Instituto Federal de Educação, Ciência e Tecnologia de Santa Catarina
Departamento Acadêmico de Eletrônica
Pós-Graduação em Desen. de Produtos Eletrônicos
Conversores Estáticos e Fontes Chaveadas

INSTITUTO FEDERAL
SANTA CATARINA

Conversores CC-CC
(Buck-Boost e Flyback)

Prof. Clovis Antonio Petry.
Prof. Joabel Moia.

Florianópolis, abril de 2014.

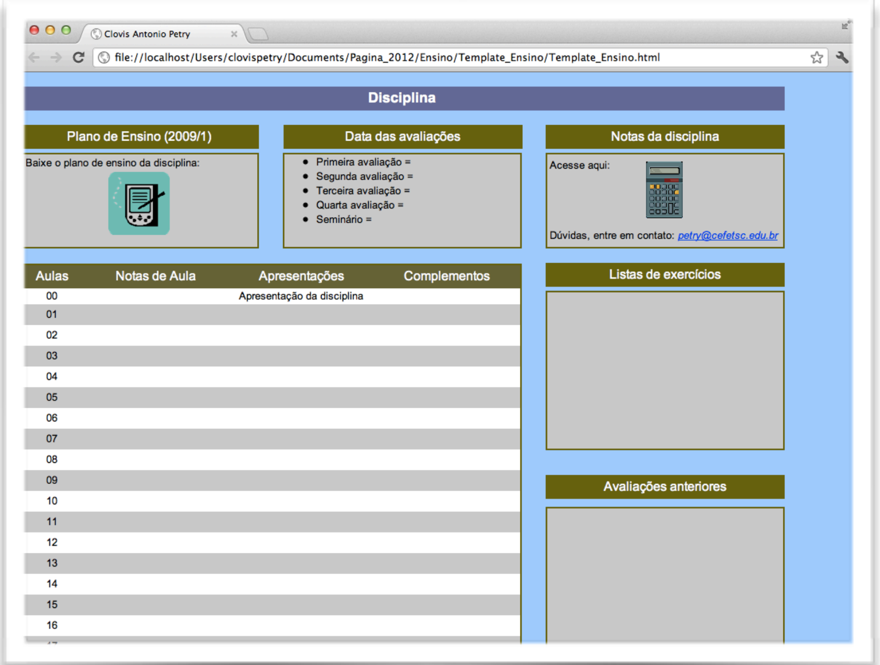
Biografia para Esta Aula

Conversores cc-cc:

- Conversor CC-CC elevador - Boost;
- Conversor CC-CC do tipo Push-Pull com entrada em corrente;
- Conversor CC-CC abaixador-elevador – Buck-Boost;
- Conversor CC-CC do Flyback;
- Outras topologias de conversores CC-CC.

Eletrônica de Potência
Ivo Barbi
Edição
Eletrônica de Potência
Ahmed
Eletrônica de Potência
de fontes
eadas
BARBI
Media Enhanced Third Edition
Power Electronics
Converters, Applications, and Design
Mohan • Undeland • Robbins

www.ProfessorPetry.com.br


Clovis Antonio Petry

file://localhost/Users/clovispetry/Documents/Pagina_2012/Ensino/Template_Ensino/Template_Ensino.html

Disciplina

Plano de Ensino (2009/1)

Baixe o plano de ensino da disciplina:

Data das avaliações

- Primeira avaliação =
- Segunda avaliação =
- Terceira avaliação =
- Quarta avaliação =
- Seminário =

Notas da disciplina

Acesse aqui:

Dúvidas, entre em contato: petry@cefetsc.edu.br

Aulas	Notas de Aula	Apresentações	Complementos
00		Apresentação da disciplina	
01			
02			
03			
04			
05			
06			
07			
08			
09			
10			
11			
12			
13			
14			
15			
16			

Listas de exercícios

Avaliações anteriores

INSTITUTO FEDERAL
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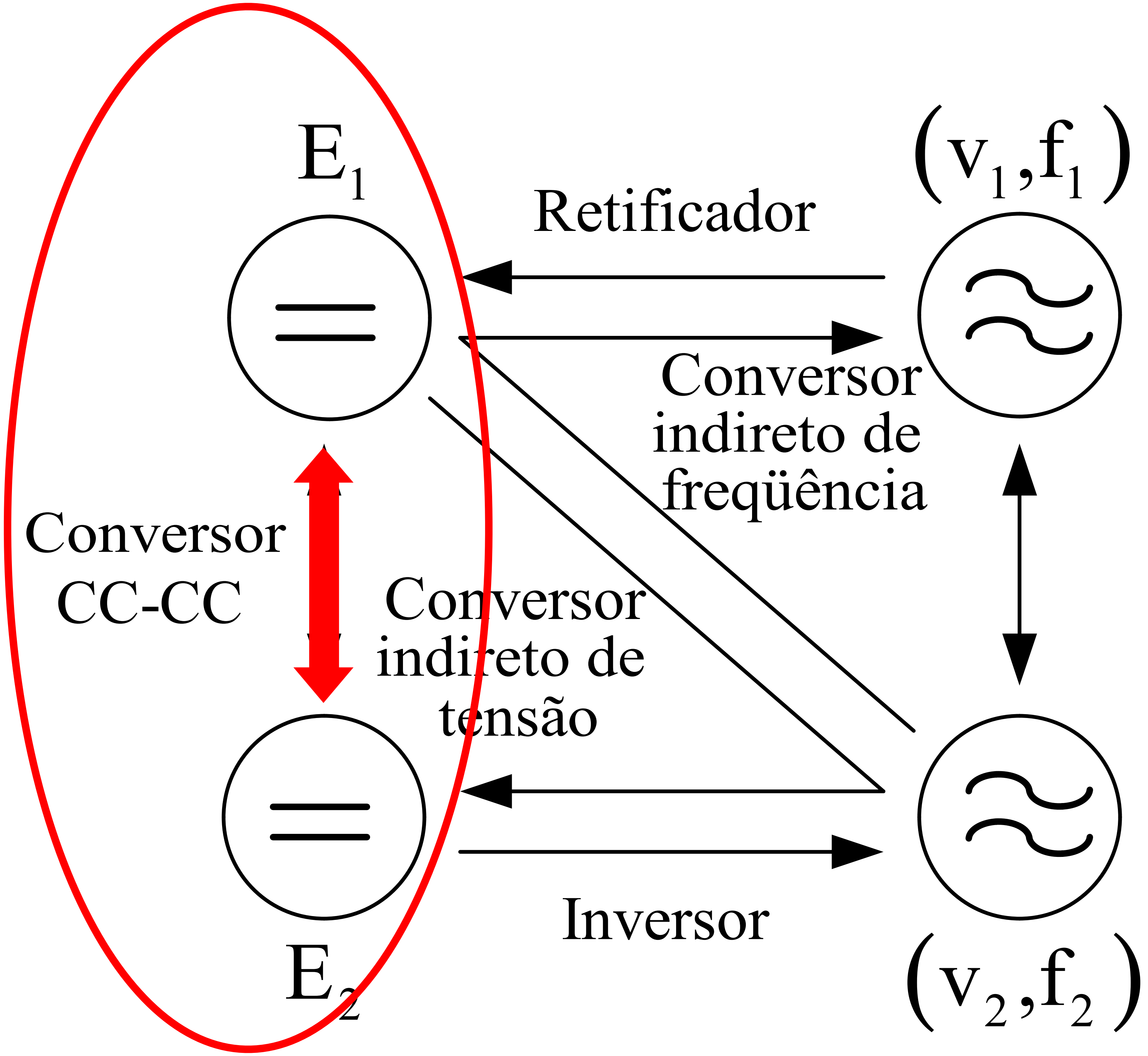
Nesta Aula

Conversores cc-cc:

- Introdução;
- Conversor CC-CC elevador - Boost;
- Conversor CC-CC do tipo Push-Pull com entrada em corrente;
- Conversor CC-CC abaixador-elevador – Buck-Boost;
- Conversor CC-CC do Flyback;
- Outras topologias de conversores CC-CC.

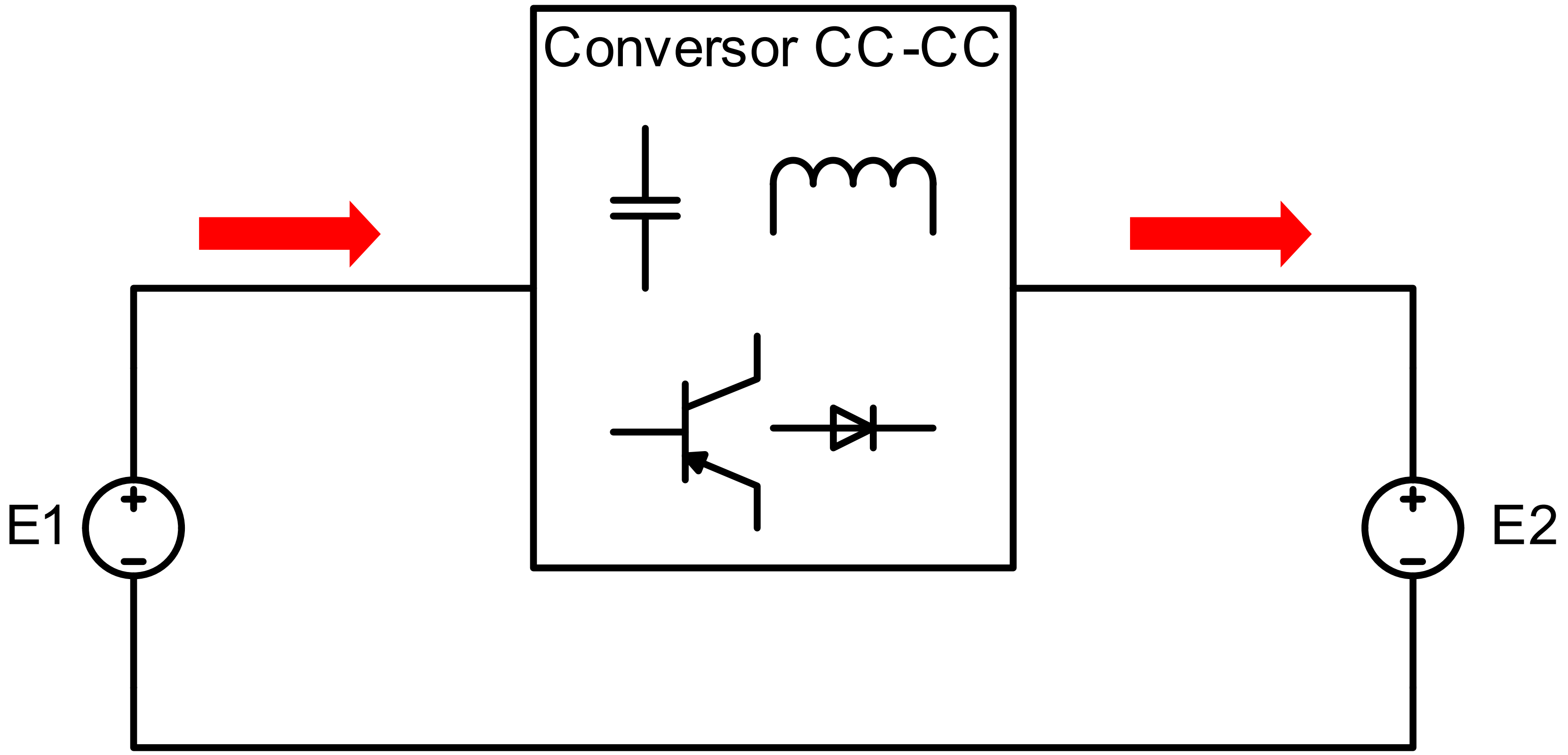
Conversores CC-CC


E_1
(v_1,f_1)
Retificador
Conversor indireto de freqüência
Conversor CC-CC
Conversor indireto de tensão
Inversor
E_2
(v_2,f_2)

Conversores CC-CC

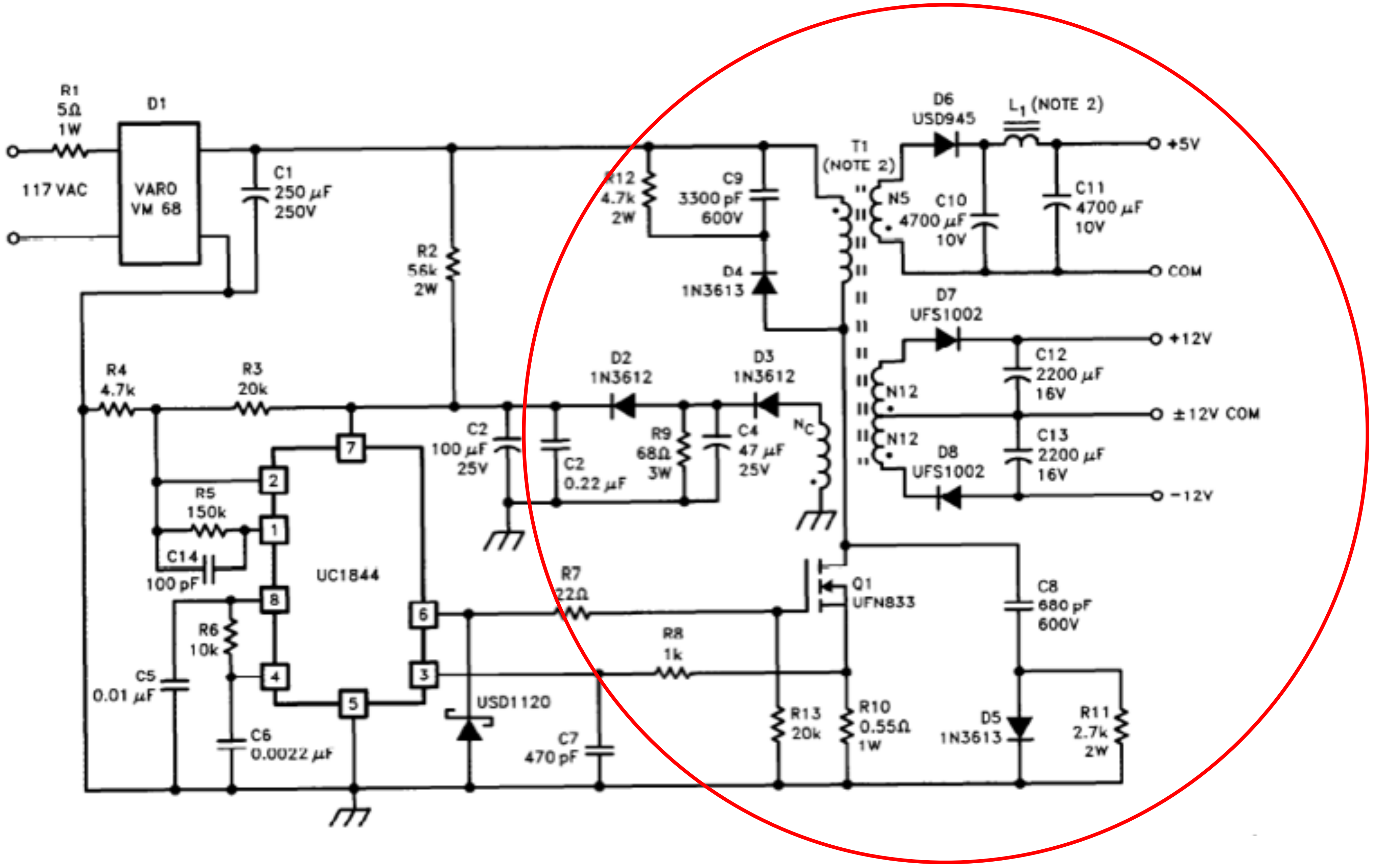
Princípio geral:

Controla o fluxo de potência entre duas fontes de tensão contínua.


Conversor CC-CC
E1
E2
+
−
+
−

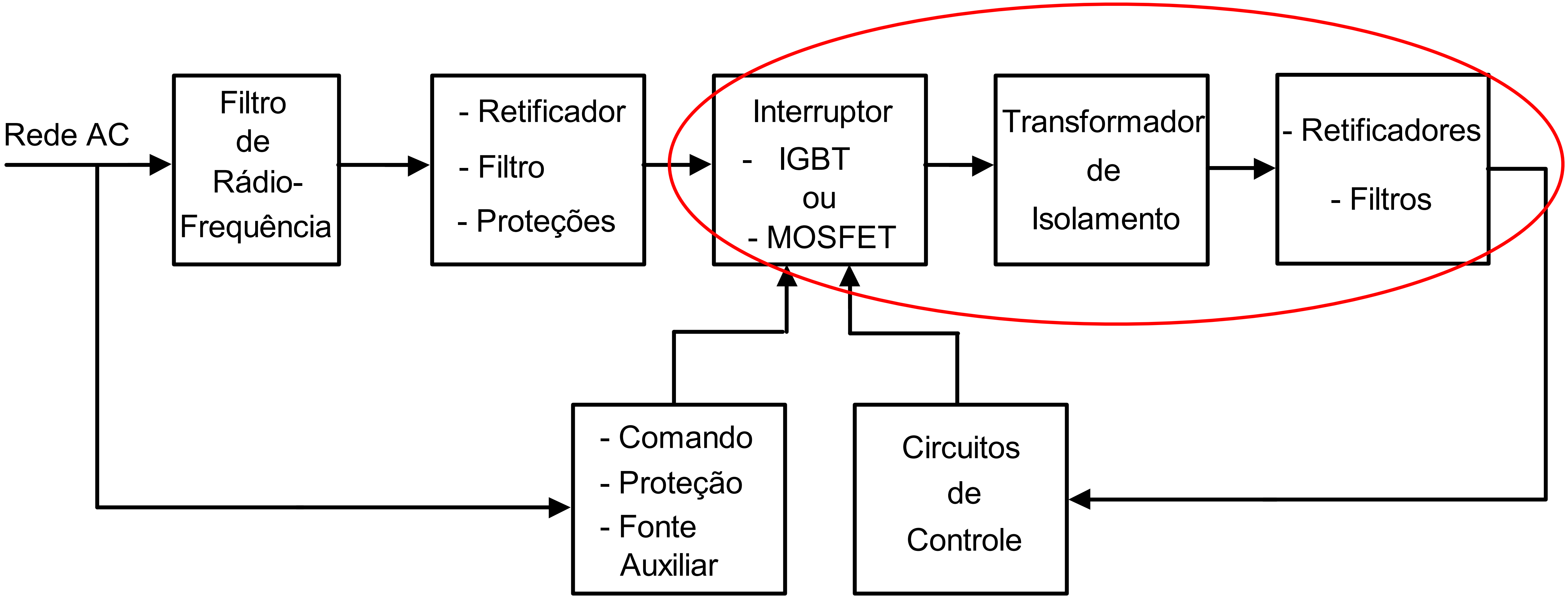
Conversores CC-CC

Estágio de conversão CC-CC de uma fonte chaveada:


R1
5Ω
1W
D1
117 VAC
VARO
VM 68
C1
250 µF
250V
R2
56k
2W
R12
4.7k
2W
C9
3300 pF
600V
D4
1N3613
T1
(NOTE 2)
D6
USD945
L1 (NOTE 2)
+5V
N5
C10
4700 µF
10V
C11
4700 µF
10V
COM
D7
UFS1002
+12V
C12
2200 µF
16V
N12
±12V COM
N12
C13
2200 µF
16V
D8
UFS1002
−12V
R4
4.7k
R3
20k
D2
1N3612
D3
1N3612
C2
100 µF
25V
C2
0.22 µF
R9
68Ω
3W
C4
47 µF
25V
Nc
7
2
R5
150k
1
C14
100 pF
UC1844
8
R6
10k
C5
0.01 µF
4
5
6
3
C6
0.0022 µF
USD1120
C7
470 pF
R7
22Ω
R8
1k
Q1
UFN833
C8
680 pF
600V
R13
20k
R10
0.55Ω
1W
D5
1N3613
R11
2.7k
2W

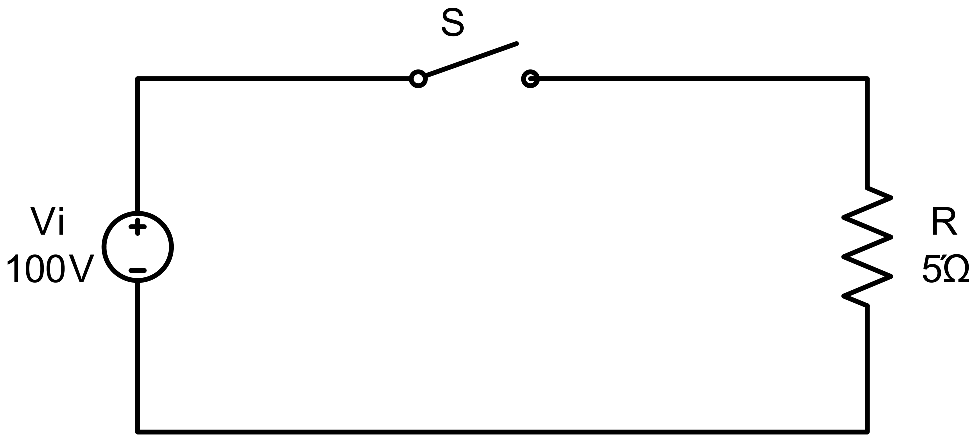
Conversores CC-CC

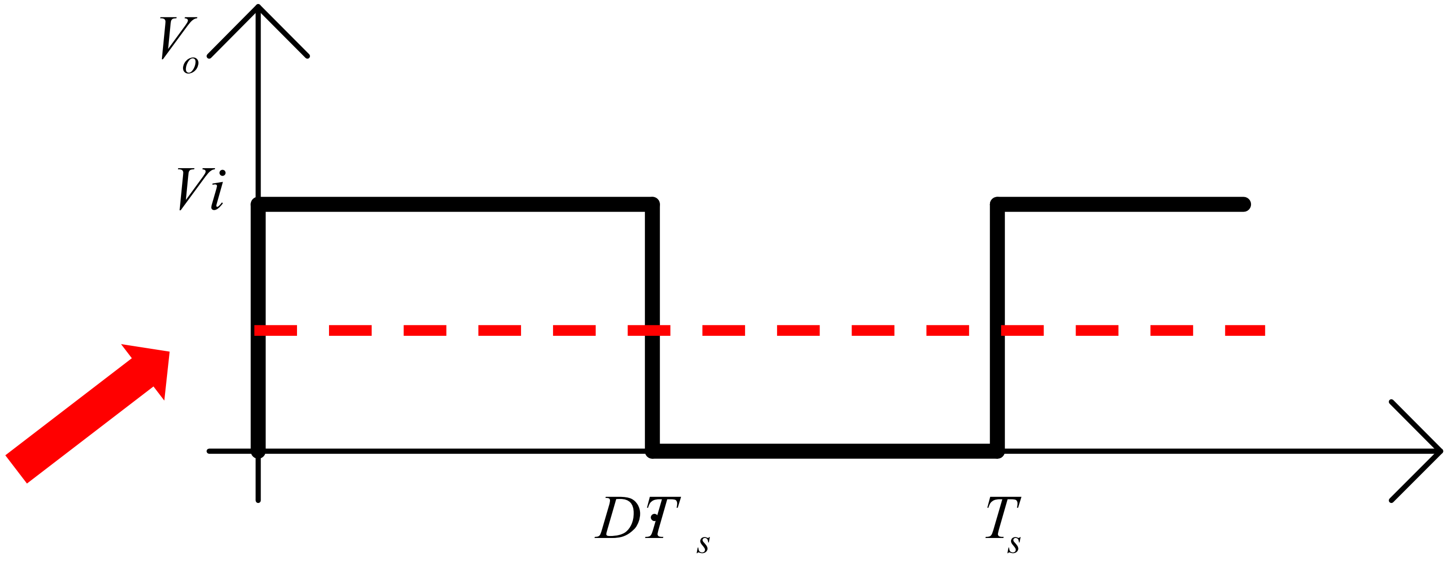
Estágio de conversão CC-CC de uma fonte chaveada:


Rede AC
Filtro de Rádio-Frequência
- Retificador
- Filtro
- Proteções
Interruptor
- IGBT
ou
- MOSFET
Transformador de Isolamento
- Retificadores
- Filtros
- Comando
- Proteção
- Fonte Auxiliar
Circuitos de Controle

Conversores CC-CC

Conversor abaixador:





Tensão média na saída:

$$V_o = \frac{1}{T_s}\int_0^{T_{on}} V_i \cdot dt = V_i \frac{T_{on}}{T_s}$$

$$V_o = D \cdot V_i$$

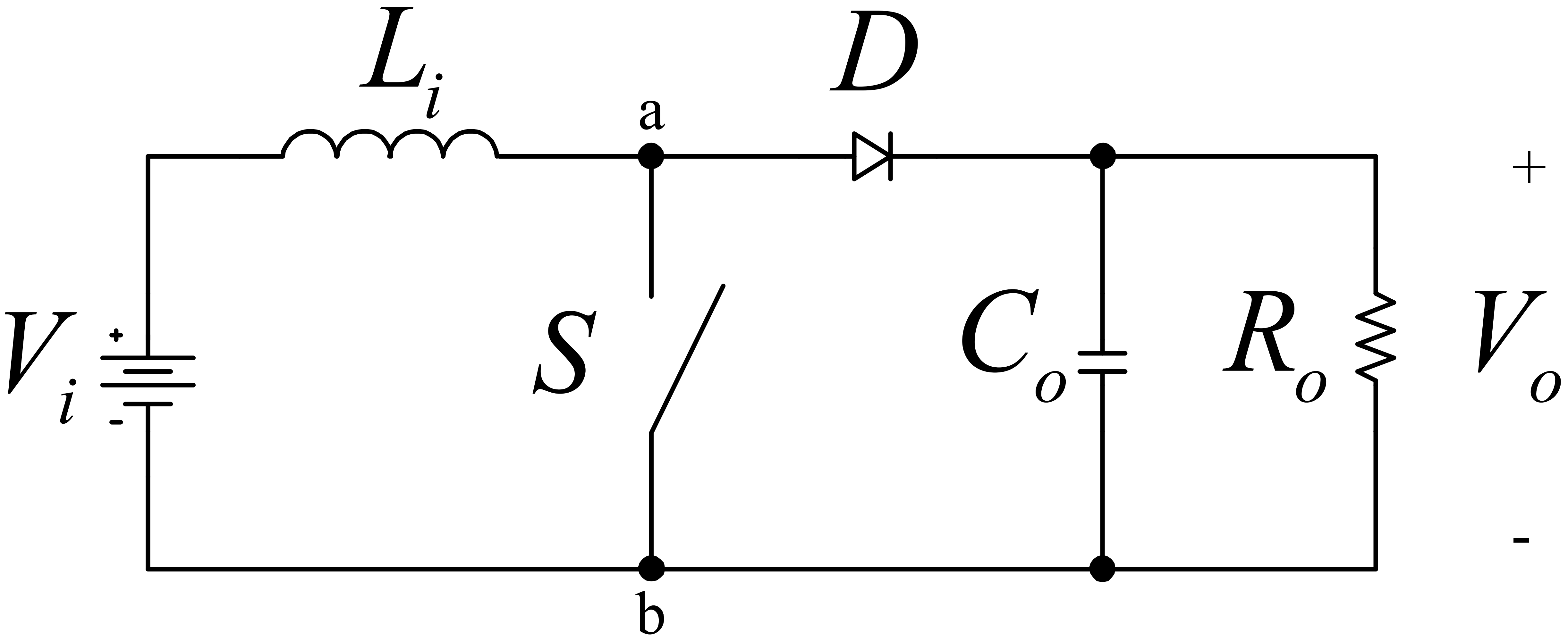
$$D = \frac{V_o}{V_i}$$

PWM:

- Modulação por largura de pulsos;
- Pulse Width Modulation.

Conversores CC-CC: Boost

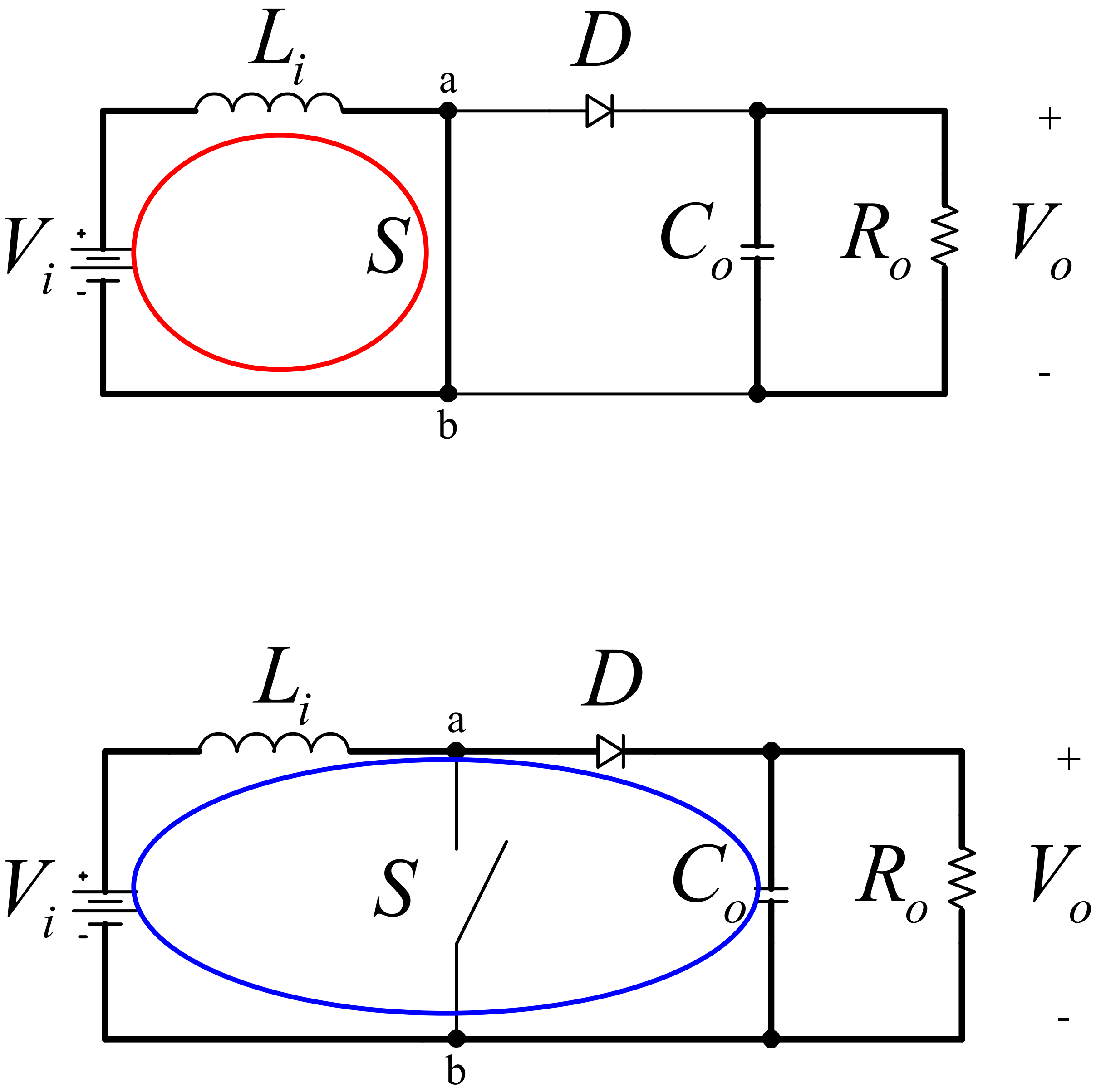
Estrutura de um conversor do tipo Boost:



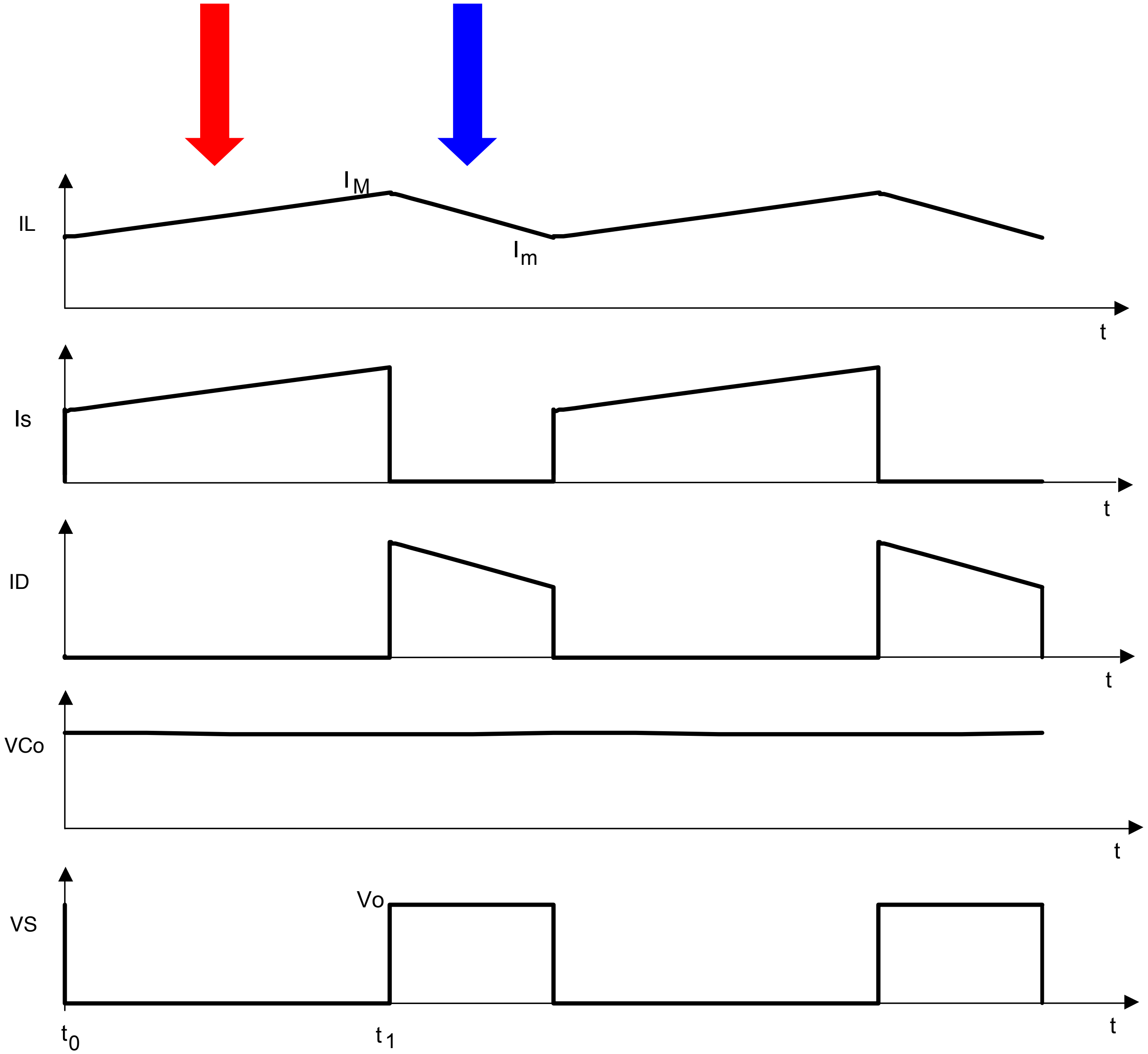
L_i
D
a
+
V_i
+
-
S
C_o
R_o
V_o
-
b

Conversores CC-CC: Boost

Etapas de operação - MCC

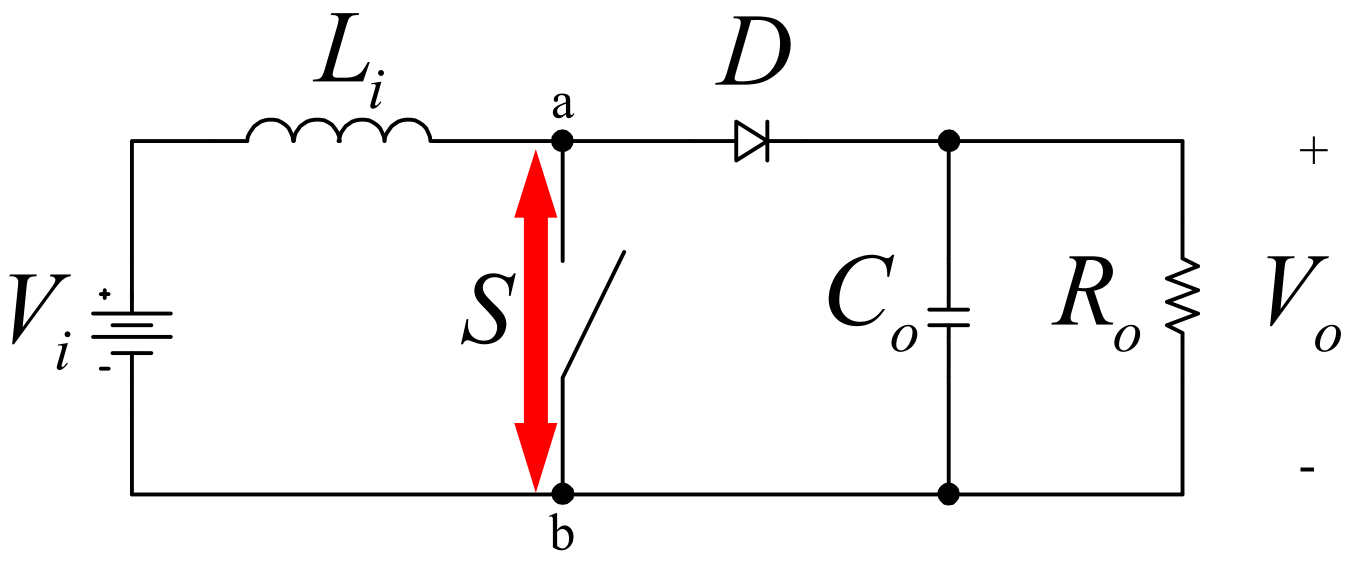

L_i
D
a
+
V_i
S
C_o
R_o
V_o
-
b
L_i
D
a
+
V_i
S
C_o
R_o
V_o
-
b

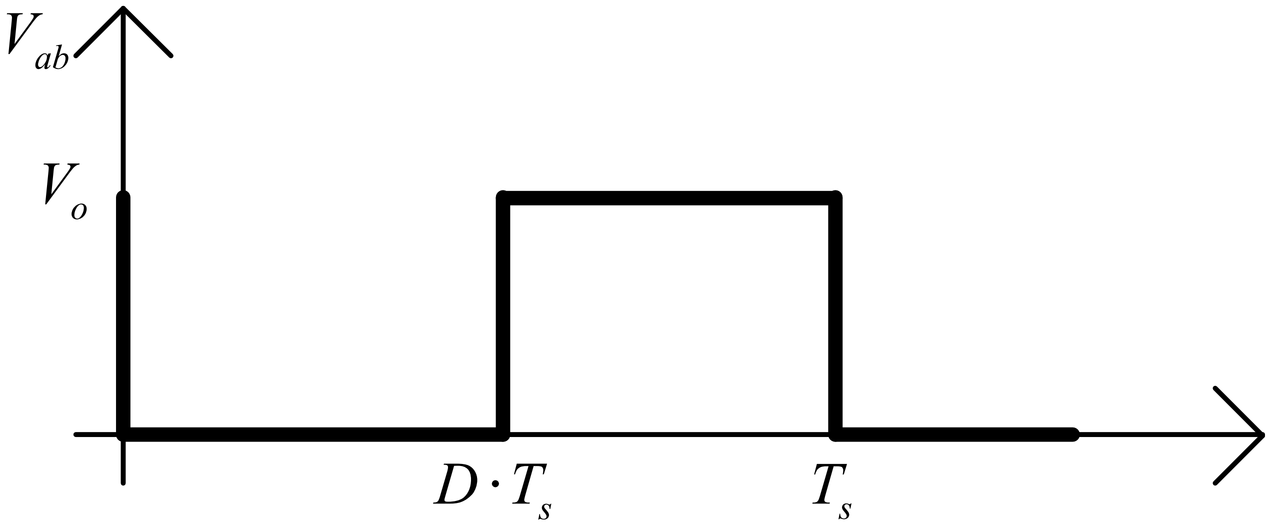
Formas de onda



Conversores CC-CC: Boost

Análise das grandezas envolvidas:





Tensão média na saída

$$V_{ab} = \frac{1}{T_s}\int_{D\cdot T_s}^{T_s} V_o \cdot dt = V_o \frac{(T_s - D \cdot T_s)}{T_s}$$

$$V_{ab} = V_o(1 - D)$$

$$V_{ab} = V_i$$

$$V_o = \frac{V_i}{1 - D}$$

$$D = 1 - \frac{V_i}{V_o}$$

Conversores CC-CC: Boost

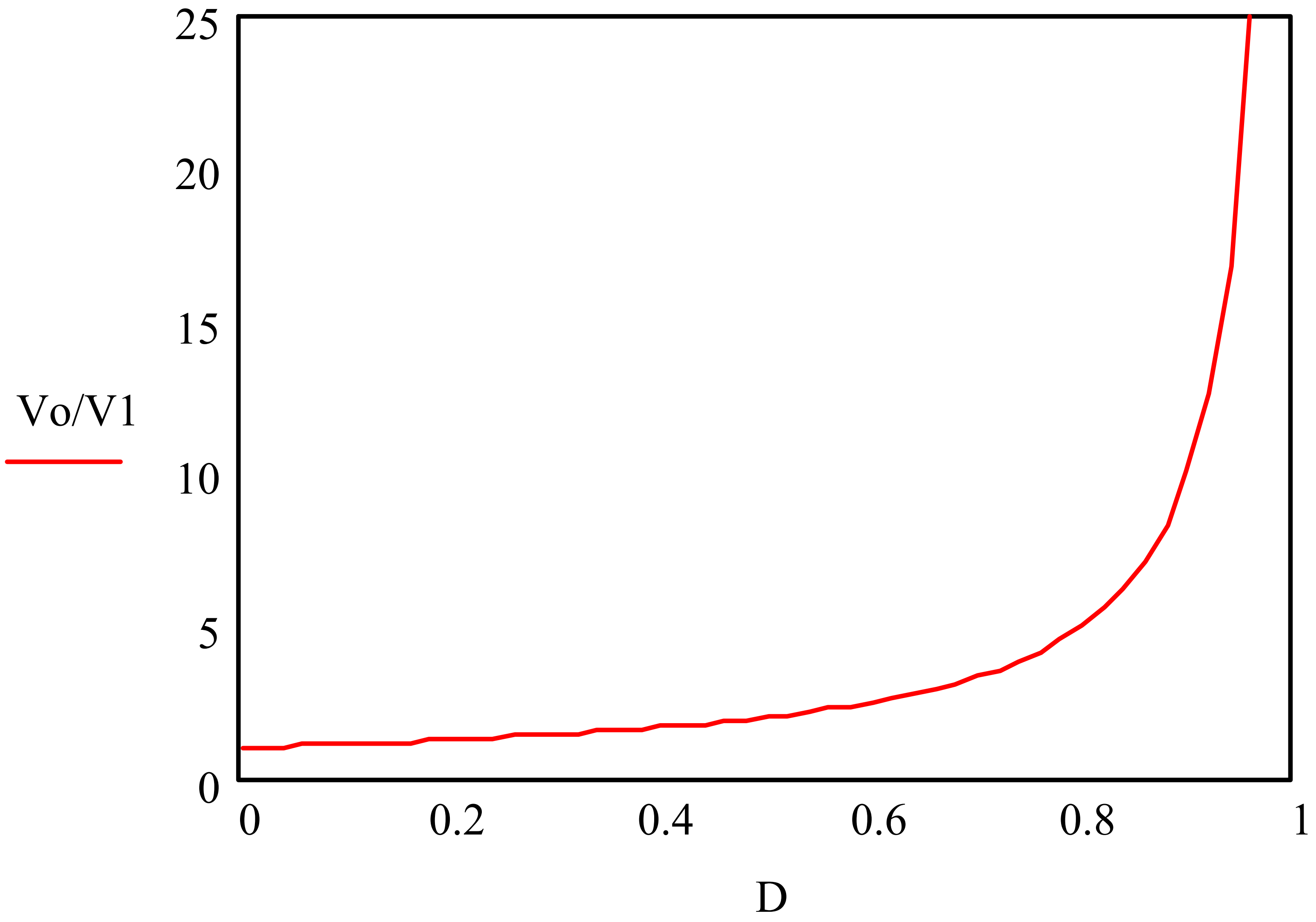
Análise das grandezas envolvidas:

Tensão média na saída

$$V_o = \frac{V_i}{1-D}$$

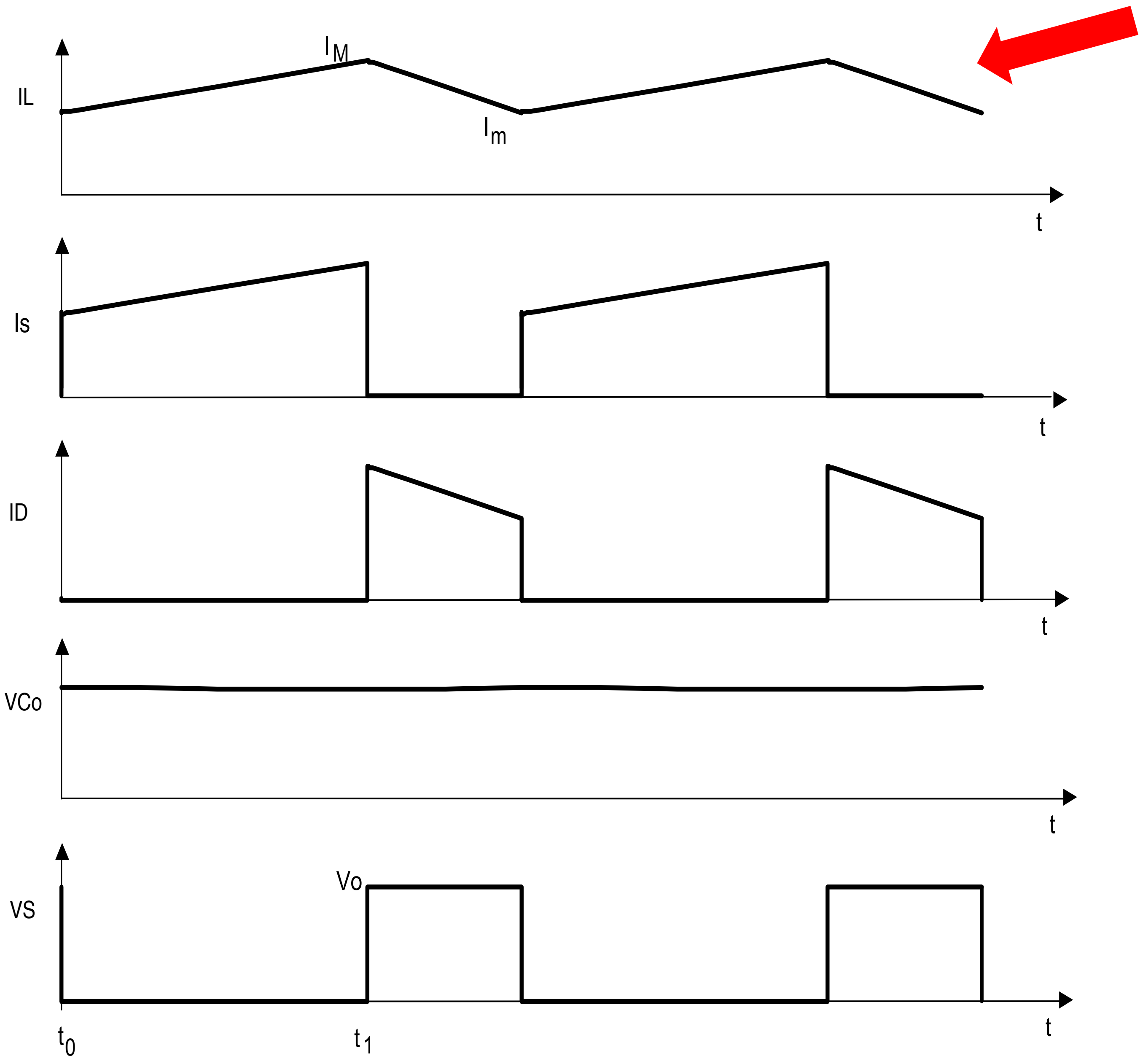
$$\boxed{\frac{V_o}{V_i} = \frac{1}{1-D}}$$

Ganho estático



Conversores CC-CC: Boost

Análise das grandezas envolvidas:


IL
IM
Im
t
Is
t
ID
t
VCo
t
VS
Vo
t
t0
t1

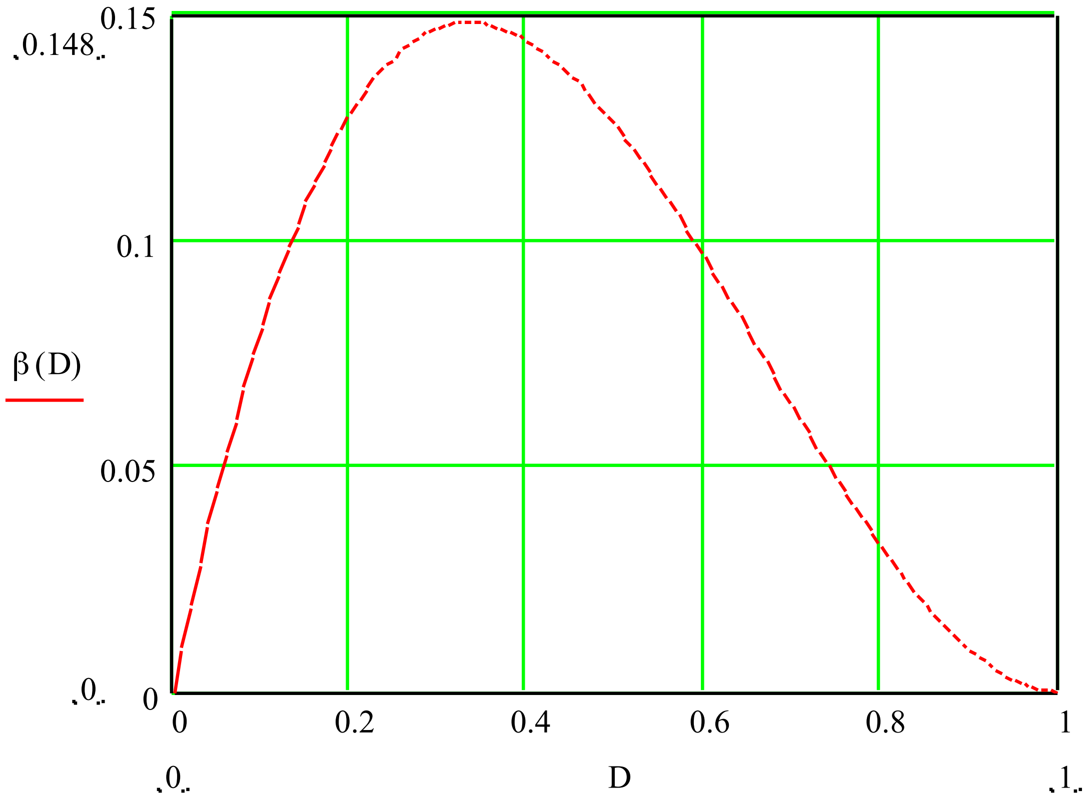
Corrente no Indutor

$$\Delta i_L = \frac{V_{in}}{L} T_1$$

$$\Delta i_L = \frac{V_{in} \cdot D}{L \cdot f}$$

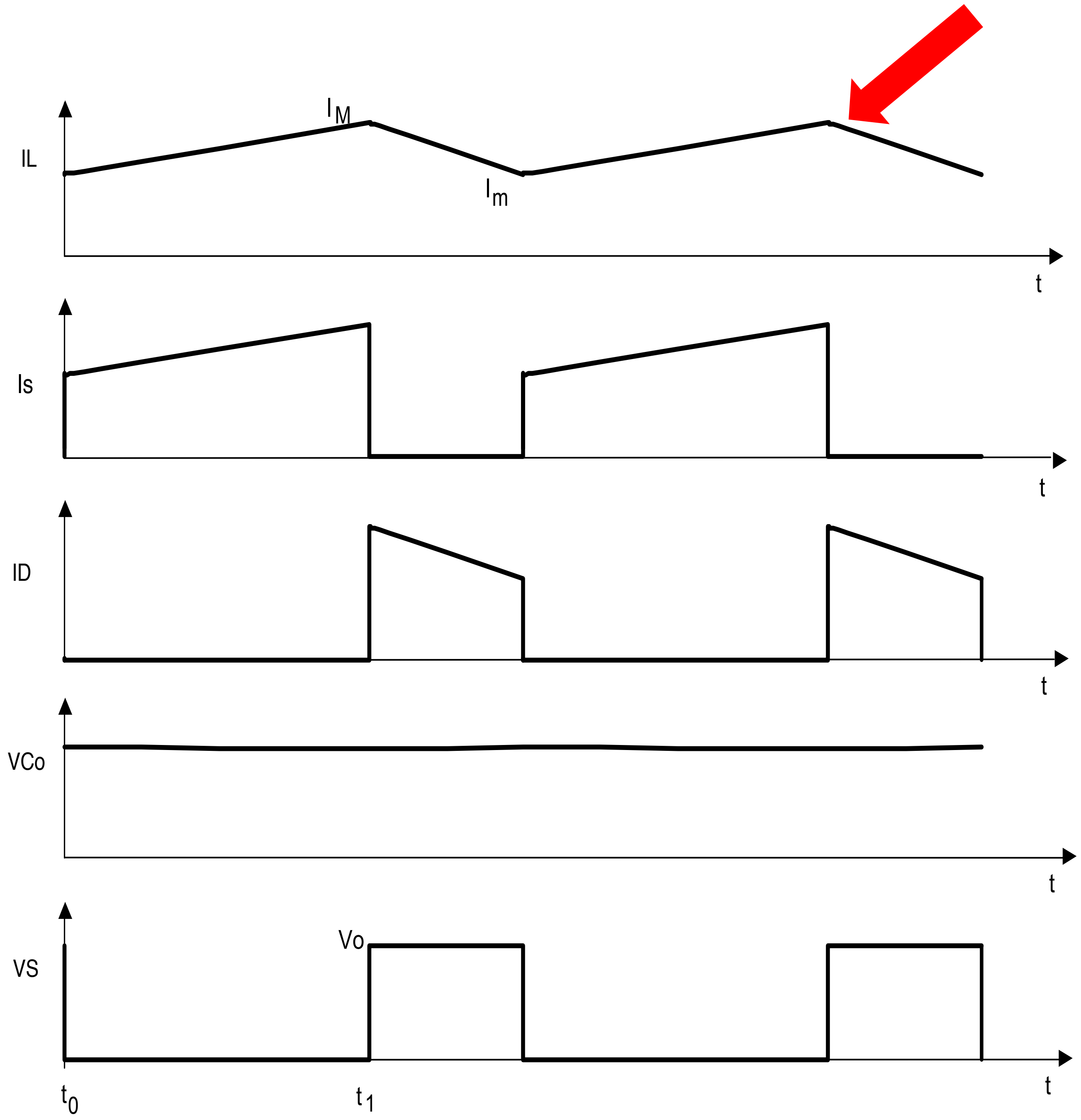
$$I_{Li} = \frac{V_i}{R_o} \cdot \frac{1}{(1-D)^2}$$

$$\frac{\Delta i_L}{I_{Li}} = \frac{R_o \cdot D \cdot (1-D)^2}{L \cdot f}$$



Conversores CC-CC: Boost

Análise das grandezas envolvidas:



Corrente de pico no Indutor

$$I_P = i_{in} + \frac{\Delta i_L}{2}$$

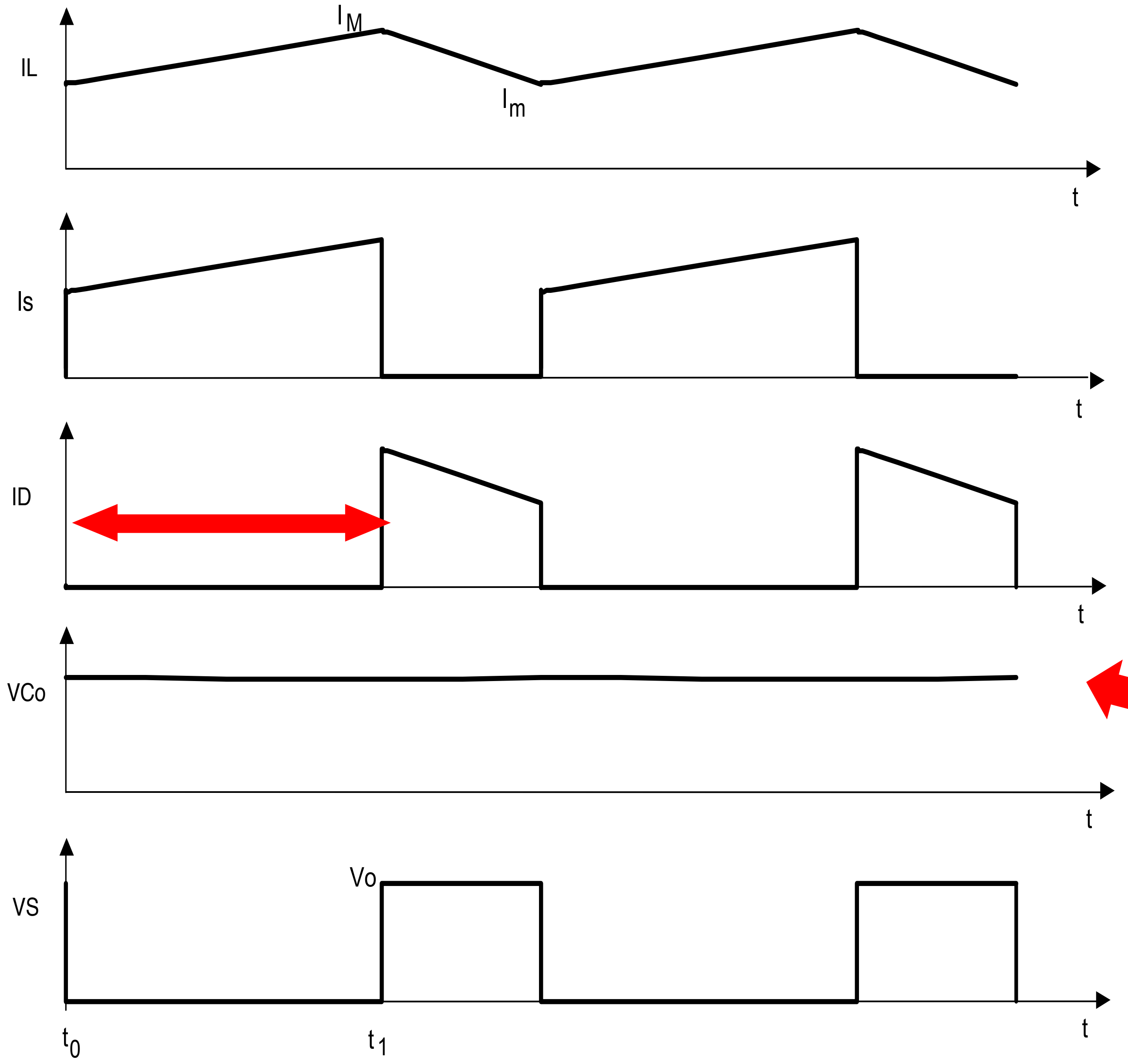
$$I_P = \frac{V_i}{R_o}\cdot\frac{1}{(1-D)^2} + \frac{V_{in}\cdot D}{2\cdot L\cdot f}$$

Corrente de pico
no transistor e no diodo

$$I_{TP} = I_{DP} = I_P$$

Conversores CC-CC: Boost

Análise das grandezas envolvidas:



Tensão no capacitor

$$i_C \cong I_{out}$$ p/ primeira etapa

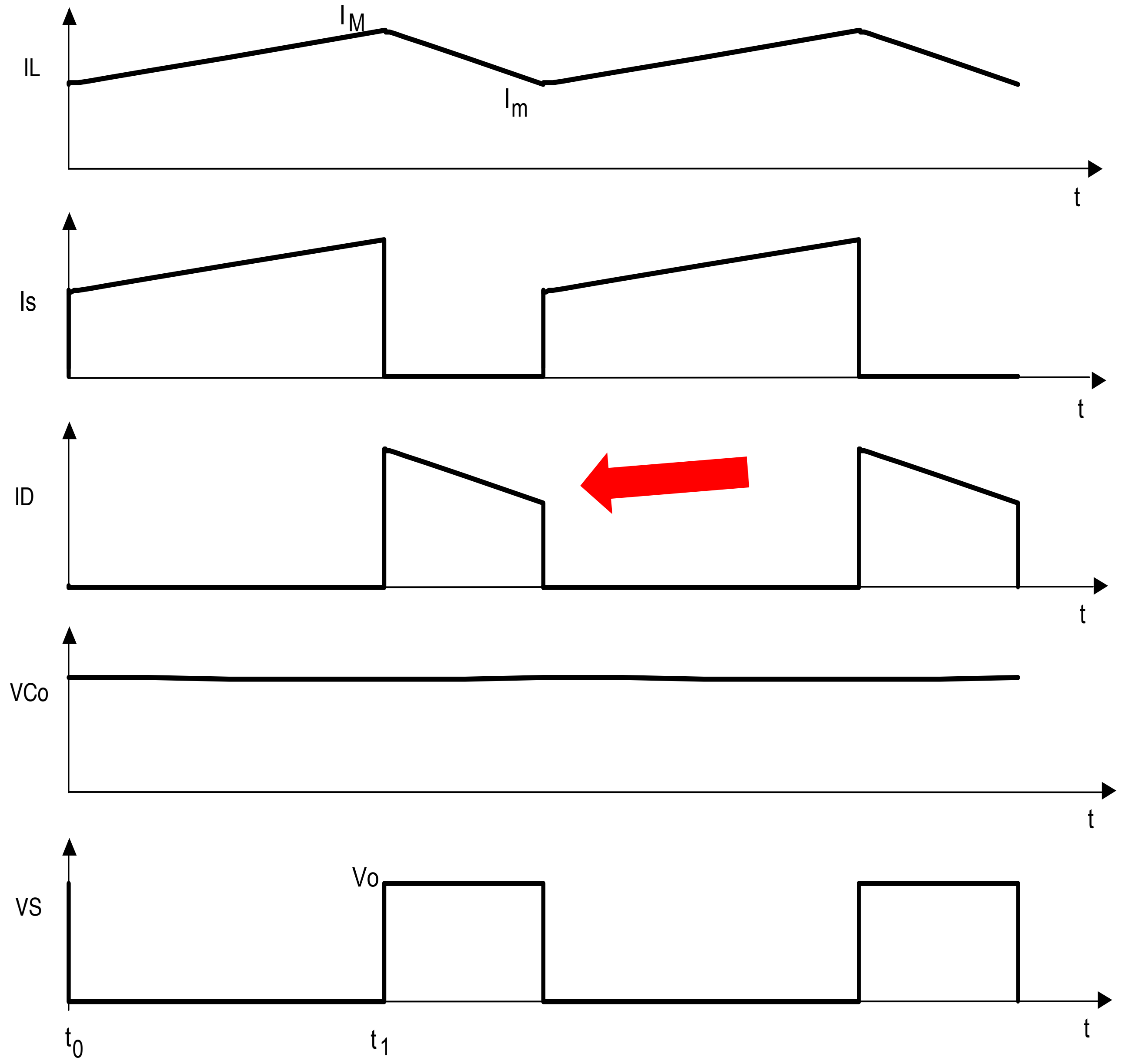
$$I_{out} = Co \cdot \frac{\Delta V_{Co}}{\Delta t}$$

$$\Delta V_{Co} = \frac{I_{out} \cdot \Delta t}{Co} = \frac{I_{out} \cdot D}{Co \cdot f}$$

$$\Delta V_{Co} = \frac{I_o}{Co \cdot f} \cdot \frac{V_o - V_i}{V_o}$$

Conversores CC-CC: Boost

Análise das grandezas envolvidas:



IL
I$_M$
I$_m$
t
Is
t
ID
t
VCo
t
VS
Vo
t
t$_0$
t$_1$

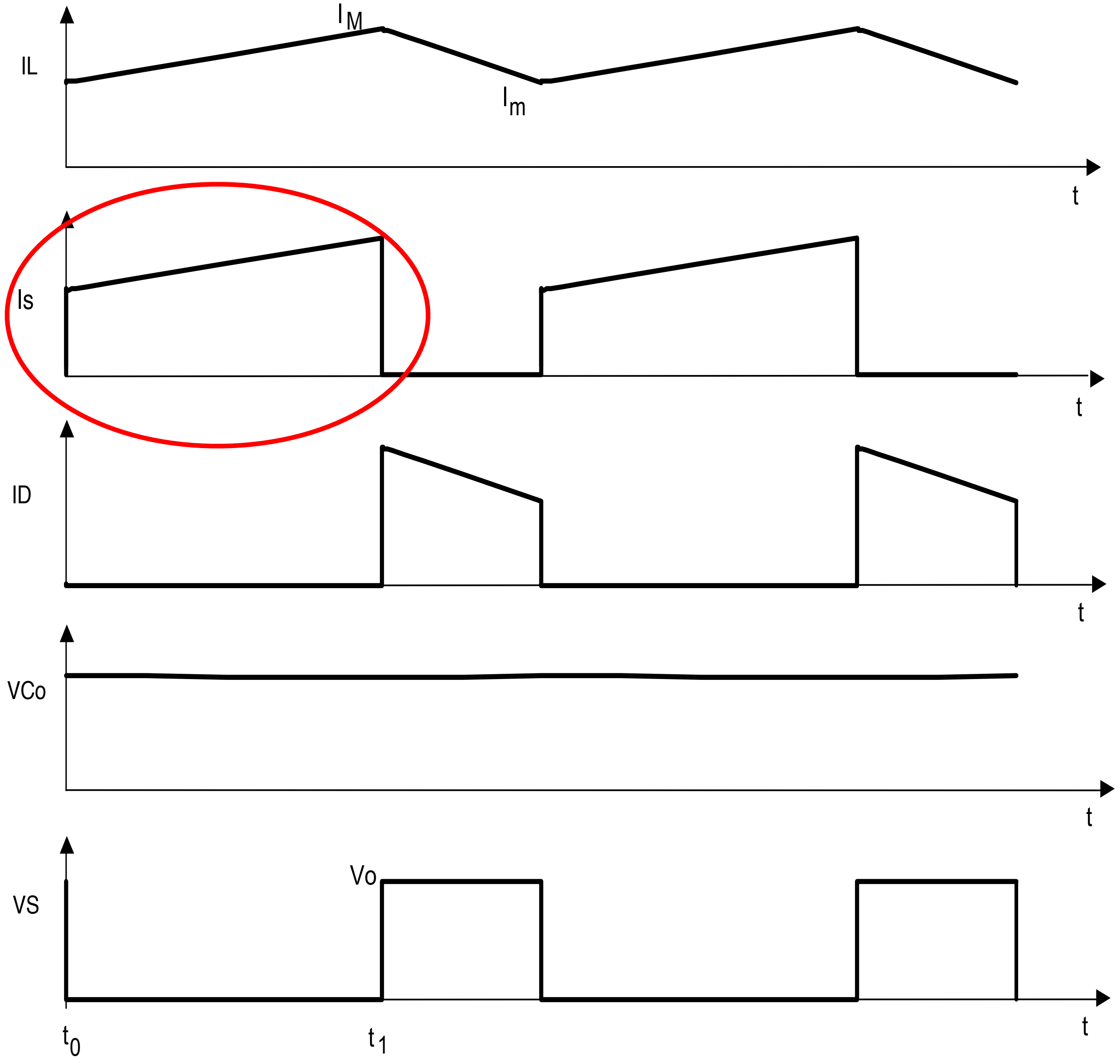
Tensão no capacitor
Efeito da RSE

$$V_{RSE} = RSE \cdot i_{D_{CA}} = RSE \cdot i_{Co}$$

$$P_{RSE} = RSE \cdot i_{D_{CAef}}{}^2 = RSE \cdot i_{Co}{}^2$$

Conversores CC-CC: Boost

Análise das grandezas envolvidas:



Correntes no transistor

Corrente média

$$I_{Tmd} = \frac{1}{T}\int_0^{D\cdot T} i_L\,dt$$

$$I_{Tmd} = D \cdot I_L$$

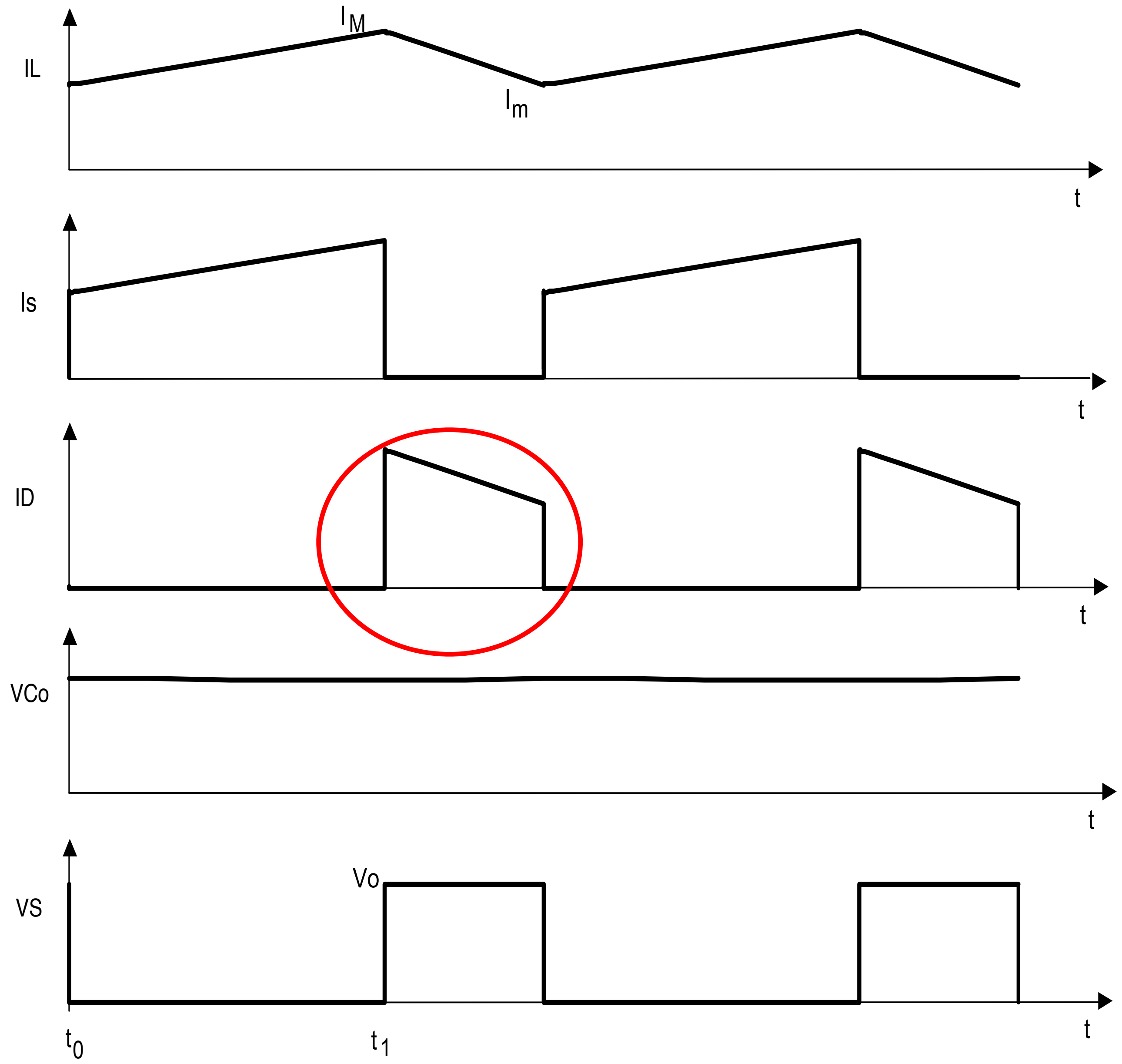
Corrente eficaz

$$I_{Tef} = \sqrt{\frac{1}{T}\int_0^{D\cdot T} {i_L}^2\,dt}$$

$$I_{Tef} = \sqrt{D} \cdot I_L$$

Conversores CC-CC: Boost

Análise das grandezas envolvidas:



IL
I_M
I_m
t
Is
t
ID
t
VCo
t
VS
Vo
t_0
t_1
t

Correntes no diodo

Corrente média

$$I_{Dmd} = \frac{1}{T}\int_{D\cdot T}^{T} i_L\,dt$$

$$I_{Dmd} = (1-D)\cdot I_L$$

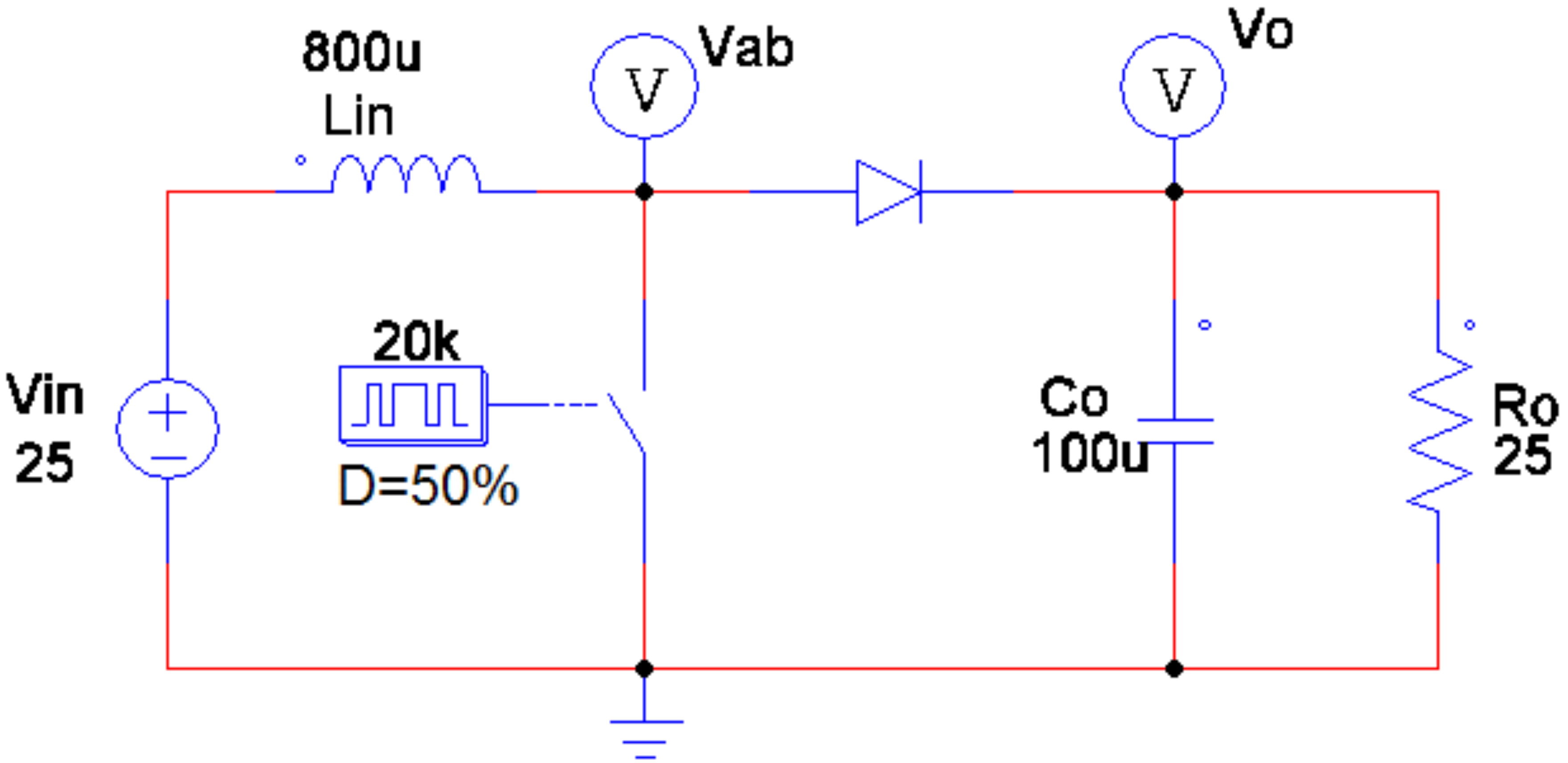
Corrente eficaz

$$I_{Def} = \sqrt{\frac{1}{T}\int_{D\cdot T}^{T} i_L^{\,2}\,dt}$$

$$I_{Def} = \sqrt{1-D}\cdot I_L$$

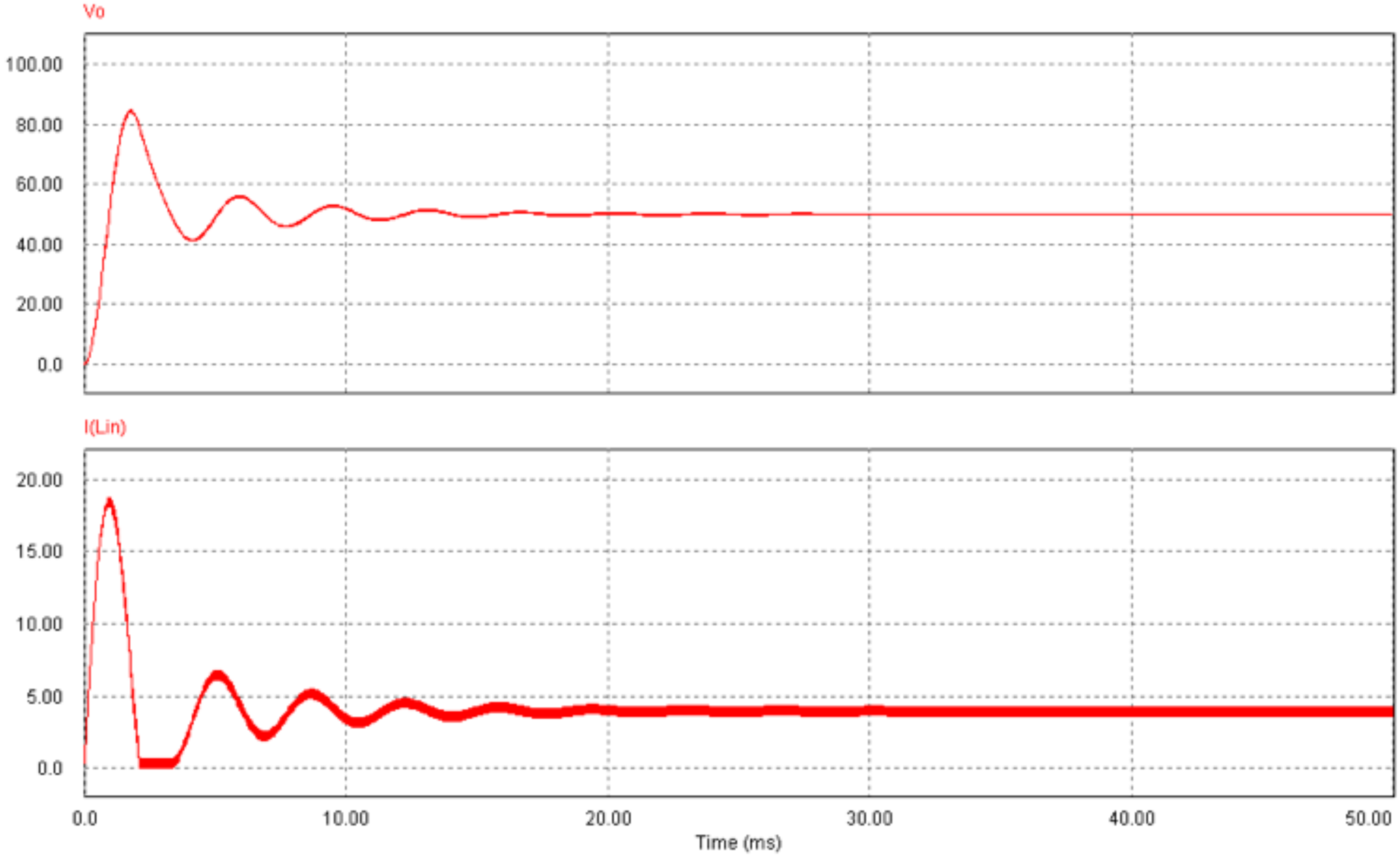
Conversores CC-CC: Boost

Principais formas de onda (circuito simulado):


800u
Lin
Vab
V
Vo
V
20k
D=50%
Vin
25
Co
100u
Ro
25

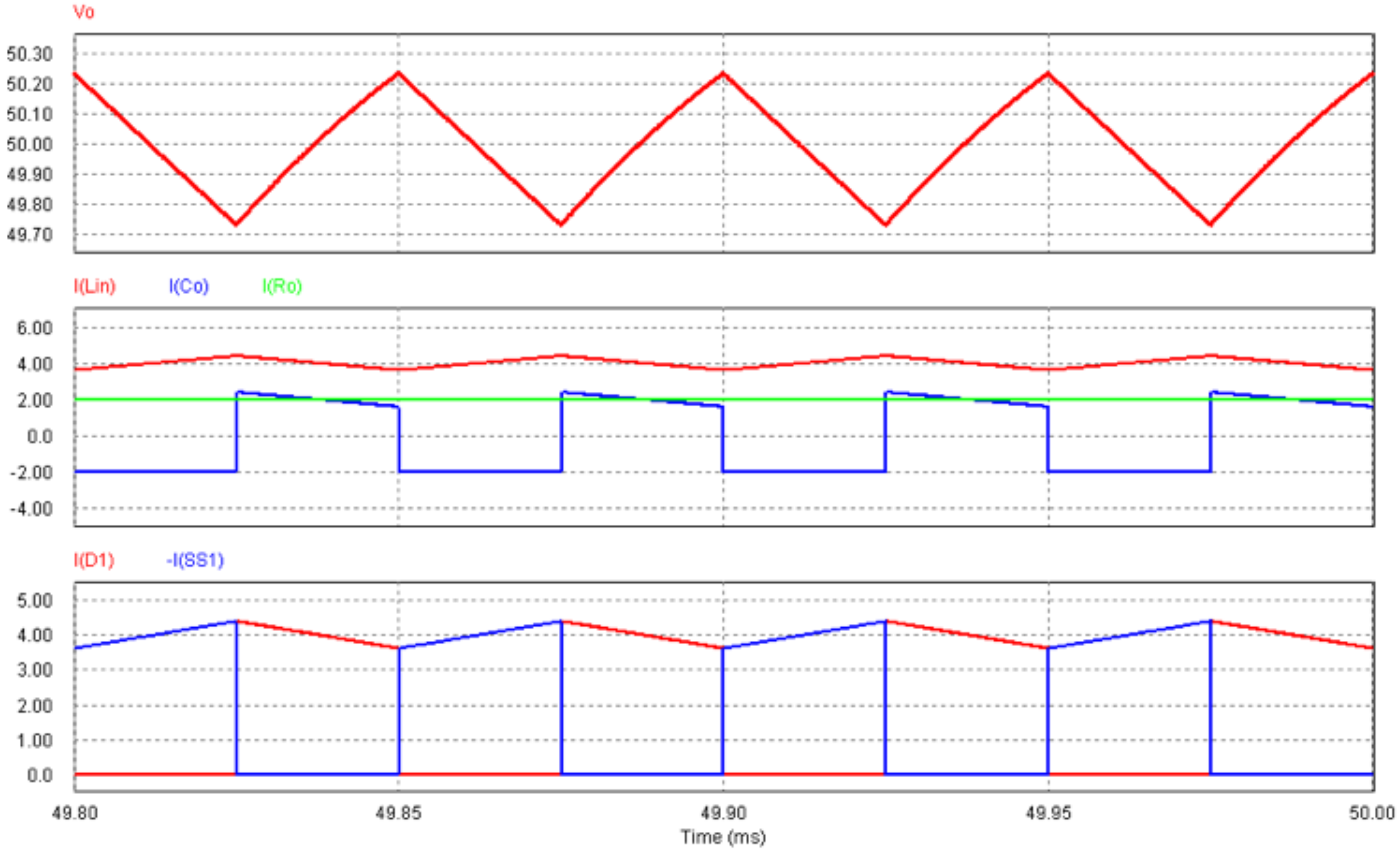
Conversores CC-CC: Boost

Principais formas de onda (transitório de partida):



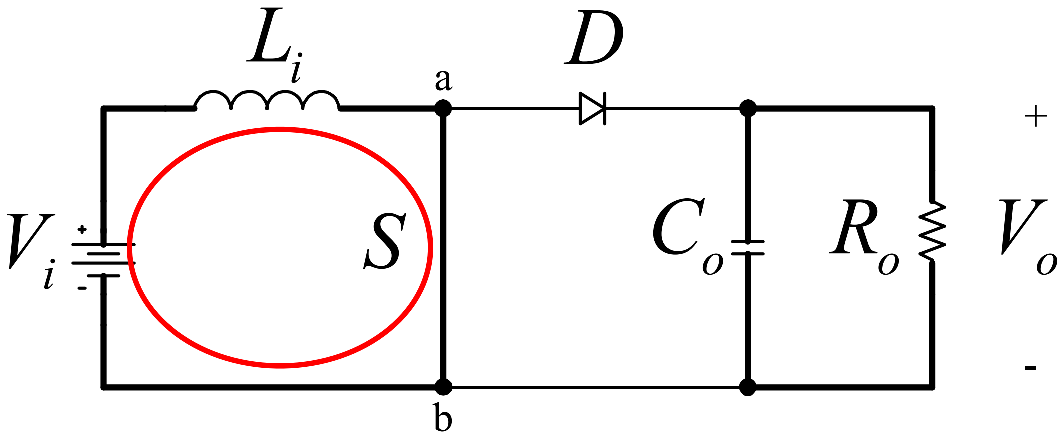
Conversores CC-CC: Boost

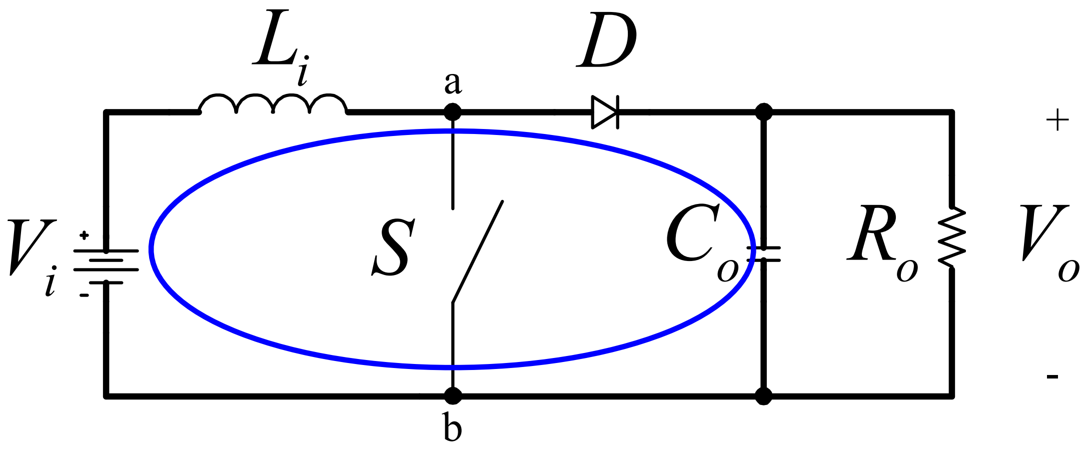
Principais formas de onda (regime permanente):

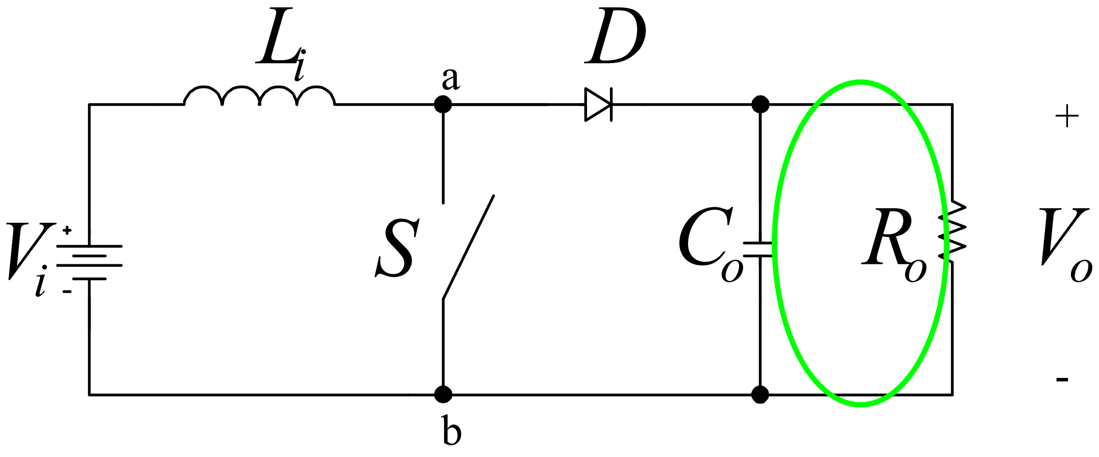


Conversores CC-CC: Boost

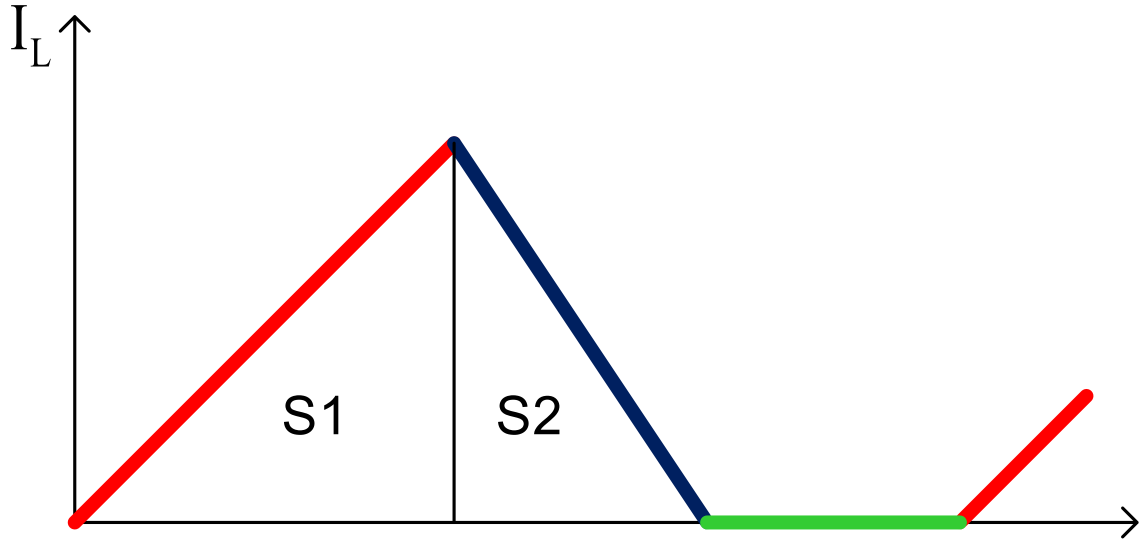
Etapas de operação - MCD


L_i
a
D
V_i
S
C_o
R_o
V_o
+
-
b


L_i
a
D
V_i
S
C_o
R_o
V_o
+
-
b


L_i
a
D
V_i
S
C_o
R_o
V_o
+
-
b

Formas de onda



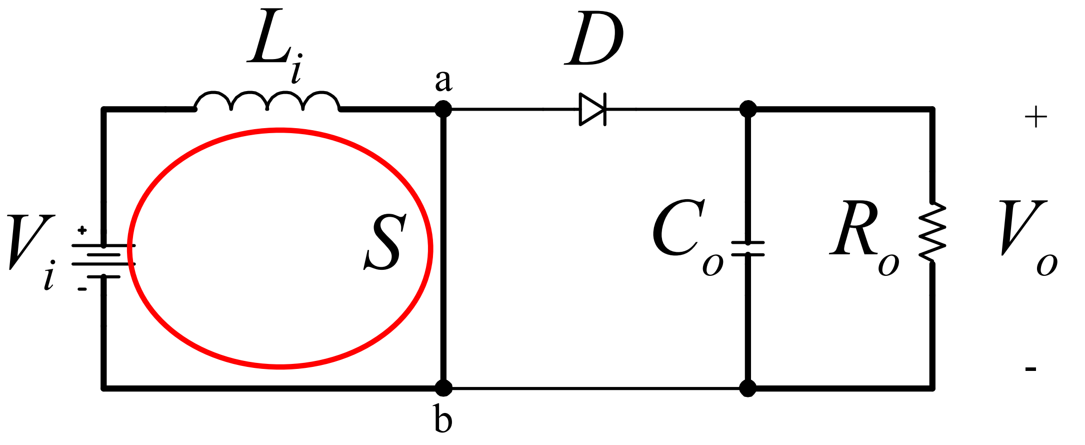
Ganho estático

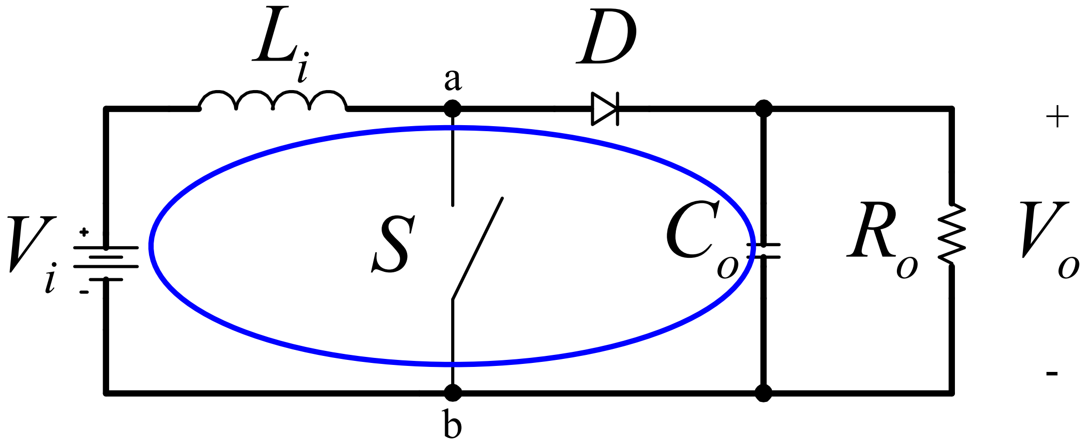
$$\frac{V_o}{V_i} = 1 + \frac{D^2}{\gamma}$$

$$\gamma = \frac{2 \cdot L \cdot Io}{V_{in} \cdot T}$$

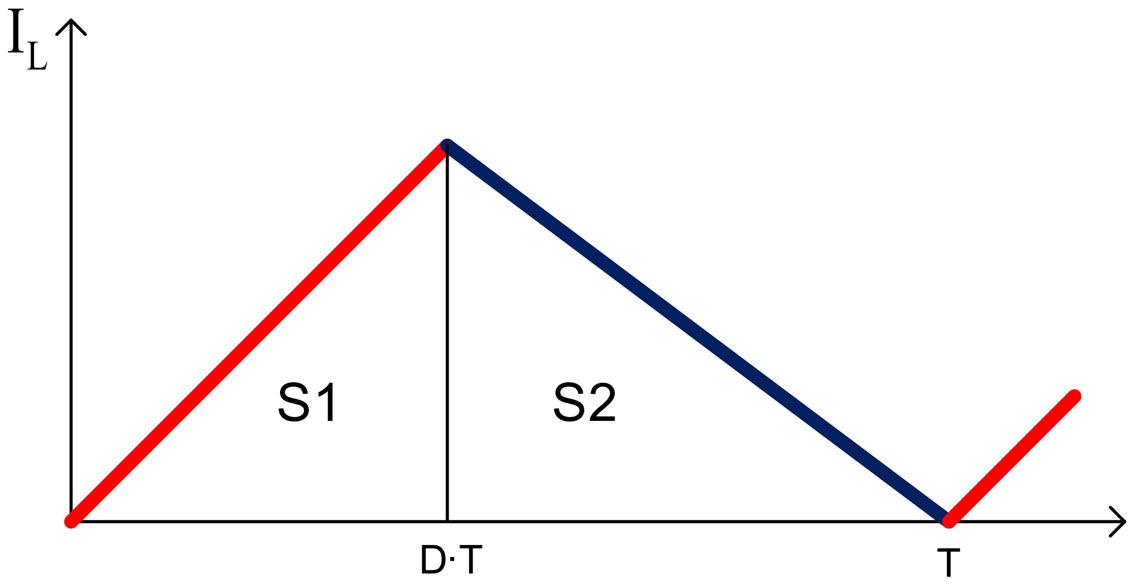
Conversores CC-CC: Boost

Etapas de operação – Condução Critica


L_i
D
a
b
V_i
S
C_o
R_o
V_o
+
-


L_i
D
a
b
V_i
S
C_o
R_o
V_o
+
-

Formas de onda



Ganho estático

$$\frac{V_o}{V_i} = 1 + \frac{D^2}{\gamma}$$

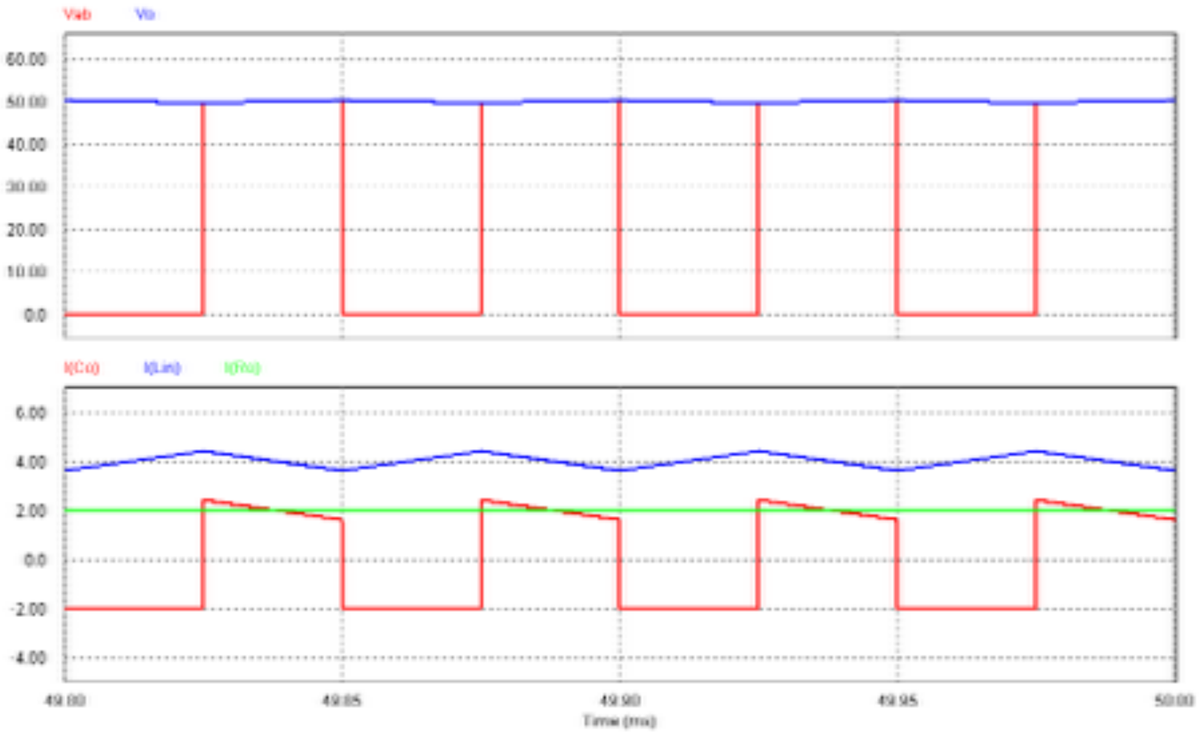
$$\frac{V_o}{V_i} = \frac{1}{1-D}$$

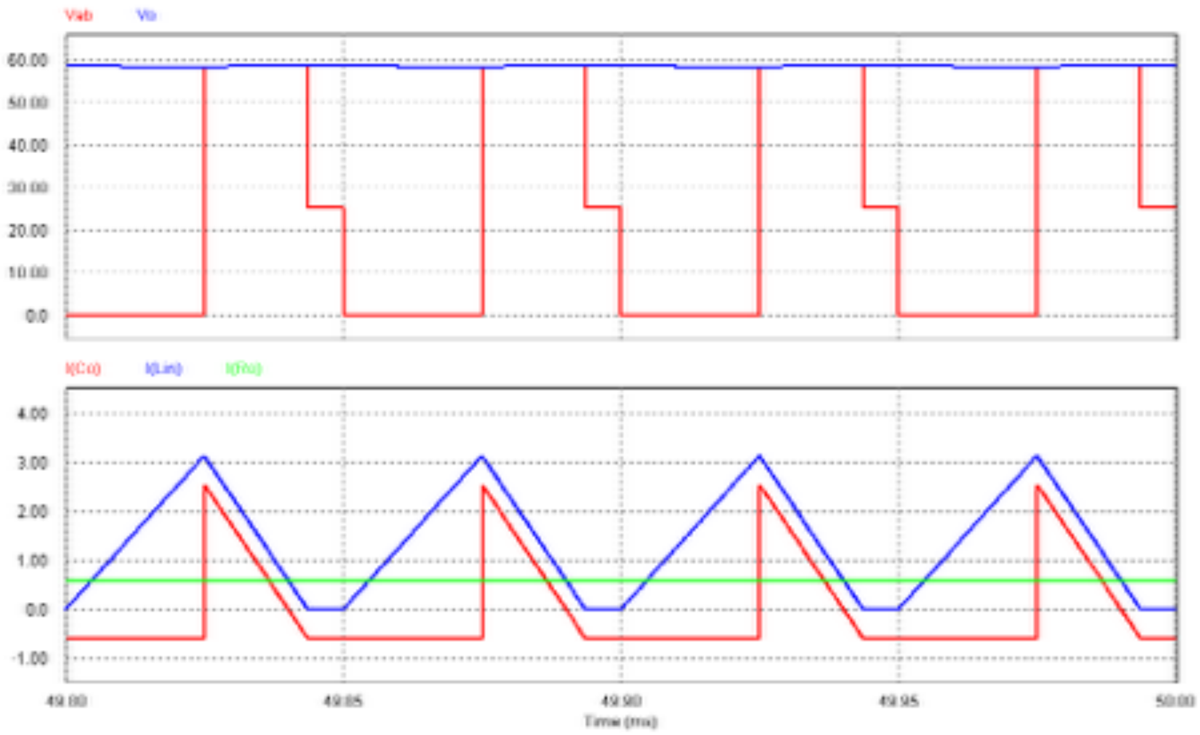
$$\gamma = \frac{2 \cdot L \cdot Io}{V_{in} \cdot T}$$

Conversores CC-CC: Boost

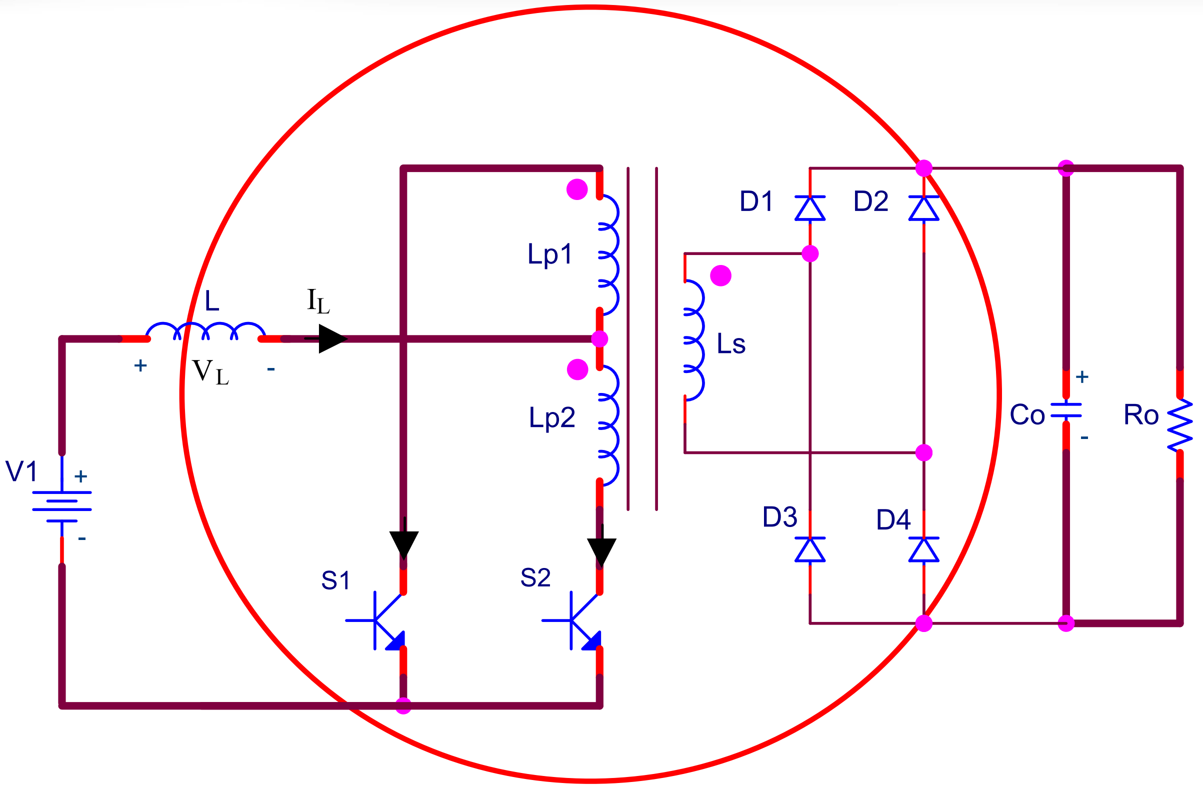
Condução contínua (MCC) para descontínua (MCD):

- Diminuição da carga;
- Indutor do filtro de entrada muito baixo;
- Alteração da freqüência de comutação;
- Alteração da tensão de entrada.



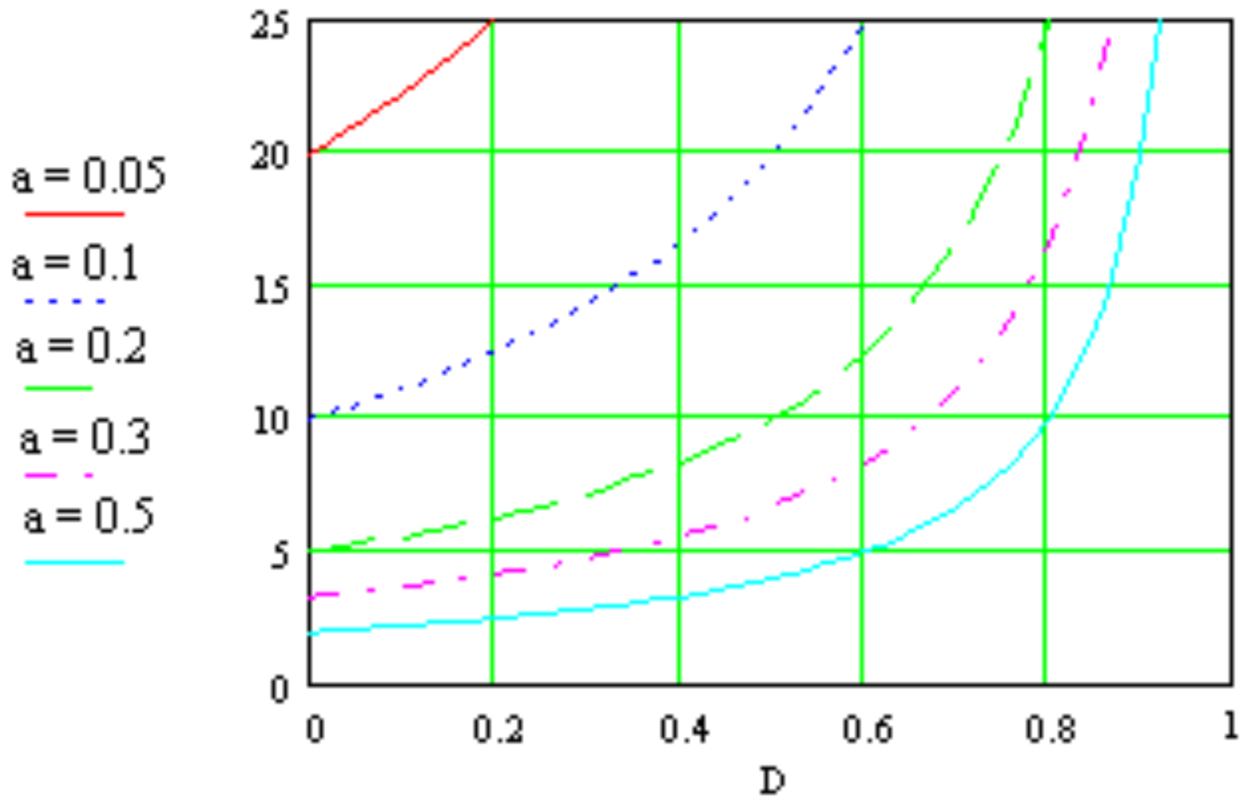


Conversores CC-CC: Push Pull com Entrada em Corrente


L
I_L
+
V_L
-
V1
+
-
Lp1
Lp2
Ls
D1
D2
D3
D4
S1
S2
Co
+
-
Ro

$$\frac{Vo}{V1} = \frac{1}{a} \cdot \frac{1}{1 - D}$$

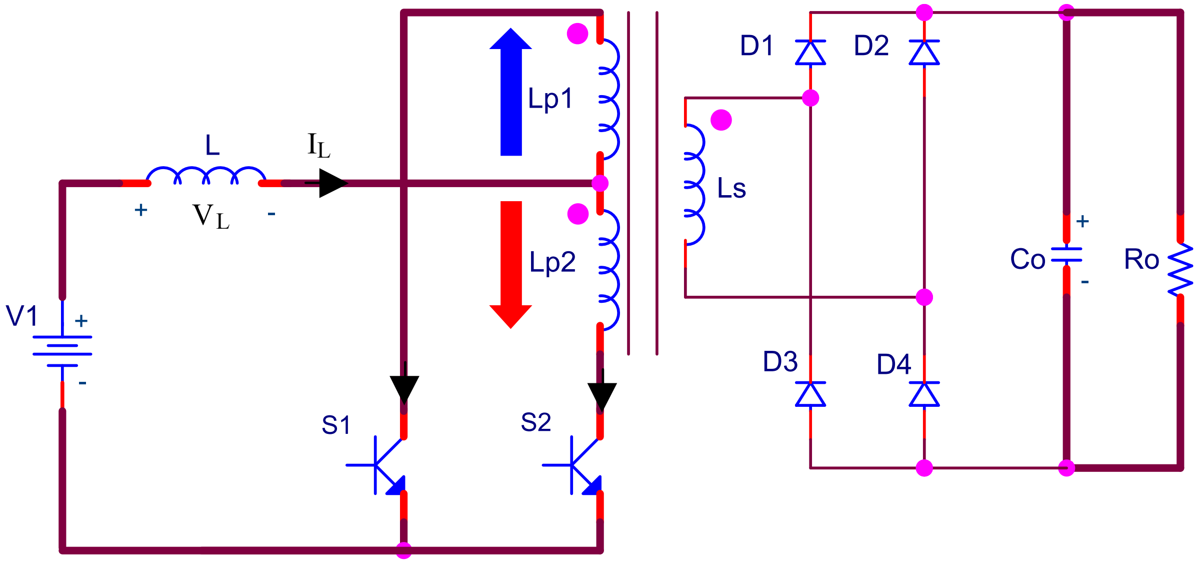
onde a = np/ns



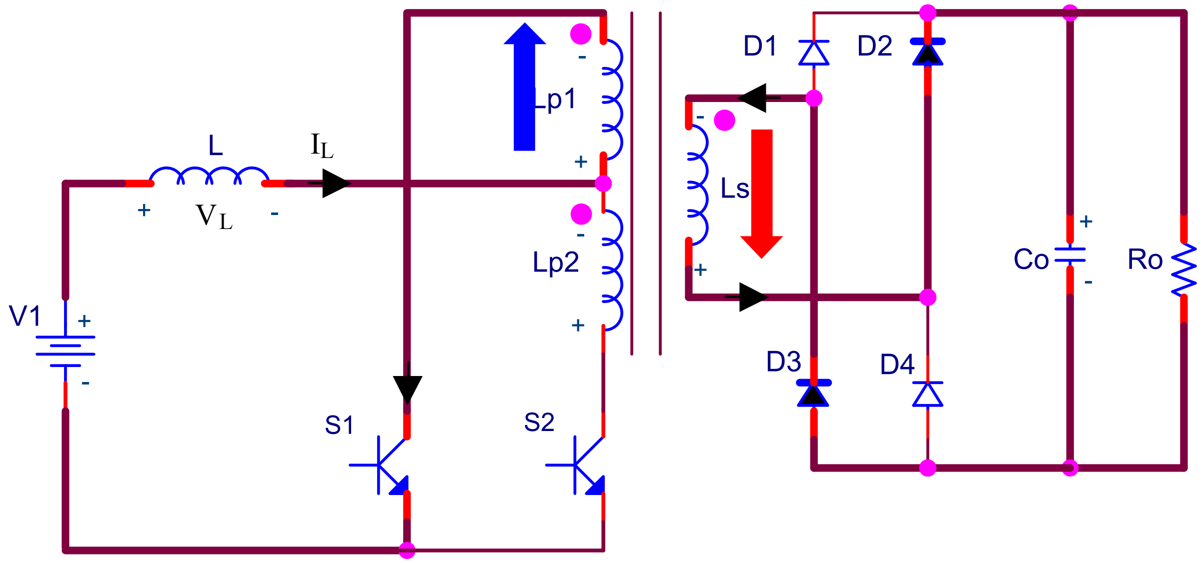
Conversores CC-CC: Push Pull com Entrada em Corrente

- Etapas de Operação

Primeira etapa


L
I_L
+
V_L
-
V1
+
-
Lp1
Lp2
Ls
D1
D2
D3
D4
Co
+
-
Ro
S1
S2

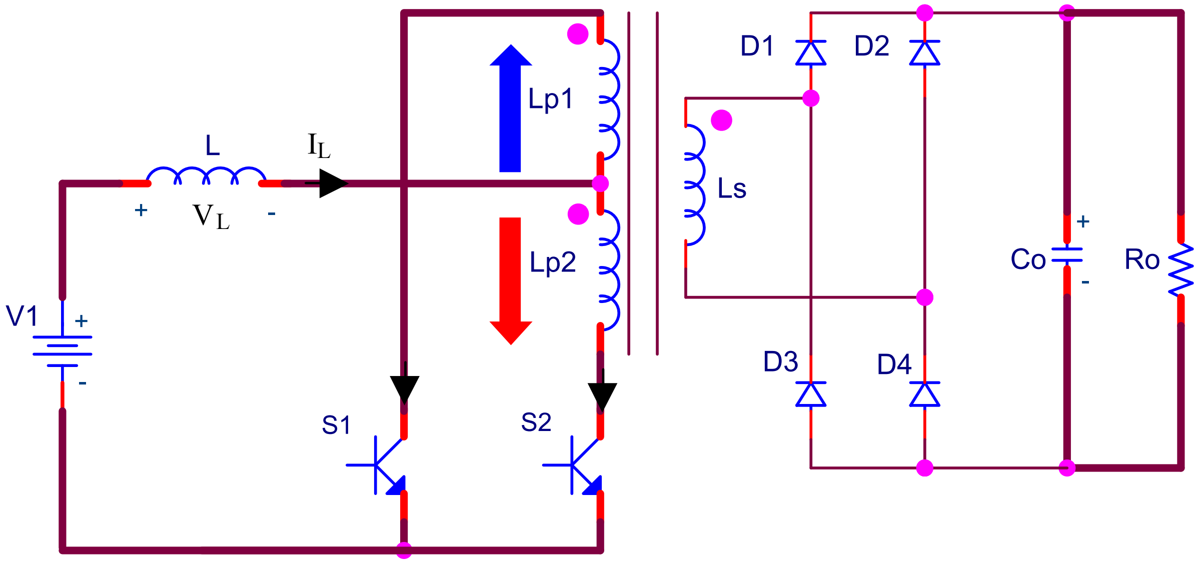
Segunda etapa


L
I_L
+
V_L
-
V1
+
-
Lp1
Lp2
Ls
D1
D2
D3
D4
Co
+
-
Ro
S1
S2

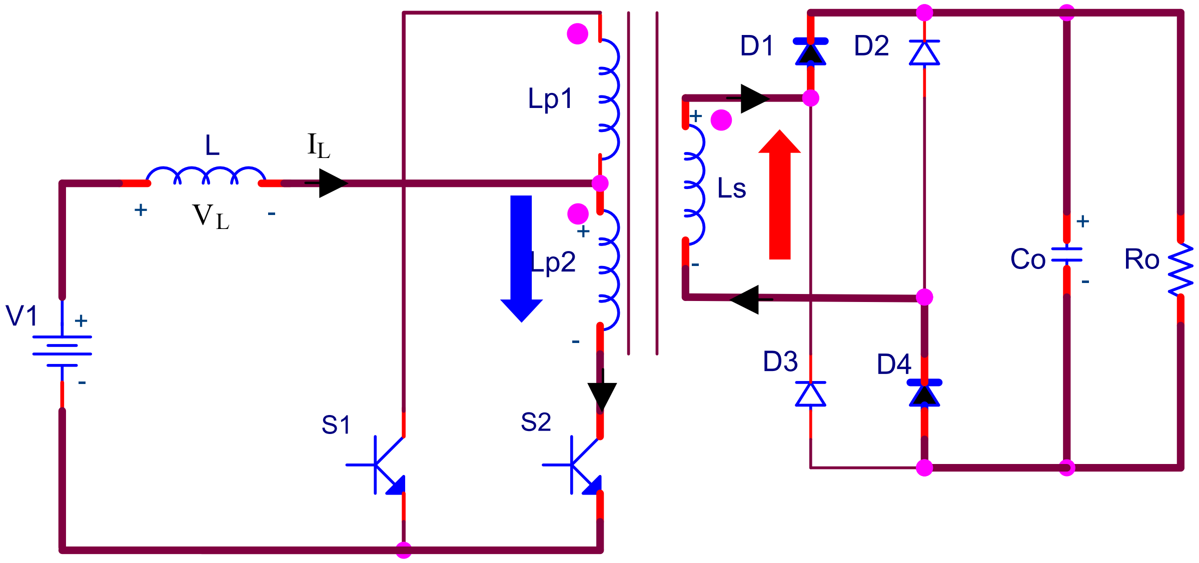
Conversores CC-CC: Push Pull com Entrada em Corrente

- Etapas de Operação

Terceira etapa

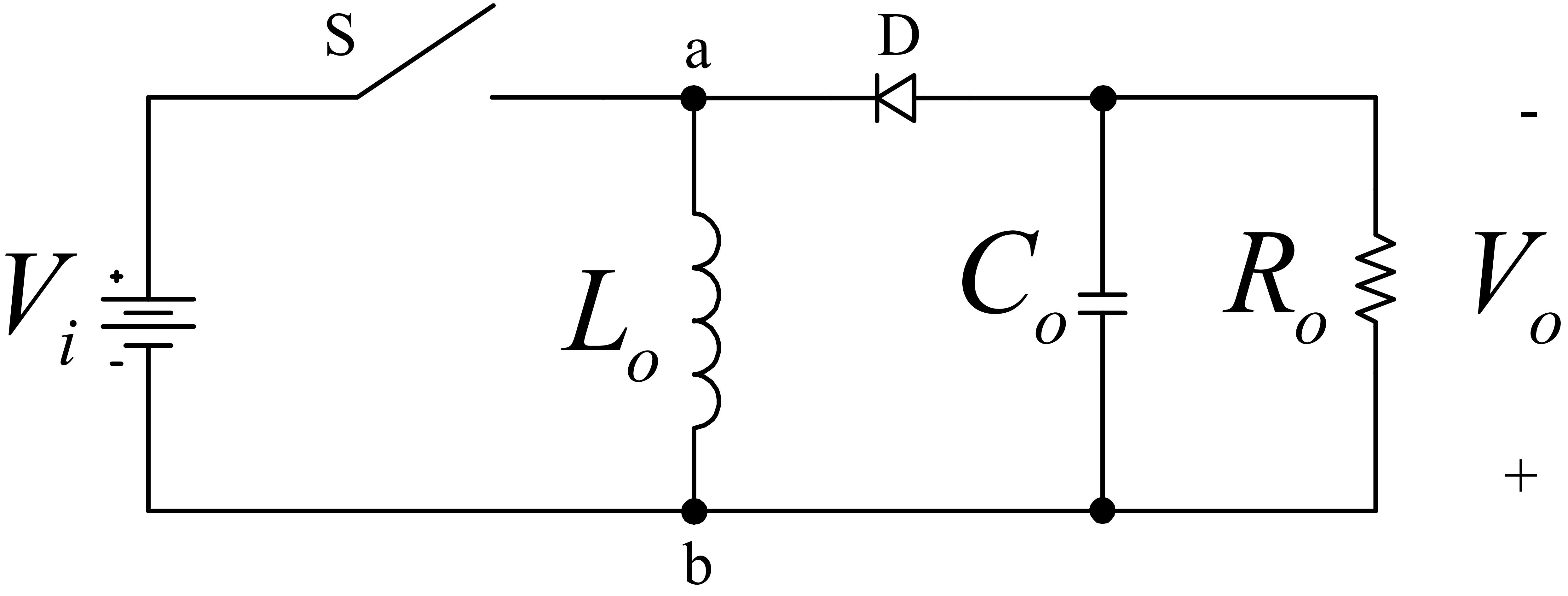

L
I_L
+
V_L
-
V1
+
-
Lp1
Lp2
S1
S2
Ls
D1
D2
D3
D4
Co
+
-
Ro

Quarta etapa


L
I_L
+
V_L
-
V1
+
-
Lp1
Lp2
+
-
S1
S2
Ls
+
-
D1
D2
D3
D4
Co
+
-
Ro

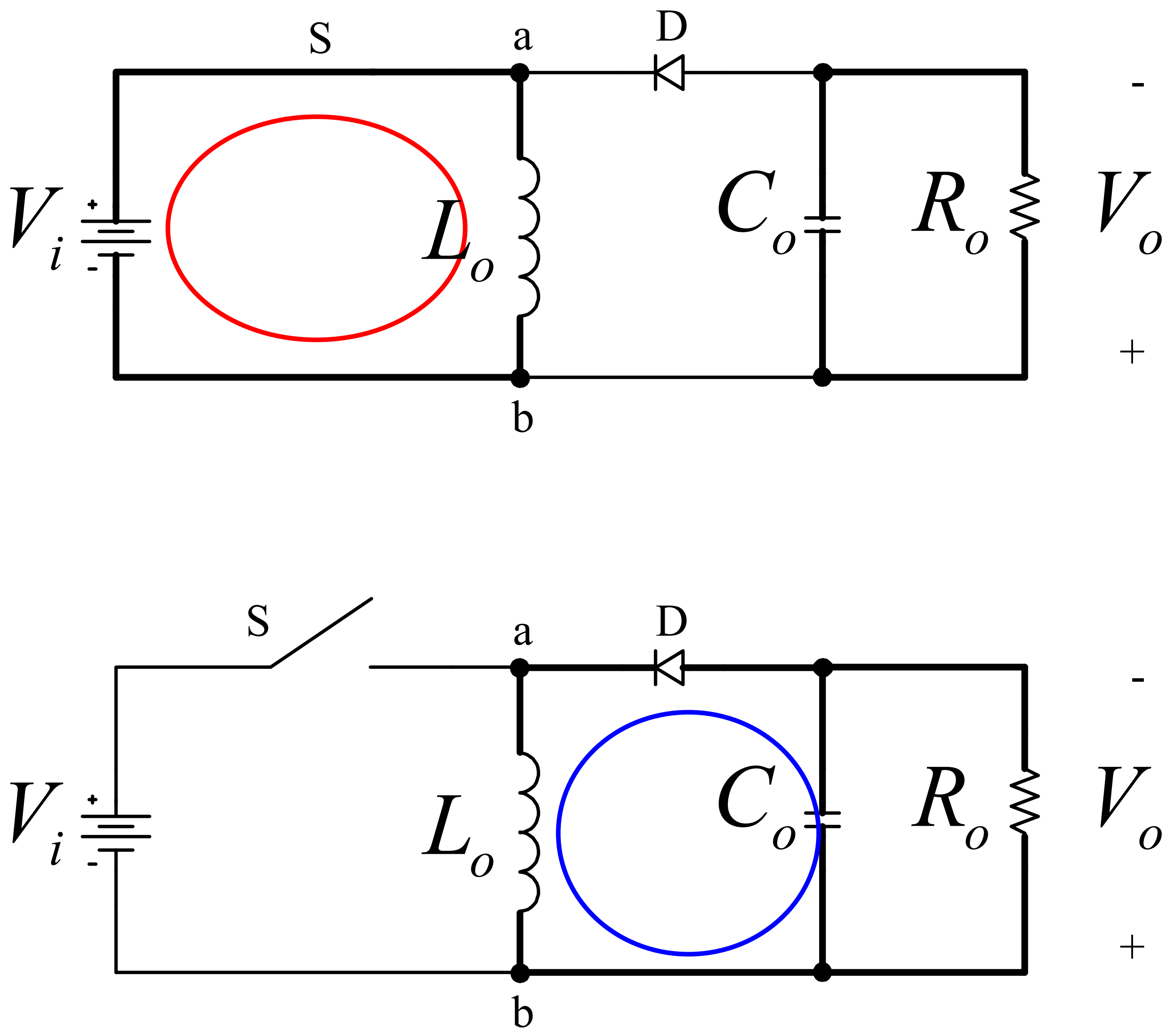
Conversores CC-CC: Buck-Boost

Estrutura de um conversor do tipo Buck-Boost

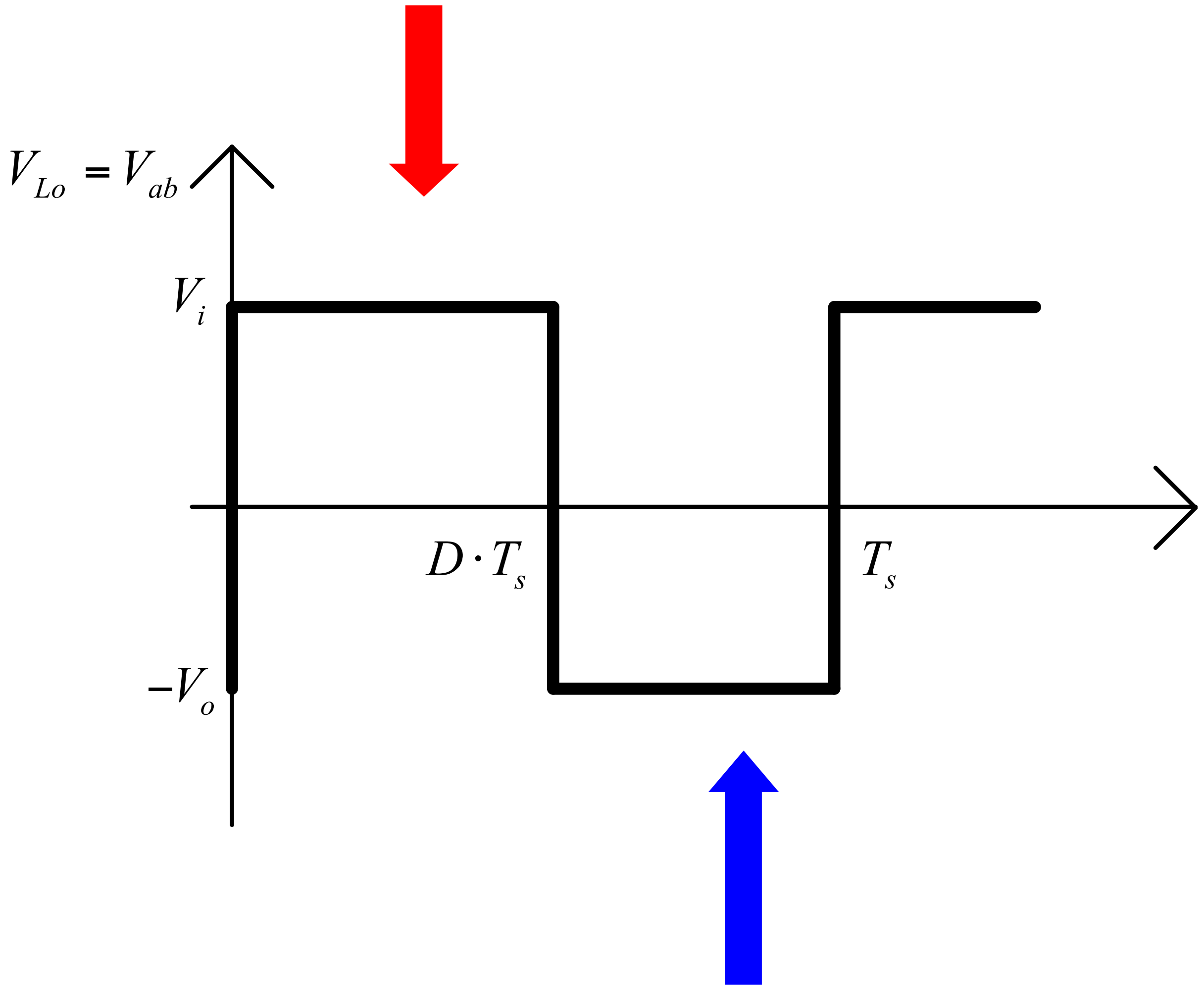

S
a
D
-
V_i
+
-
L_o
C_o
R_o
V_o
+
b

Conversores CC-CC: Buck-Boost

Etapas de operação - MCC

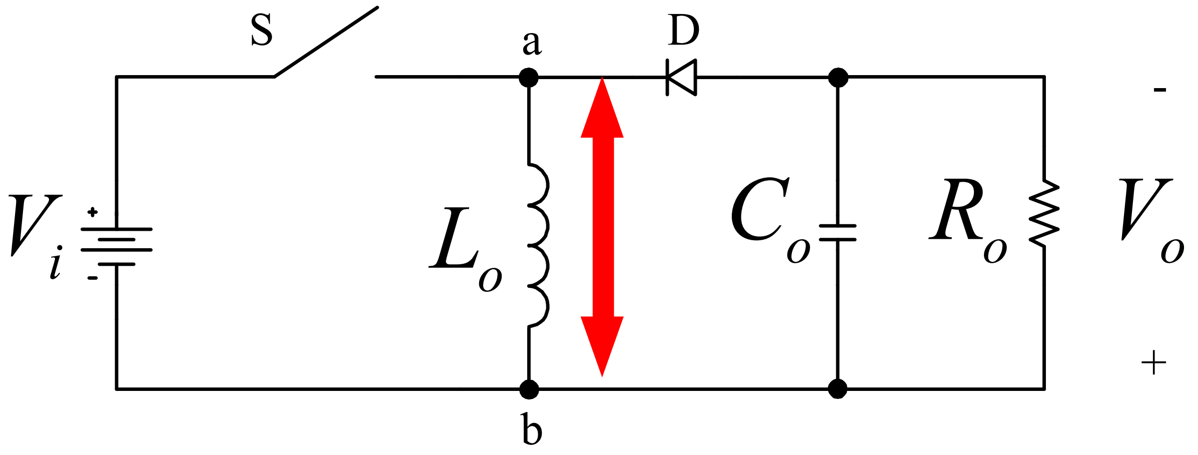

S
a
D
b
V_i
+
-
L_o
C_o
R_o
V_o
-
+
S
a
D
b
V_i
+
-
L_o
C_o
R_o
V_o
-
+

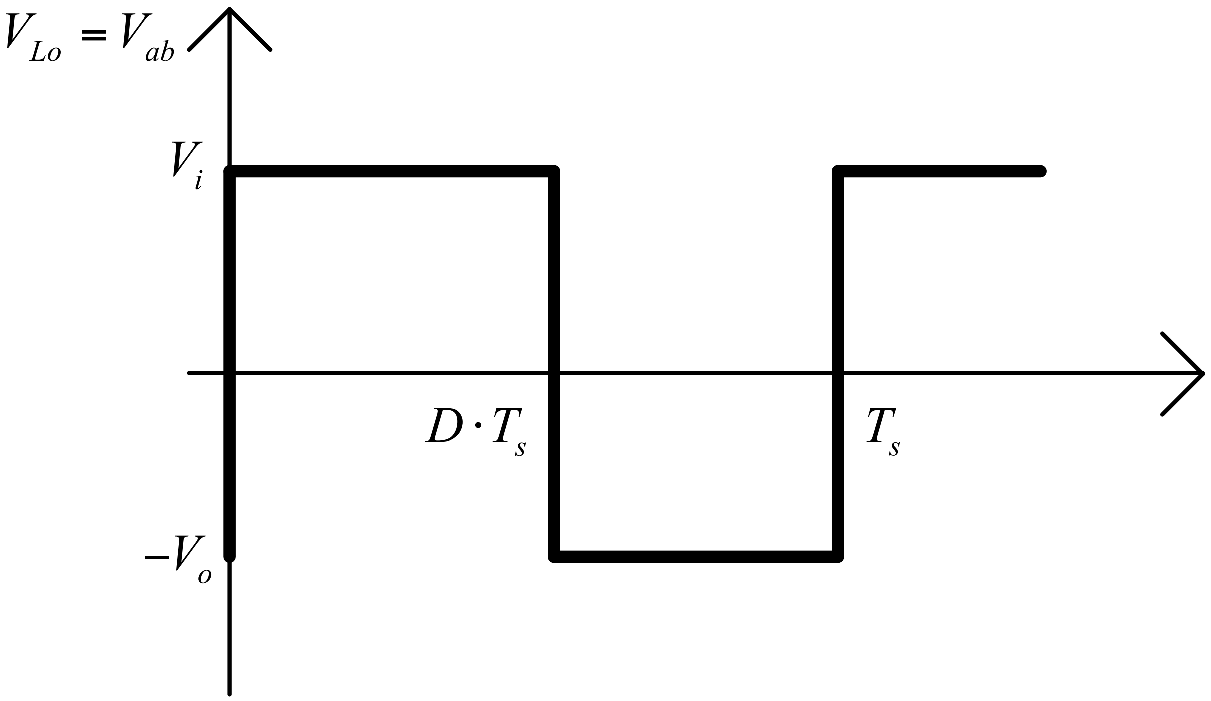
Formas de onda



Conversores CC-CC: Buck-Boost

Análise das grandezas envolvidas:





Tensão média na saída:

$$V_{ab} = \frac{1}{T_s}\int_0^{D\cdot T_s} V_i \cdot dt + \frac{1}{T_s}\int_{D\cdot T_s}^{T_s} (-V_o)\cdot dt$$

$$V_{ab} = \frac{V_i \cdot (D \cdot T_s - 0) - V_o \cdot (T_s - D \cdot T_s)}{T_s}$$

$$V_{ab} = V_i \cdot D - V_o \cdot (1 - D)$$

$$V_{ab} = V_i \cdot D - V_o \cdot (1 - D) = 0$$

$$V_i \cdot D = V_o \cdot (1 - D)$$

$$V_o = V_i \cdot \frac{D}{1 - D}$$

$$D = 1 + \frac{V_o}{V_i}$$

Conversores CC-CC: Buck-Boost

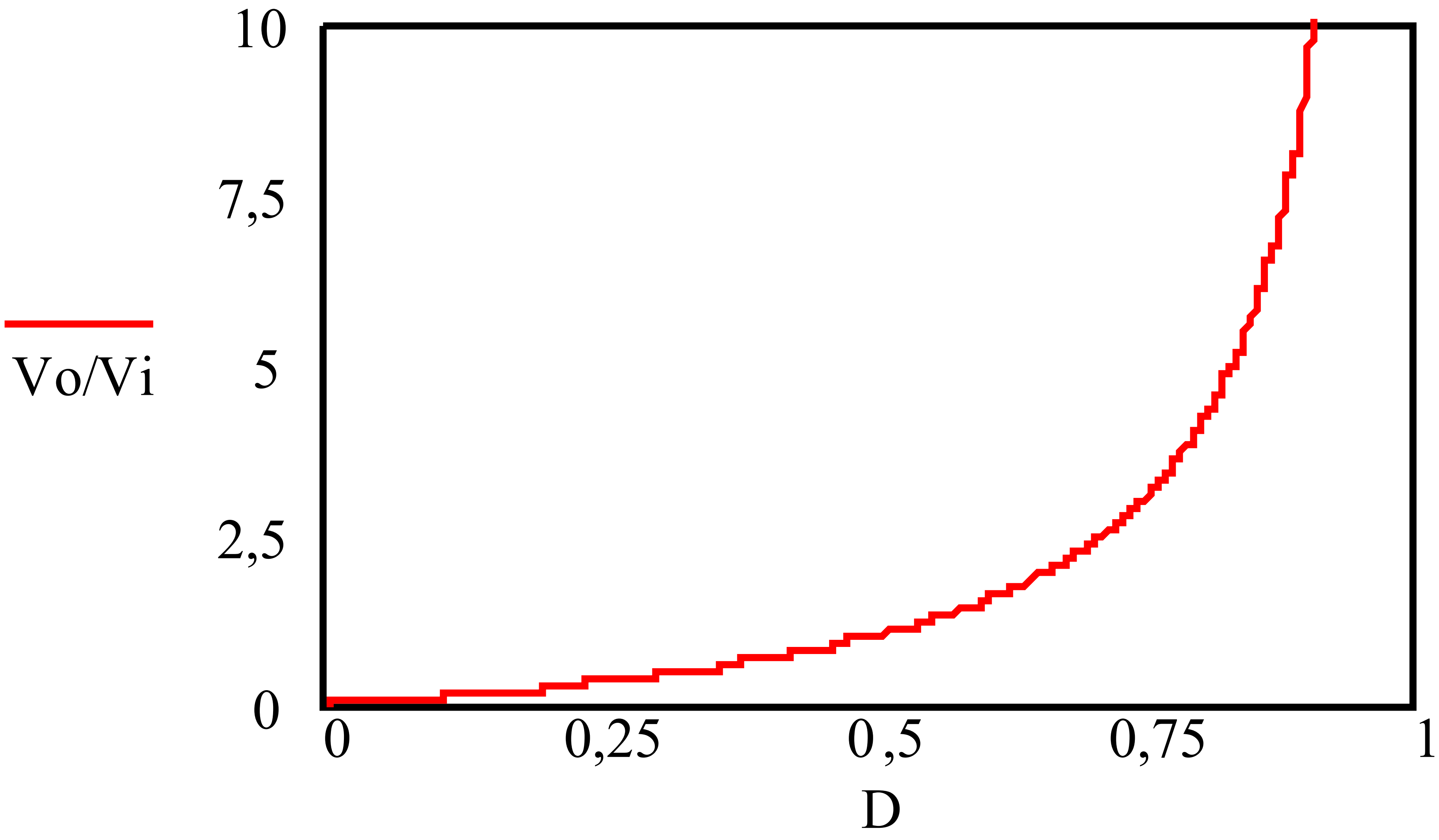
Análise das grandezas envolvidas:

Tensão média na saída:

$$V_o = V_i \cdot \frac{D}{1 - D}$$

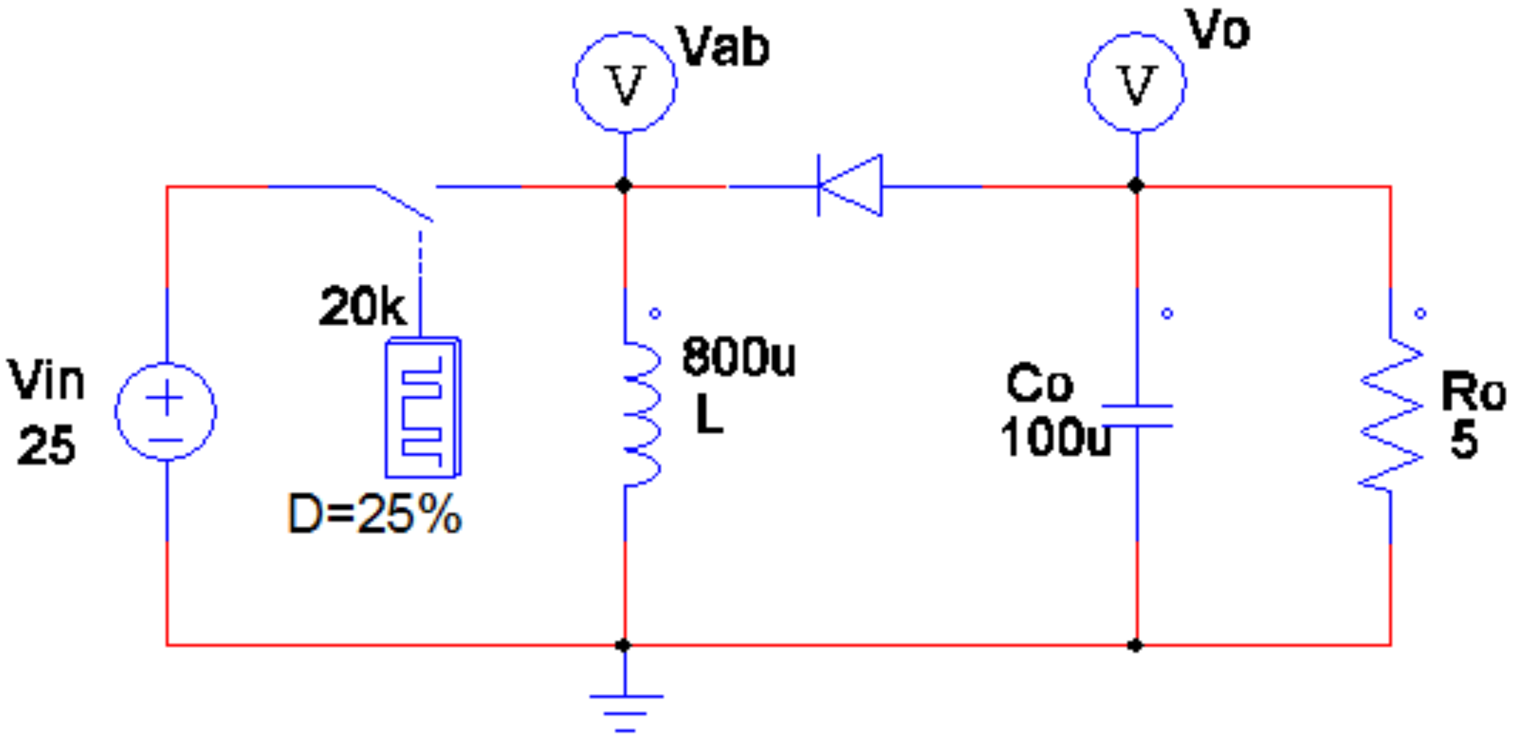
$$\boxed{\frac{V_o}{V_i} = \frac{D}{1 - D}}$$

Ganho estático



Conversores CC-CC: Buck-Boost

Principais formas de onda (circuito simulado):

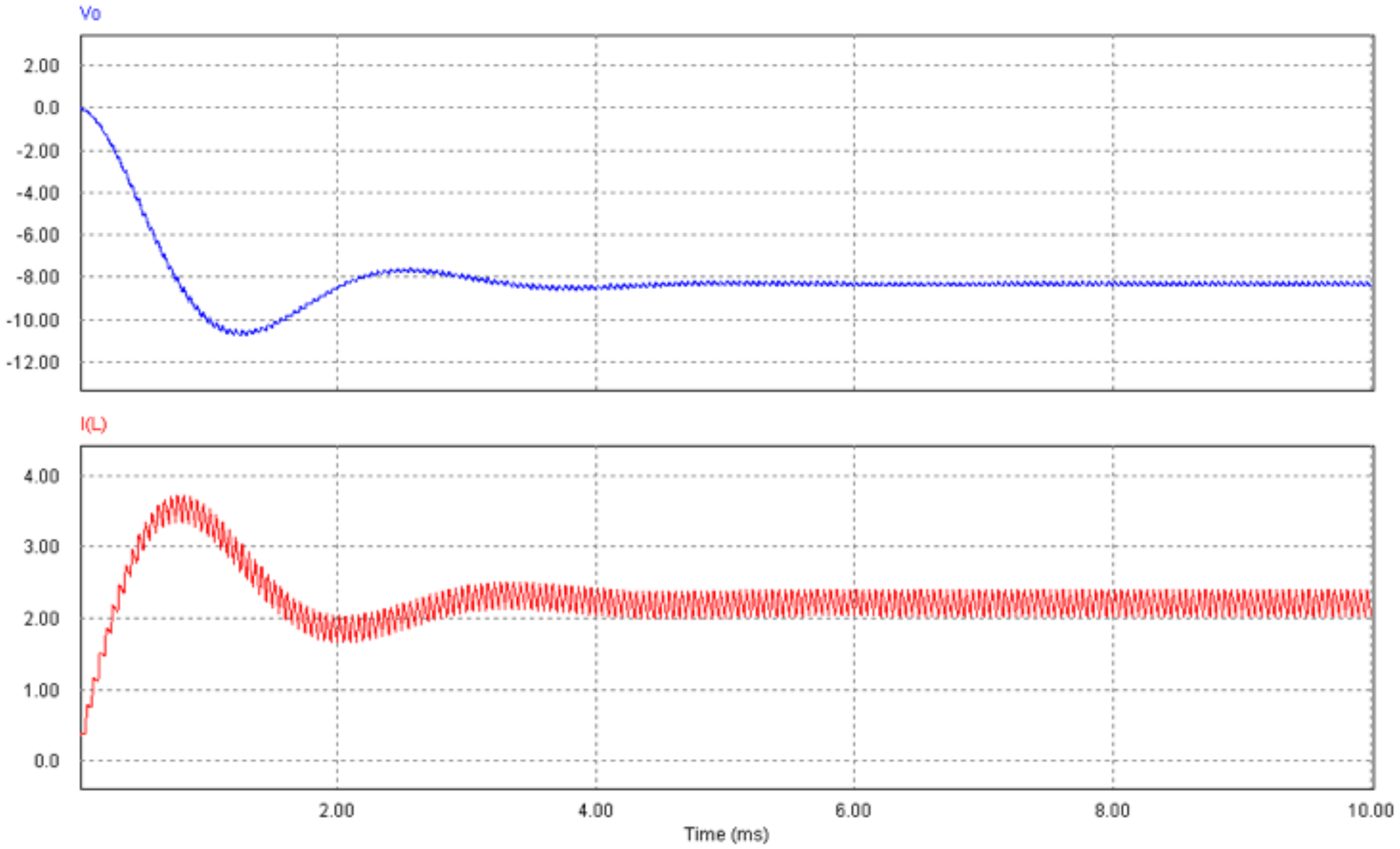

Vab
V
Vo
V
20k
Vin
25
D=25%
800u
L
Co
100u
Ro
5

$$\frac{V_o}{V_i} = \frac{D}{1-D}$$

$$\frac{V_o}{V_i} = \frac{0,25}{1-0,25} = \frac{1}{3}$$

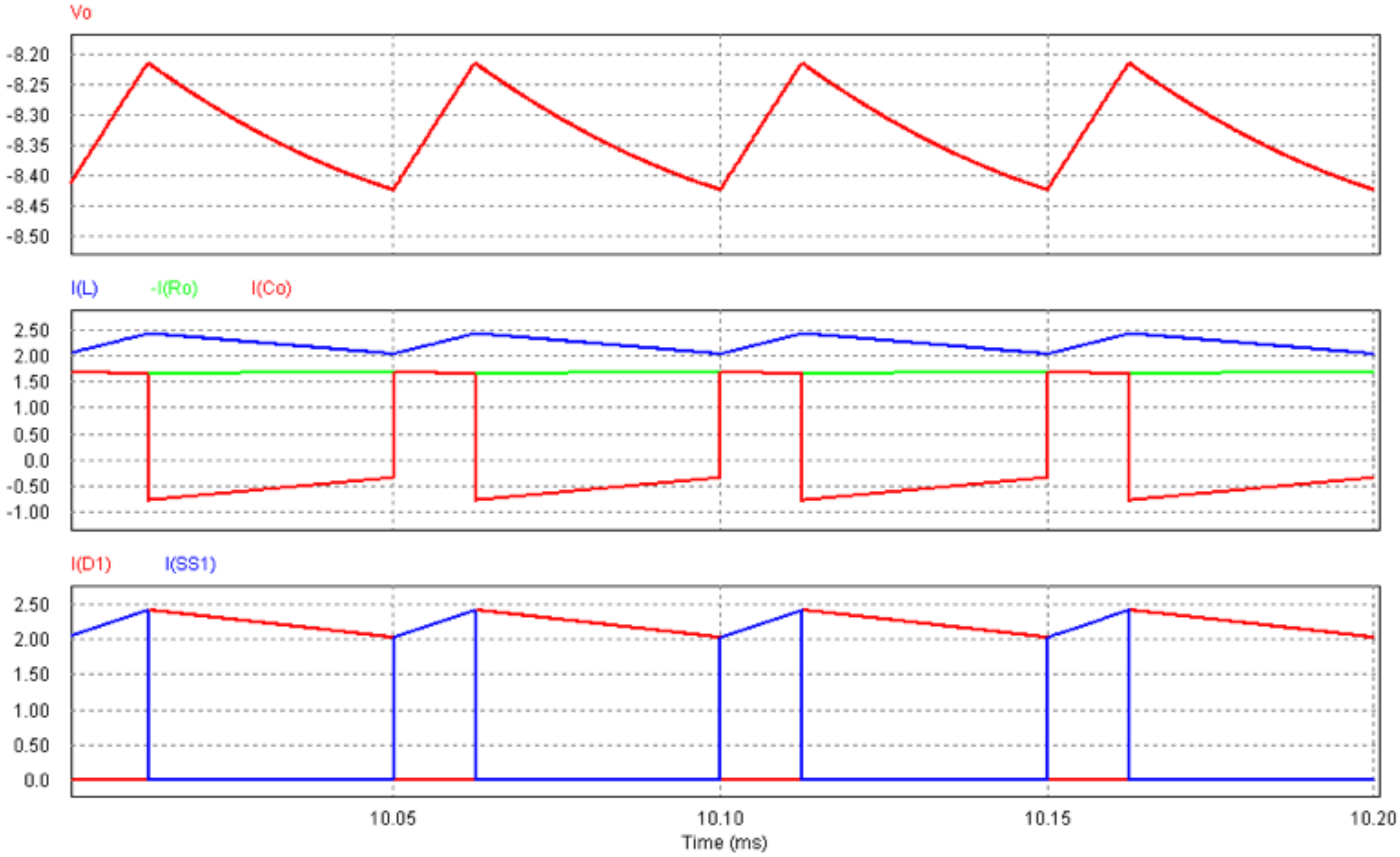
Conversores CC-CC: Buck-Boost

Principais formas de onda (transitório de partida):



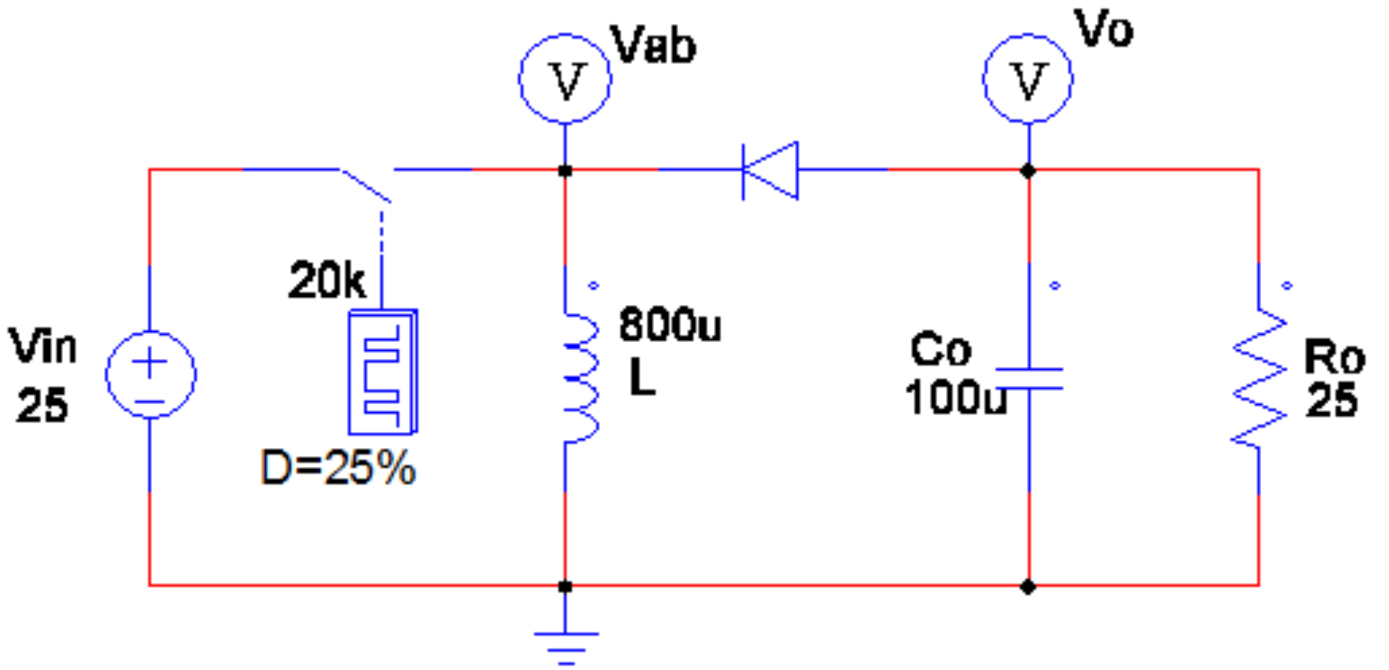
Conversores CC-CC: Buck-Boost

Principais formas de onda (regime permanente):



Conversores CC-CC: Buck-Boost

Principais formas de onda (circuito simulado):

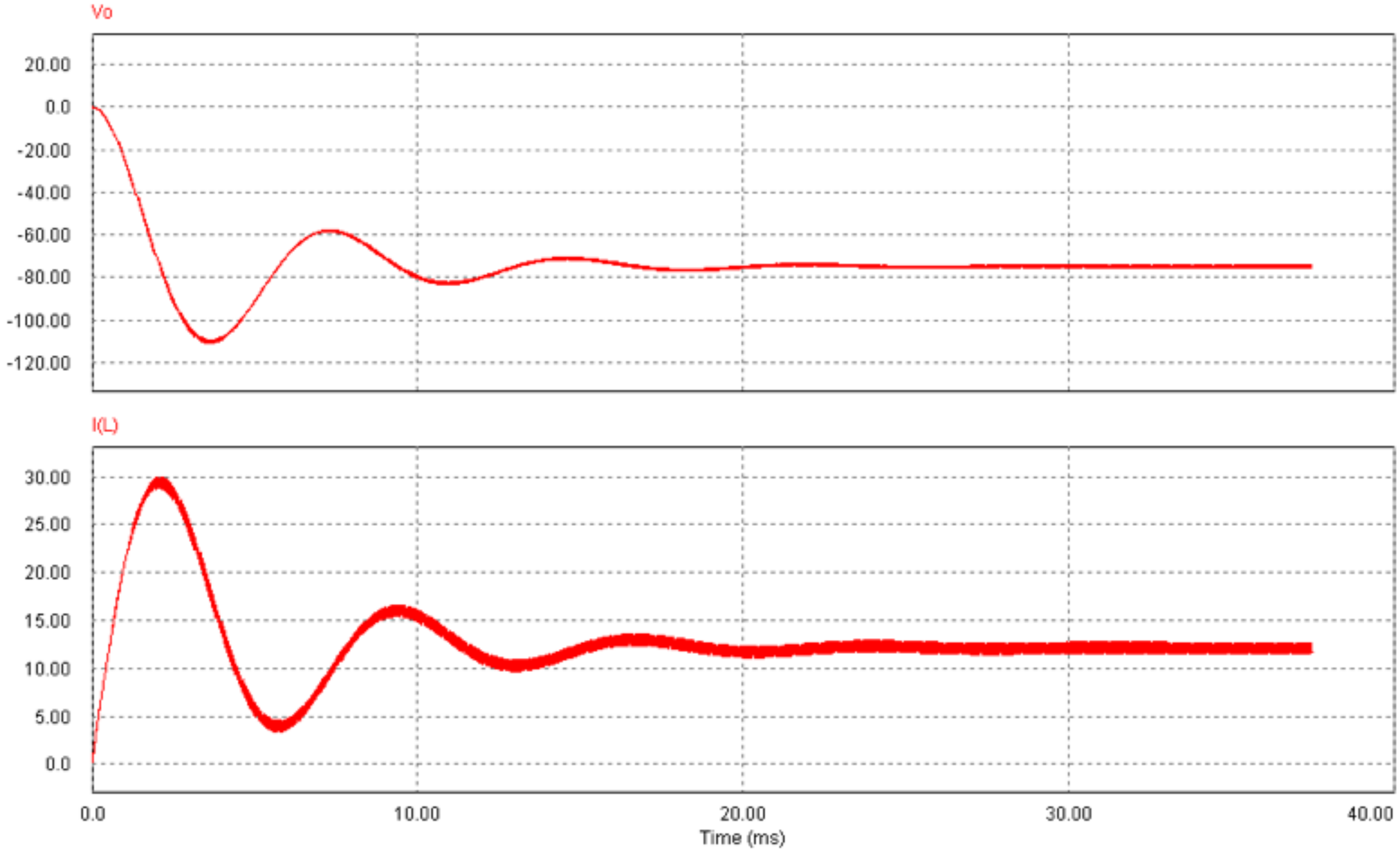

Vab
V
Vo
V
20k
Vin
25
D=25%
800u
L
Co
100u
Ro
25

$$\frac{V_o}{V_i} = \frac{D}{1-D}$$

$$\frac{V_o}{V_i} = \frac{0,75}{1-0,75} = 3$$

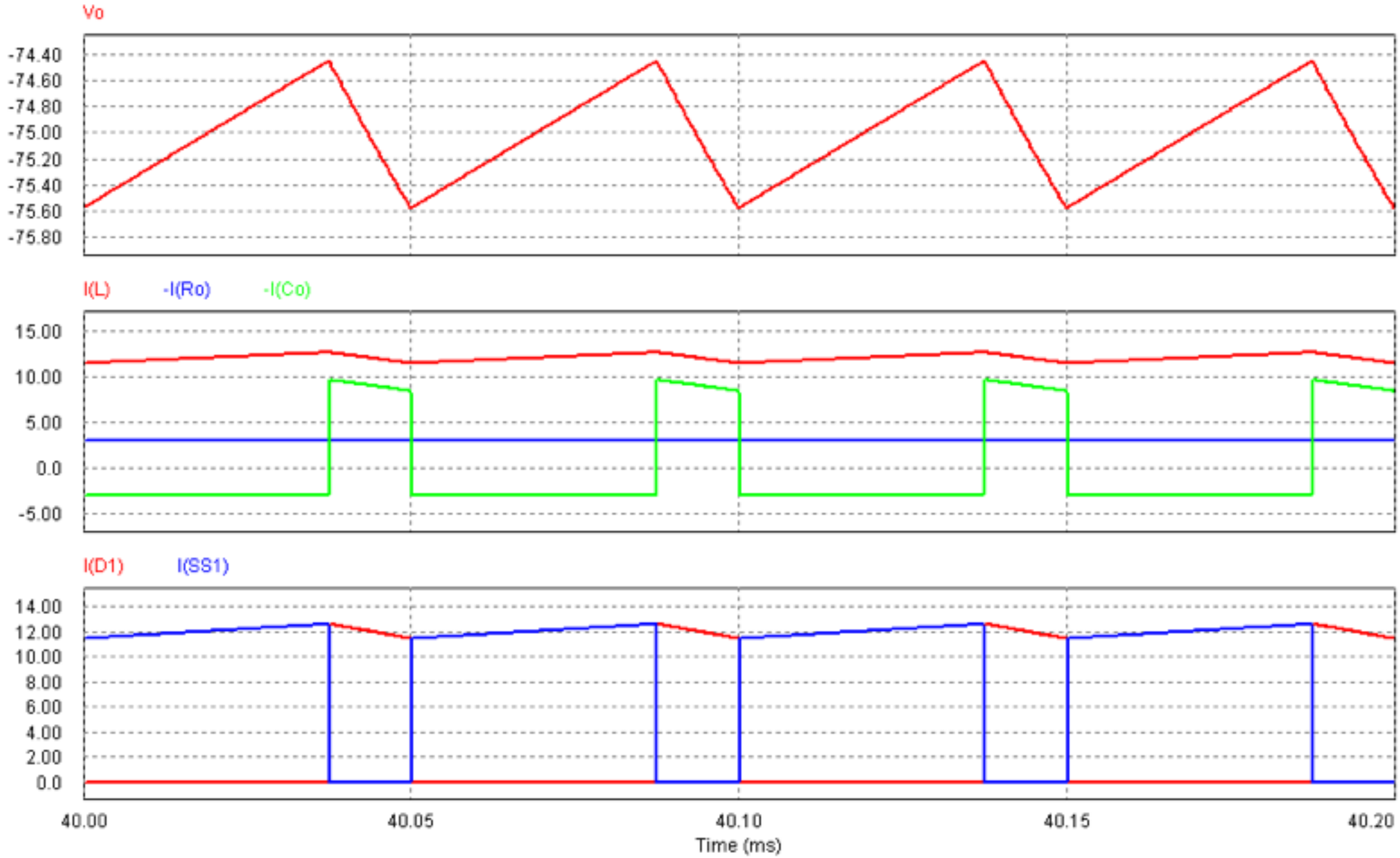
Conversores CC-CC: Buck-Boost

Principais formas de onda (transitório de partida):



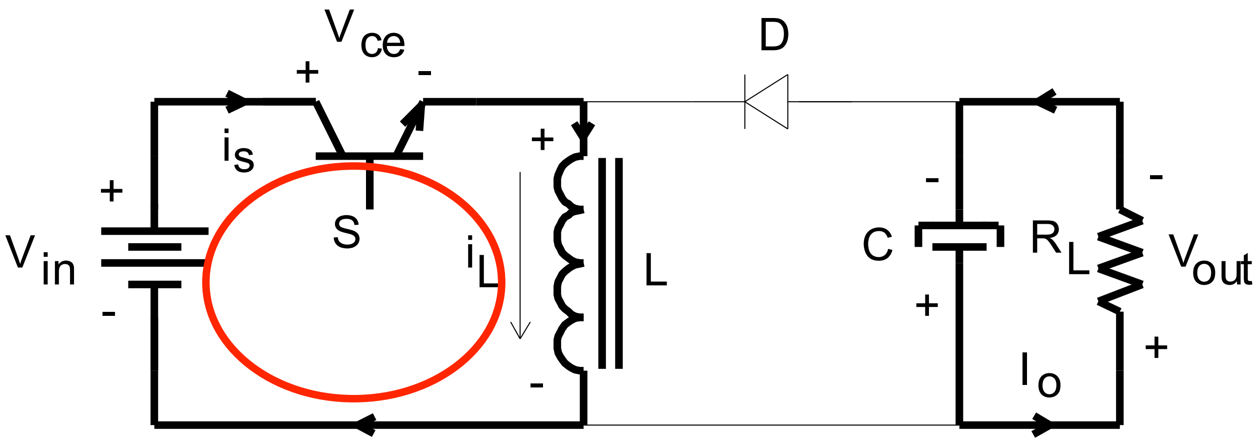
Conversores CC-CC: Buck-Boost

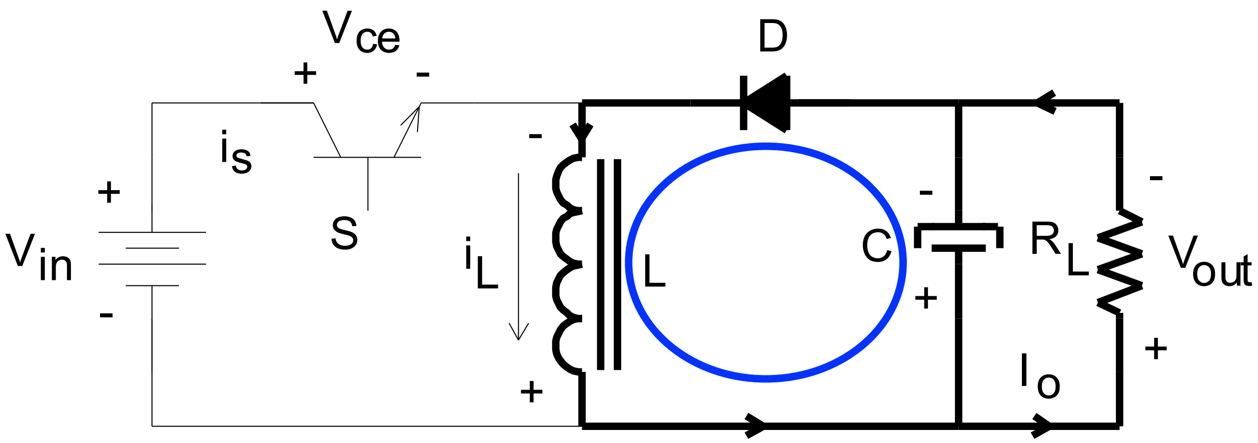
Principais formas de onda (regime permanente):

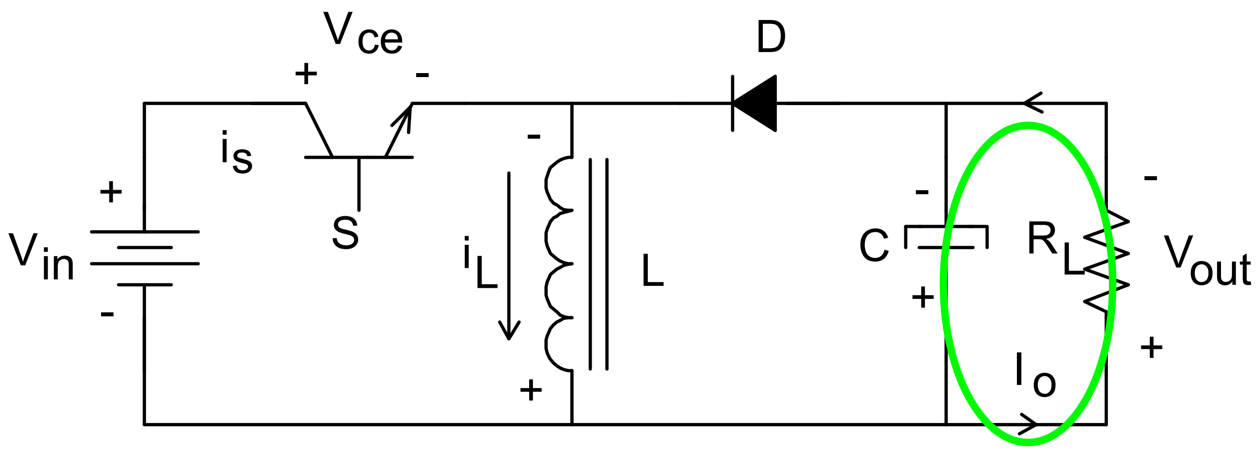


Conversores CC-CC: Buck-Boost

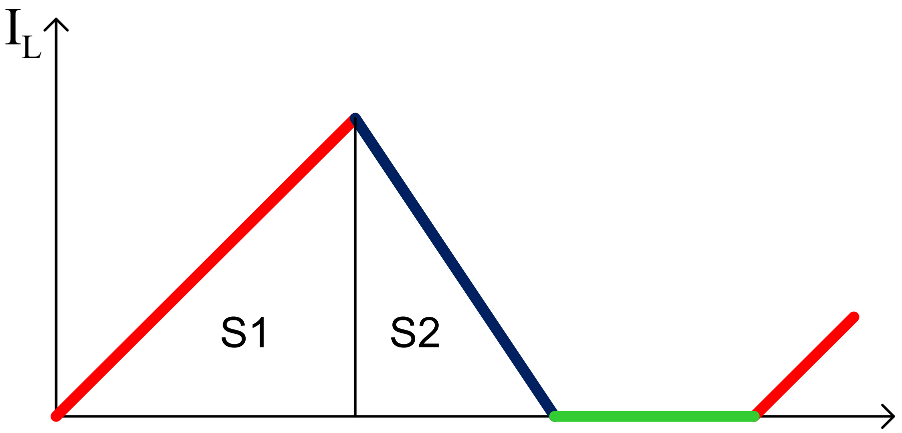
Etapas de operação - MCD


V ce
+
-
D
is
S
iL
L
C
RL
Vout
Vin
Io
+
-


V ce
+
-
D
is
S
iL
L
C
RL
Vout
Vin
Io
+
-


V ce
+
-
D
is
S
iL
L
C
RL
Vout
Vin
Io
+
-

Formas de onda

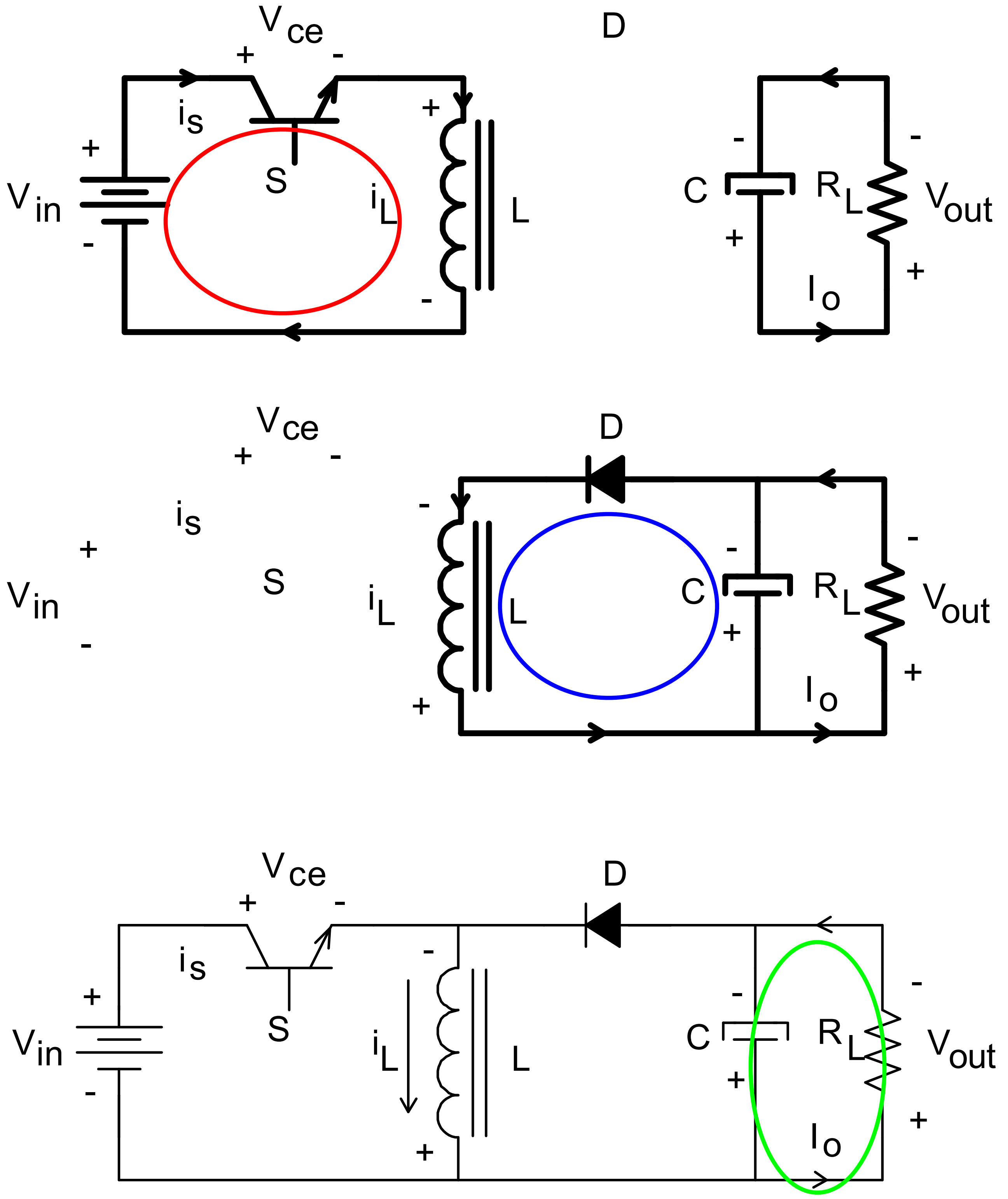


Ganho estático

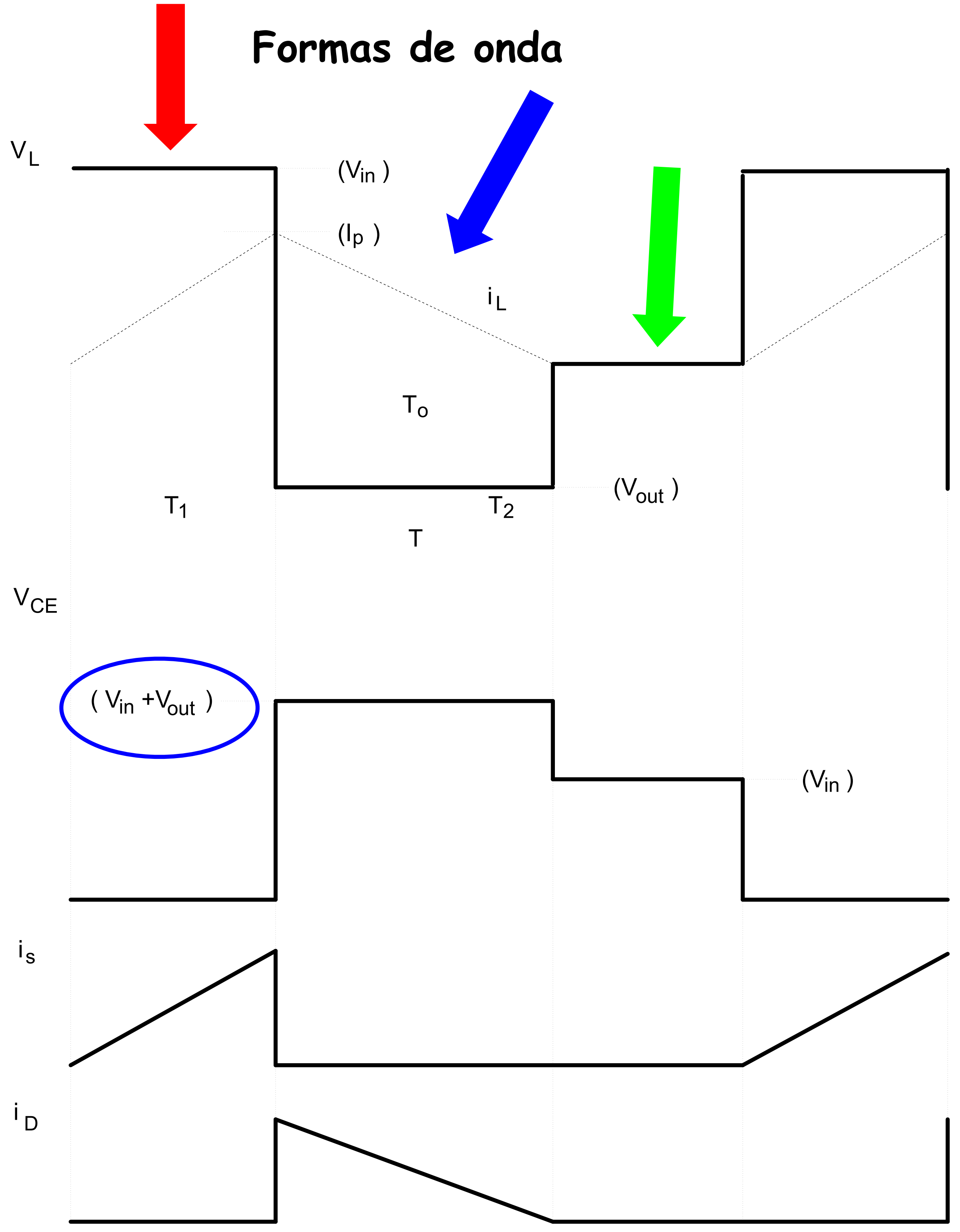
$$\frac{V_o}{V_i} = D \cdot \sqrt{\frac{R_L}{2 \cdot f \cdot L}}$$

Conversores CC-CC: Buck-Boost

Etapas de operação - MCD

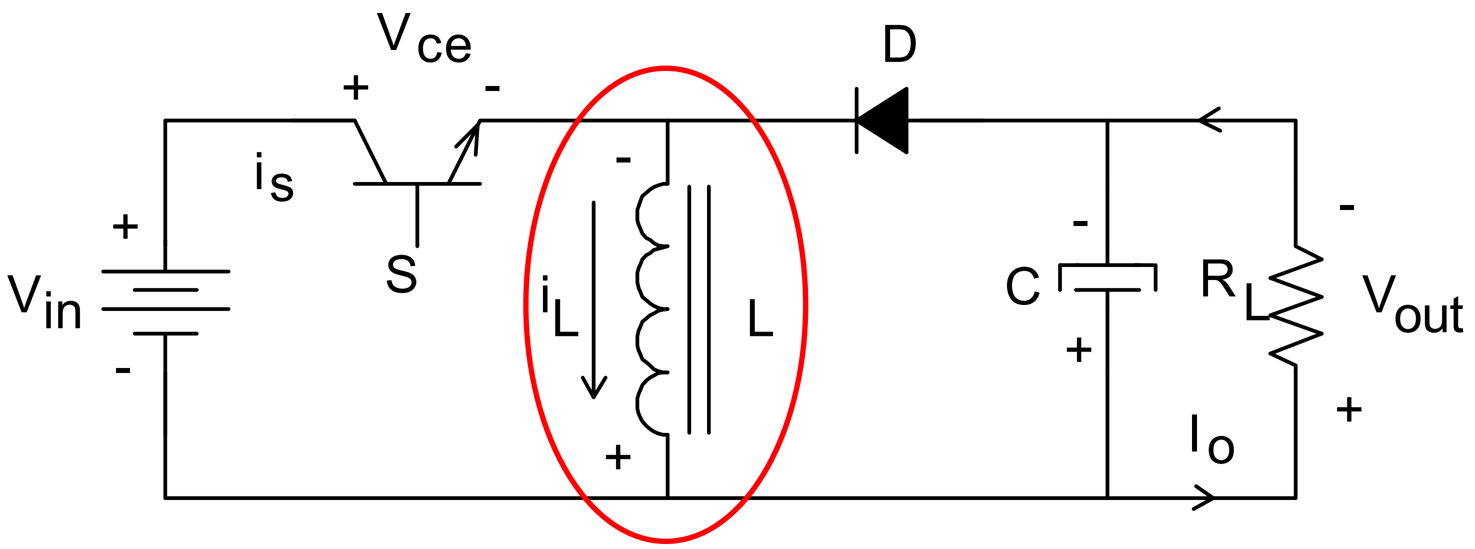

Vce
+
-
D
is
S
iL
L
Vin
+
-
C
RL
Vout
Io

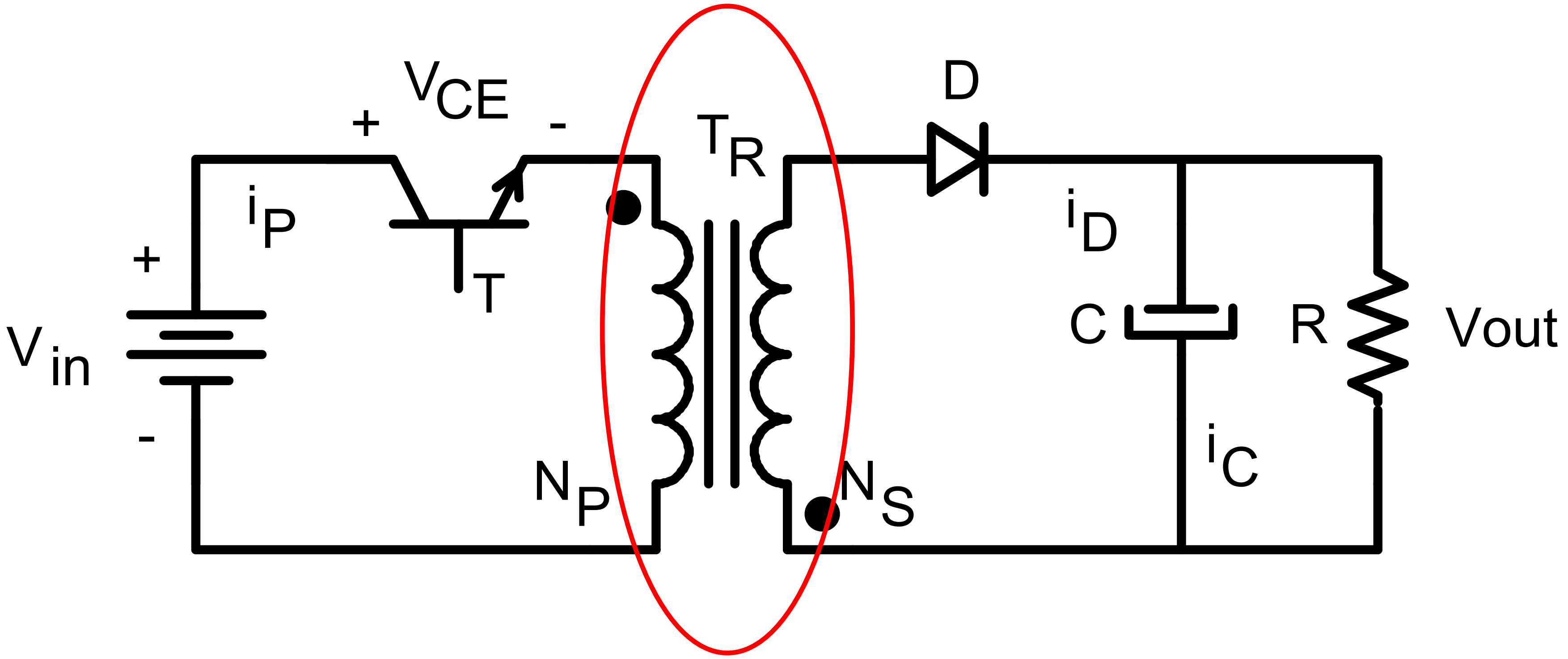
Formas de onda



Conversores CC-CC: Flyback (Buck Boost Isolado)

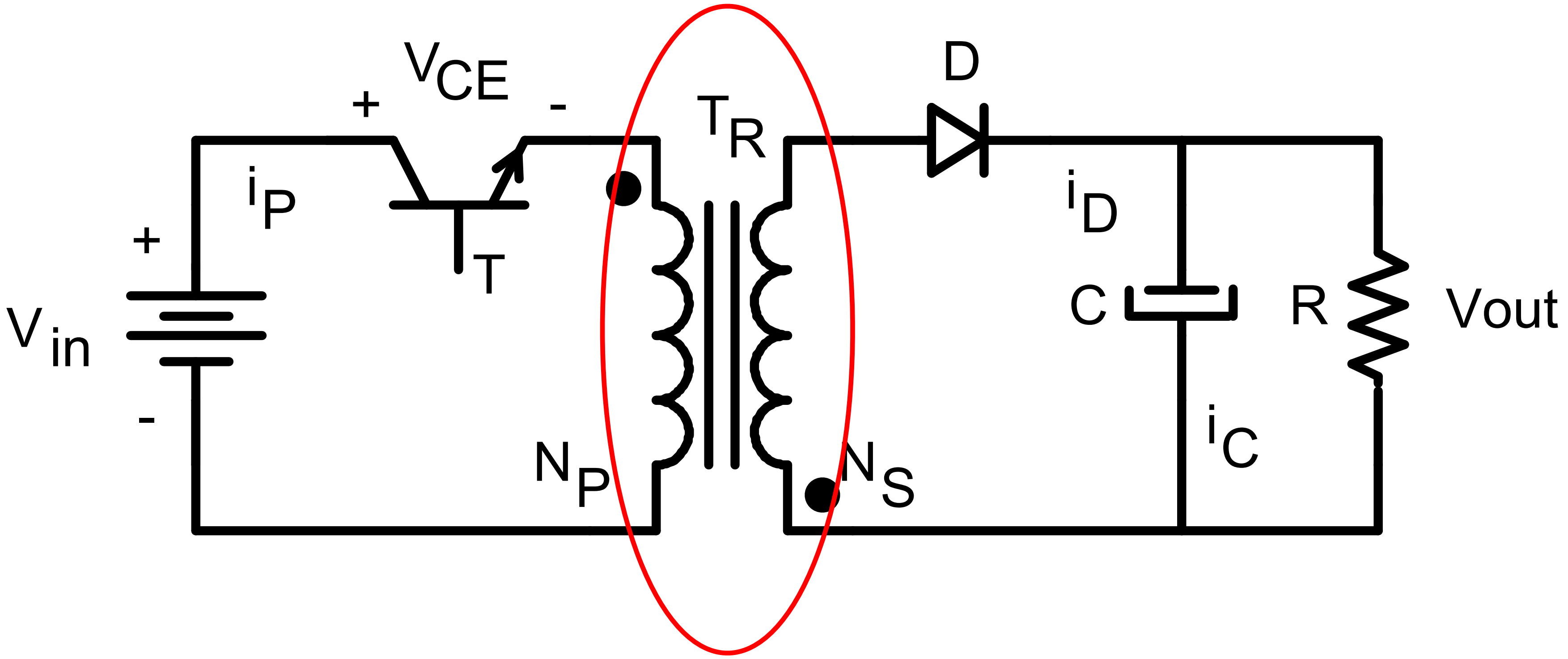
Estrutura


V_{ce}
+
-
D
i_S
S
+
V_{in}
-
-
i_L
L
+
-
C
+
R_L
-
V_{out}
+
I_O


V_{CE}
+
-
T_R
D
i_P
T
+
V_{in}
-
N_P
N_S
i_D
C
R
Vout
i_C

Conversores CC-CC: Flyback (Buck Boost Isolado)

Estrutura


V_{CE}
+
-
D
T_R
i_P
+
T
V_{in}
-
N_P
N_S
i_D
C
R
Vout
i_C

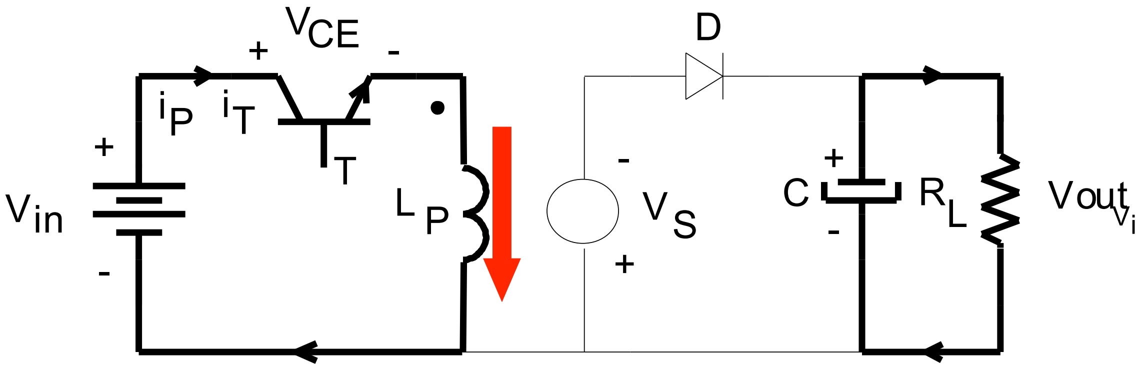
O transformador TR tem três funções:

- Propicia o isolamento entre a fonte e a carga;
- Faz a acumulação de energia quando o transistor T é fechado;
- Adapta a tensão necessária no secundário.

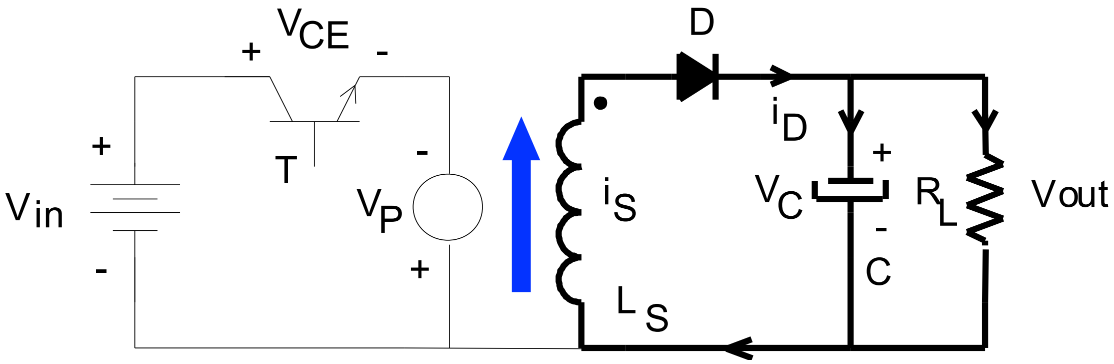
Conversores CC-CC: Flyback (Buck Boost Isolado)

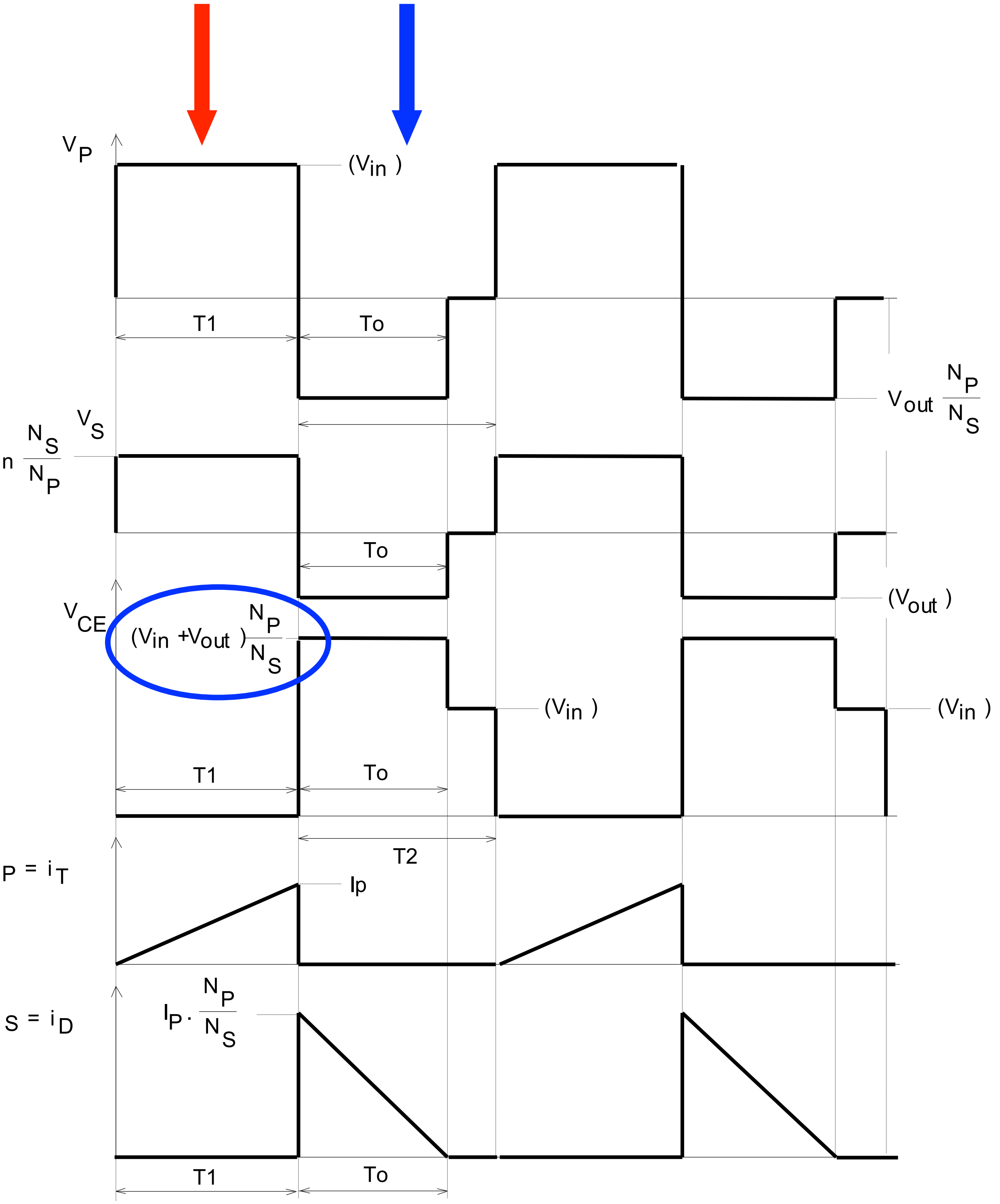
Etapas de operação – MCC

Primeira Etapa


VCE
+
-
D
iP
iT
T
+
Vin
-
LP
-
VS
+
C
+
-
RL
Vout

Segunda Etapa


VCE
+
-
D
T
+
Vin
-
VP
-
+
iS
LS
iD
VC
+
-
C
RL
Vout



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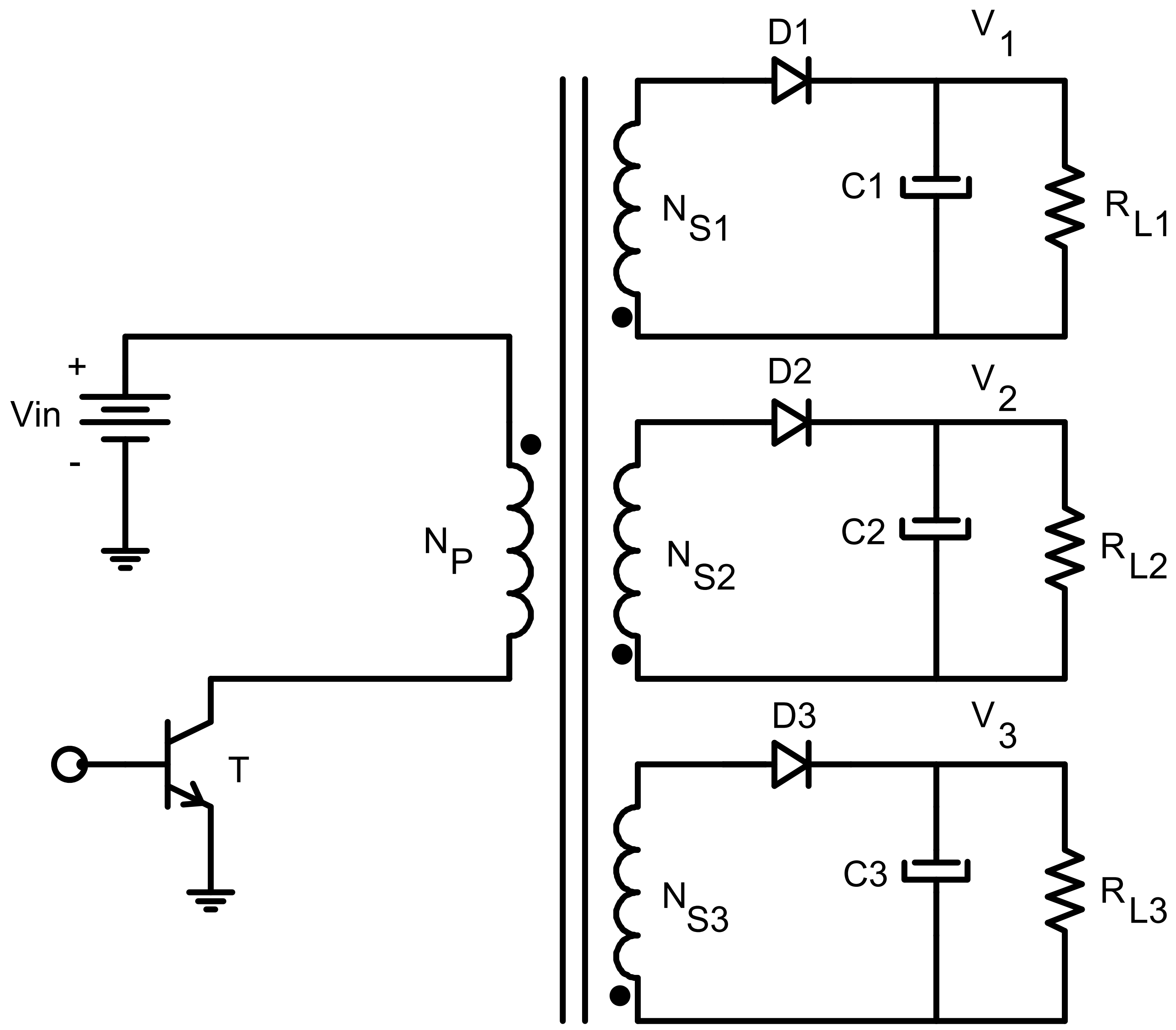
Conversores CC-CC: Flyback (Buck Boost Isolado)

Flyback com múltiplas saídas


D1
V1
C1
NS1
RL1
+
Vin
-
NP
T
D2
V2
C2
NS2
RL2
D3
V3
C3
NS3
RL3

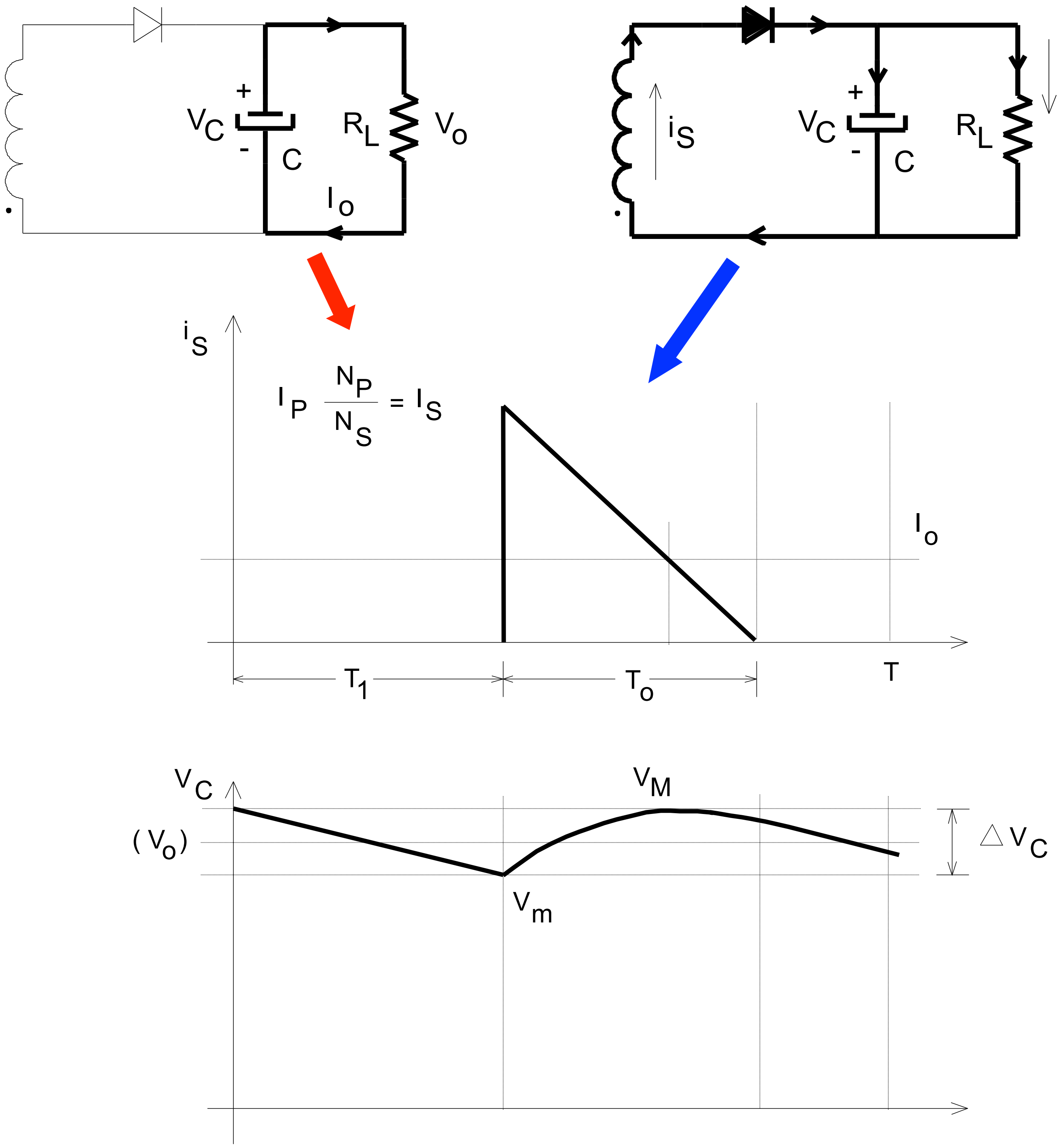
Conversores CC-CC: Flyback (Buck Boost Isolado)

Principais características:

- Baixo custo;
- Saídas múltiplas;
- Aceita grande variação da resistência de carga;
- Propicia isolamento entre a entrada e a saída;
- Boa regulação cruzada;
- Dispensa indutor de filtragem;
- Como a condução é descontínua, permite o emprego de diodos lentos;
- Resposta rápida;
- Fácil de ser estabilizada, por apresentar um pólo simples na FT.

Conversores CC-CC: Flyback (Buck Boost Isolado)

Filtro de saída



V_C
+
-
C
R_L
V_o
I_o
i_S
V_C
+
-
C
R_L
I_o
V_o
i_S
$I_P \frac{N_P}{N_S} = I_S$
I_o
T_1
T_o
T
V_C
(V_o)
V_M
V_m
ΔV_C

$$\Delta V_C = \frac{T_1 I_o}{C}$$

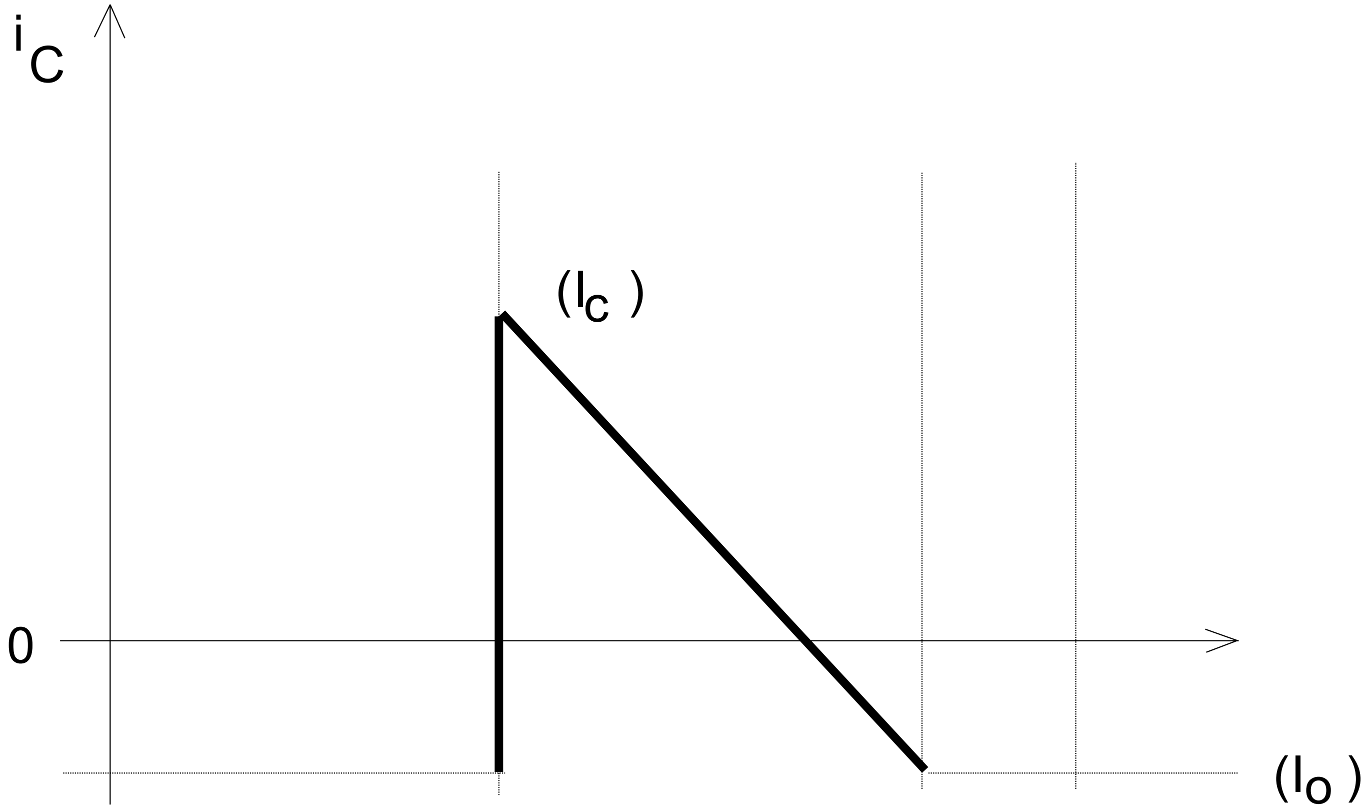
$$C = \frac{I_o D_{max}}{f \Delta V_C}$$

$$\Delta e = RSE I_S$$

$$RSE < \frac{\Delta e}{I_S}$$

Conversores CC-CC: Flyback (Buck Boost Isolado)

Filtro de saída



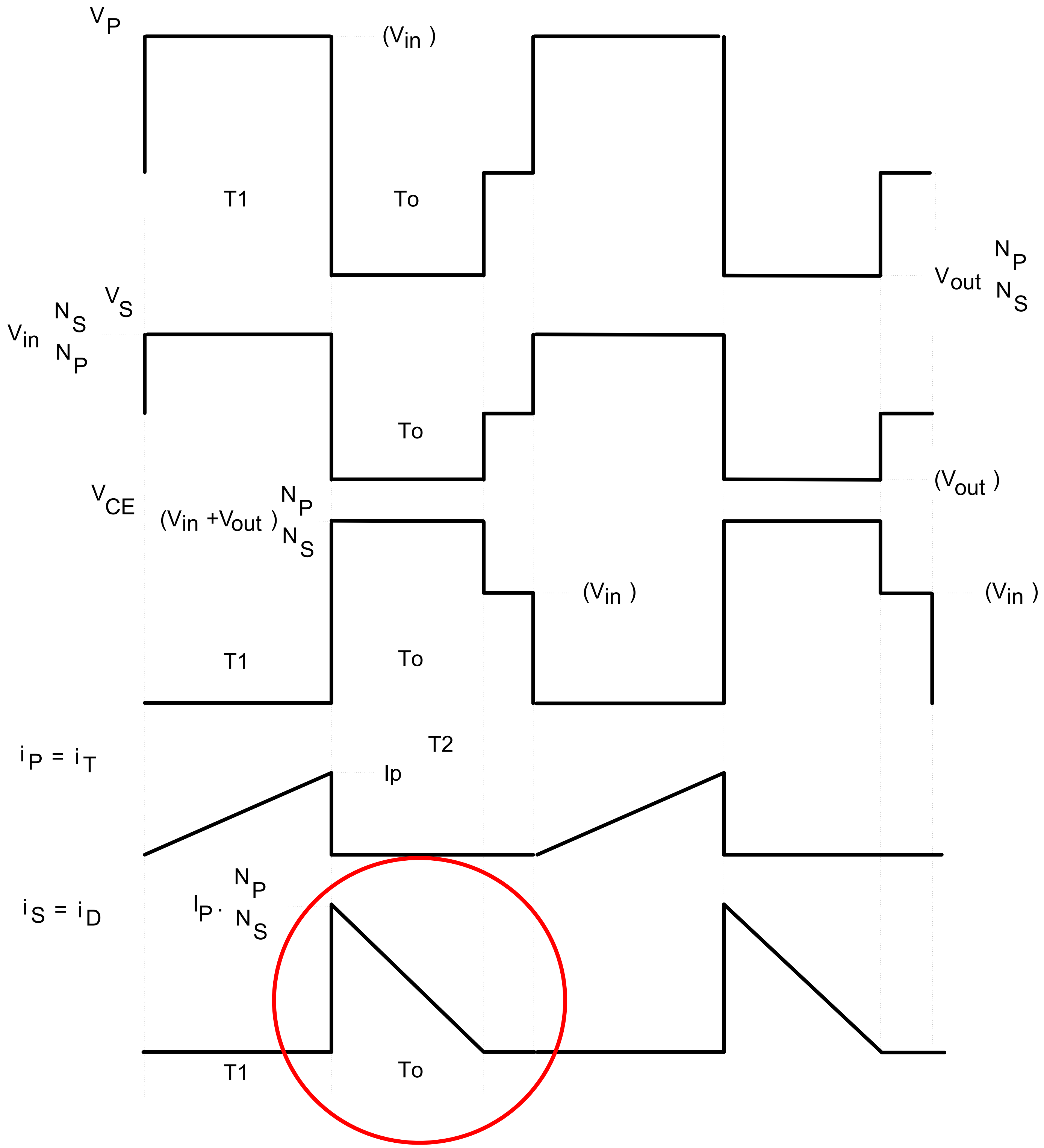
$$I_{S_{ef}} = \sqrt{\frac{1}{T}\int_0^{T_0} I_S^2 \left(1-\frac{t}{T_0}\right)^2 dt}$$

$$I_{C_{ef}} = \sqrt{i_{S_{ef}}^2 - I_o^2} = \sqrt{I_S^2 \frac{T_0}{3T} - I_o^2}$$

$$I_{C_{ef}} = \sqrt{I_S^2 \frac{T_0}{3T} - \left(\frac{I_S T_0}{2T}\right)^2}$$

Conversores CC-CC: Flyback (Buck Boost Isolado)

Análise das grandezas envolvidas:


V_P
(V_{in})
T1
To
$V_{out}\frac{N_P}{N_S}$
V_S
$V_{in}\frac{N_S}{N_P}$
To
(V_{out})
V_{CE}
$(V_{in}+V_{out})\frac{N_P}{N_S}$
(V_{in})
(V_{in})
T1
To
$i_P = i_T$
T2
Ip
$i_S = i_D$
$I_P \cdot \frac{N_P}{N_S}$
T1
To

Correntes no diodo

Corrente de pico

$$I_{DP} = I_S = I_P \frac{N_P}{N_S}$$

Corrente média

$$I_{D_{md}} = \frac{V_{out}}{R_L}$$

Corrente eficaz

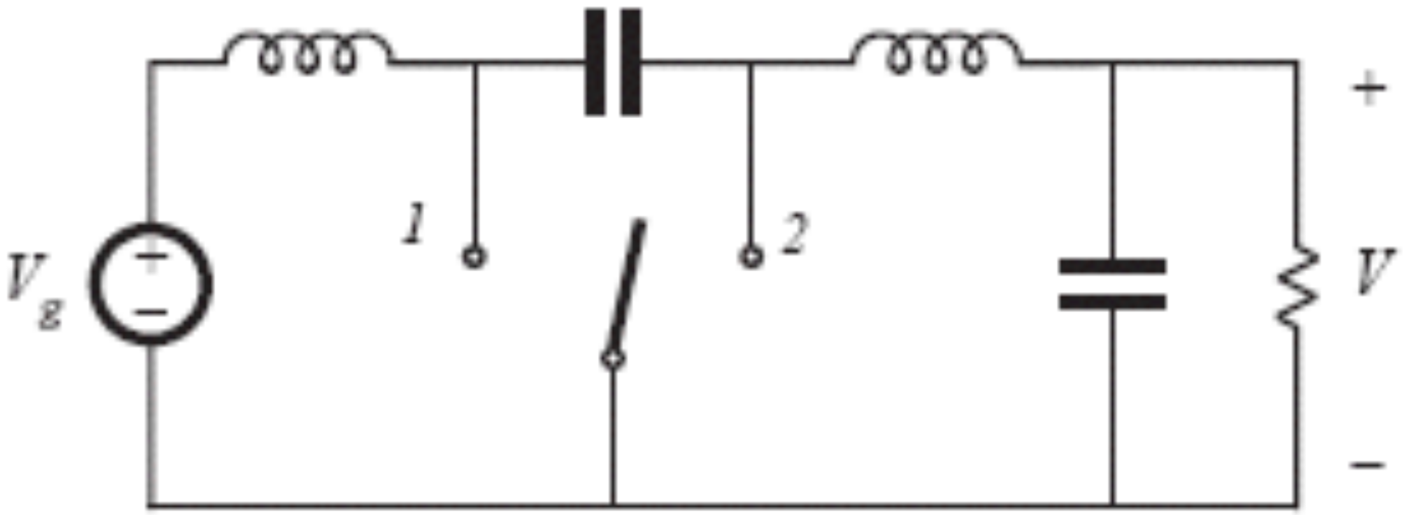
$$I_{D_{ef}} = I_S\sqrt{\frac{T_0}{3T}} = I_P \frac{N_P}{N_S}\sqrt{\frac{T_0}{3T}}$$

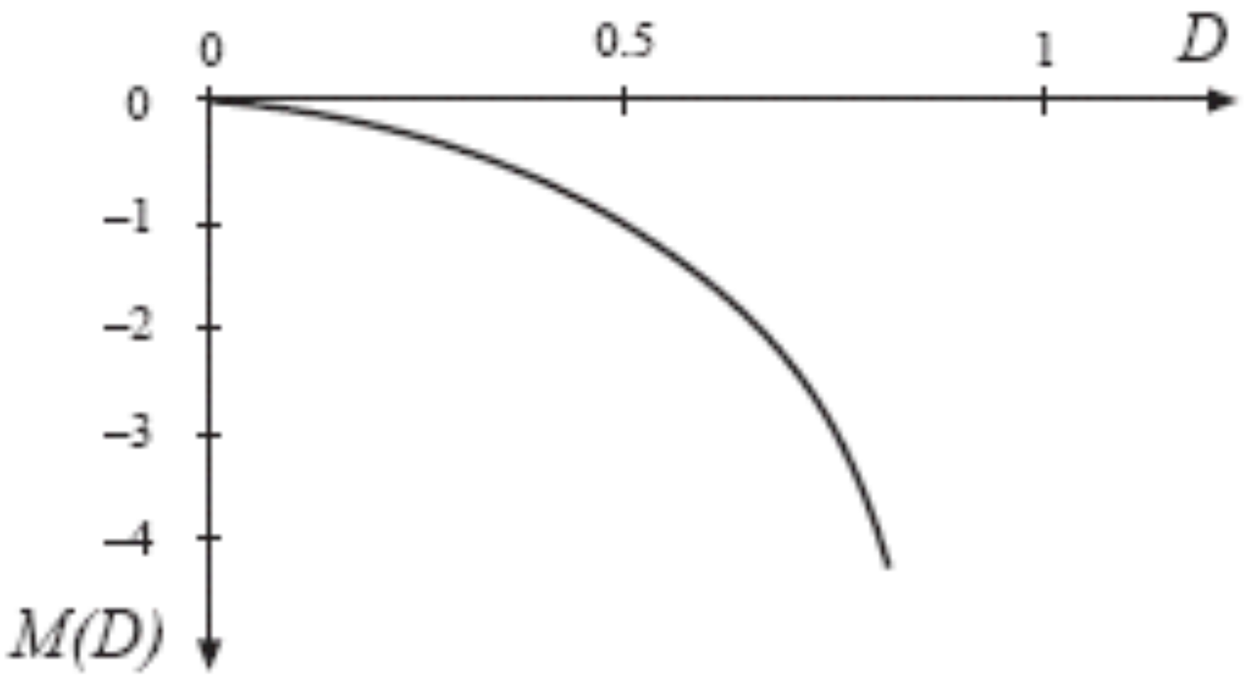
Conversores CC-CC: Outras Topologias

Cuk

1. *Cuk*

$$M(D) = -\frac{D}{1-D}$$



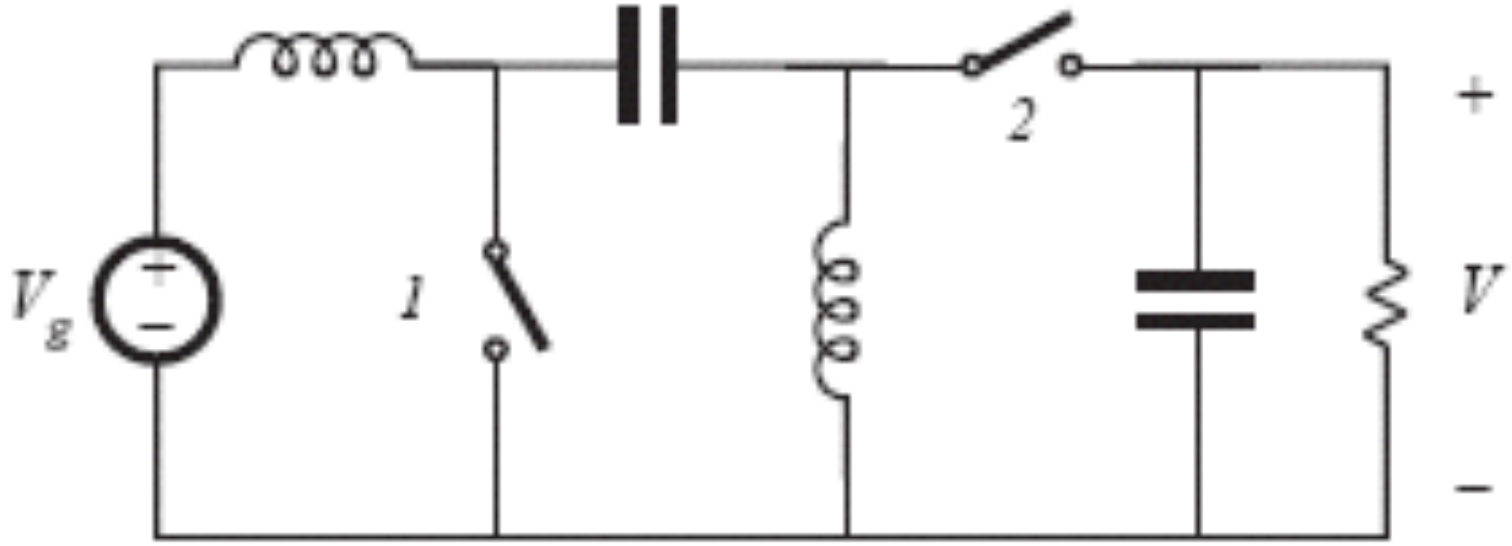


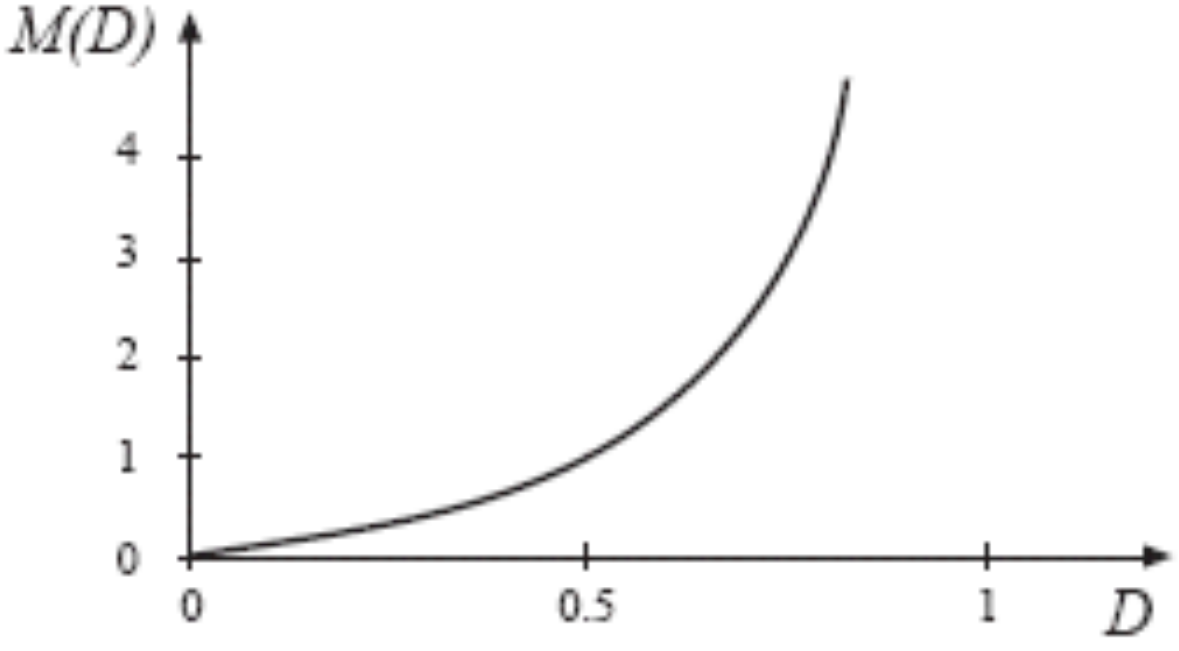
Conversores CC-CC: Outras Topologias

Sepic

2. SEPIC

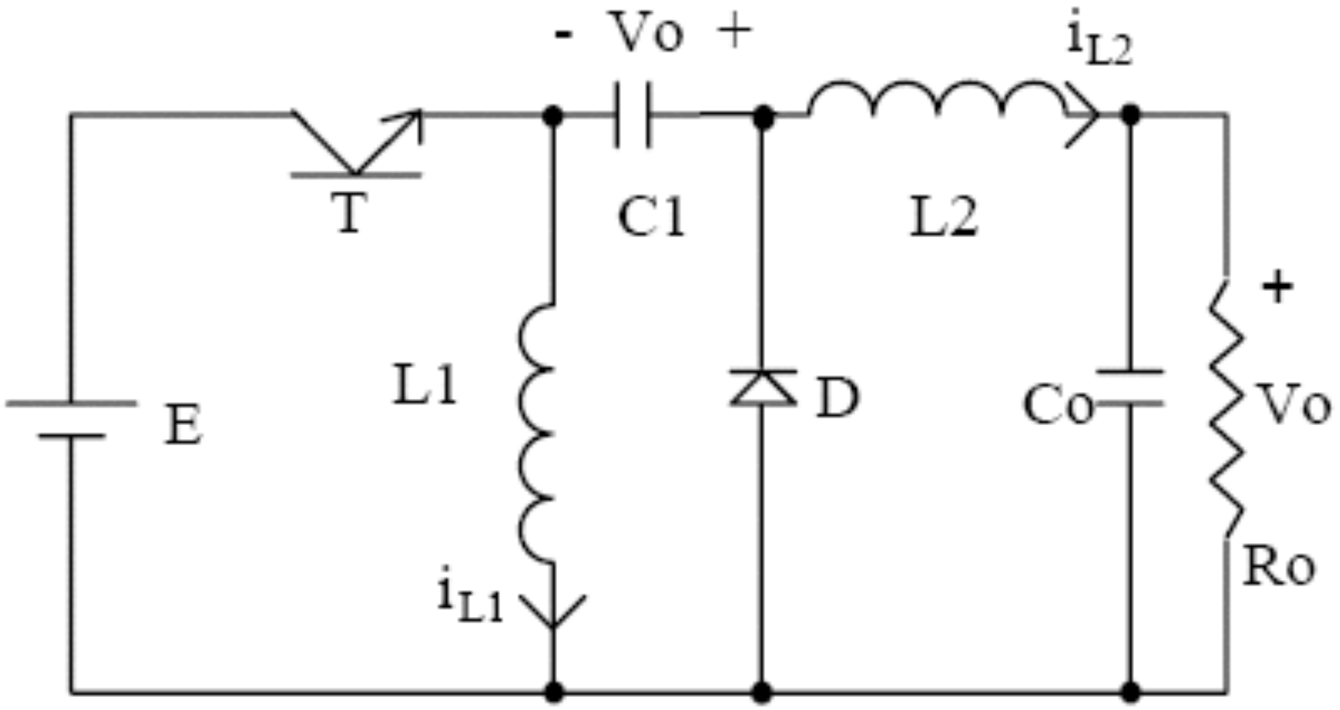
$$M(D) = \frac{D}{1 - D}$$



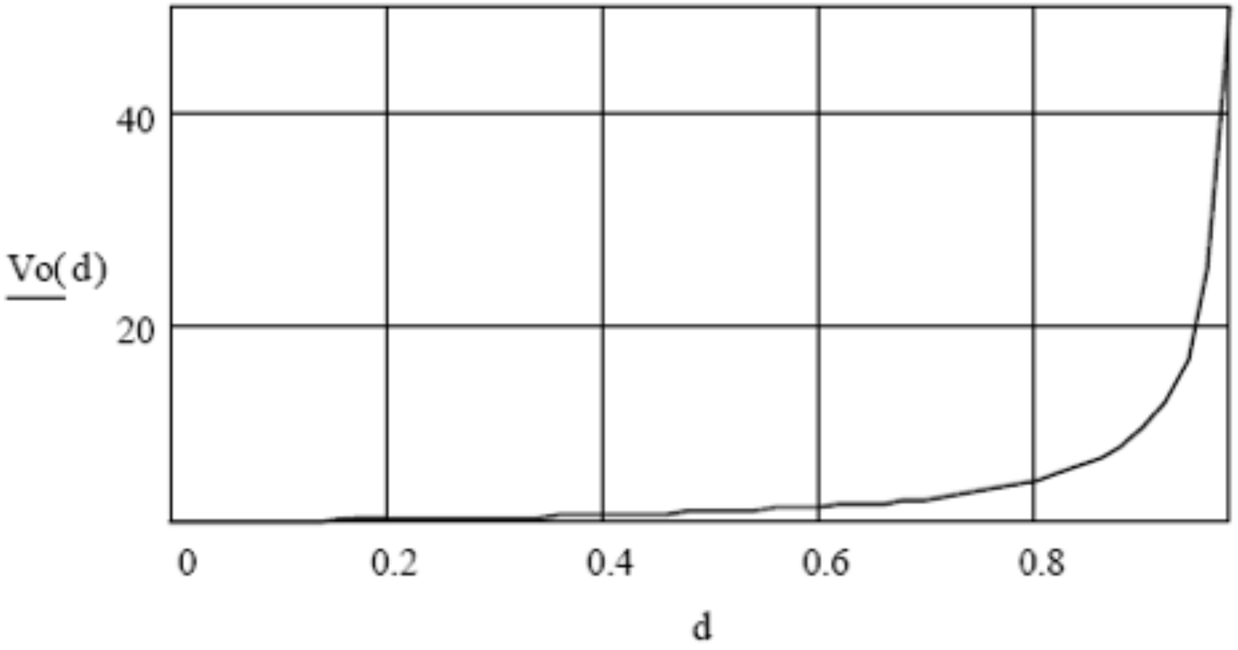


Conversores CC-CC: Outras Topologias

Zeta


- Vo +
i_{L2}
T
C1
L2
+
L1
D
Co
Vo
E
Ro
i_{L1}

$$\frac{V_o}{V_i} = \frac{D}{1-D}$$



Conversores CC-CC

Conversor	Ganho estático	Característica
Buck	$\frac{V_o}{V_i} = D$	Abaixador
Boost	$\frac{V_o}{V_i} = \frac{1}{1-D}$	Elevador
Buck-Boost	$\frac{V_o}{V_i} = \frac{D}{1-D}$	Abaixador/Elevador
Cuk	$\frac{V_o}{V_i} = -\frac{D}{1-D}$	Abaixador/Elevador
Sepic	$\frac{V_o}{V_i} = \frac{D}{1-D}$	Abaixador/Elevador
Zeta	$\frac{V_o}{V_i} = \frac{D}{1-D}$	Abaixador/Elevador

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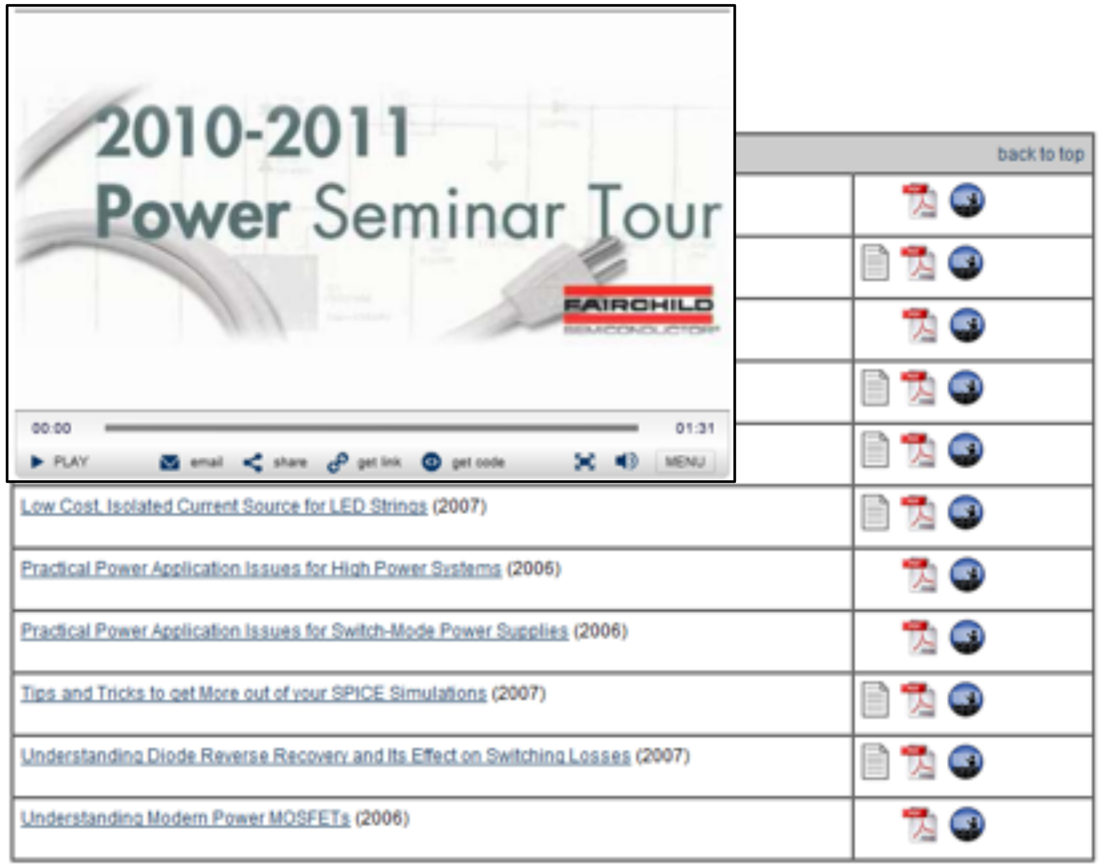
Conversores CC-CC


2010-2011
Power Seminar Tour
FAIRCHILD
SEMICONDUCTOR
00:00
01:31
PLAY
email
share
get link
get code
MENU
back to top

Low Cost, Isolated Current Source for LED Strings (2007)

Practical Power Application Issues for High Power Systems (2006)

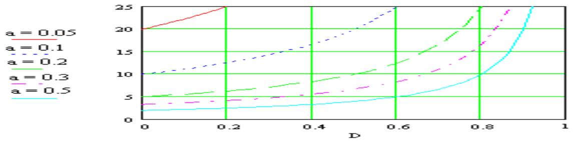
Practical Power Application Issues for Switch-Mode Power Supplies (2006)

Tips and Tricks to get More out of your SPICE Simulations (2007)

Understanding Diode Reverse Recovery and Its Effect on Switching Losses (2007)

Understanding Modern Power MOSFETs (2006)

http://www.fairchildsemi.com



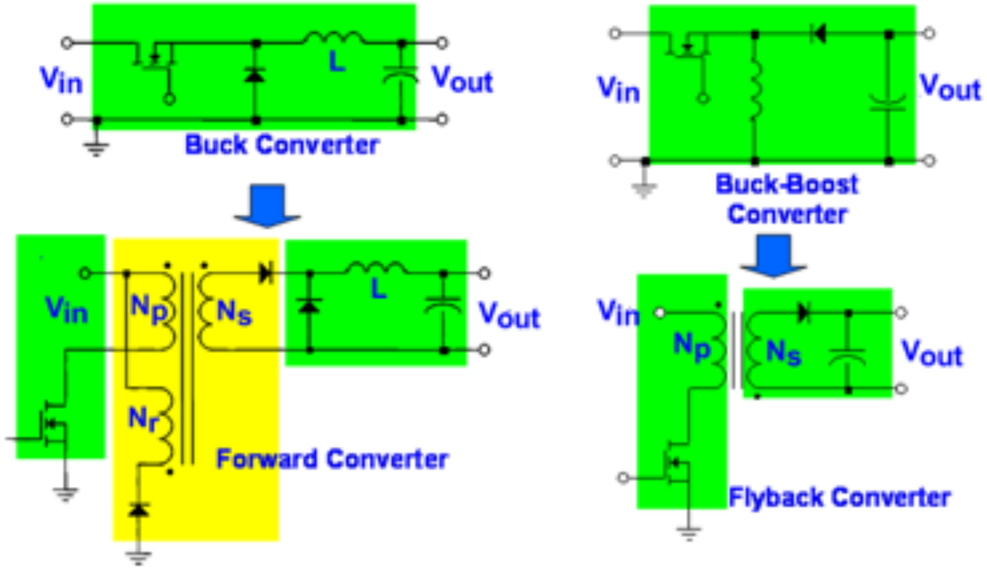
2006 Design Seminar Presentations

2007 Design Seminar Presentations

http://www.powerint.com

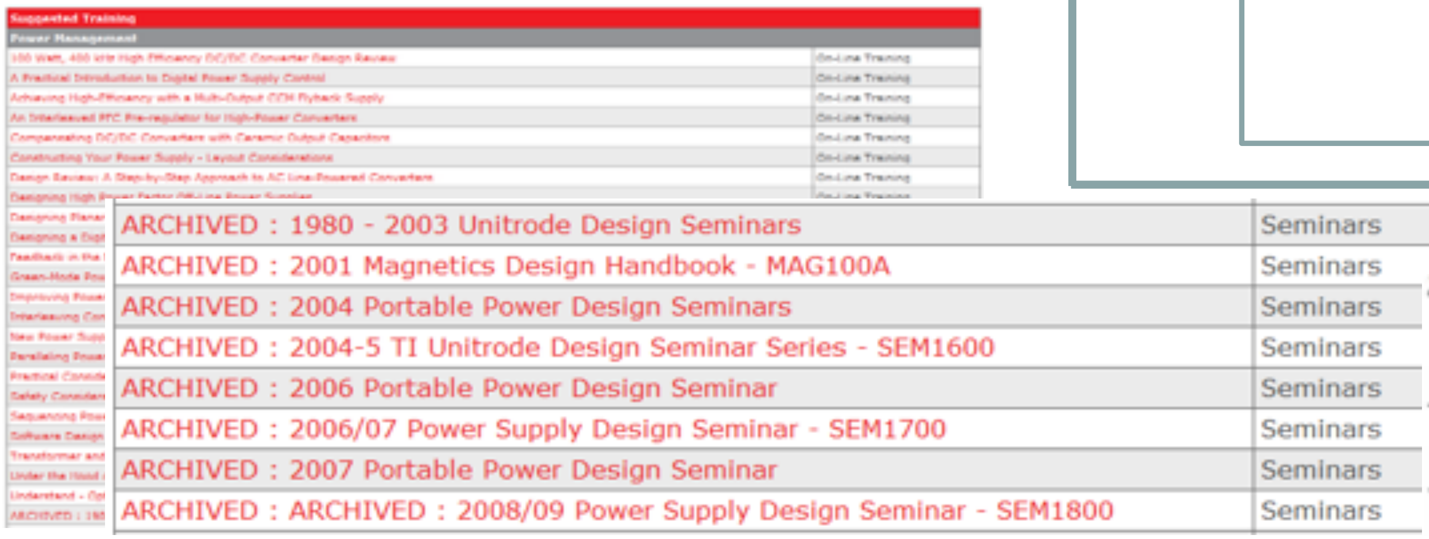
National Semiconductor

PowerWise®
Design University


Vin
L
Vout
Buck Converter
Vin
Vout
Buck-Boost Converter
Vin
Np
Ns
L
Vout
Nr
Forward Converter
Vin
Np
Ns
Vout
Flyback Converter

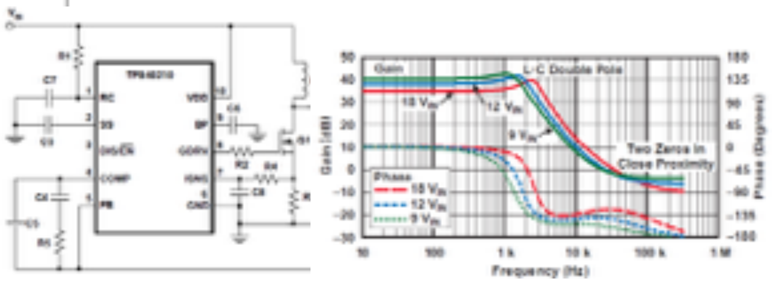
http://www.national.com

TEXAS INSTRUMENTS



Suggested Training	
Power Management	
100 Watt, 400 kHz High Efficiency DC/DC Converter Design Review	On-Line Training
A Practical Introduction to Digital Power Supply Control	On-Line Training
Achieving High-Efficiency with a Multi-Output CCM Flyback Supply	On-Line Training
An Interleaved PFC Pre-regulator for High-Power Converters	On-Line Training
Compensating DC/DC Converters with Ceramic Output Capacitors	On-Line Training
Constructing Your Power Supply - Layout Considerations	On-Line Training
Design Review: A Step-by-Step Approach to AC Line-Powered Converters	On-Line Training
Designing High Power Factor Off-Line Power Supplies	On-Line Training

ARCHIVED : 1980 - 2003 Unitrode Design Seminars	Seminars
ARCHIVED : 2001 Magnetics Design Handbook - MAG100A	Seminars
ARCHIVED : 2004 Portable Power Design Seminars	Seminars
ARCHIVED : 2004-5 TI Unitrode Design Seminar Series - SEM1600	Seminars
ARCHIVED : 2006 Portable Power Design Seminar	Seminars
ARCHIVED : 2006/07 Power Supply Design Seminar - SEM1700	Seminars
ARCHIVED : 2007 Portable Power Design Seminar	Seminars
ARCHIVED : ARCHIVED : 2008/09 Power Supply Design Seminar - SEM1800	Seminars

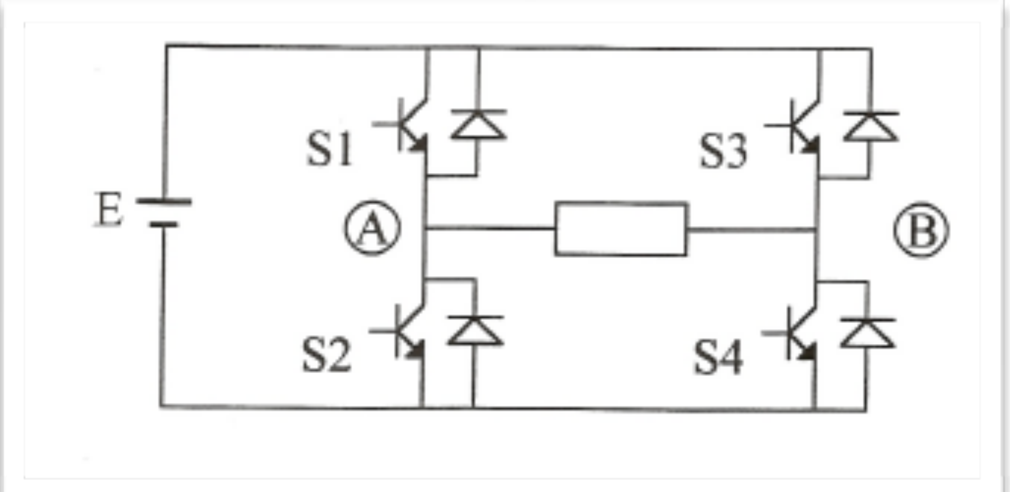
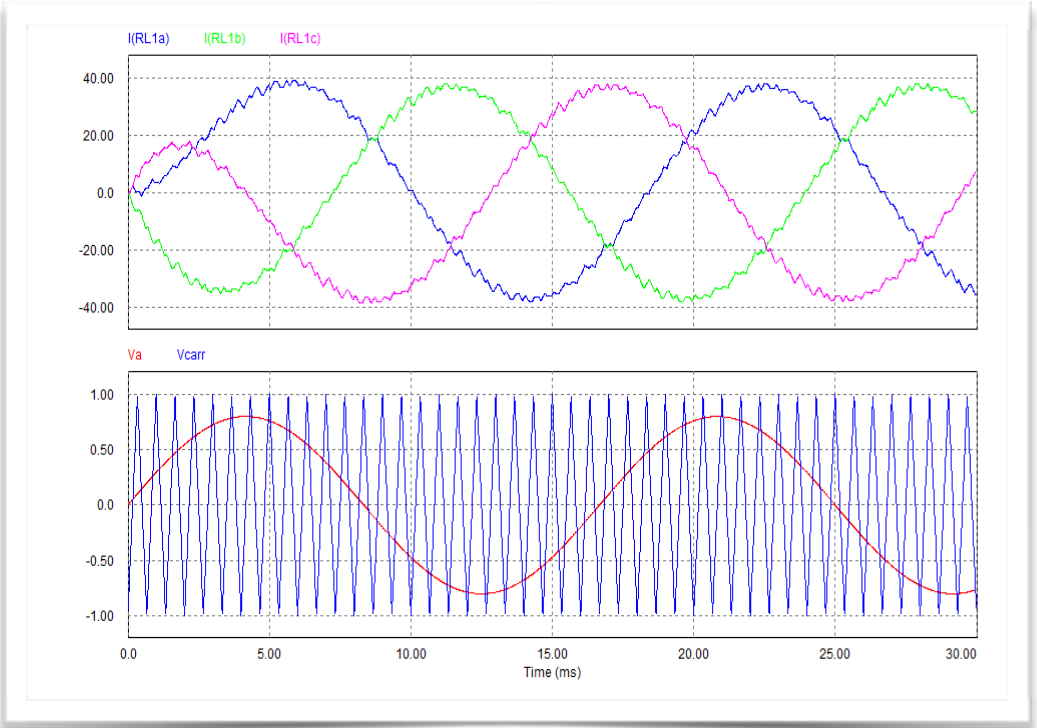

TPS40210
RC
SS
DIS/EN
COMP
FB
VDD
BP
GDRV
ISNS
GND
Gain
L-C Double Pole
18 V_IN
12 V_IN
9 V_IN
Two Zeros in Close Proximity
Phase
Gain (dB)
Phase (Degrees)
Frequency (Hz)
50
40
30
20
10
0
-10
-20
-30
180
135
90
45
0
-45
-90
-135
-180
10
100
1 k
10 k
100 k
1 M

http://www.ti.com

Próxima Aula

Conversores cc-ca e ca-ca:

- Inversores de tensão e corrente;
- Estabilizadores e condicionadores de tensão.


E
S1
S3
A
B
S2
S4