Fig 3.8 p 74

Inductor voltage and capacitor current waveforms

Two steady state equations

(1) Average inductor voltage:

$$\langle v_L(t) \rangle = \frac{1}{T_s}\int_0^{T_s} v_L(t)dt$$
$$= D(V_g - I R_L) + D'(V_g - I R_L - V)$$

Inductor volt-second balance:

$$0 = V_g - I R_L - D'V$$

(2) Average capacitor current:

$$\langle i_C(t) \rangle = D\,(-V/R) + D'\,(I - V/R)$$

Capacitor charge balance:

$$0 = D'I - V/R$$

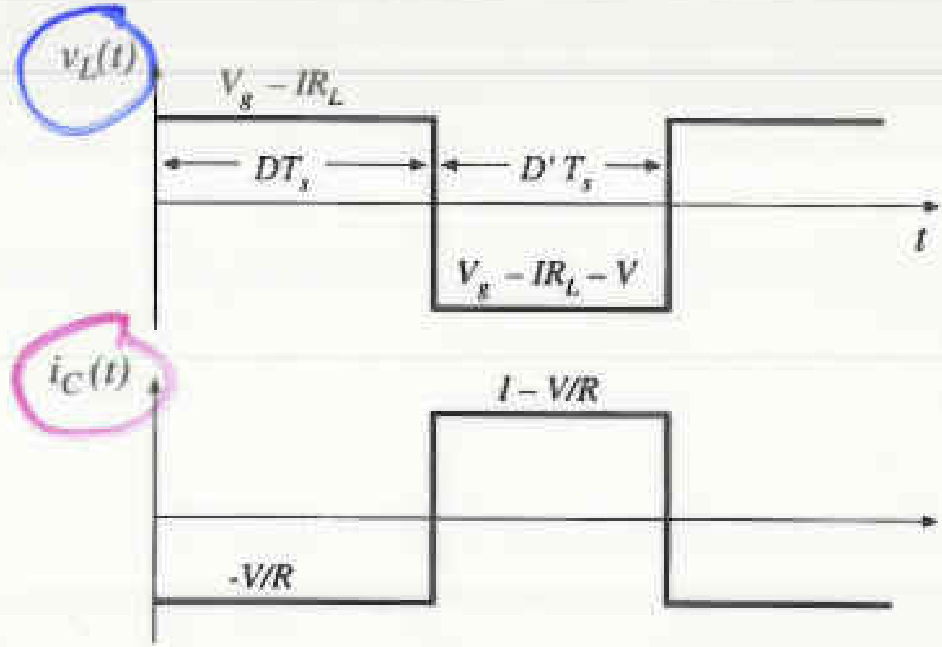


Fig3.9 p45

Solution for output voltage

We now have two equations and two unknowns:

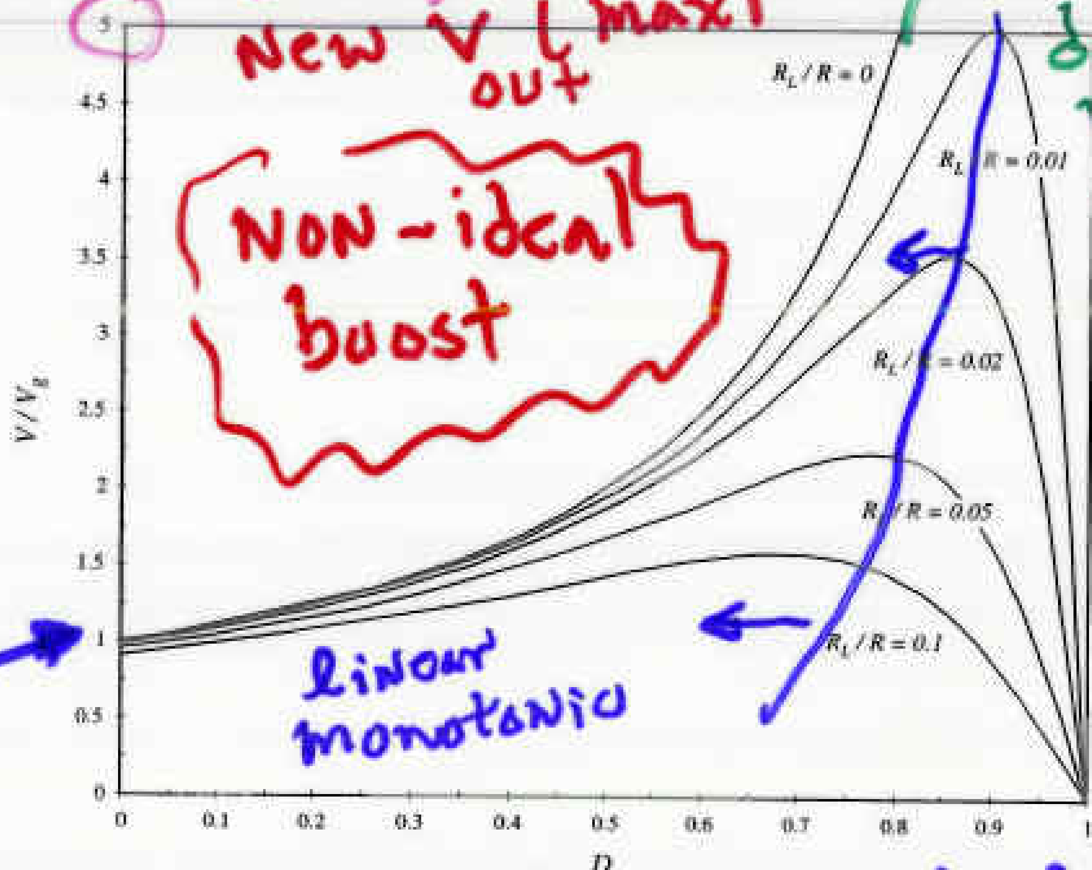
$$0 = V_g - I\,R_L - D'V$$

$$0 = D'I - V\,/\,R$$

Eliminate I and solve for V:

$$\frac{V}{V_g} = \frac{1}{D'}\,\frac{1}{(1 + R_L\,/\,D'^2 R)}$$

ideal Ch2 — Ch3



Usual boost lower limit

$R_L = \frac{\text{Load R}}{100}$

New V_{out} (max)

NON-ideal boost

linear monotonic

V(D) is double valued

lossy buck No # 10 V_g possible

double value V_{out}

HW3.8 what D is highest efficiency

Solution for output voltage

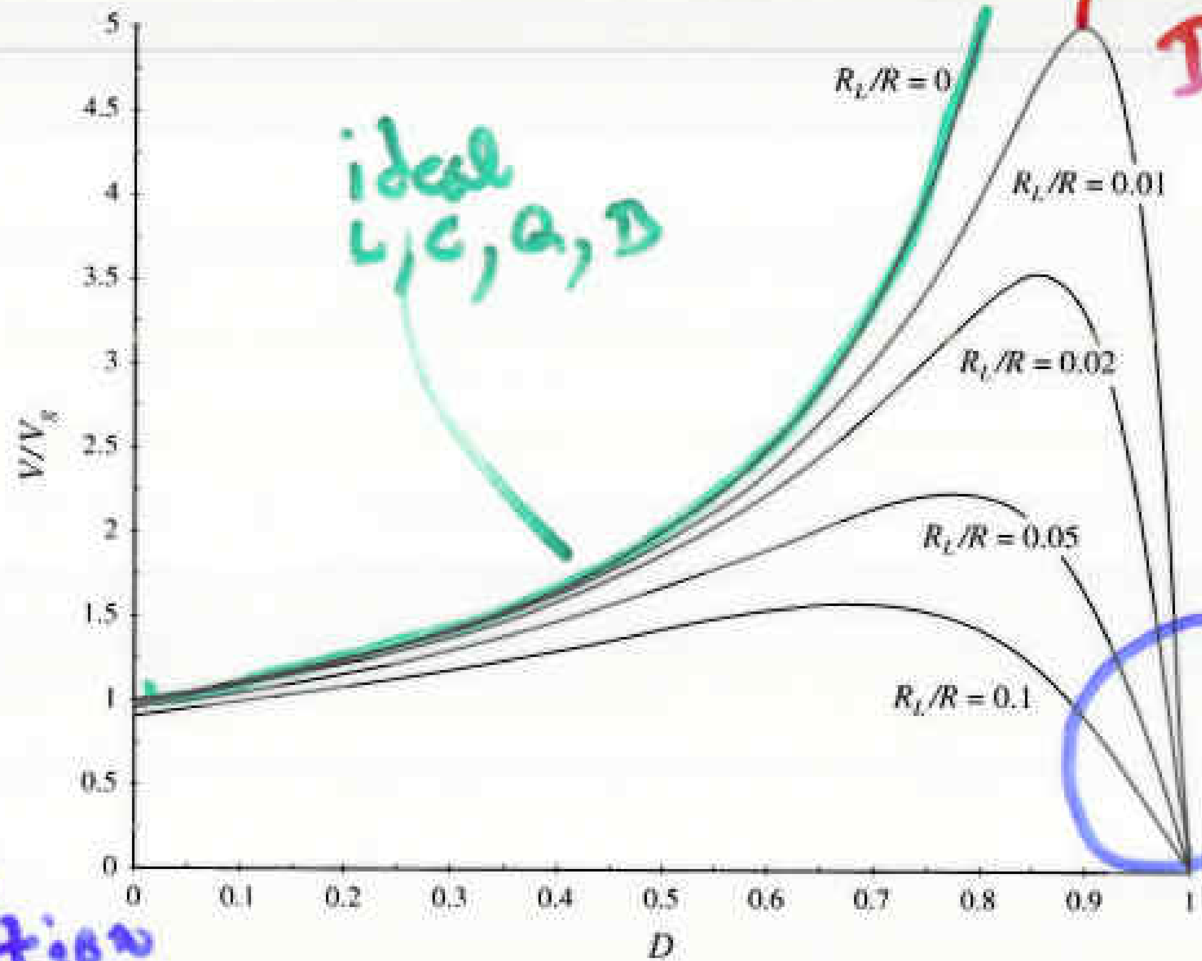
We now have two equations and two unknowns:

$$0 = V_g - I\,R_L - D'V$$

$$0 = D'I - V\,/\,R$$

Eliminate I and solve for V:

$$\frac{V}{V_g} = \frac{1}{D'}\,\frac{1}{(1 + R_L\,/\,D'^2R)}$$



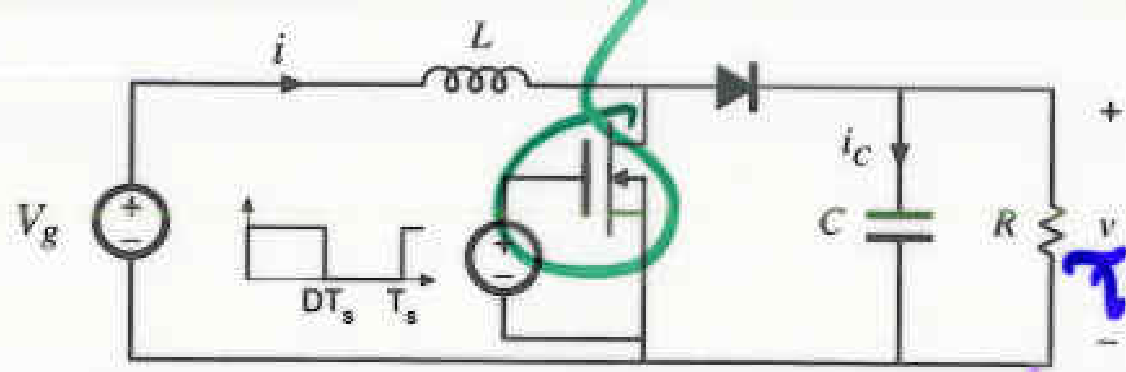
Pg52

3.5. Example: inclusion of semiconductor conduction losses in the boost converter model

Losses are?

Boost converter example

Fig 3.22 Pg 52



Typical FET:

R_{ON} (lowest) 30 mΩ

100 A ⇒ V_{ON} = 3V

Models of on-state semiconductor devices:

1. MOSFET: on-resistance R_{on}
2. Diode: constant forward voltage V_D plus on-resistance R_D

Insert these models into subinterval circuits

Two components

V_D R_{ON} ≈ f(D)

Analysis of nonideal boost converter

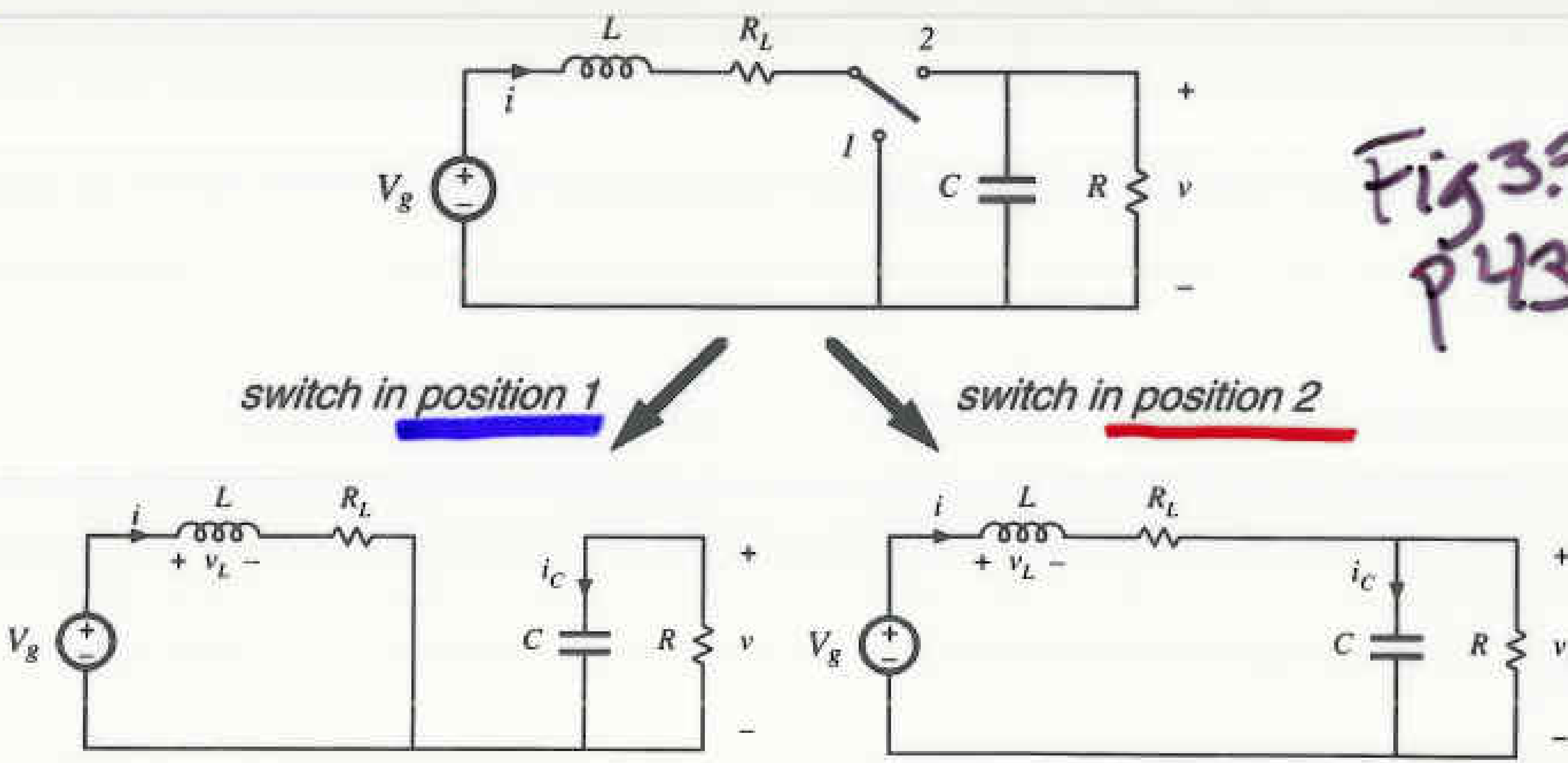


Fig 3.7 p43

Fig 3.8 p 74

Inductor voltage and capacitor current waveforms

Two steady state equations

(1) Average inductor voltage:

$$\langle v_L(t) \rangle = \frac{1}{T_s}\int_0^{T_s} v_L(t)dt$$
$$= D(V_g - I\,R_L) + D'(V_g - I\,R_L - V)$$

Inductor volt-second balance:

$$0 = V_g - I\,R_L - D'V$$

(2) Average capacitor current:

$$\langle i_C(t) \rangle = D\,(-V/R) + D'\,(I - V/R)$$

Capacitor charge balance:

$$0 = D'I - V/R$$

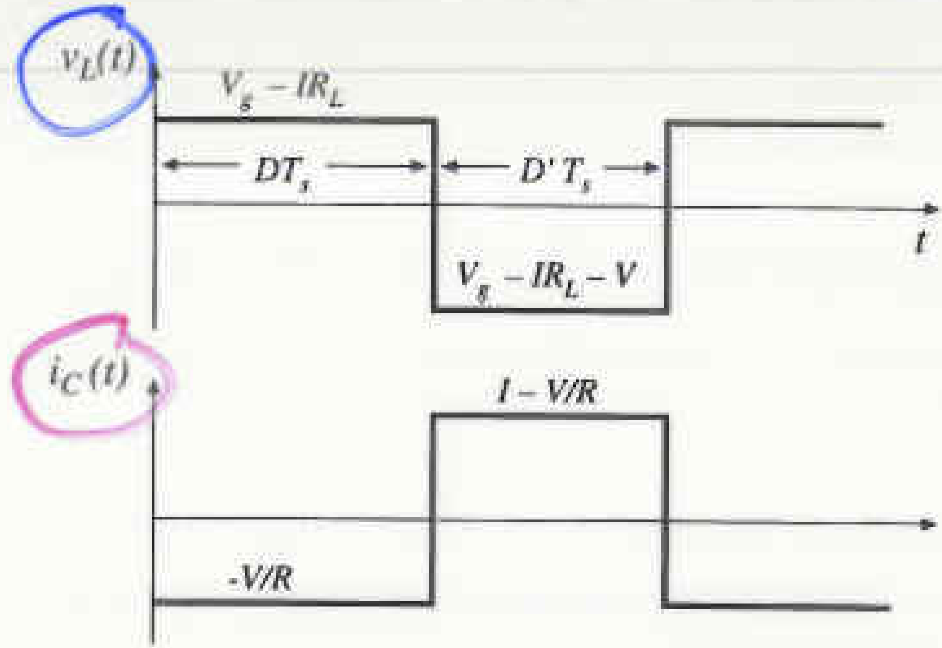


Fig 3.9 p45

Solution for output voltage

We now have two equations and two unknowns:

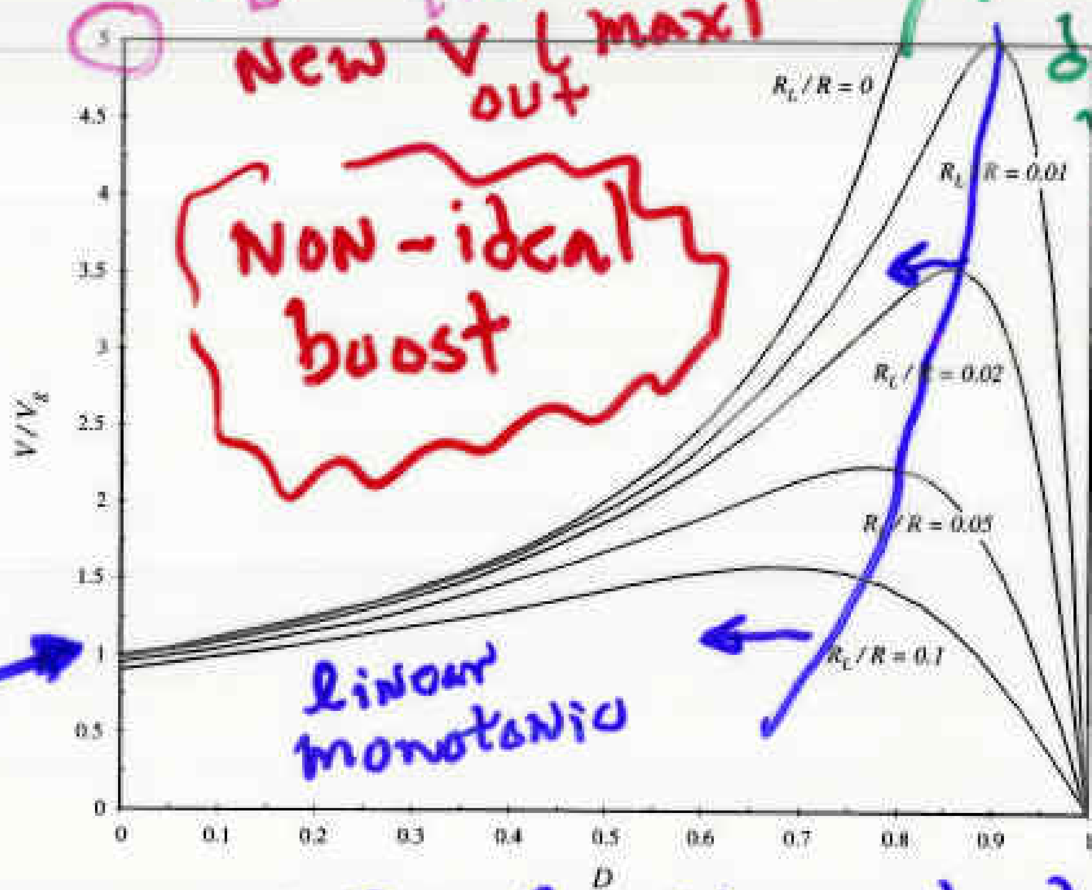
$$0 = V_g - I R_L - D'V$$

$$0 = D'I - V / R$$

Eliminate I and solve for V:

$$\frac{V}{V_g} = \frac{1}{D'} \frac{1}{(1 + R_L / D'^2 R)}$$

ideal Ch2 · Ch3 · usual boost lower limit



V(D) is double valued

HW 3.8 what D is highest efficiency

Solution for output voltage

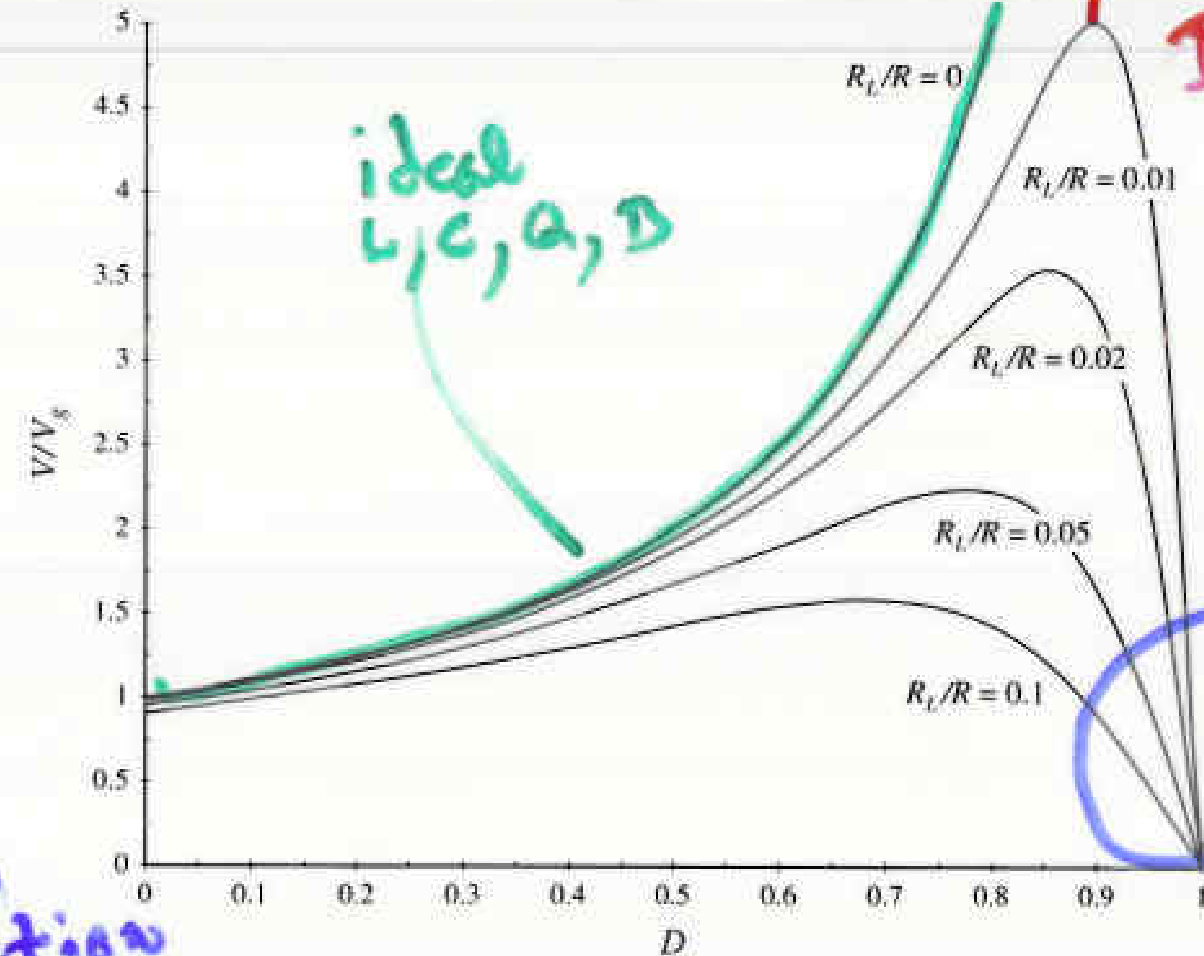
We now have two equations and two unknowns:

$$0 = V_g - I\,R_L - D'V$$

$$0 = D'I - V\,/\,R$$

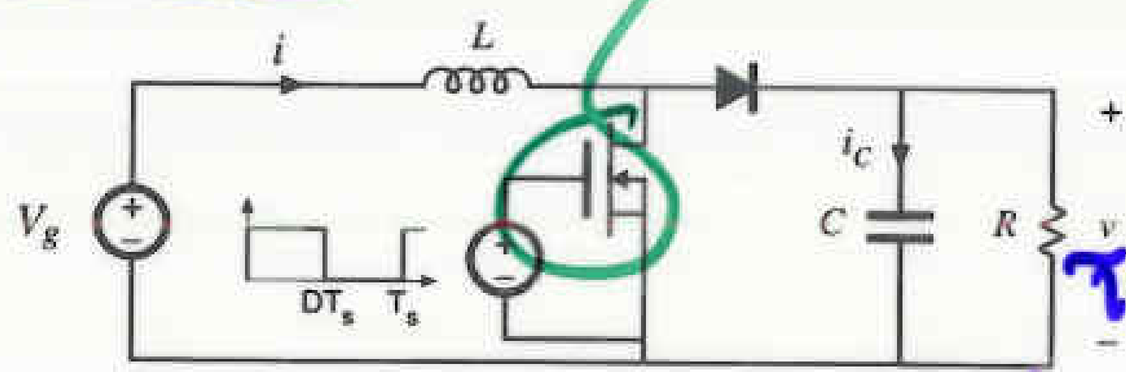
Eliminate I and solve for V:

$$\frac{V}{V_g} = \frac{1}{D'}\,\frac{1}{(1 + R_L\,/\,D'^2 R)}$$



3.5. Example: inclusion of semiconductor conduction losses in the boost converter model

Boost converter example

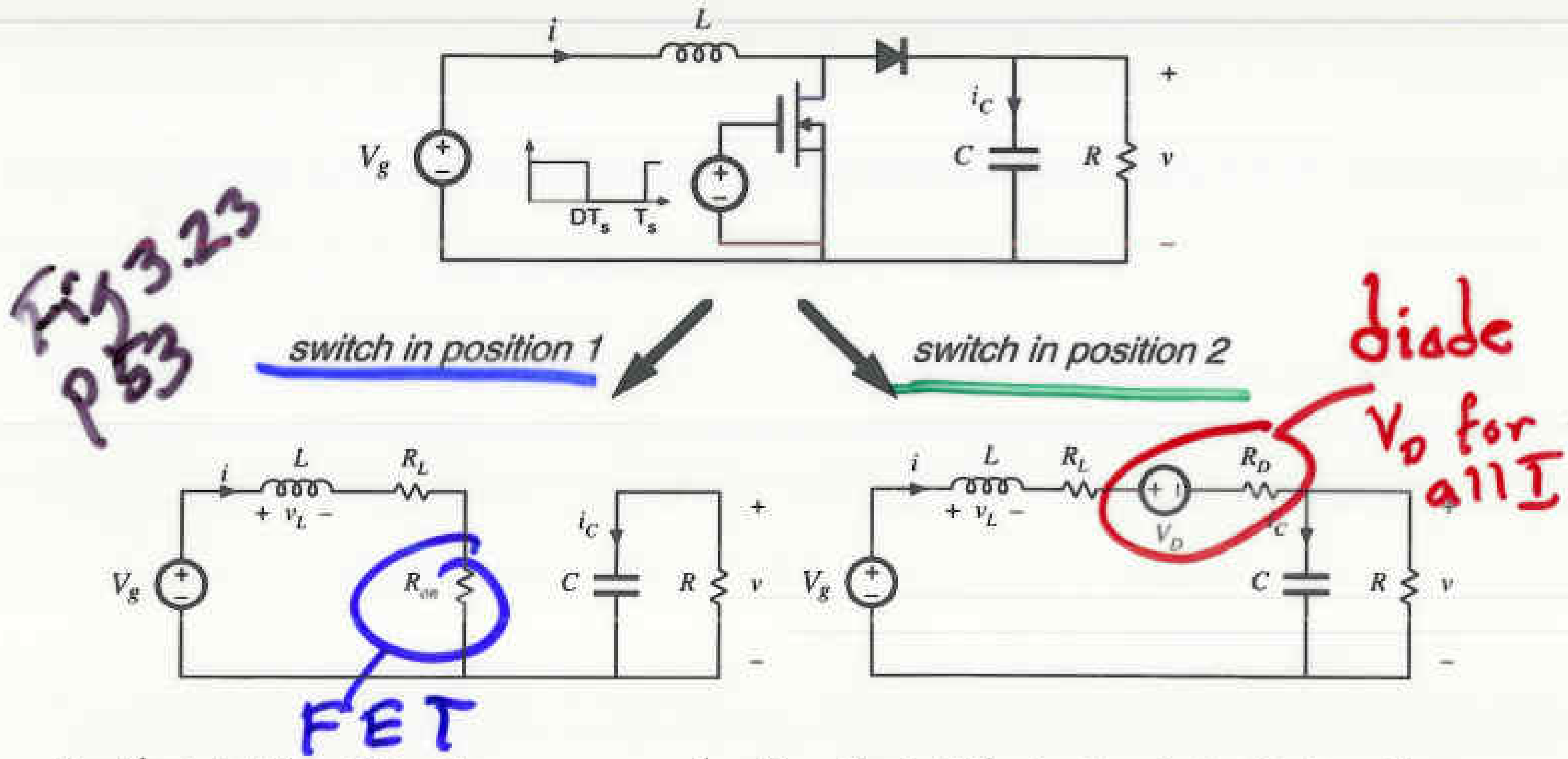


Models of on-state semiconductor devices:

1. MOSFET: on-resistance R_{on}
2. Diode: constant forward voltage V_D plus on-resistance R_D

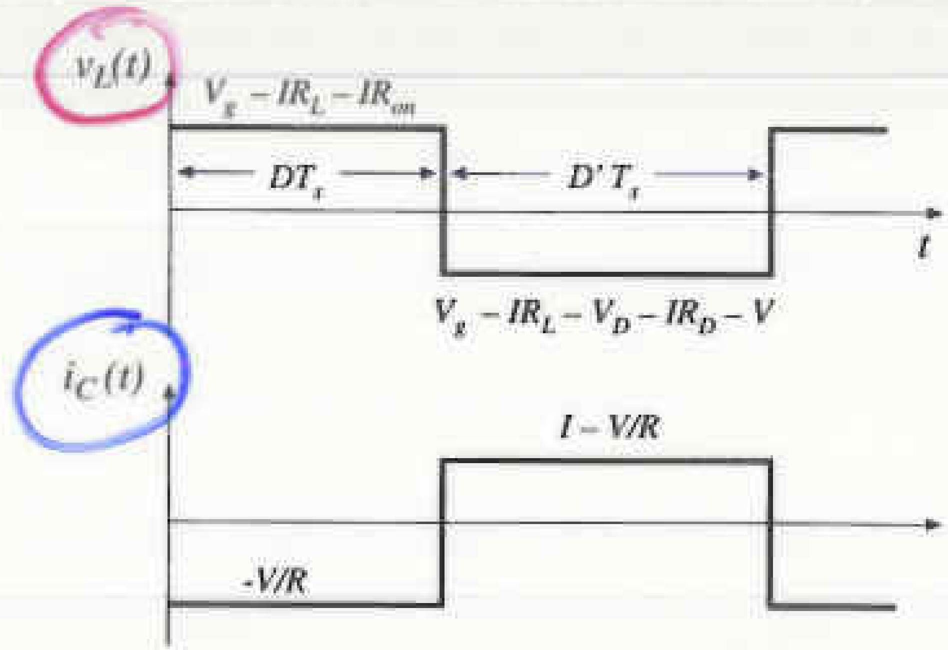
Insert these models into subinterval circuits

Boost converter example: circuits during subintervals 1 and 2



Average inductor voltage and capacitor current

Fig 3.24
P 53



$$\langle v_L \rangle = D(V_g - IR_L - IR_{on}) + D'(V_g - IR_L - V_D - IR_D - V) = 0$$

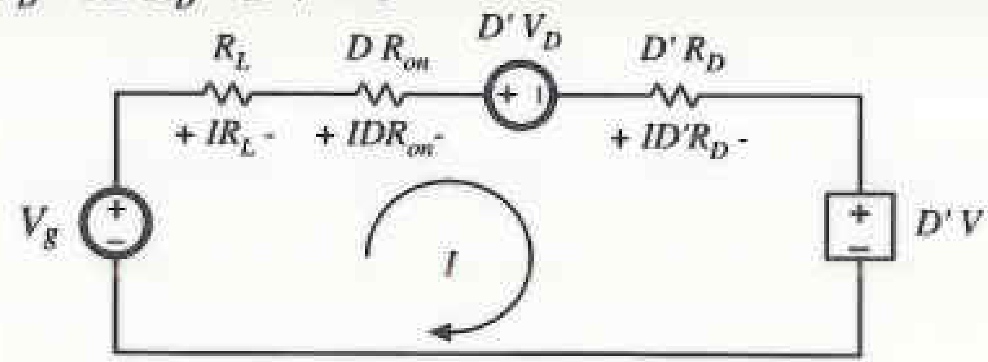
$$\langle i_C \rangle = D(-V/R) + D'(I - V/R) = 0$$

Fig 3.25 / 3.26 Pg 54

Construction of equivalent circuits

$\langle v_L \rangle = 0$ Input Circuit Loop

$$V_g - IR_L - IDR_{on} - D'V_D - ID'R_D - D'V = 0$$



$\langle i_C \rangle = 0$ Output Loop

$$D'I - V/R = 0$$

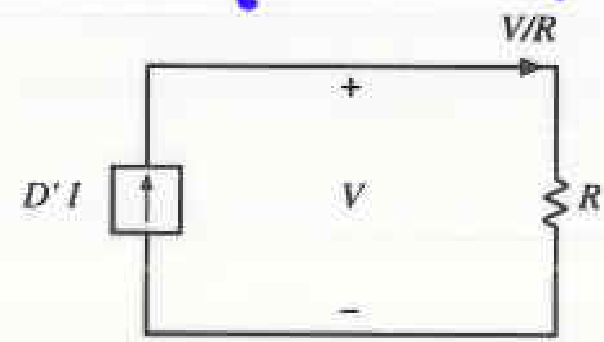
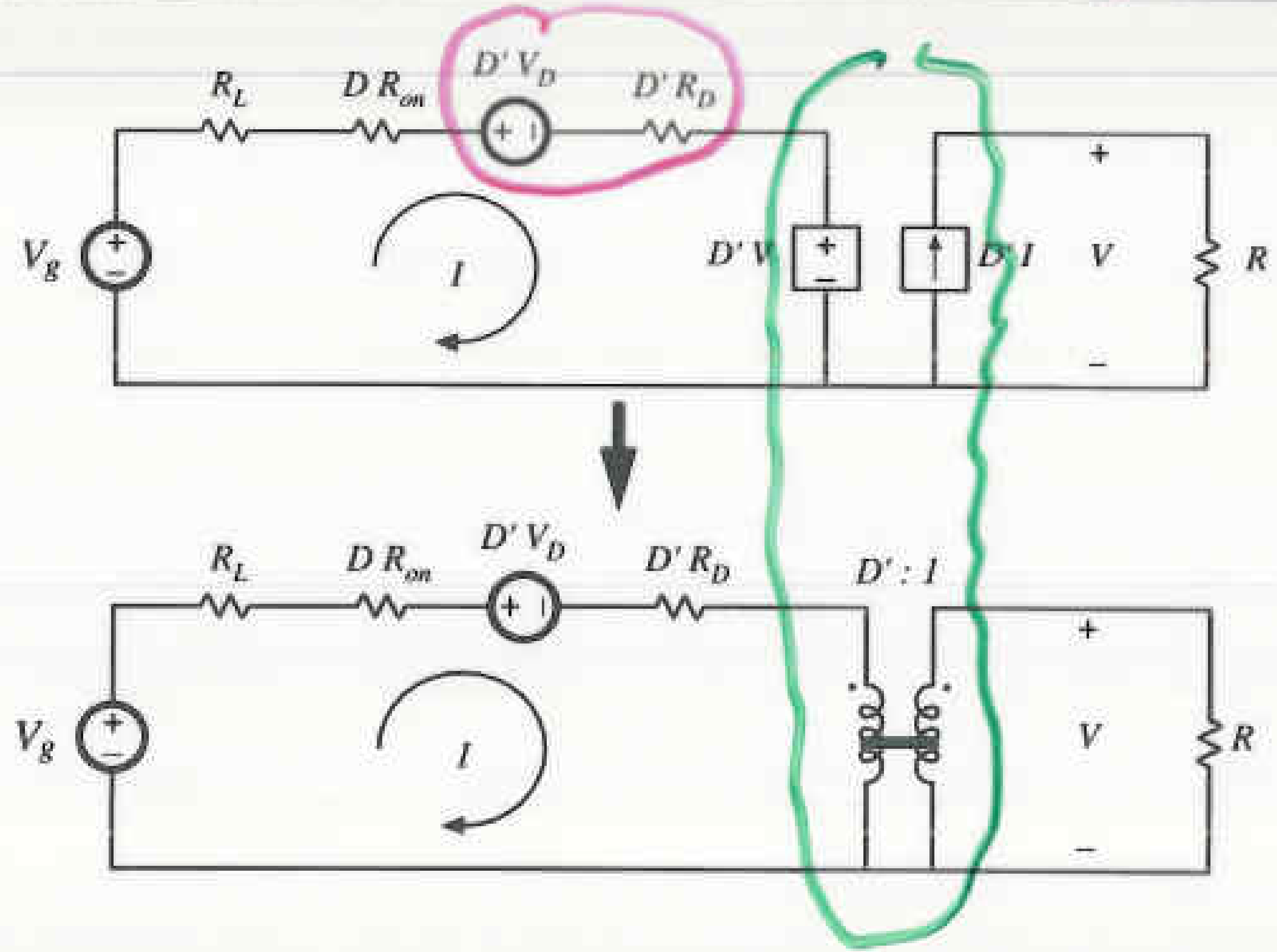


Fig 3.27 / 3.28
P55

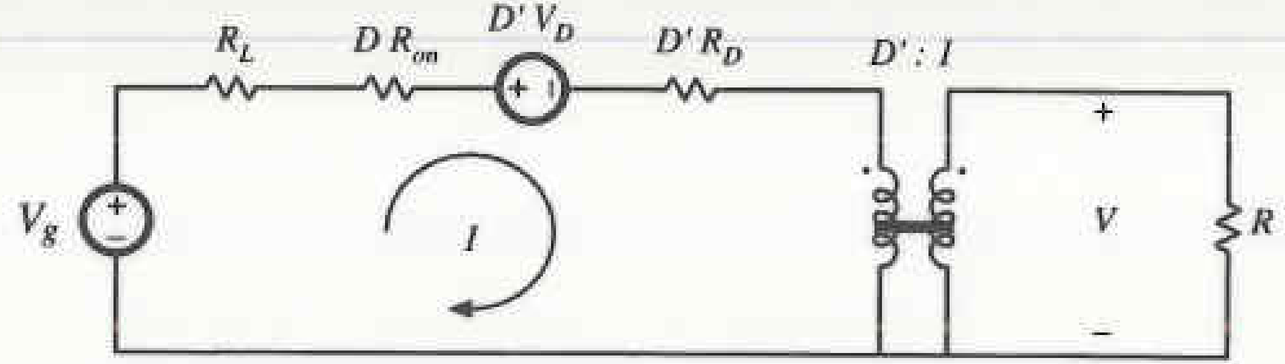
Complete equivalent circuit

Combine bath loops togeather



Solution for output voltage

Fig 3.28



diode losses

$$V = \left(\frac{1}{D'}\right)\left(V_g - D'V_D\right)\left(\frac{D'^2R}{D'^2R + R_L + DR_{on} + D'R_D}\right)$$

$$\frac{V}{V_g} = \left(\frac{1}{D'}\right)\left(1 - \frac{D'V_D}{V_g}\right)\left(\frac{1}{1 + \frac{R_L + DR_{on} + D'R_D}{D'^2R}}\right)$$

Eq 3.34

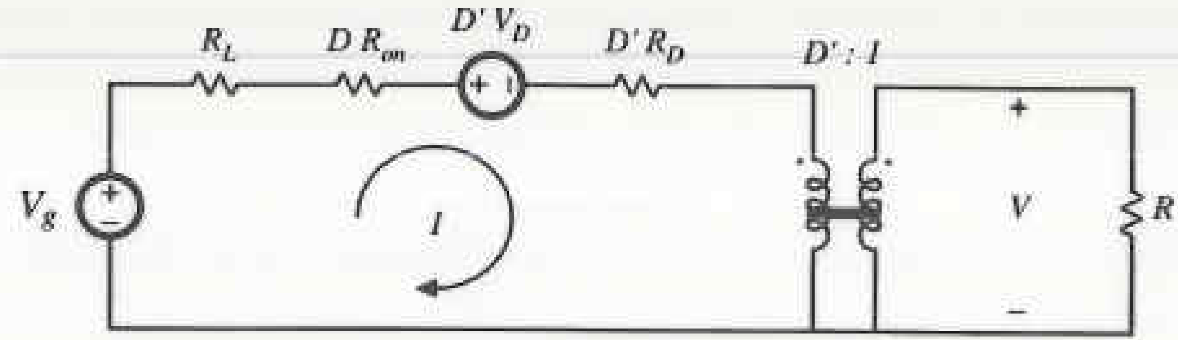
ideal boost

switch loss corrections

Solution for converter efficiency

$P_{in} = (V_g)(I)$

$P_{out} = (V)(D'I)$



$$\eta = D' \frac{V}{V_g} = \frac{\left(1 - \frac{D'V_D}{V_g}\right)}{\left(1 + \frac{R_L + DR_{on} + D'R_D}{D'^2 R}\right)}$$

Conditions for high efficiency: ← Battery Operated Boost

$V_g / D' >> V_D$

and $D'^2 R >> R_L + DR_{on} + D'R_D$

Pg 45 Boost Analysis via

3.3. Construction of equivalent circuit model

Solve for $\eta(D)$

Results of previous section (derived via inductor volt-sec balance and capacitor charge balance):

$$\langle v_L \rangle = 0 = V_g - I\,R_L - D'V$$
$$\langle i_C \rangle = 0 = D'I - V / R$$

View these as loop and node equations of the equivalent circuit. Reconstruct an equivalent circuit satisfying these equations

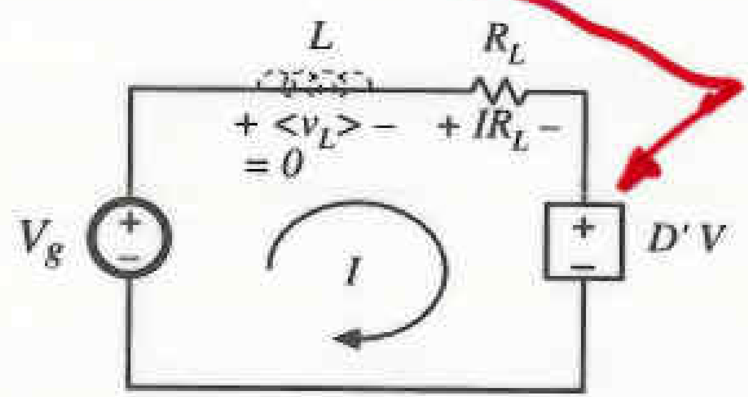
Inductor voltage equation

Equation → circuit loop

Fig 3.10
p 46

$$\langle v_L \rangle = 0 = V_g - I\,R_L - D'V$$

- Derived via Kirchoff's voltage law, to find the inductor voltage during each subinterval
- Average inductor voltage then set to zero
- This is a loop equation: the dc components of voltage around a loop containing the inductor sum to zero



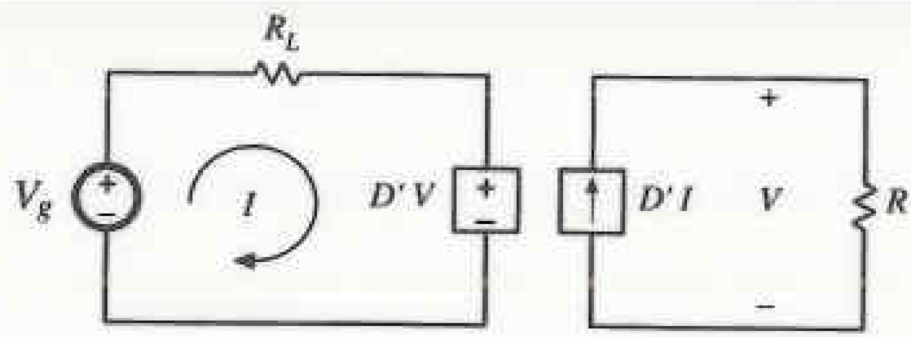
- IR_L term: voltage across resistor of value R_L having current I
- $D'V$ term: for now, leave as dependent source

Complete equivalent circuit

Both circuits togeather

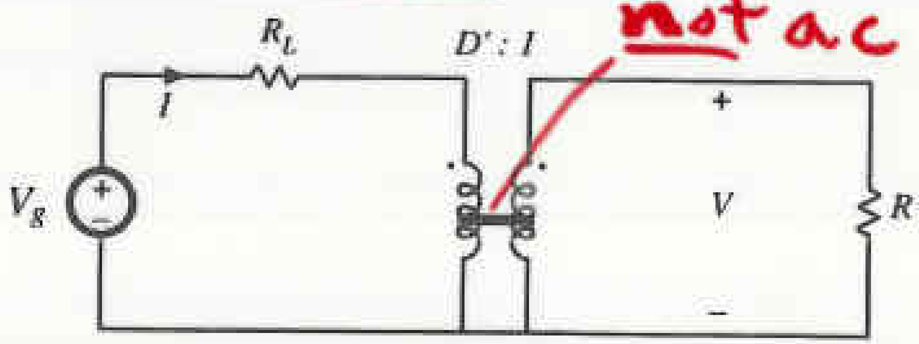
Figs 3.12 3.13 Pg 47

The two circuits, drawn together:

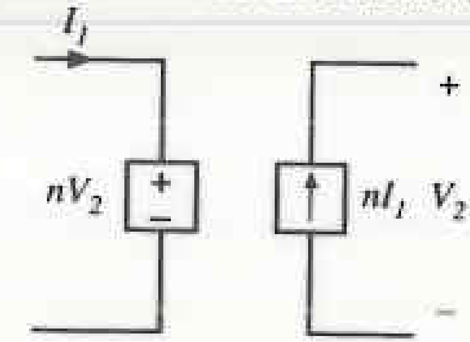


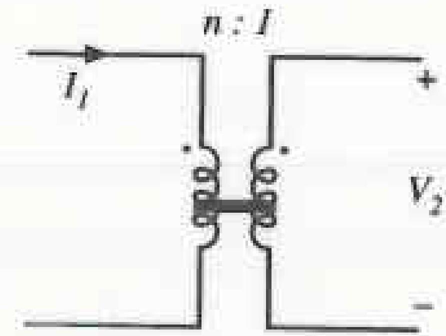
The dependent sources are equivalent to a $D' : I$ transformer:

DC Trf
not ac



Dependent sources and transformers





- *sources have same coefficient*
- *reciprocal voltage/current dependence*

Capacitor current equation

2nd Eq. → 2nd circuit

$$\langle i_C \rangle = 0 = D'I - V/R$$

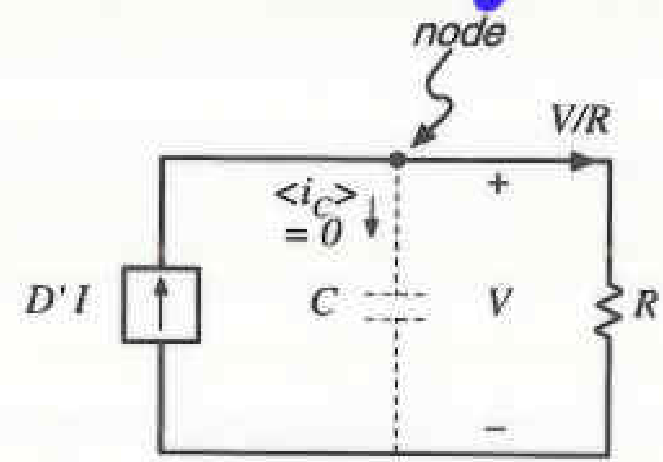


Fig 3.11 P46

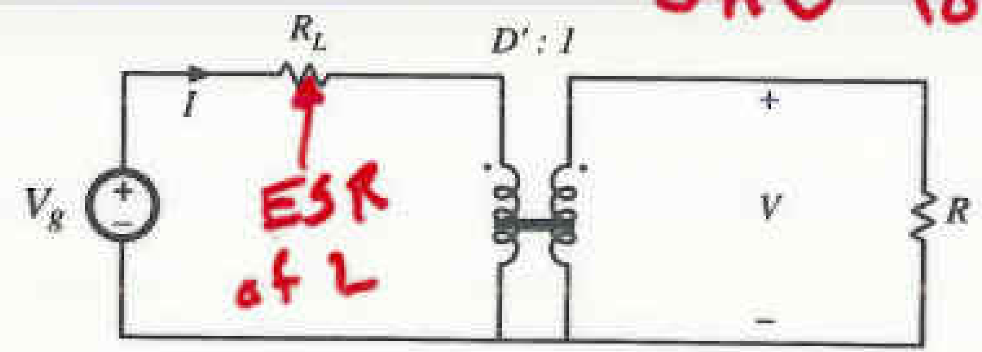
- Derived via Kirchoff's current law, to find the capacitor current during each subinterval
- Average capacitor current then set to zero
- This is a node equation: the dc components of current flowing into a node connected to the capacitor sum to zero

- V/R term: current through load resistor of value R having voltage V
- $D'I$ term: for now, leave as dependent source

Solution of equivalent circuit

Use trf rules to: reduce two loops to one loop

Converter equivalent circuit



Circuits are More insightful? than equations

Refer all elements to transformer secondary:

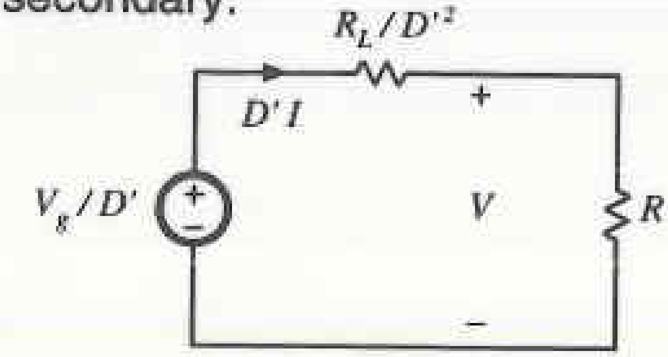


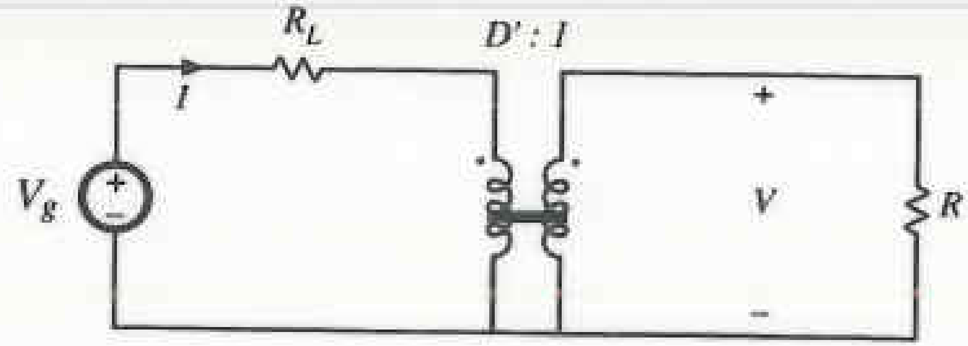
Fig 3.14 p48

Solution for output voltage using voltage divider formula:

$$V = \frac{V_g}{D'} \frac{R}{R + \frac{R_L}{D'^2}} = \frac{V_g}{D'} \frac{1}{1 + \frac{R_L}{D'^2 R}}$$

Boost

Solution for input (inductor) current



$$I = \frac{V_g}{D'^2 R + R_L} = \frac{V_g}{D'^2} \frac{1}{1 + \frac{R_L}{D'^2 R}}$$

"Average" inductor current

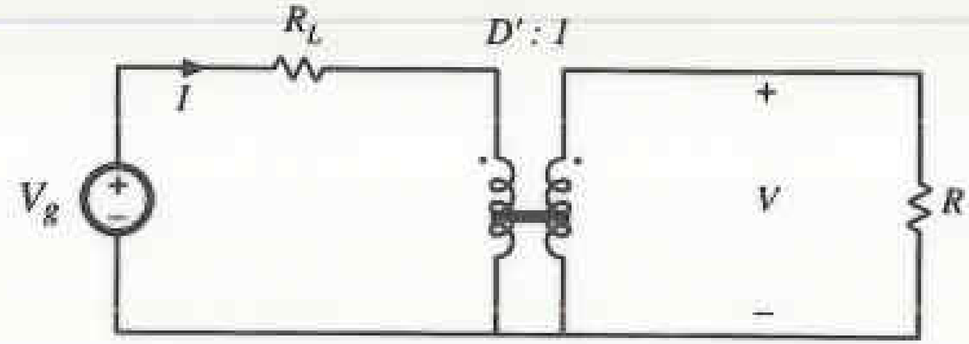
ideal boost

correction factor

Eq 3.19 pg 48

Solution for converter efficiency

Now DC efficiency is f(D)



$$P_{in} = (V_g)(I)$$

$$P_{out} = (V)(D'I)$$

$$\eta = \frac{P_{out}}{P_{in}} = \frac{(V)(D'I)}{(V_g)(I)} = \frac{V}{V_g} D'$$

$$\eta = \frac{1}{1 + \frac{R_L}{D'^2 R}}$$

Eq 3.23
pg 48

Could/should you run boost at high D

Efficiency, for various values of R_L

Adding Inductor Losses

$$\eta = \frac{1}{1 + \frac{R_L}{D'^2 R}}$$

Fig 3.15 pg 49