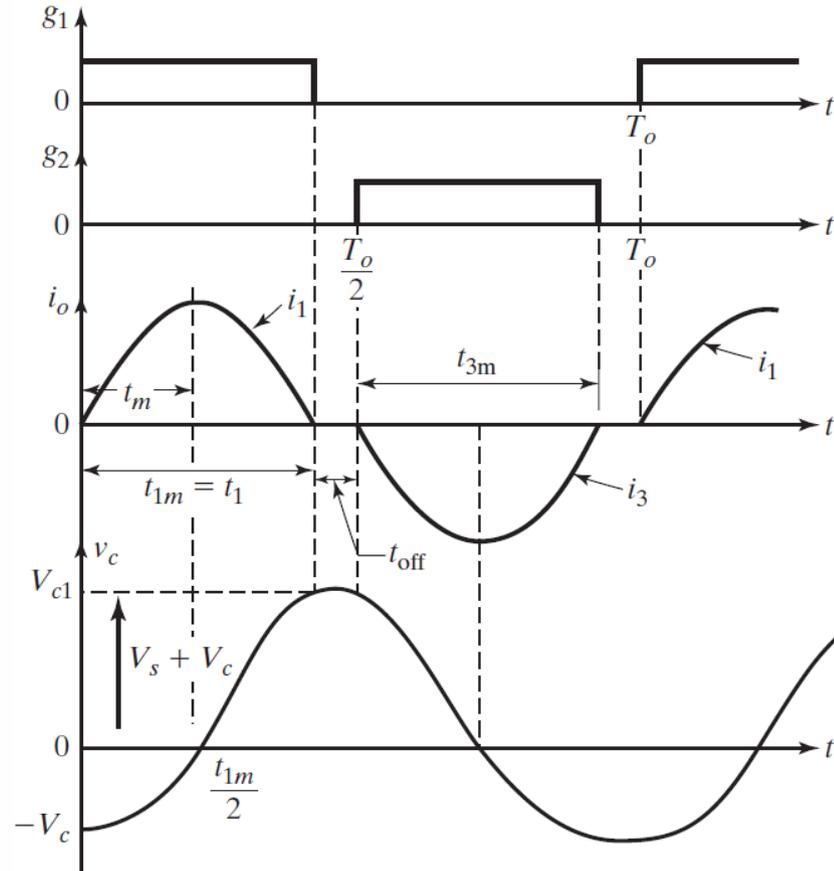


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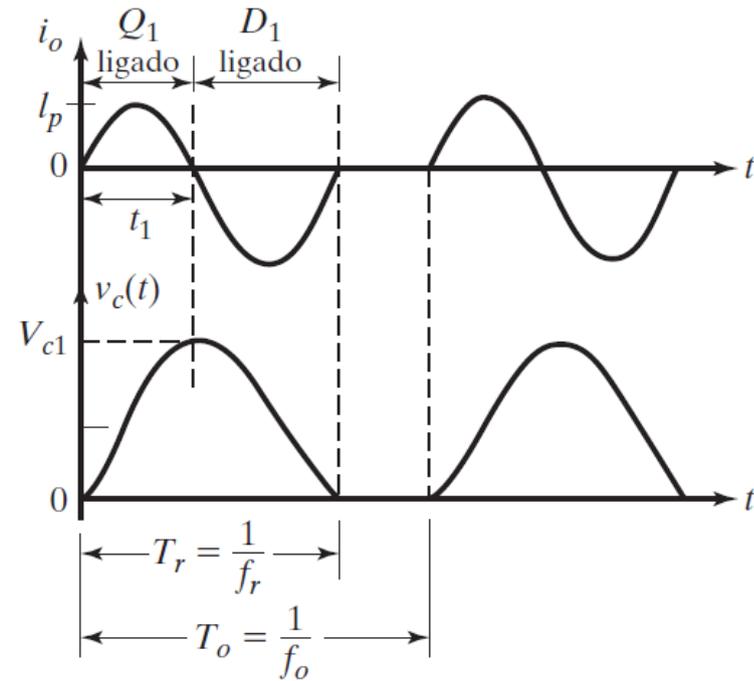
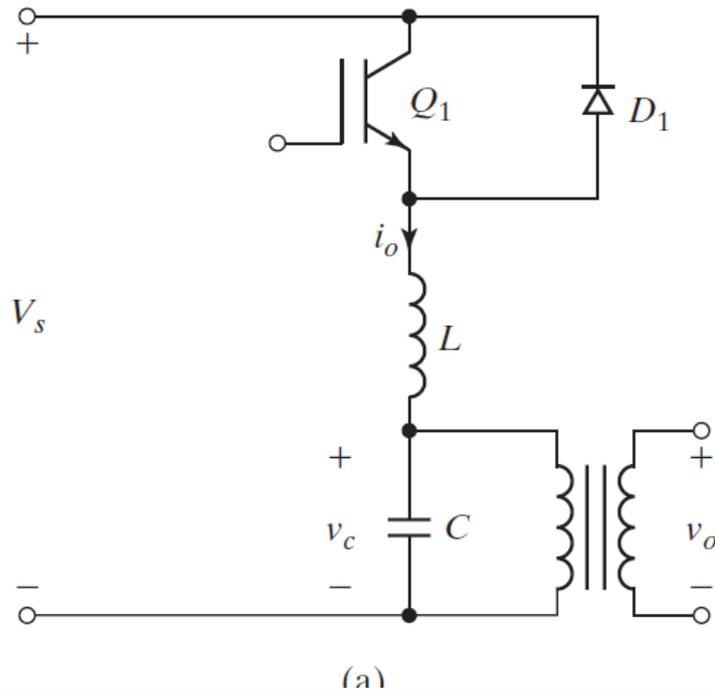


Modo 3

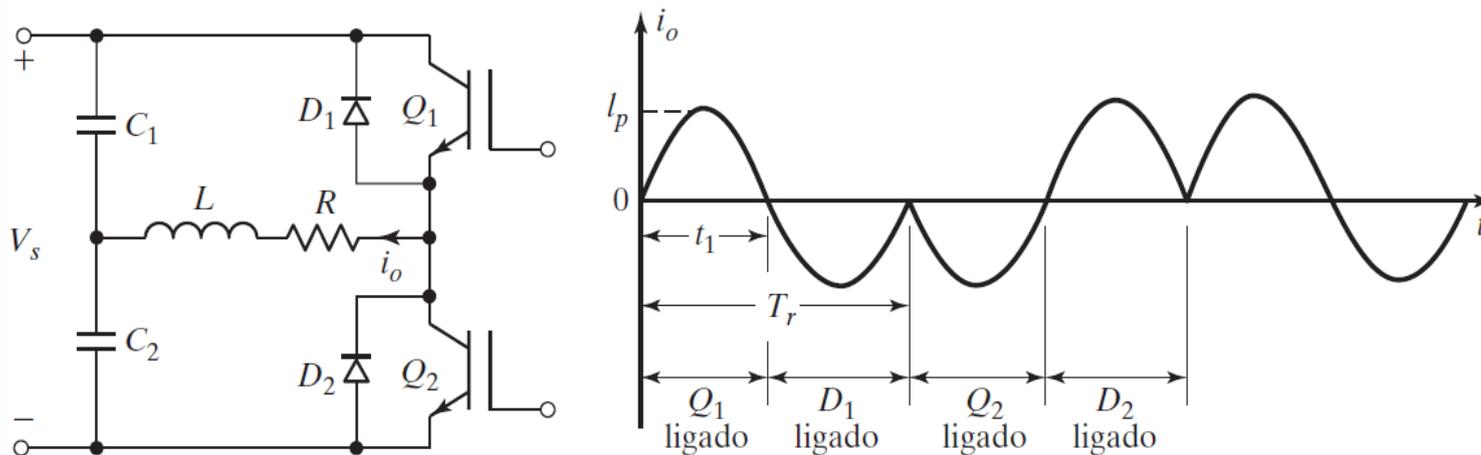
Inversores ressonantes série básico



Inversores ressonantes série básico

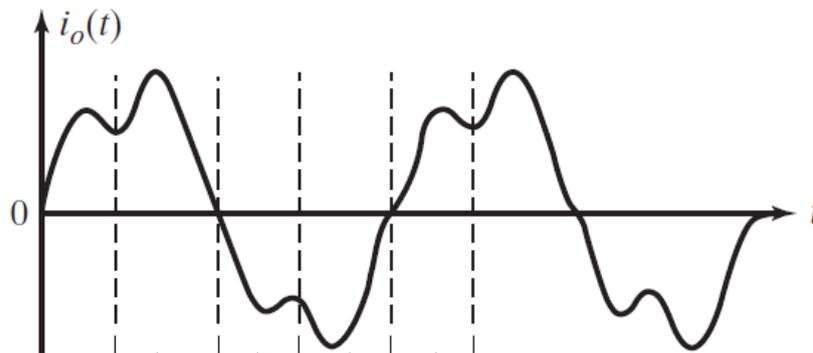
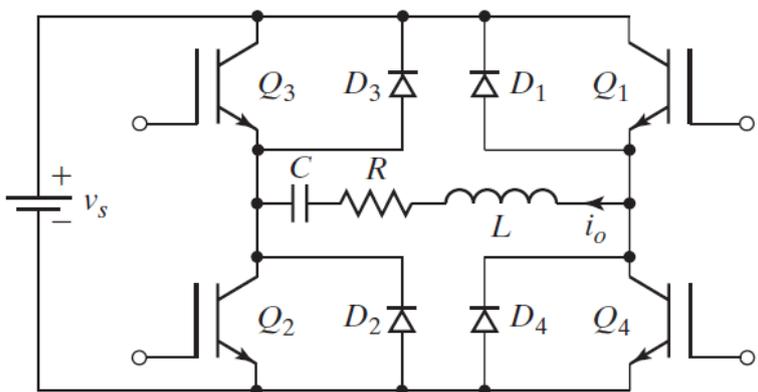


Inversores ressonantes série



Inversores ressonantes série

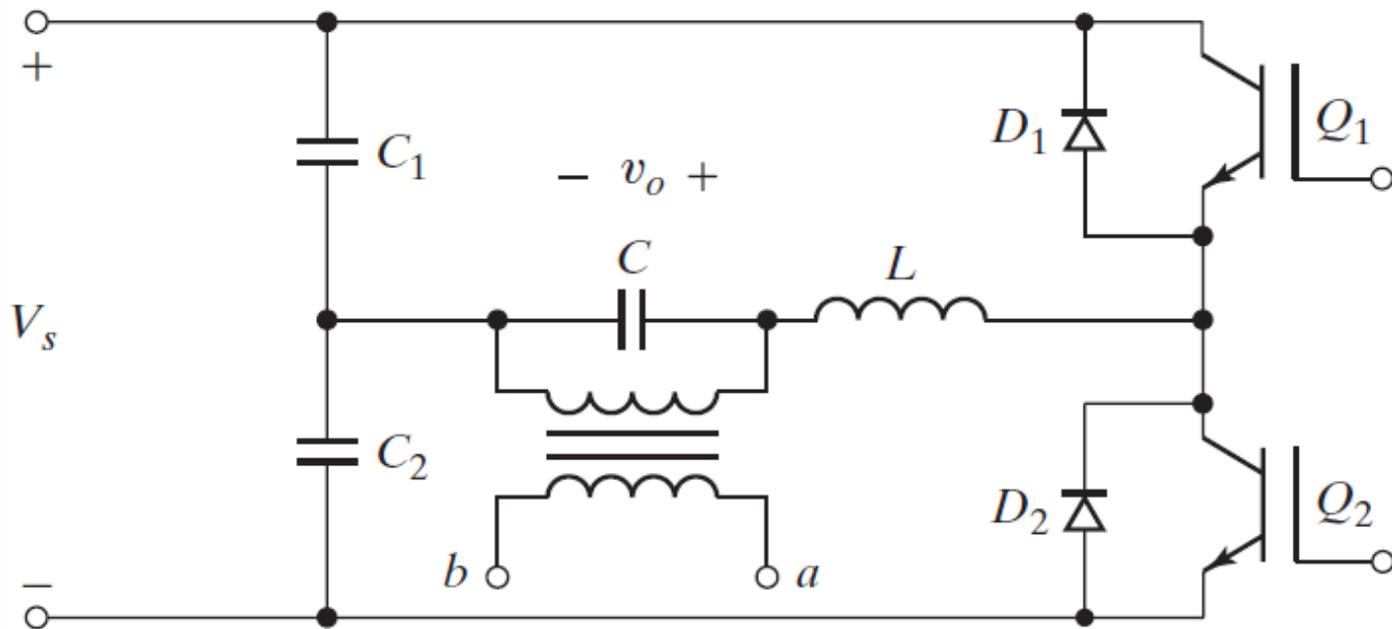
- Inversores série em ponte completa com chaves bidirecionais:



Q1	D1	Q3	D3
Q2	D2	Q4	D4

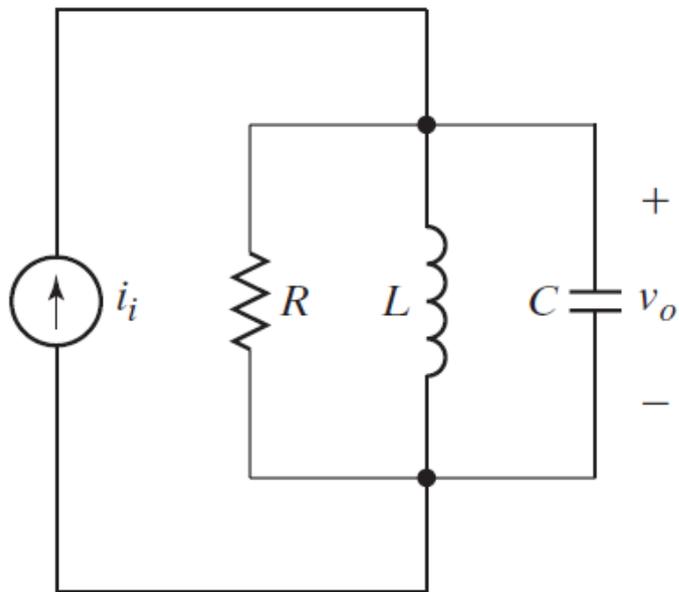
Inversores ressonantes série

- Inversor ressonante em meia ponte com transformador:

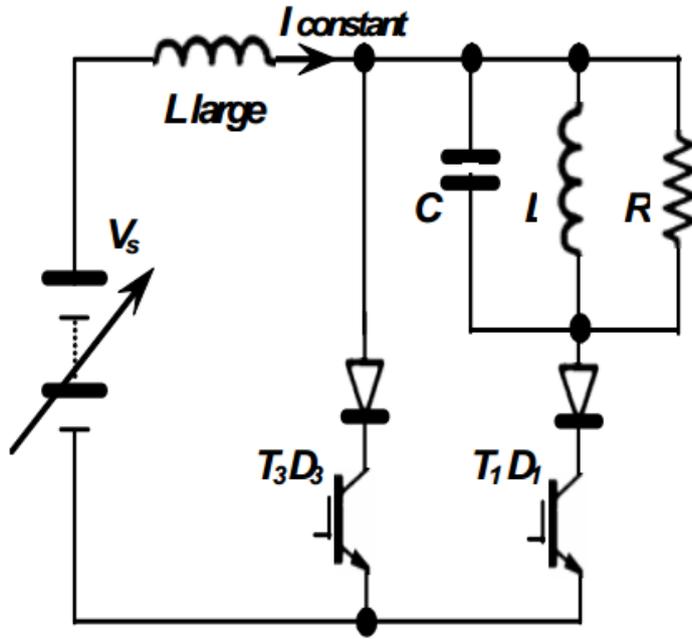


Inversores ressonantes paralelo

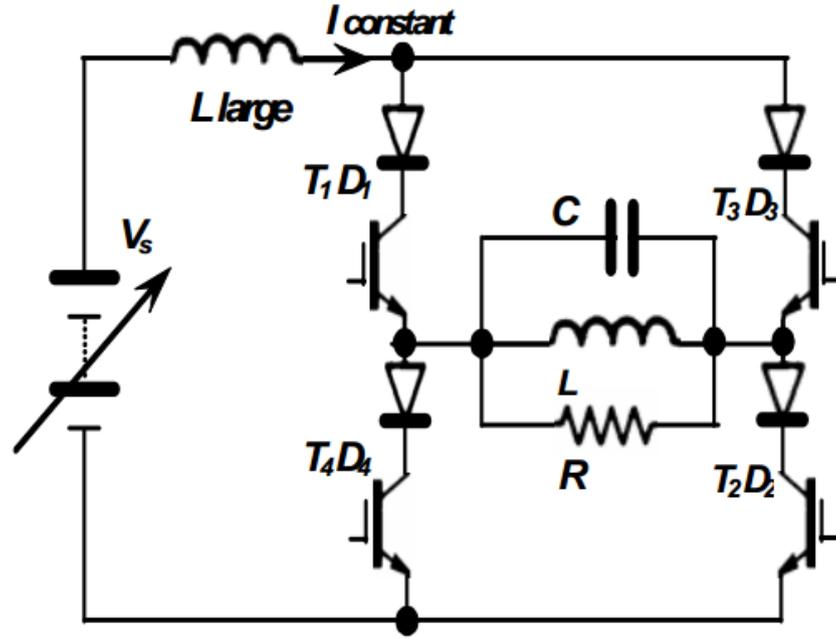
- Um inversor ressonante paralelo é o dual de um inversor ressonante série.
- Ele é alimentado a partir de uma fonte de corrente.



Inversores resonantes paralelo

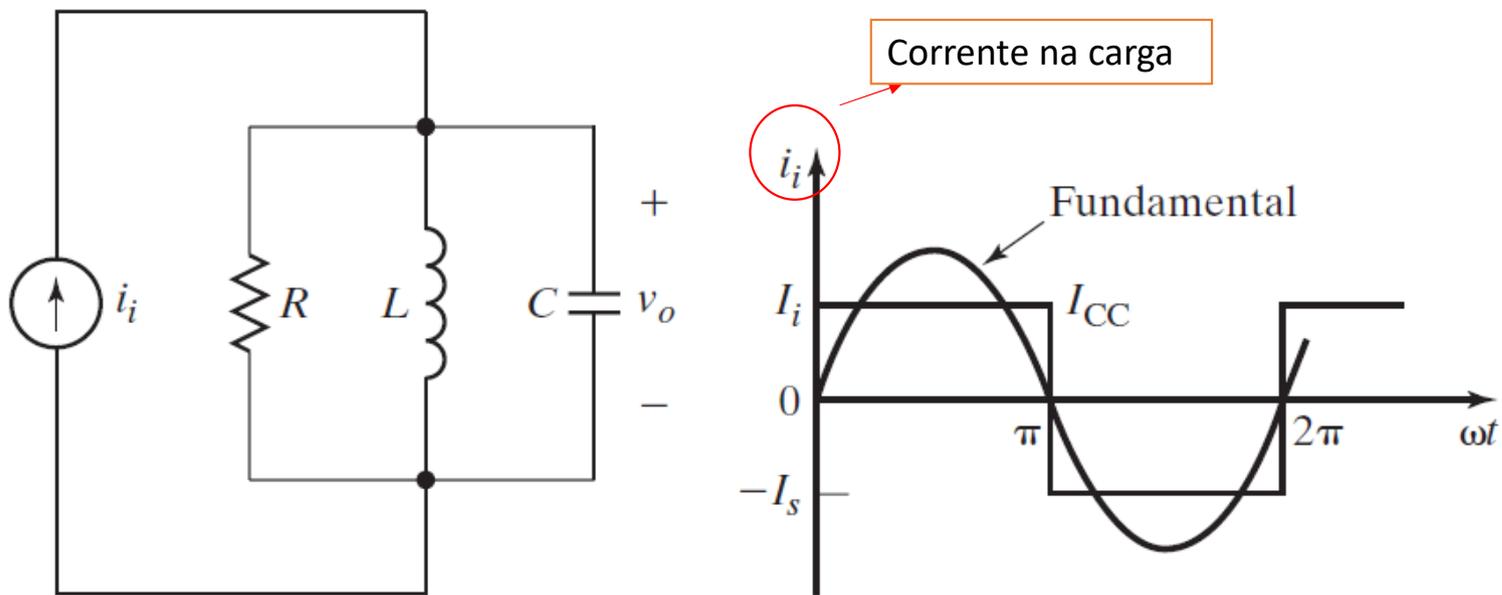


CSI

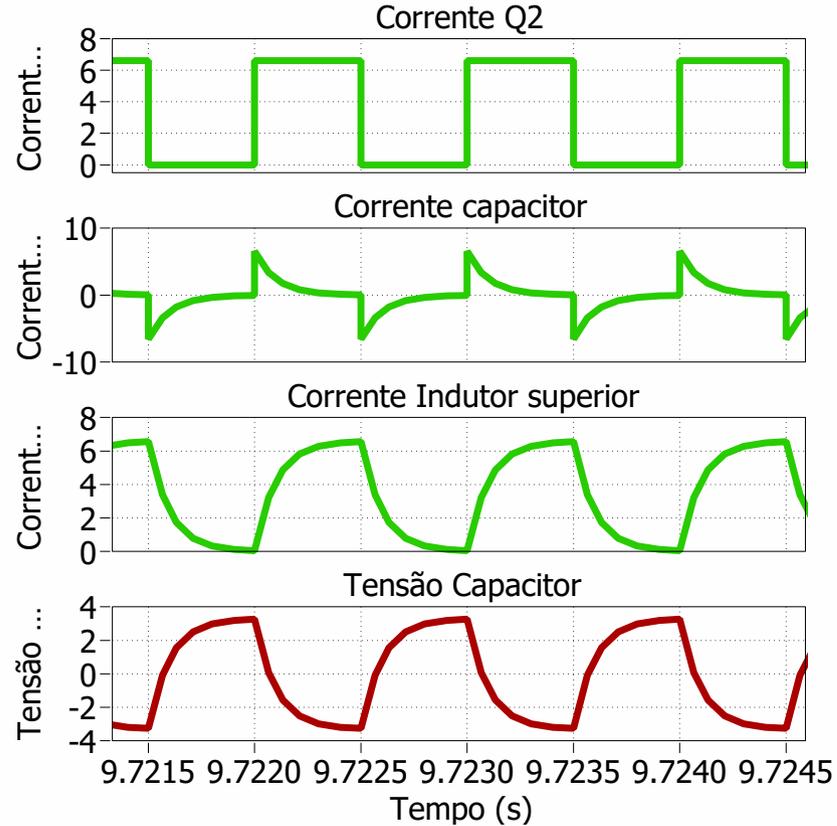
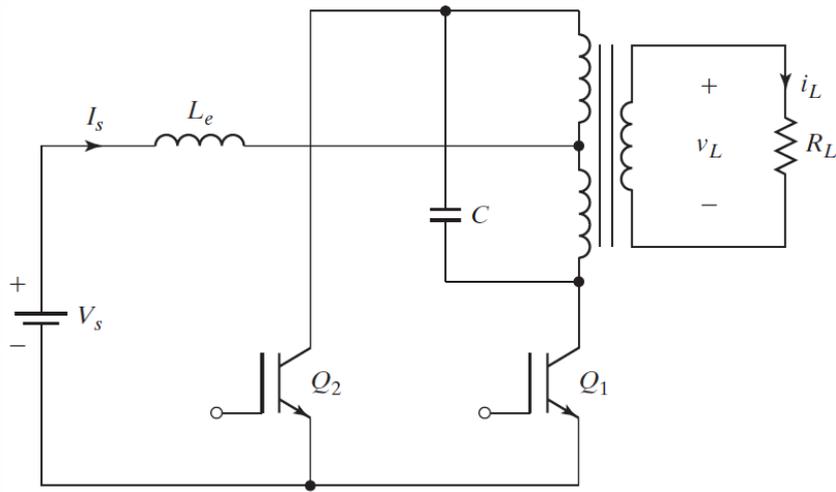


Inversores ressonantes paralelo

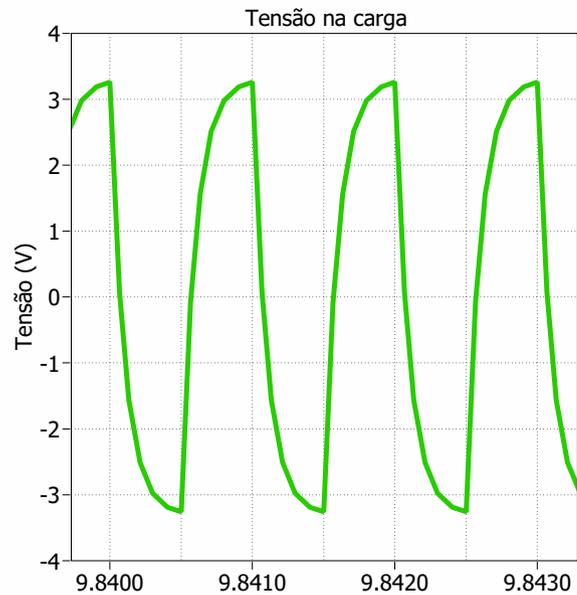
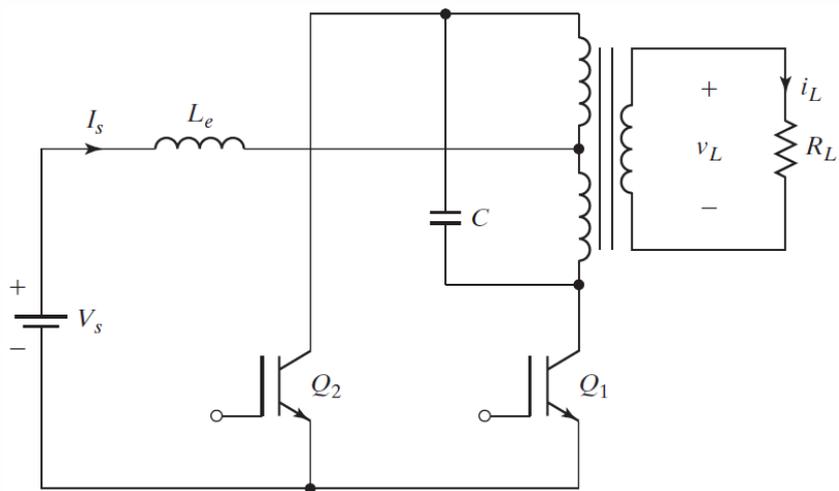
- Um inversor ressonante paralelo é o dual de um inversor ressonante série.
- Ele é alimentado a partir de uma fonte de corrente.



Inversores ressonantes paralelo



Inversores ressonantes paralelo





Abraço

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Aula 10 – Inversores de pulso ressonante

Parte 2 – Inversor e Retificador ressonantes classe E
+ ZCS e ZVS

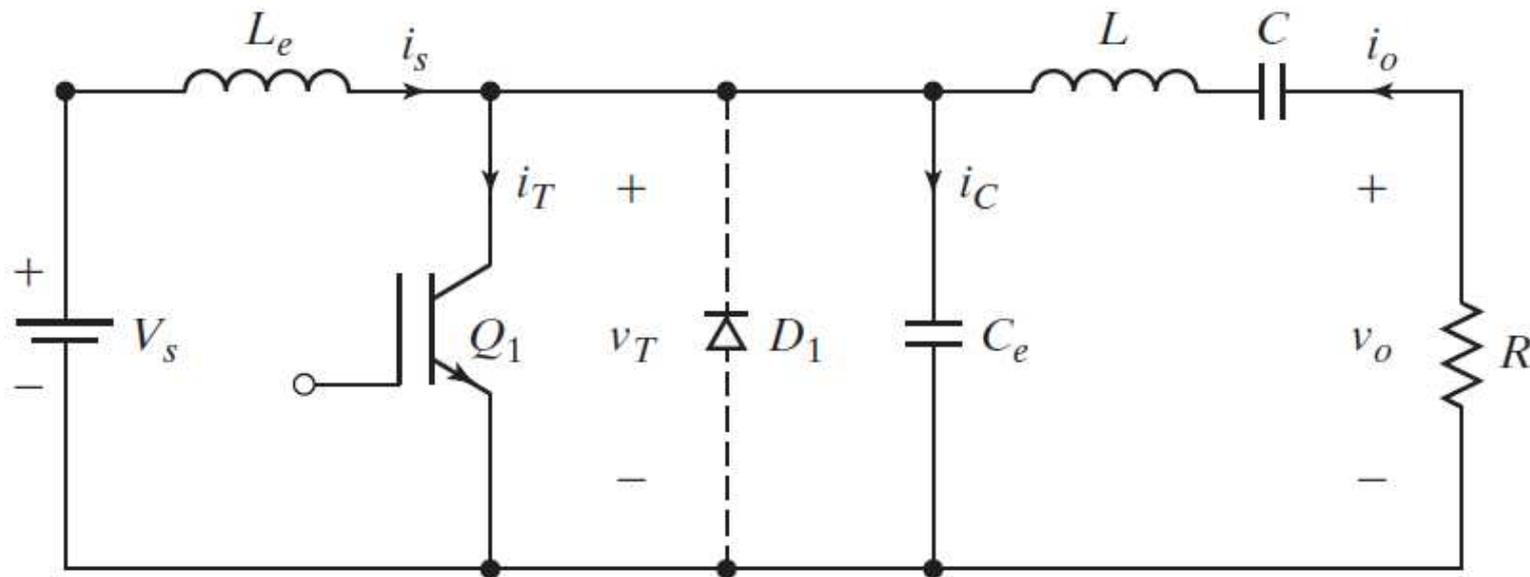


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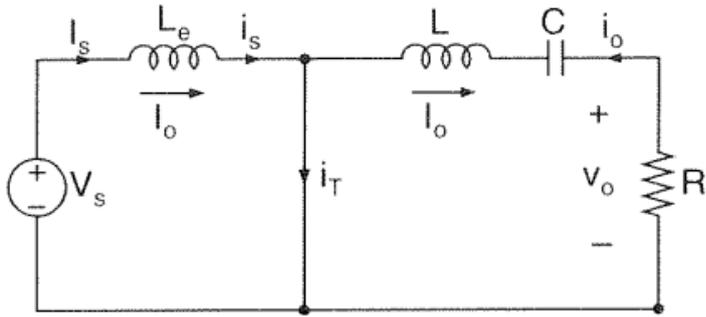


Inversores ressonantes classe E

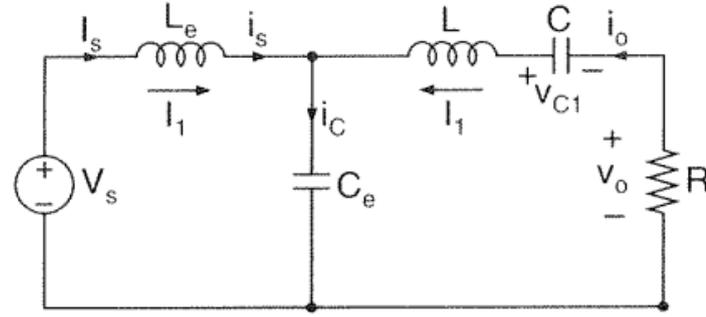
- Utiliza apenas um transistor e tem baixas perdas por chaveamento, com uma alta eficiência de mais de 95%:



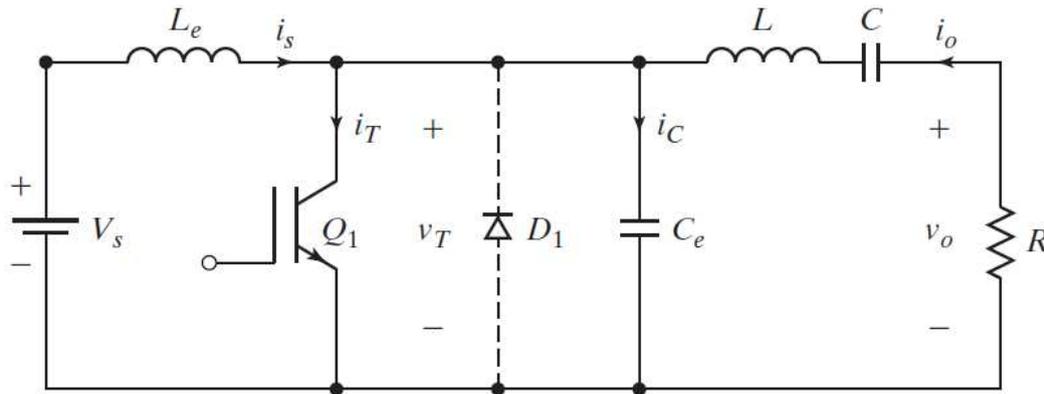
Inversores ressonantes classe E



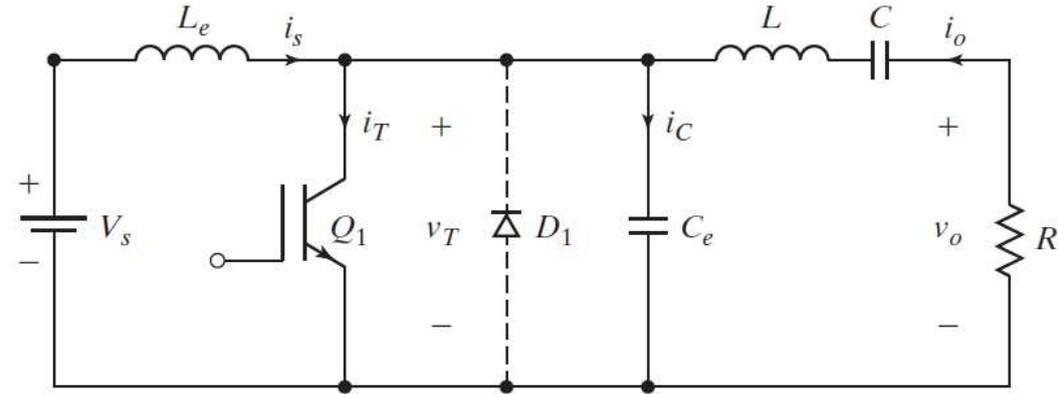
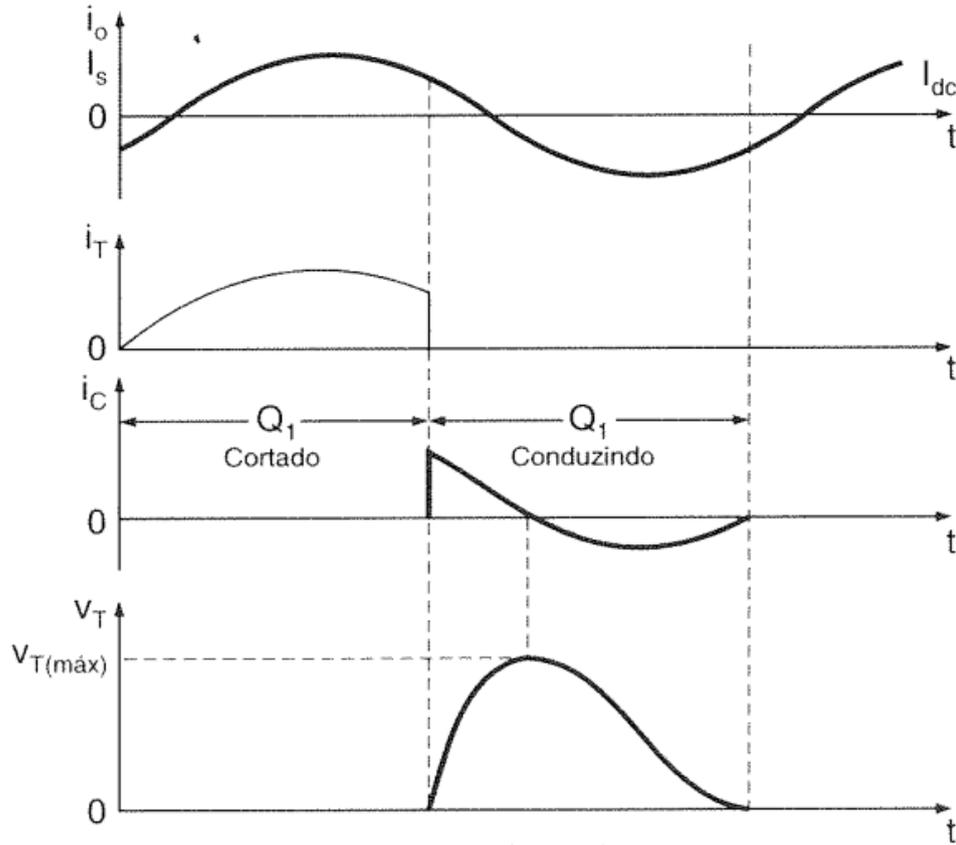
Modo 1



Modo 2

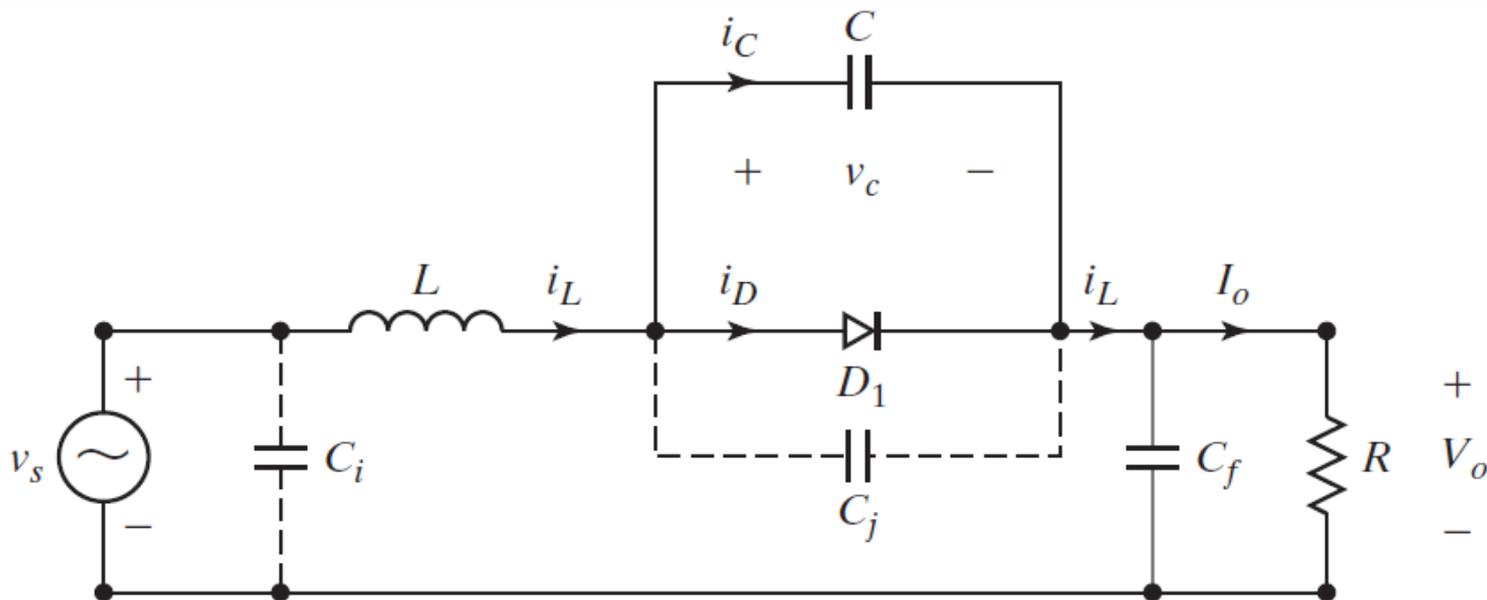


Inversores ressonantes classe E

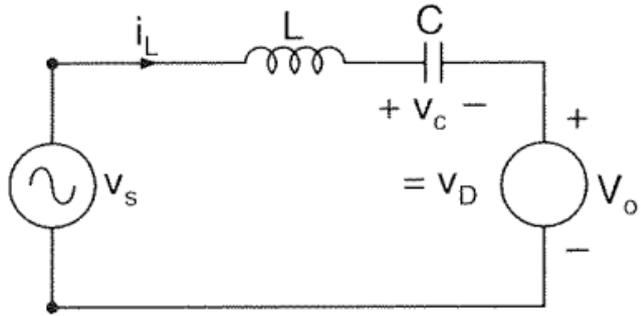


Retificador ressonantes classe E

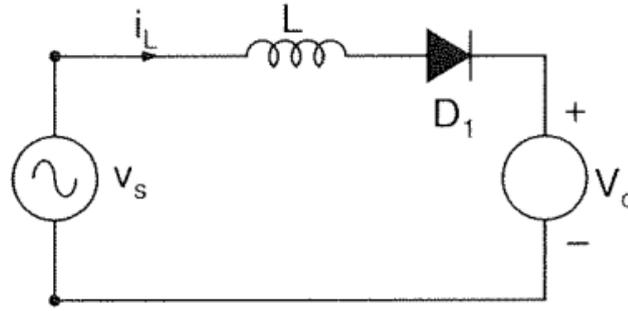
- Um retificador ressonante classe E usa o princípio de chaveamento em tensão zero do diodo.
- Isto é, o diodo desliga em tensão zero.



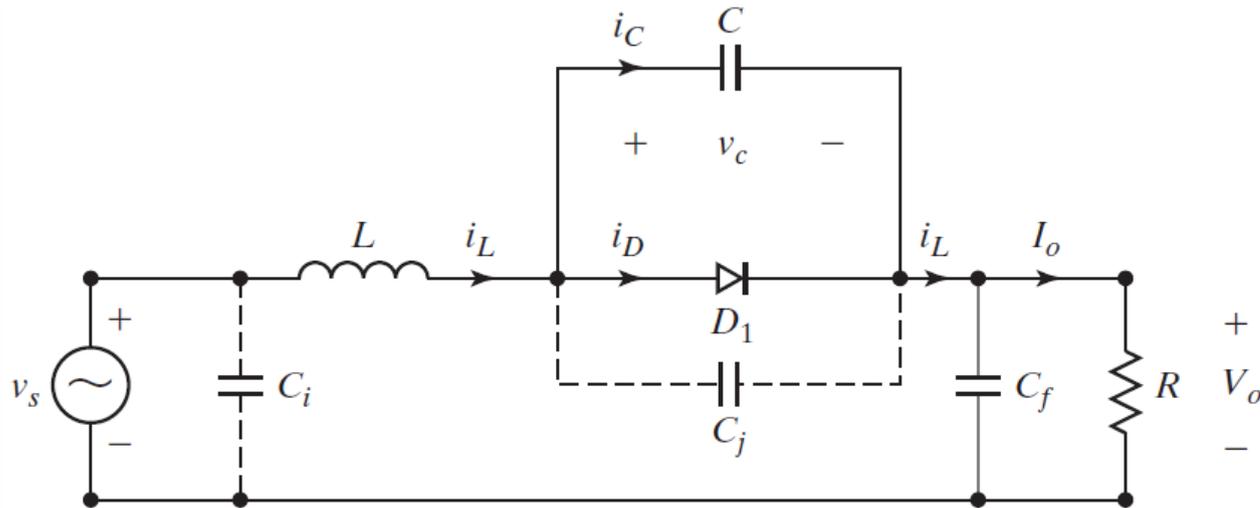
Retificador ressonantes classe E



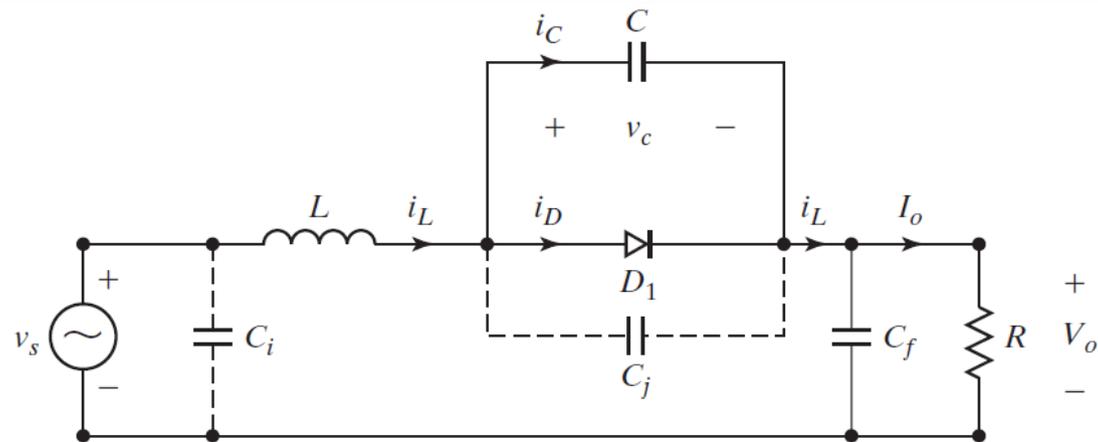
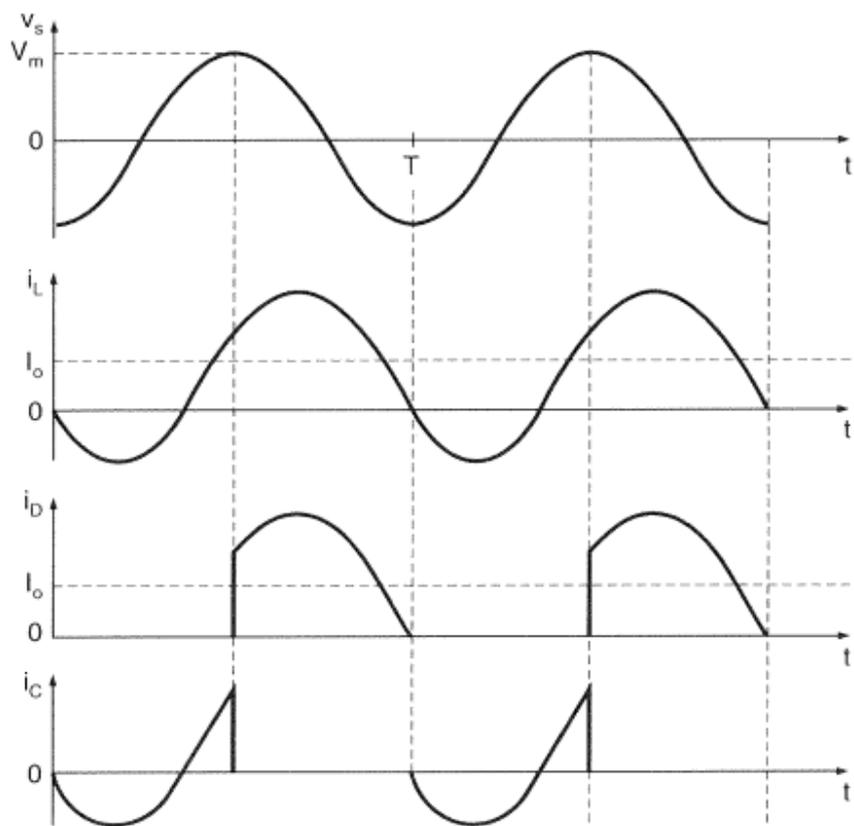
Modo 1



Modo 2



Retificador ressonantes classe E



Class E—A New Class of High-Efficiency Tuned Single-Ended Switching Power Amplifiers

NATHAN O. SOKAL, SENIOR MEMBER, IEEE, AND ALAN D. SOKAL

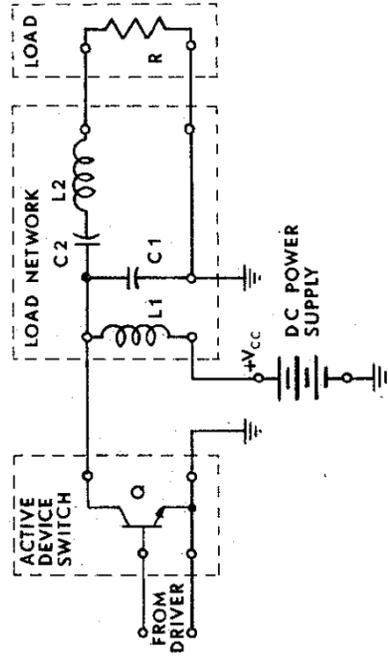
$$L2 = Q_L R / 2\pi f, \quad \text{from the definition of } Q_L. \quad (2)$$

To satisfy the conditions $V_{CE} = 0$ and $dV_{CE}/dt = 0$ at $t = 0.5/f$ after switch turnoff, given the chosen Q_L ,

$$C1 = 1/2\pi f R \left(\frac{\pi^2}{4} + 1 \right) \left(\frac{\pi}{2} \right) = 1/2\pi f R 5.447, \quad (3)$$

and

$$C2 \approx \left(\frac{1}{(2\pi f)^2 L2} \right) \left(1 + \frac{1.42}{Q_L - 2.08} \right) \approx C1 \left(\frac{5.447}{Q_L} \right) \left(1 + \frac{1.42}{Q_L - 2.08} \right). \quad (4)$$



Class E – A New Class of High-Efficiency Tuned Single-Ended Switching Power Amplifiers

NATHAN O. SOKAL, SENIOR MEMBER, IEEE, AND ALAN D. SOKAL

Class E-A new class of high-efficiency tuned single-ended switching power amplifiers

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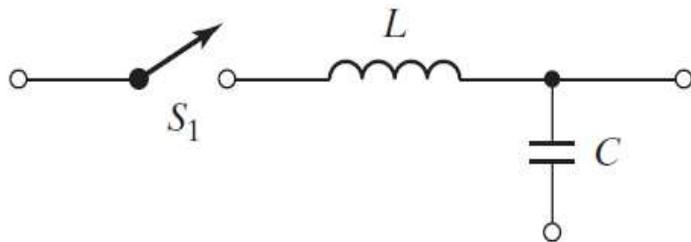
1130
Paper
Citations

72
Patent
Citations

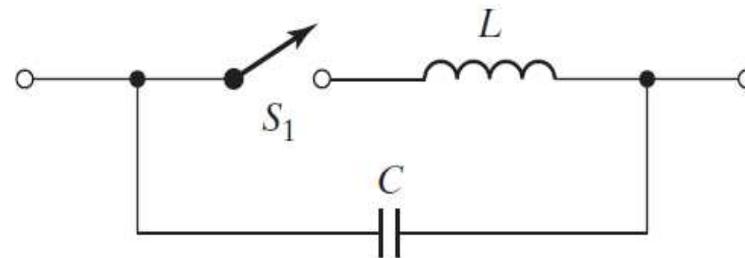
9532
Full
Text Views

Conversores ressonantes com comutação com corrente zero

- As chaves do conversor ressonante com comutação com corrente zero (ZCS) são ligadas e desligadas com corrente nula:



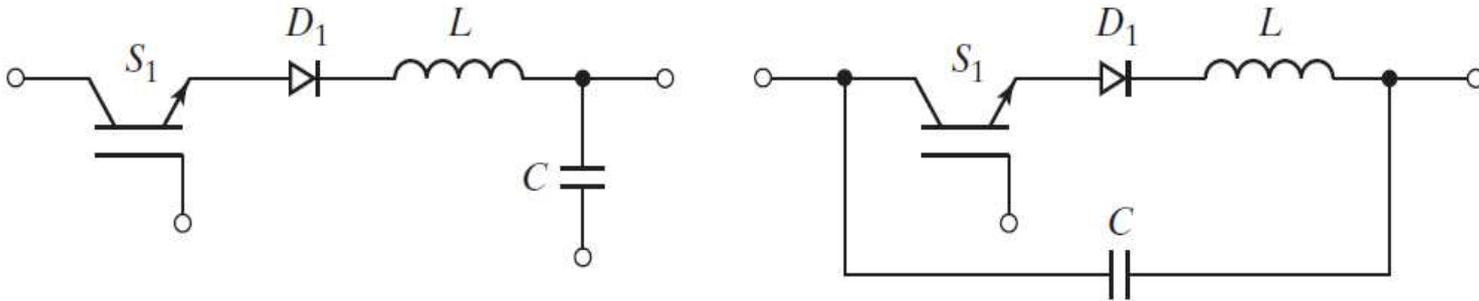
Tipo L



Tipo M

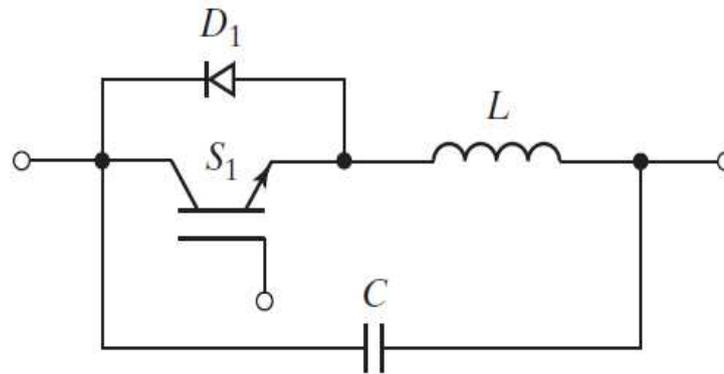
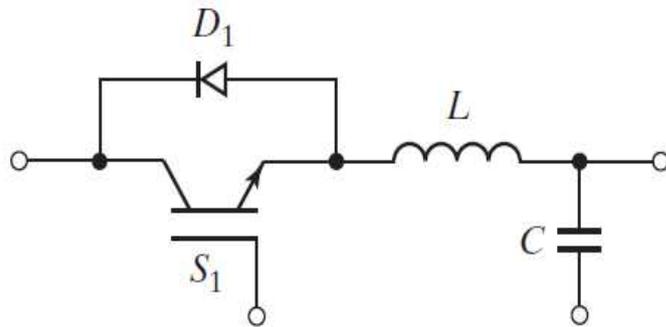
Conversores ressonantes com comutação com corrente zero

- A chave pode ser implementada com uma configuração em meia onda:



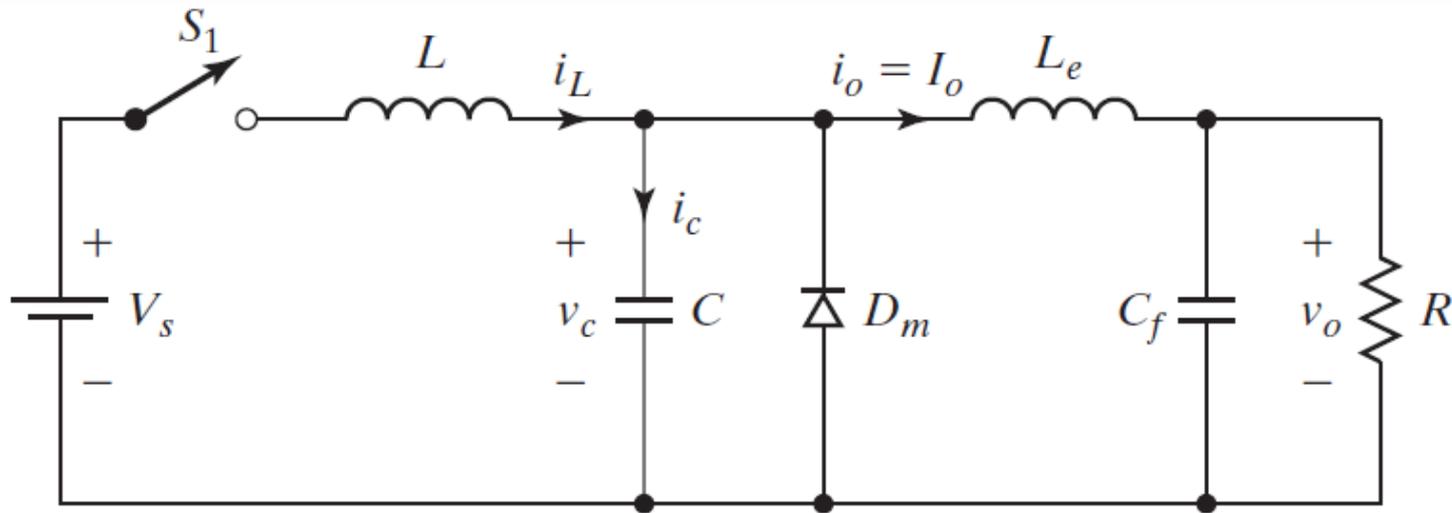
Conversores ressonantes com comutação com corrente zero

- Tipos em onda completa:



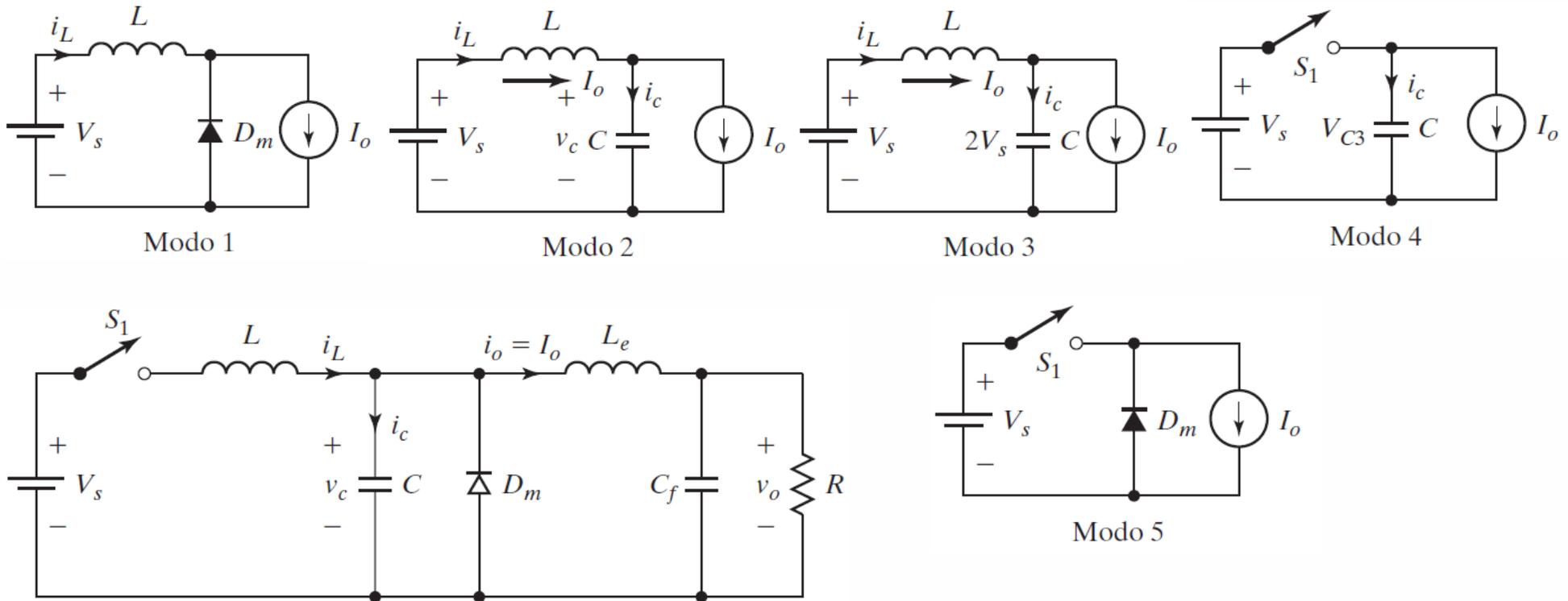
Conversores ressonantes com comutação com corrente zero

- Conversor ressonante ZCS tipo L .

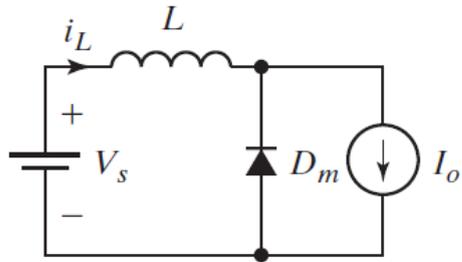


Conversores ressonantes com comutação com corrente zero

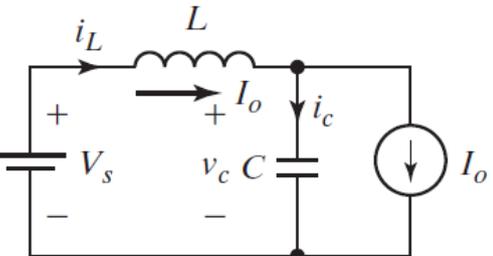
- Conversor ressonante ZCS tipo L .



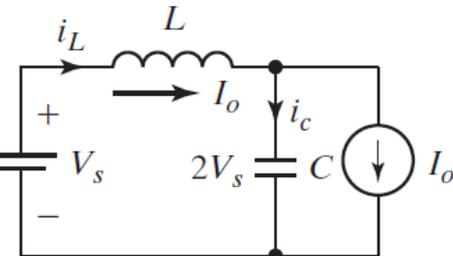
Conversores ressonantes com comutação com corrente zero



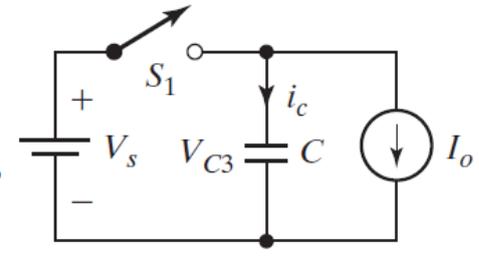
Modo 1



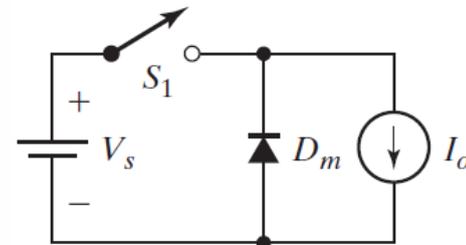
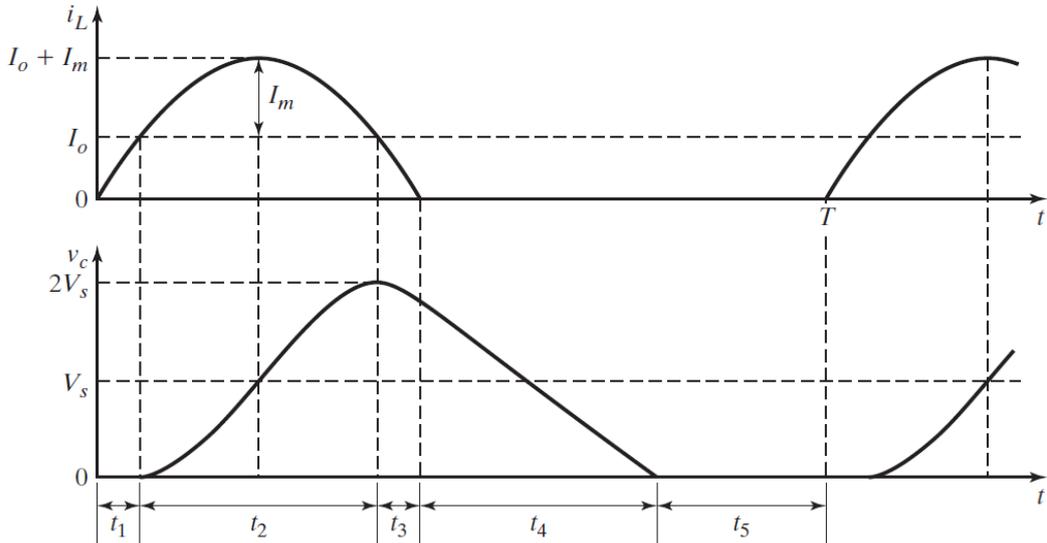
Modo 2



Modo 3



Modo 4



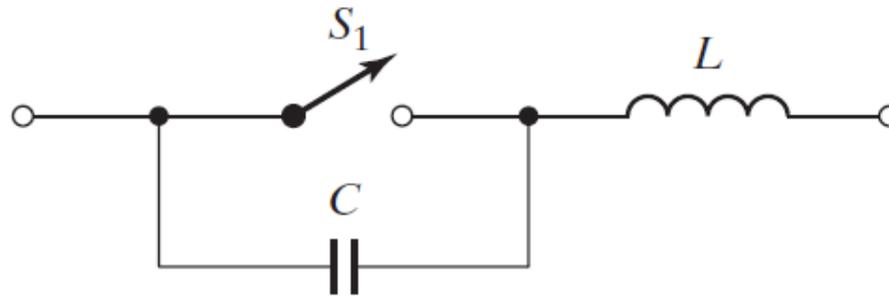
Modo 5

Conversores ressonantes com comutação com corrente zero

- Conversor ressonante ZCS tipo L . Corrente do indutor e tensão no capacitor:

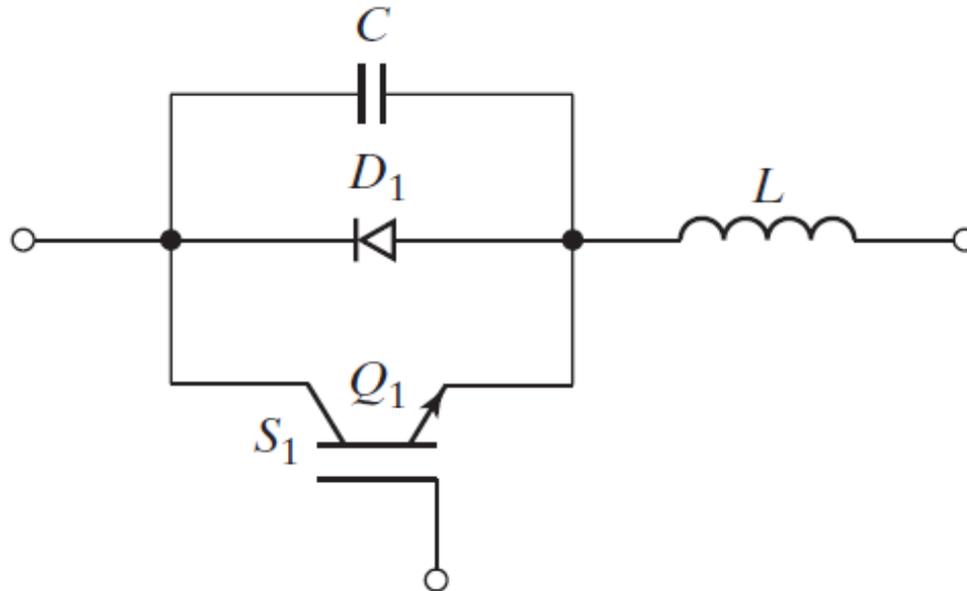
Conversores ressonantes com comutação com tensão zero

- As chaves de um conversor ressonante ZVS ligam e desligam com tensão nula:



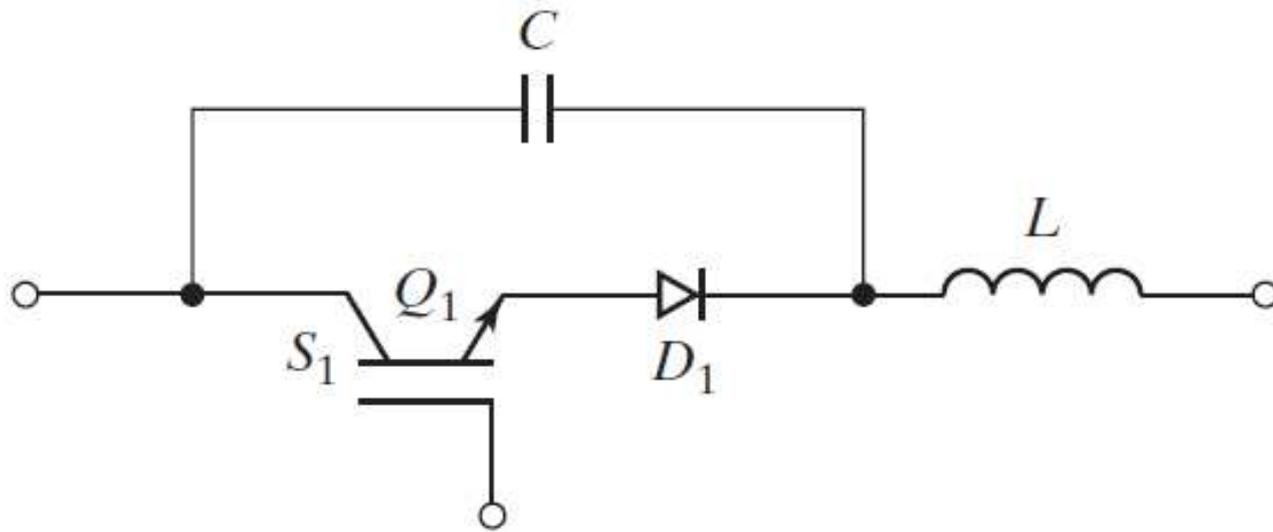
Conversores ressonantes com comutação com tensão zero

- Se a chave for implementada com um transistor Q_1 e um diodo em antiparalelo D_1 , a tensão sobre C é grampeada por D_1 , e a chave opera em uma configuração de meia onda:



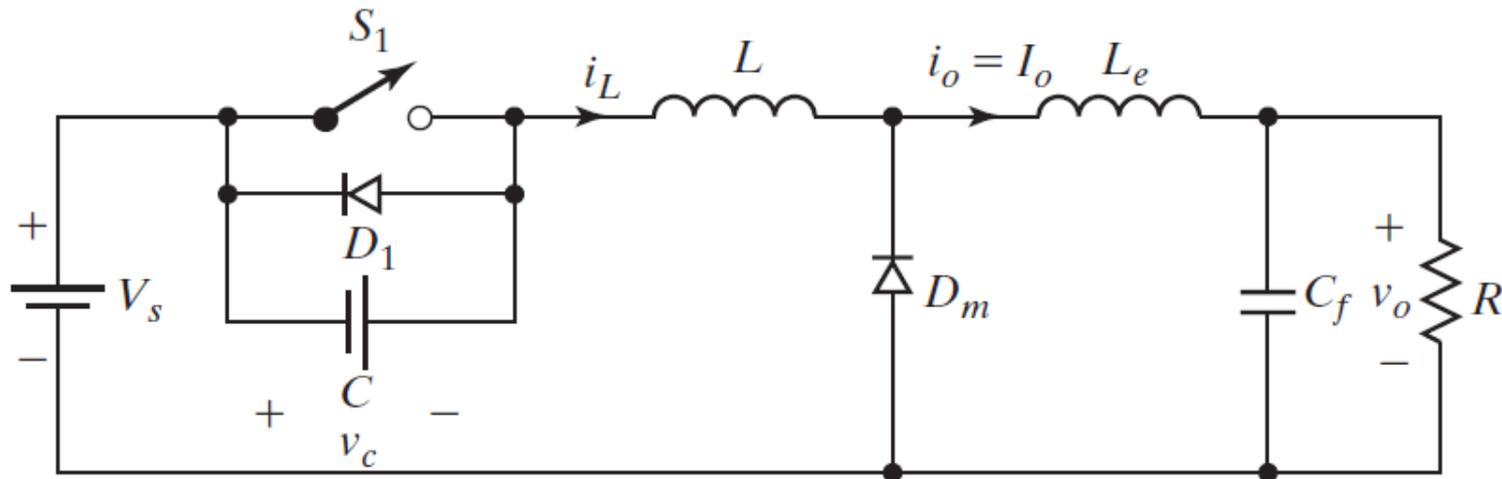
Conversores ressonantes com comutação com tensão zero

- Se o diodo D_1 for conectado em série com Q_1 , a tensão sobre C pode oscilar livremente, e a chave opera em uma configuração de onda completa:



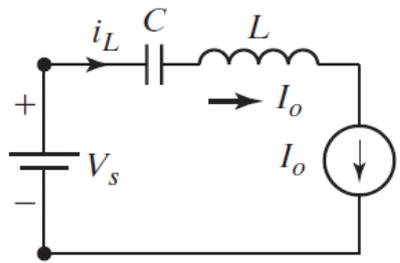
Conversores ressonantes com comutação com tensão zero

- Conversor ressonante ZVS.

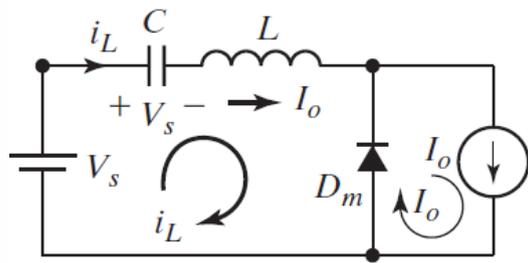


Conversores ressonantes com comutação com tensão zero

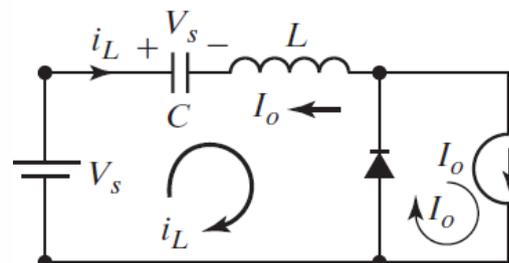
- Conversor ressonante ZVS. Circuitos equivalentes:



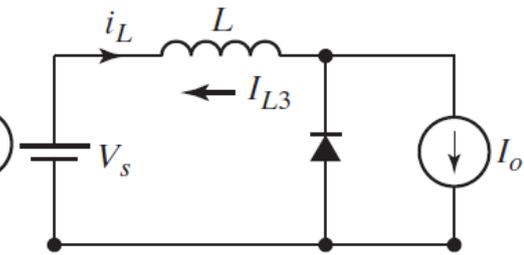
Modo 1



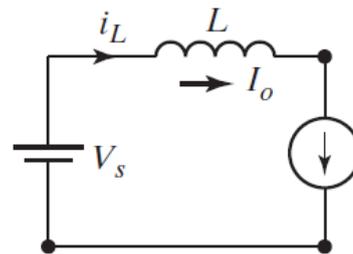
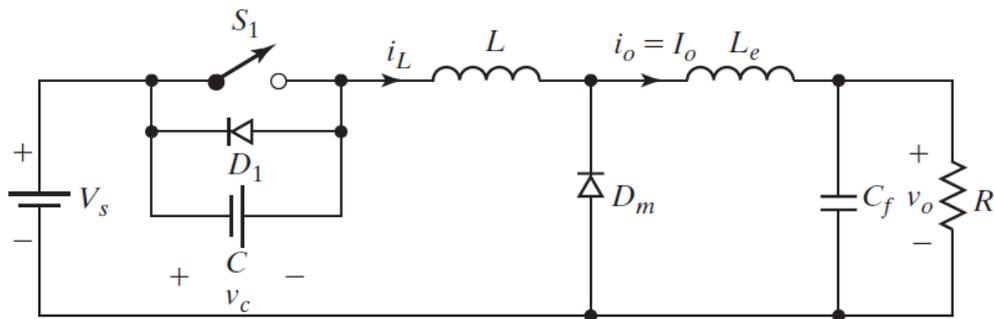
Modo 2



Modo 3

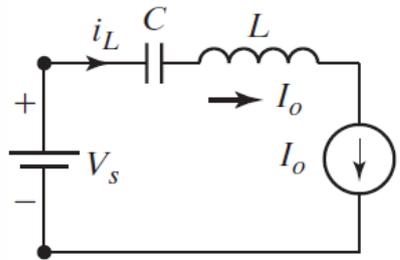


Modo 4

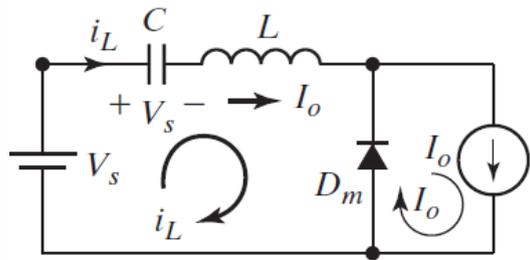


Modo 5

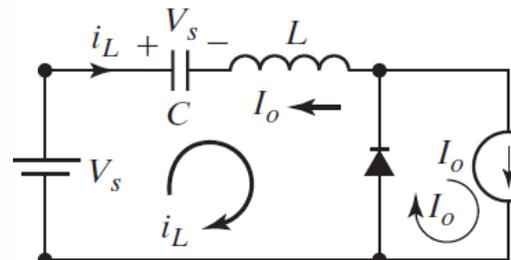
Conversores ressonantes com comutação com tensão zero



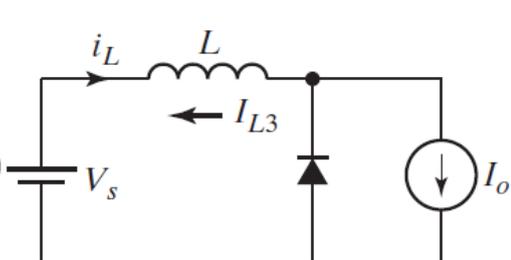
Modo 1



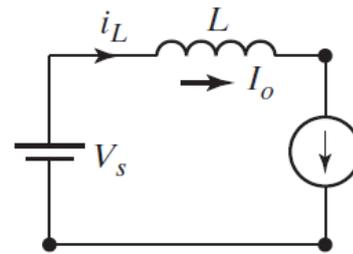
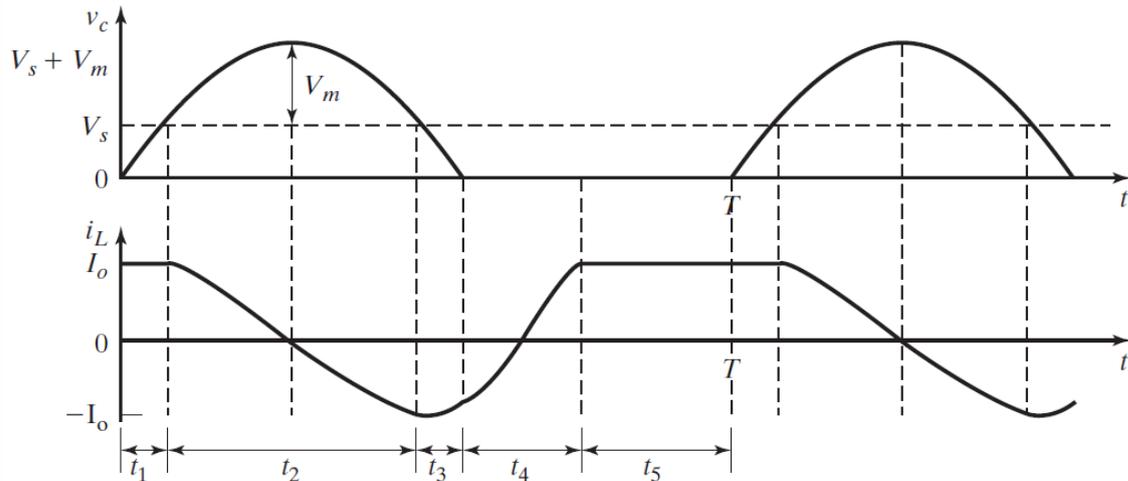
Modo 2



Modo 3



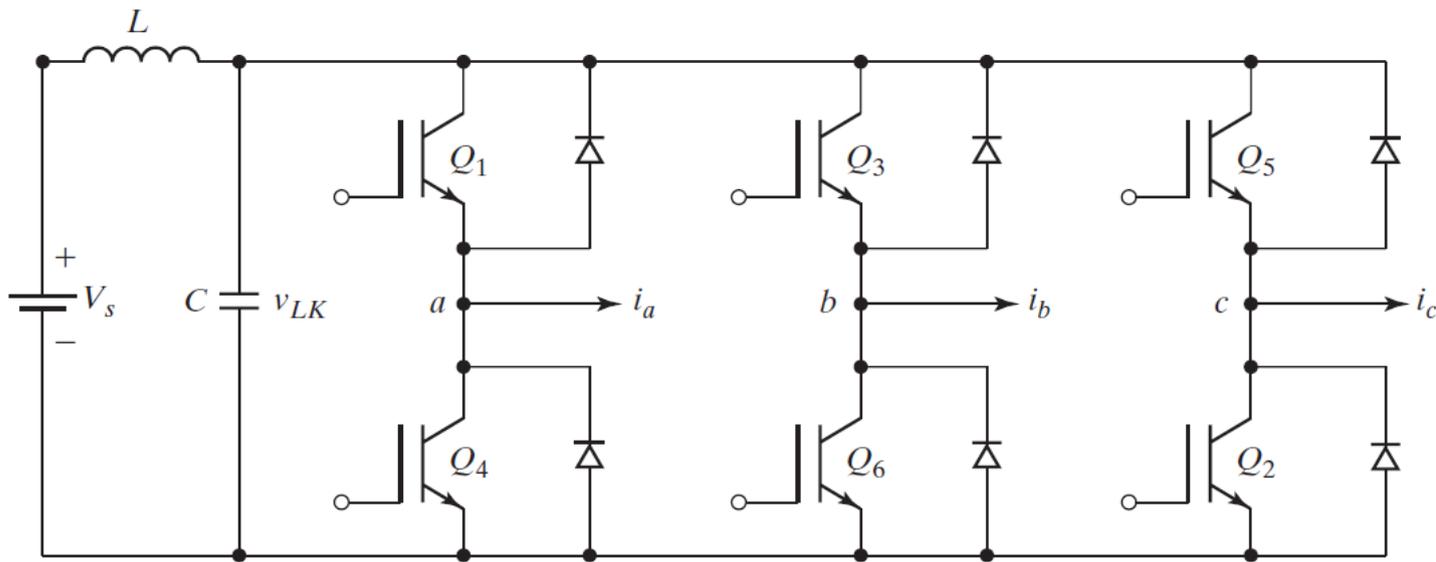
Modo 4



Modo 5

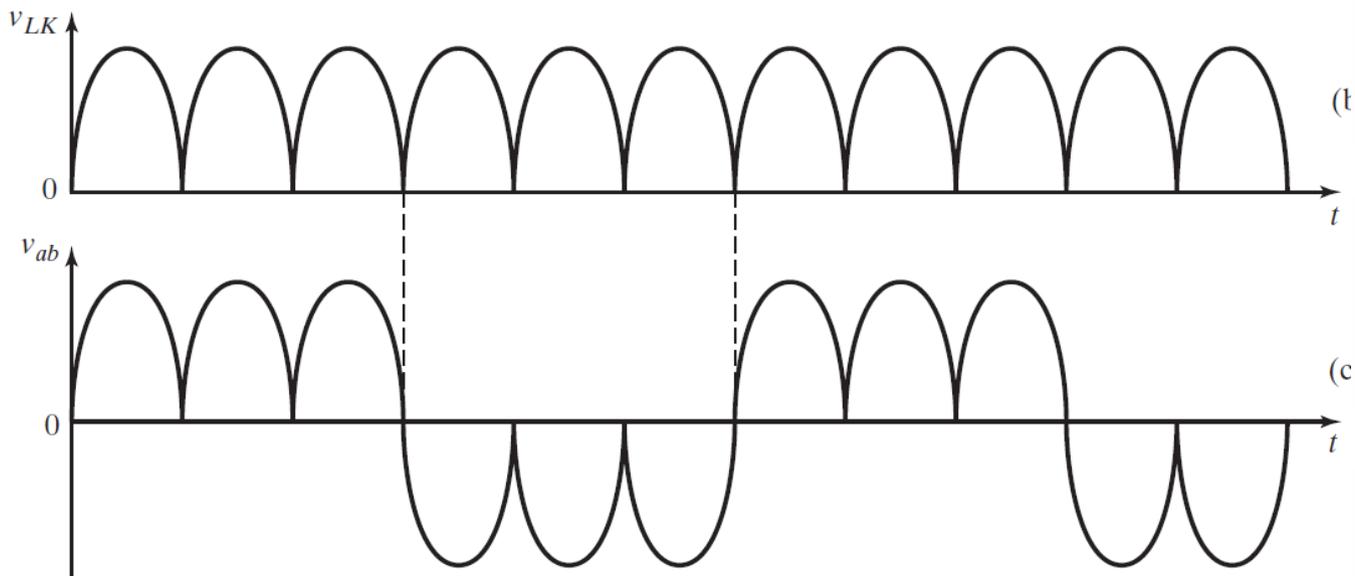
Inversores com barramento CC ressonante

- Inversor trifásico com barramento CC ressonante.



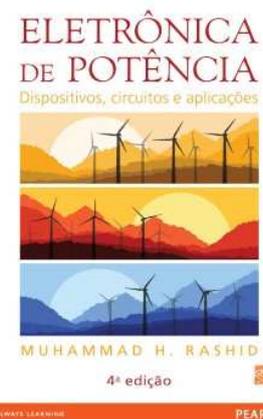
Inversores com barramento CC ressonante

- Inversor trifásico com barramento CC ressonante. Tensão do tanque e tensão de saída:



Capítulo 7 do Livro

M. H. Rashid: Eletrônica de Potência: Dispositivos, circuitos e aplicações. 4ª. Edição, Pearson, 2014



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