Switched Mode Power Conversion

Prior Art

How was Power Conversion Done

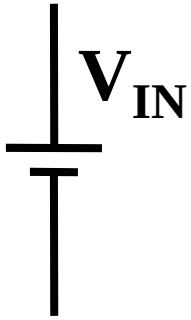
before the Introduction of Electronic Switches?

Switched Mode Power Conversion

Prior Art

DC-DC Converters

A DC Voltage Source of V_{IN} is Available

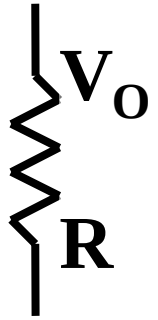


Switched Mode Power Conversion

Prior Art

DC-DC Converters

A Resistive Load Requires a Voltage of V_O



Switched Mode Power Conversion

Prior Art

DC-DC Converters

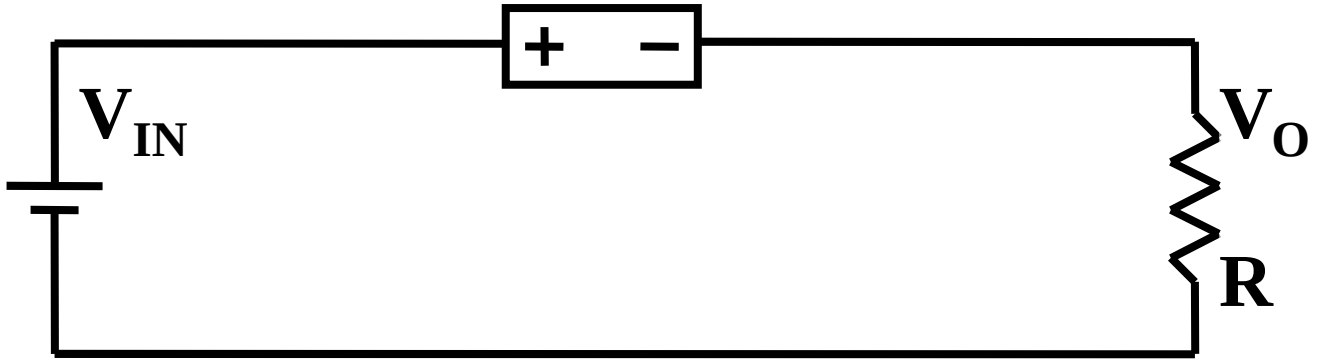
How to Deliver V_O to the Load from A Source Voltage of V_{IN}?

Switched Mode Power Conversion

Prior Art

DC-DC Converters

Conceptual Solution



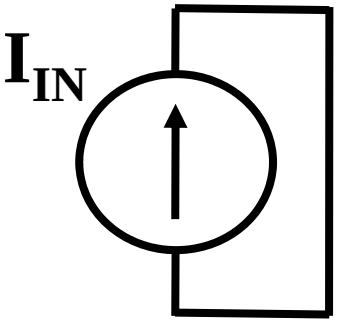
Drop the Excess Voltage in a Series Element

Switched Mode Power Conversion

Prior Art

DC-DC Converters

A DC Current Source of I_{IN} is Available

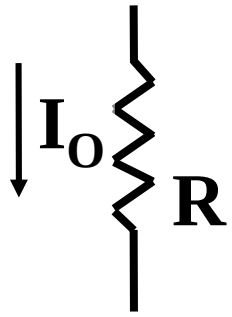


Switched Mode Power Conversion

Prior Art

DC-DC Converters

A Resistive Load Requires a Current of I_O

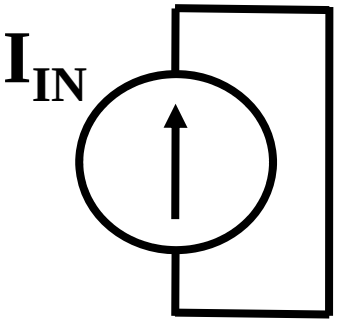


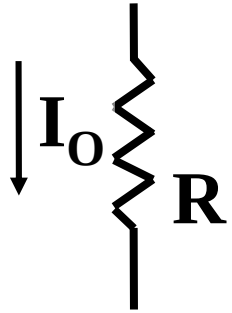
Switched Mode Power Conversion

Prior Art

DC-DC Converters

How to Deliver I_O to the Load from A Source Current of I_{IN}?



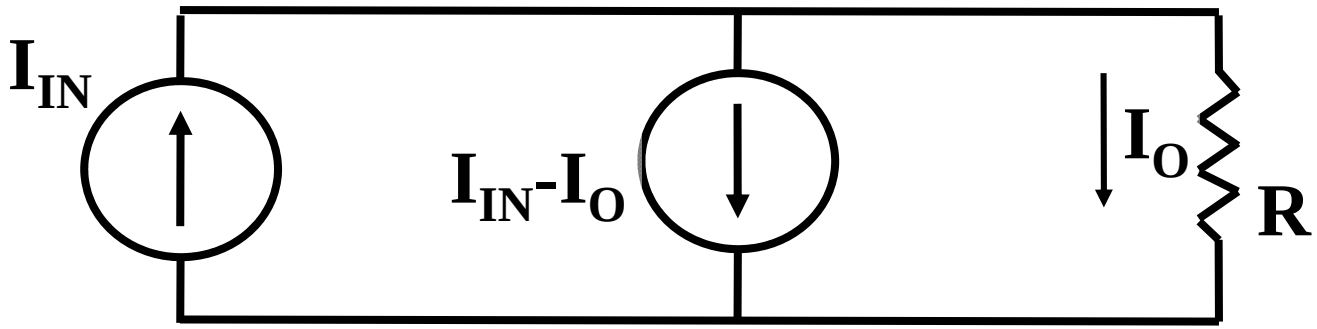


Switched Mode Power Conversion

Prior Art

DC-DC Converters

Conceptual Solution



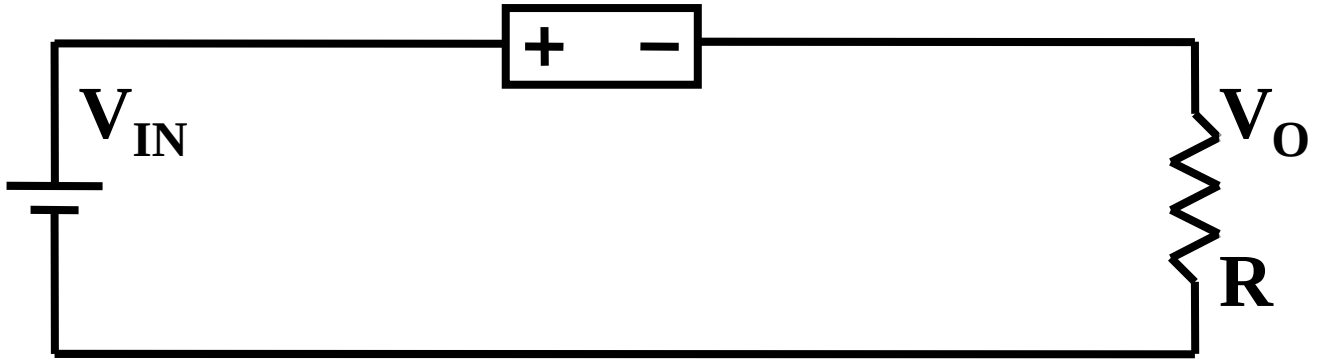
Divert the Excess Current in a Shunt Element

Switched Mode Power Conversion

Prior Art

DC-DC Converters

Conceptual Solution



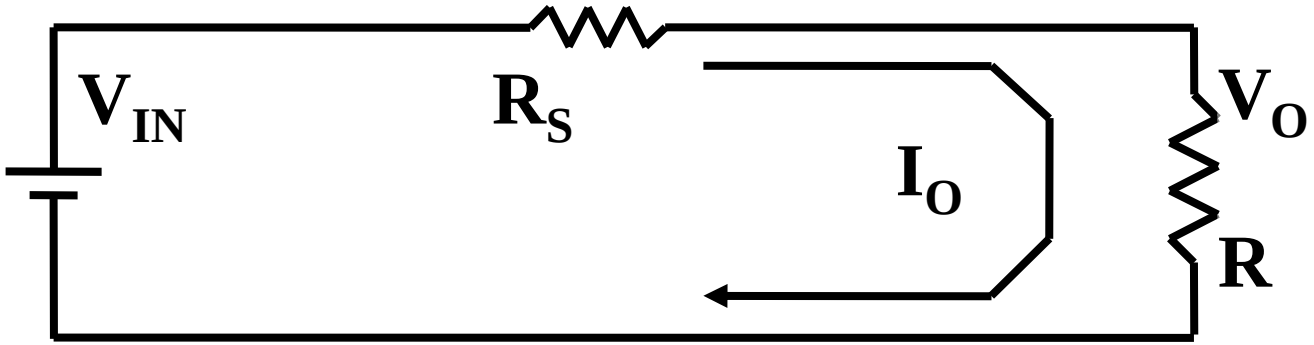
Drop the Excess Voltage in a Series Element

Switched Mode Power Conversion

Prior Art

DC-DC Converters

Circuit Model



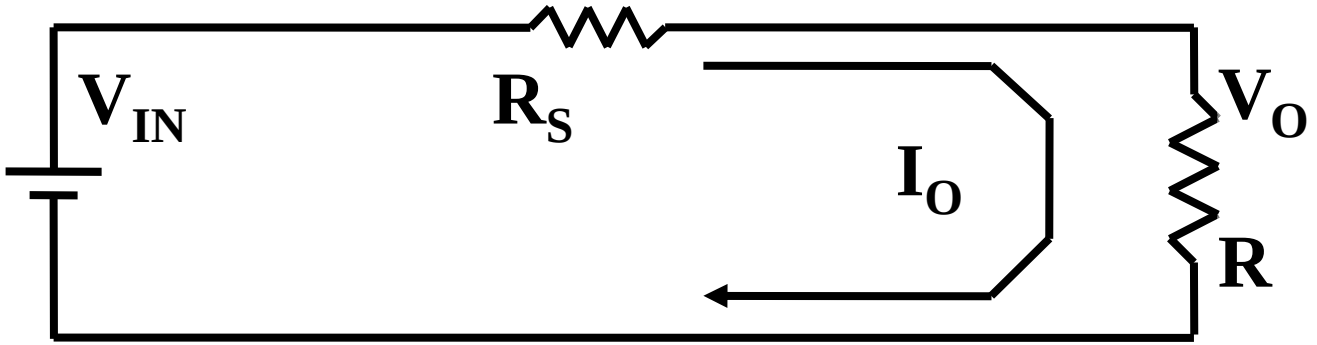
Drop the Excess Voltage in a Series Resistor

Switched Mode Power Conversion

Prior Art

Selection of R_S

$$V_O = V_{IN}\frac{R}{R+R_S} \qquad R_S = R\left(\frac{V_{IN}}{V_O}-1\right)$$

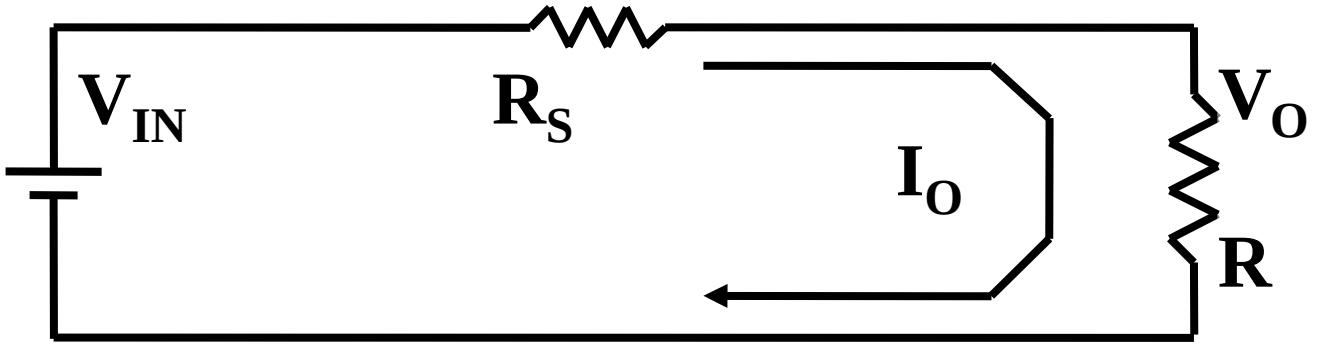


Switched Mode Power Conversion

Prior Art

Efficiency of Power Conversion

$$\eta = \frac{P_O}{P_{IN}} = \frac{V_O\, I_O}{V_{IN}\, I_O} = \frac{V_O}{V_{IN}}$$



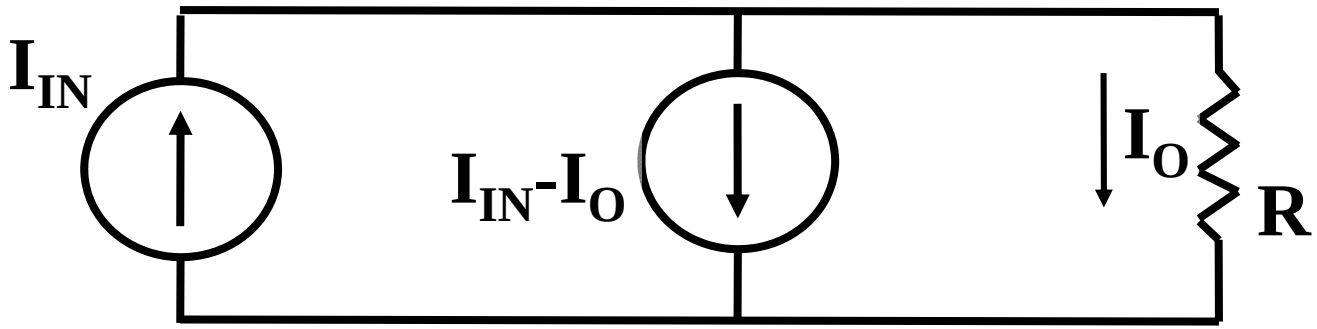
At Low Ratio of Conversion η is very Poor

Switched Mode Power Conversion

Prior Art

DC-DC Converters

Conceptual Solution



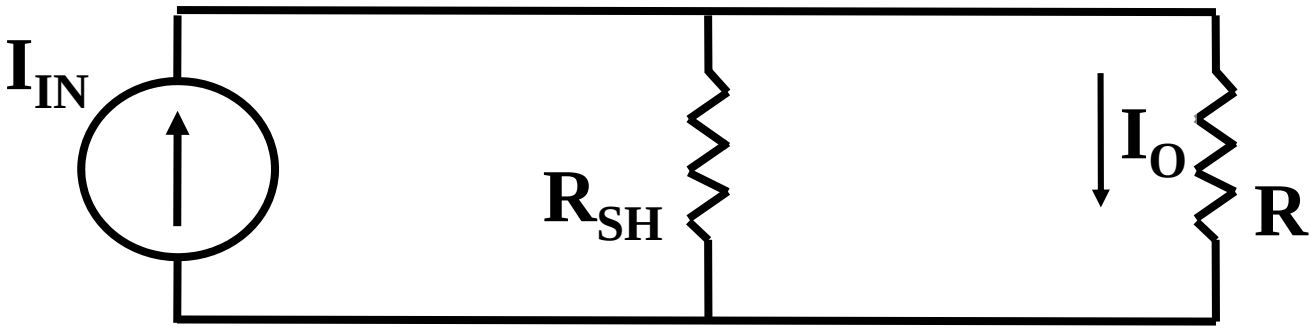
Divert the Excess Current in a Shunt Element

Switched Mode Power Conversion

Prior Art

DC-DC Converters

Circuit Model



Divert the Excess Current in a Shunt Resistance

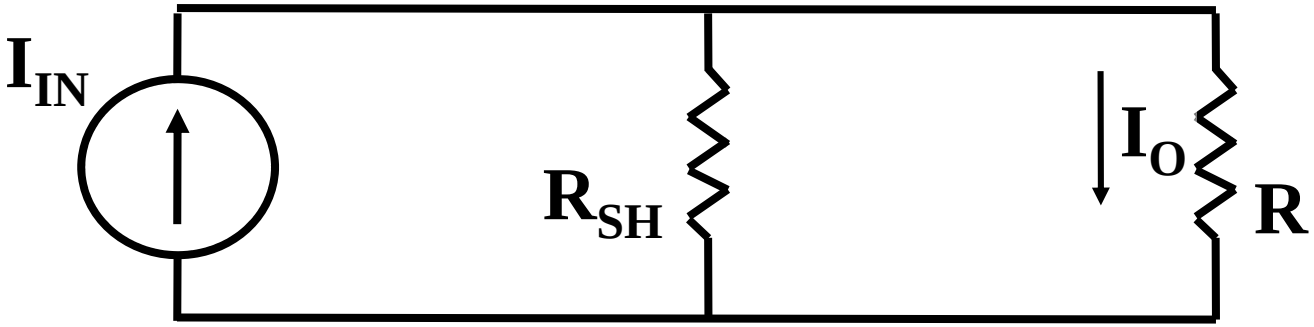
Switched Mode Power Conversion

Prior Art

Selection of R_{SH}

$$I_O = I_{IN} \frac{R_{SH}}{R + R_{SH}}$$

$$R_{SH} = \frac{R}{\left(\left(I_{IN} / I_O \right) - 1 \right)}$$

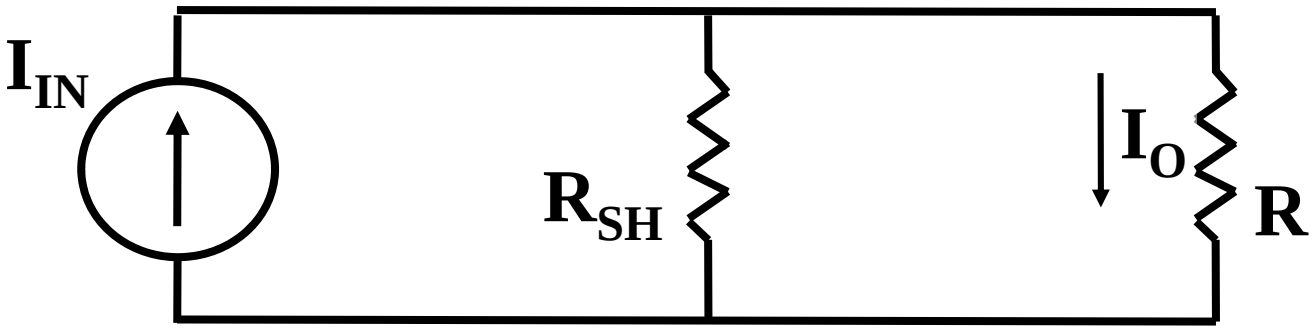


Switched Mode Power Conversion

Prior Art

Efficiency of Power Conversion

$$\eta = \frac{P_O}{P_{IN}} = \frac{V_O\, I_O}{V_{IN}\, I_{IN}} = \frac{I_O}{I_{IN}}$$

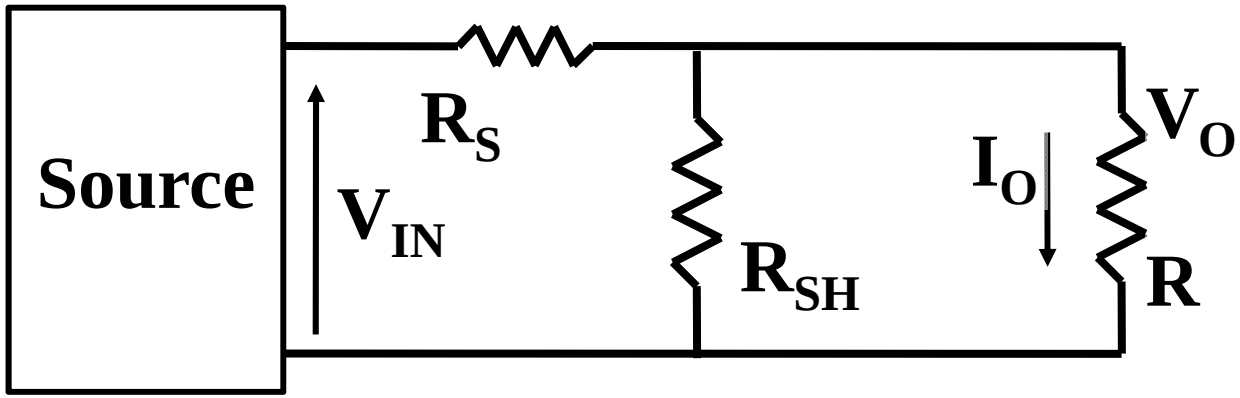


At Low Ratio of Conversion η is very Poor

Switched Mode Power Conversion

Prior Art

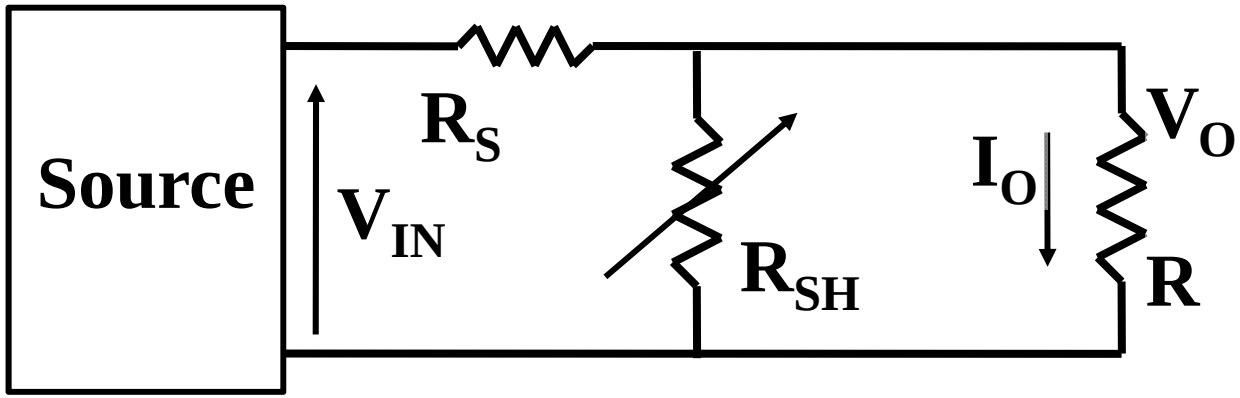
General Linear Power Converter



Switched Mode Power Conversion

Prior Art

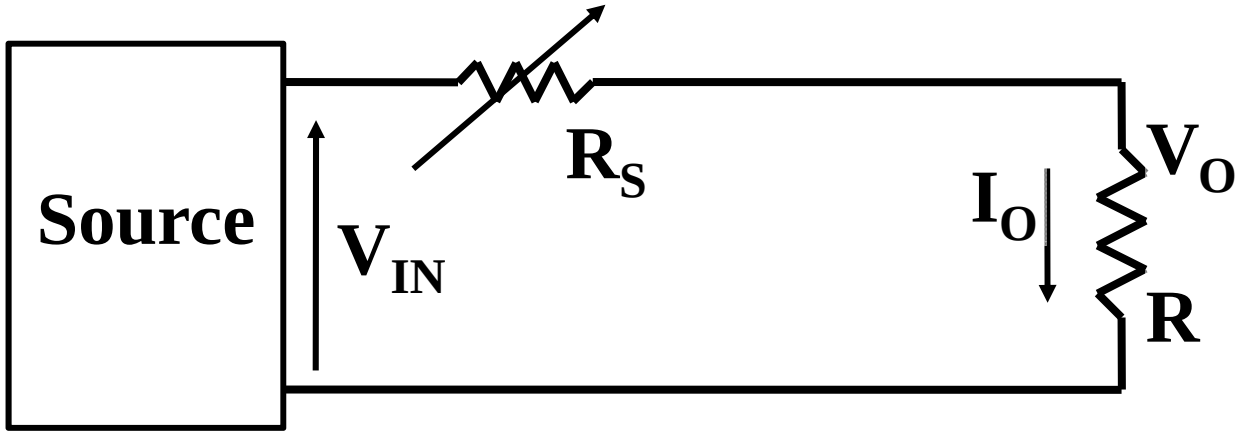
Shunt Controlled Converter



Switched Mode Power Conversion

Prior Art

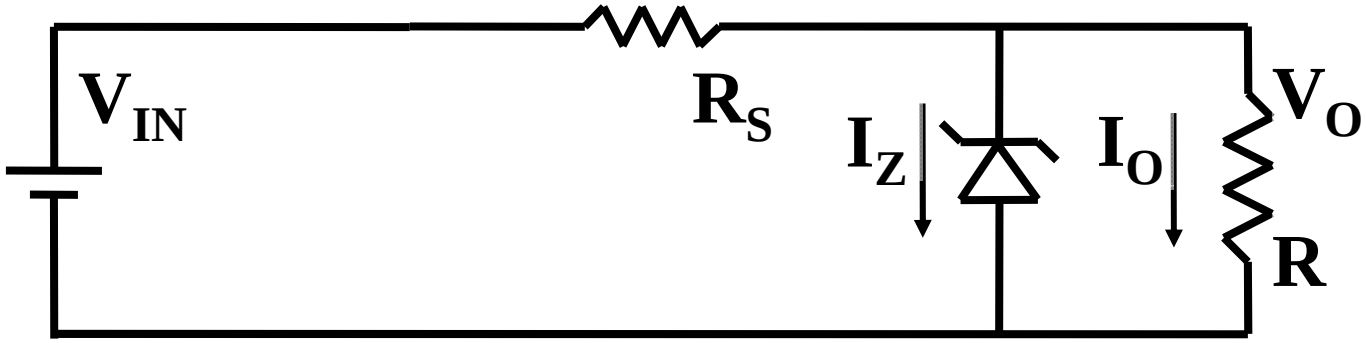
Series Controlled Converter



Shunt Controlled Converter

Sample Design

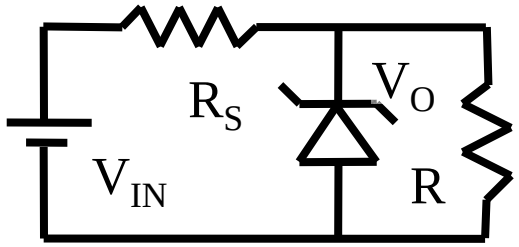
Zener Regulator



Shunt Controlled Converter

Sample Design

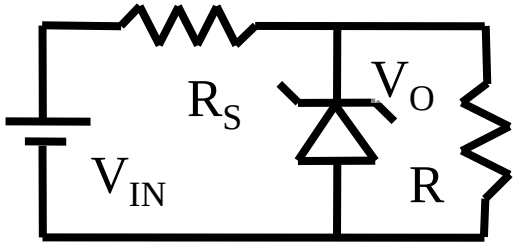
Zener Regulator

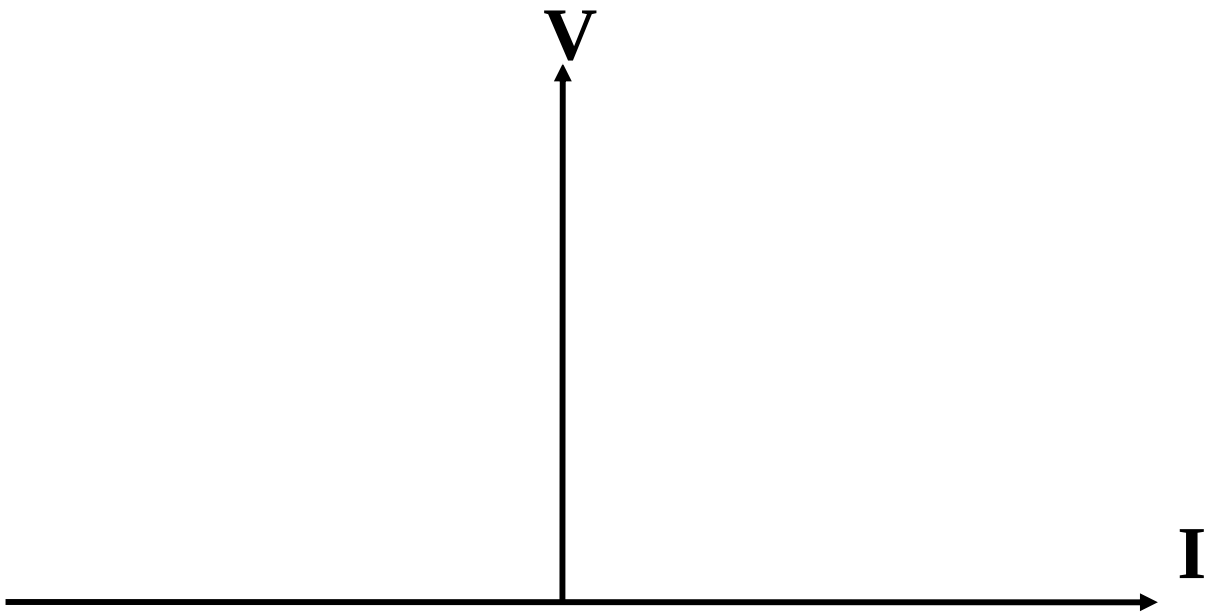


Shunt Controlled Converter

Sample Design

Zener Regulator

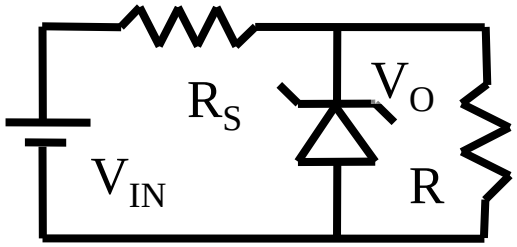


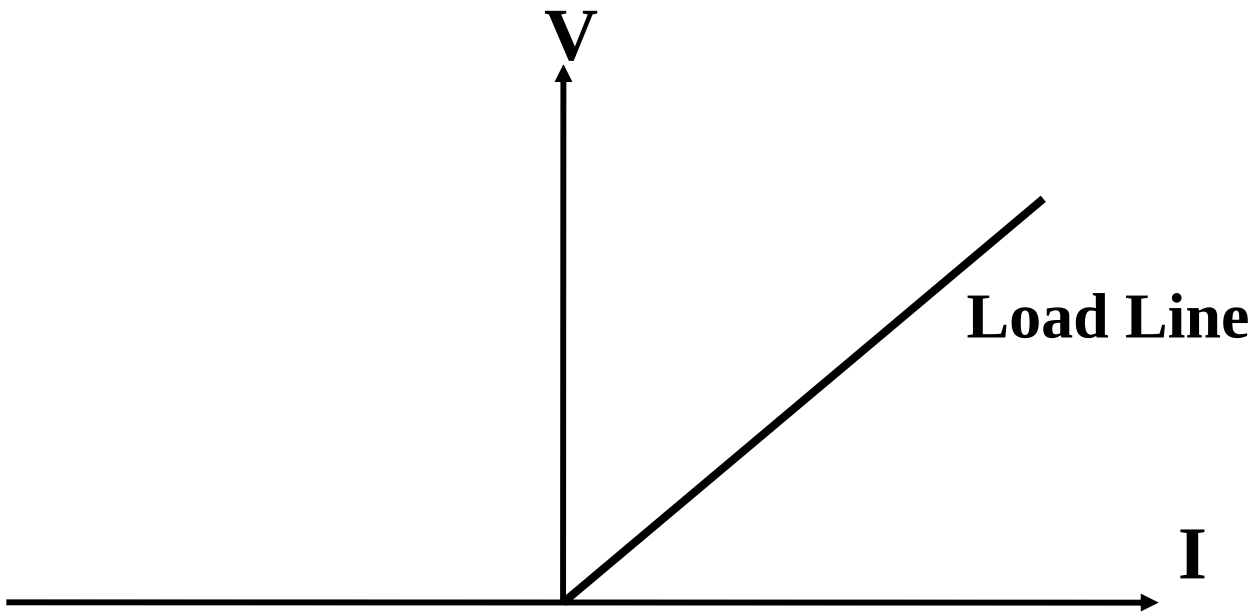


Shunt Controlled Converter

Load Line

Zener Regulator

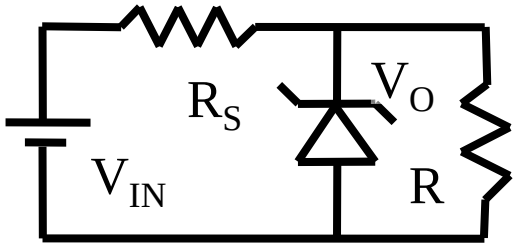


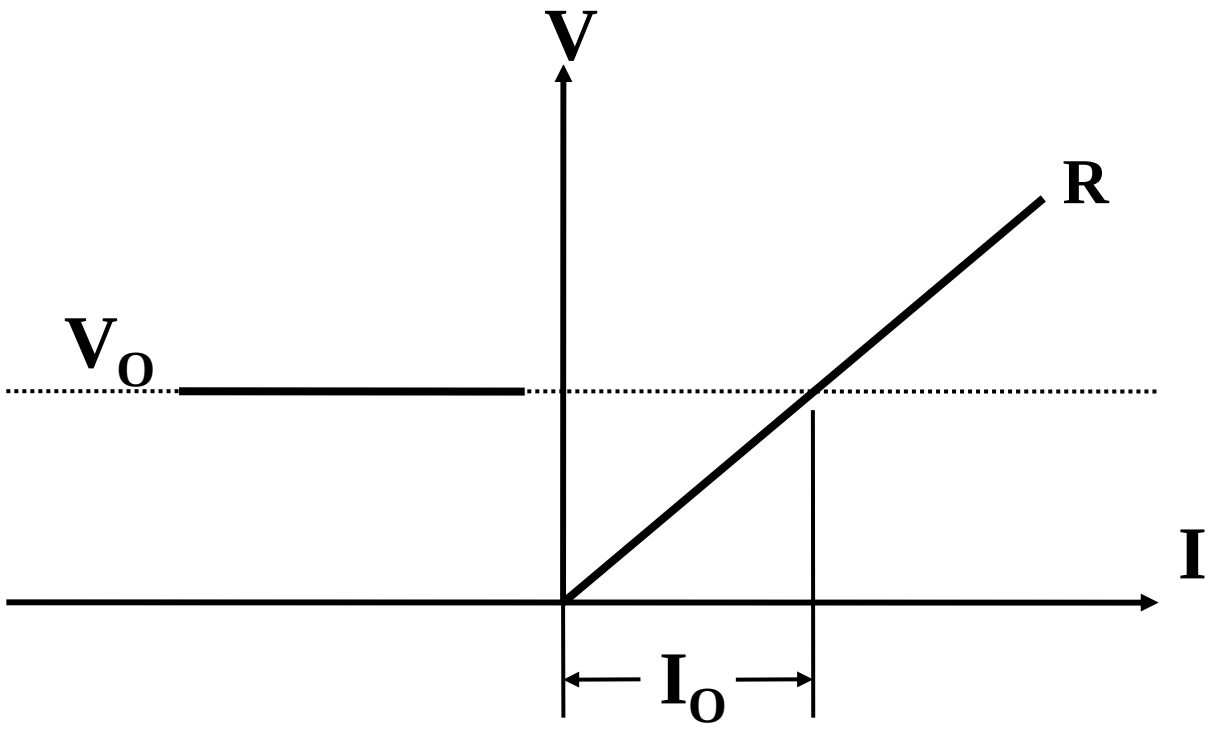


Shunt Controlled Converter

Output Voltage

Zener Regulator

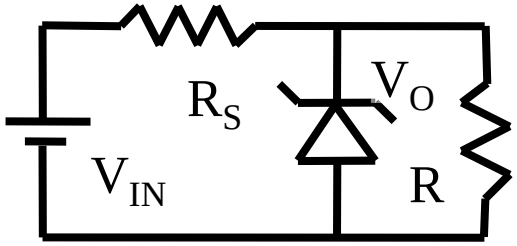


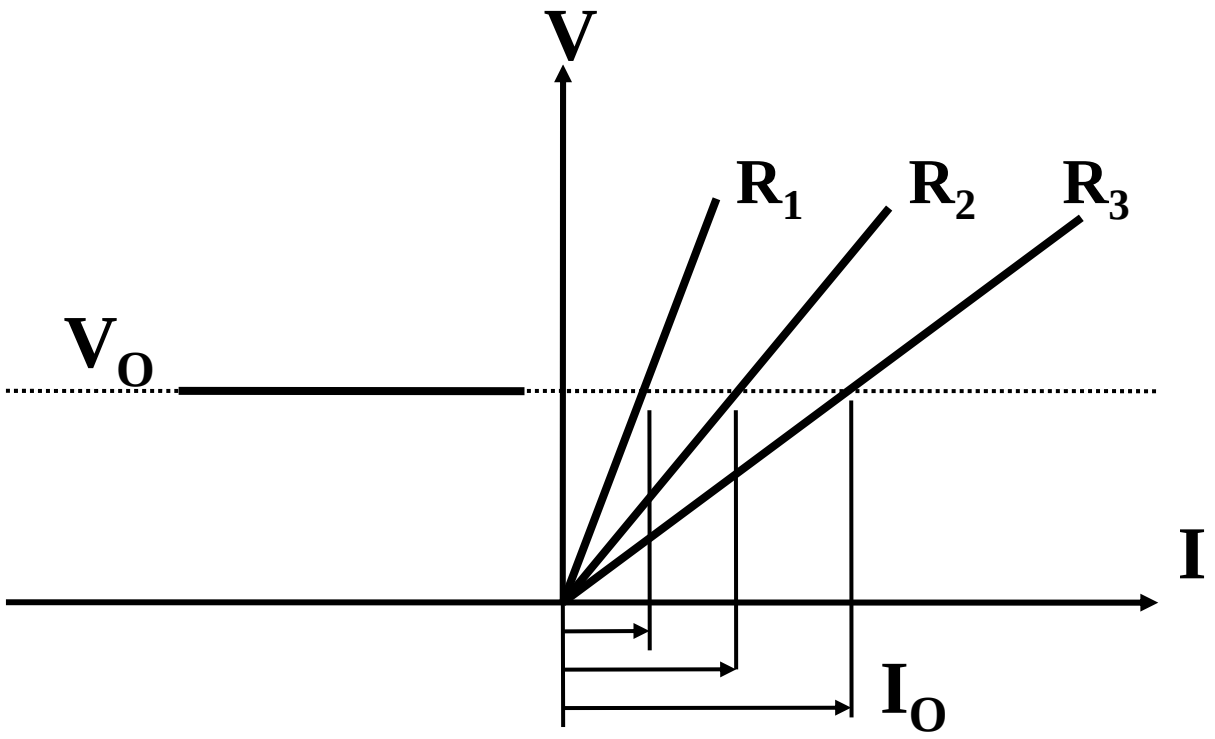


Shunt Controlled Converter

Load Variation

Zener Regulator

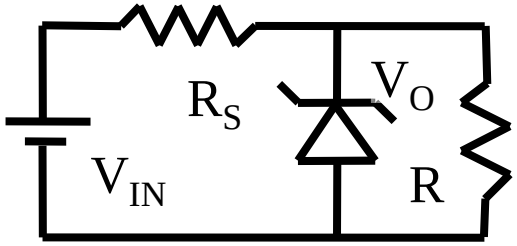


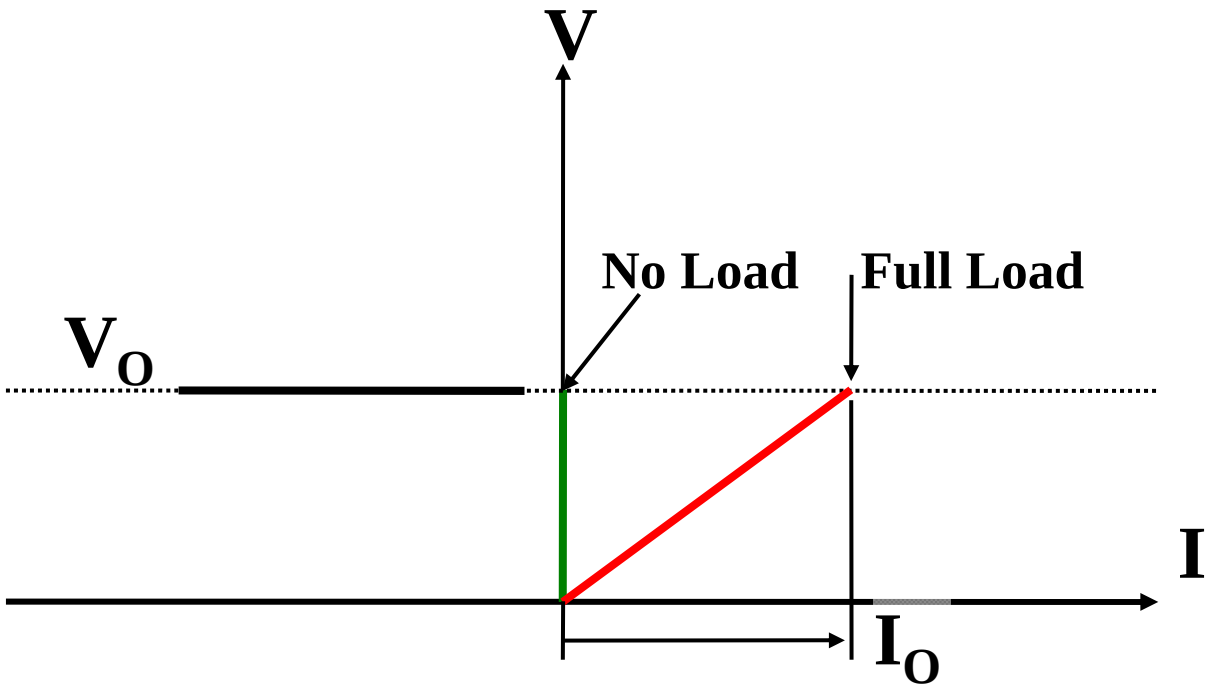


Shunt Controlled Converter

No Load & Full Load Lines

Zener Regulator

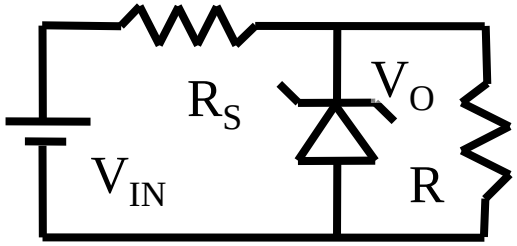


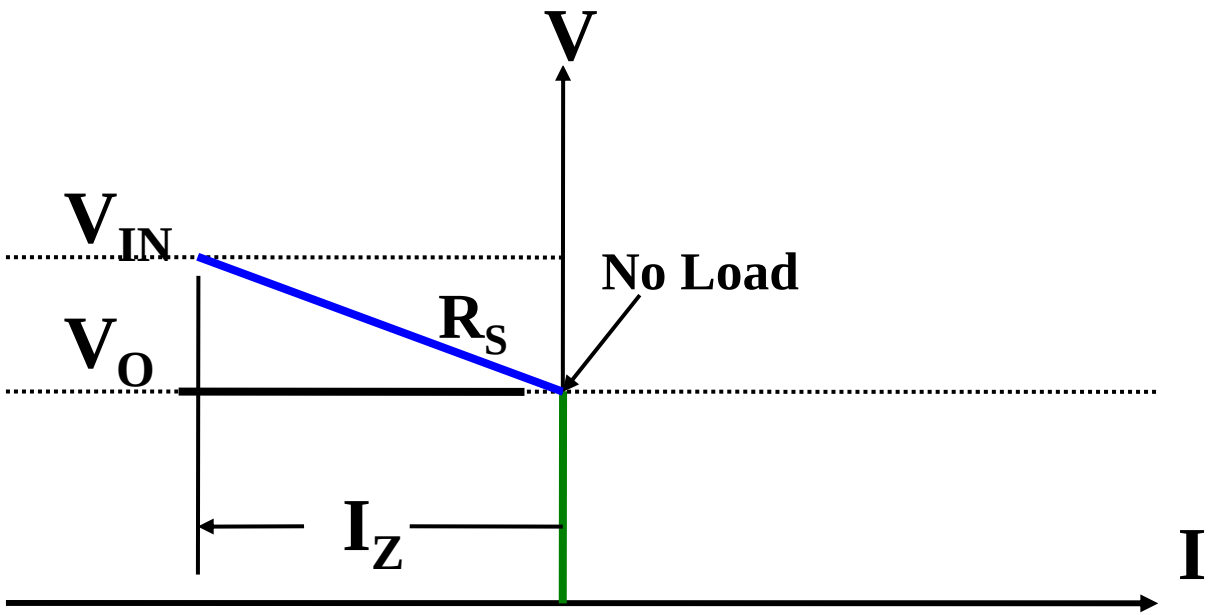


Shunt Controlled Converter

Source Line

Zener Regulator

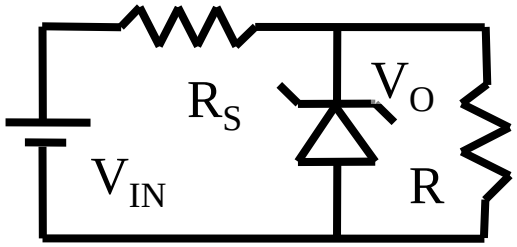


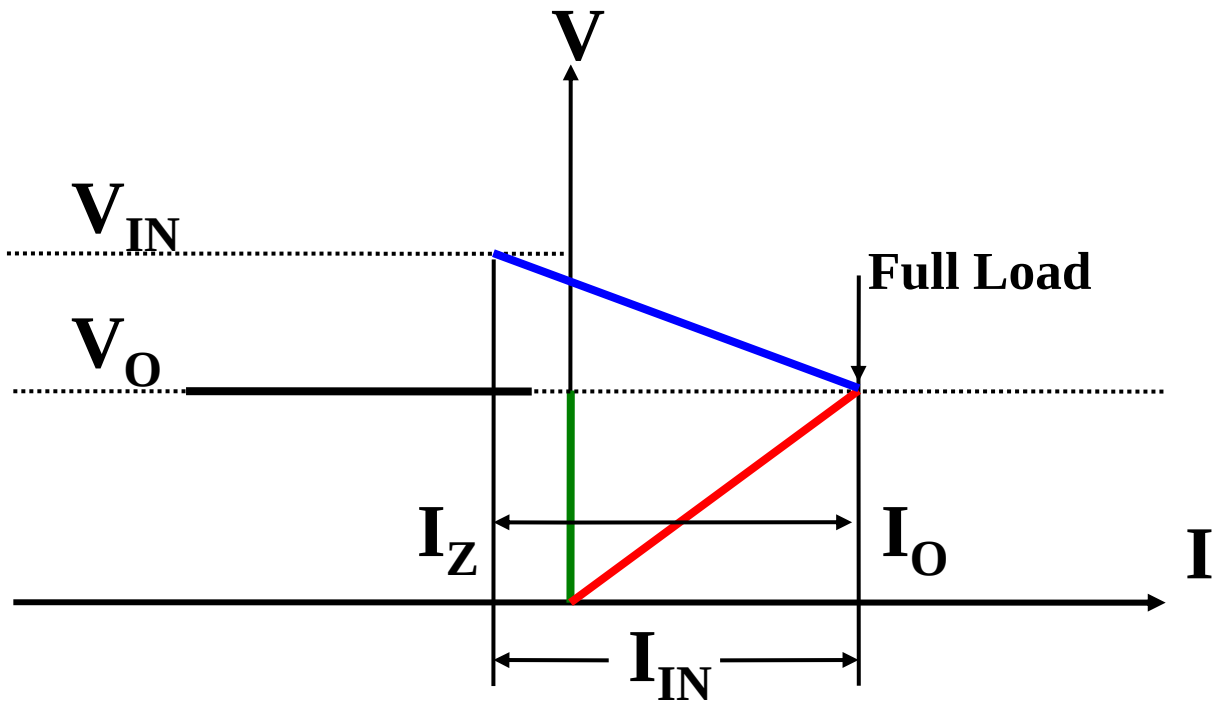


Shunt Controlled Converter

Minimum Zener Current

Zener Regulator

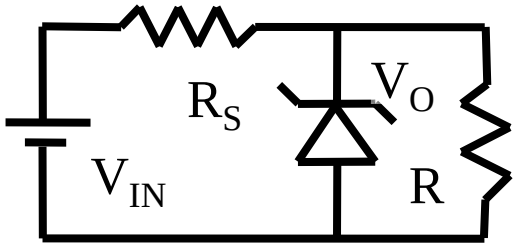


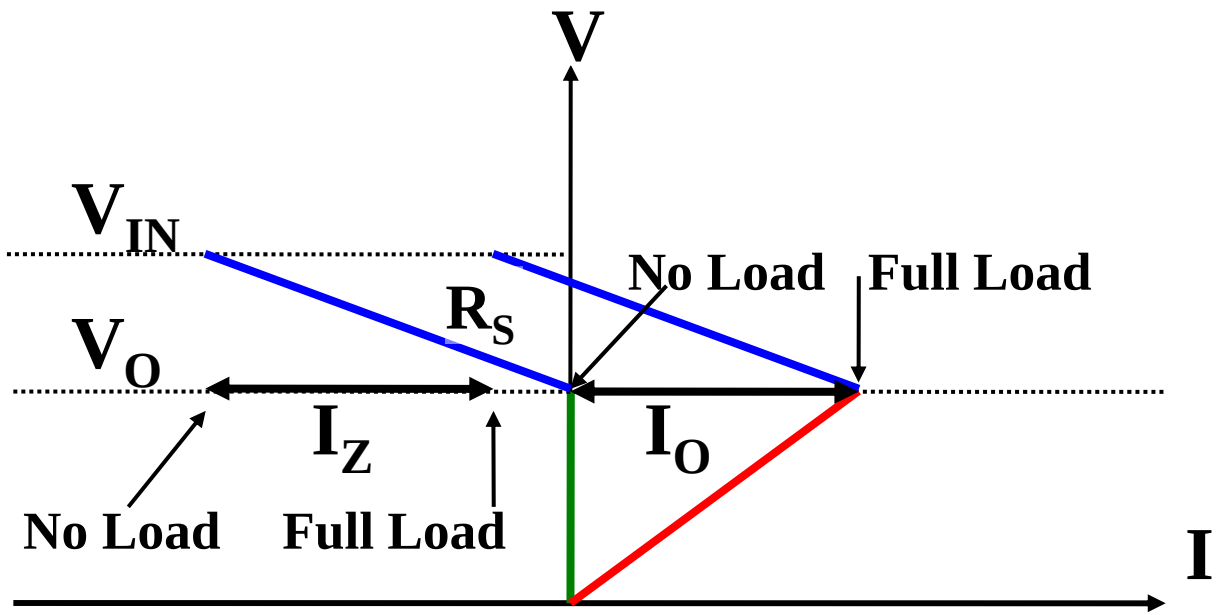


Shunt Controlled Converter

Zener Current Variation

Zener Regulator

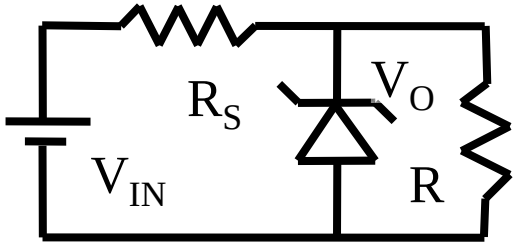


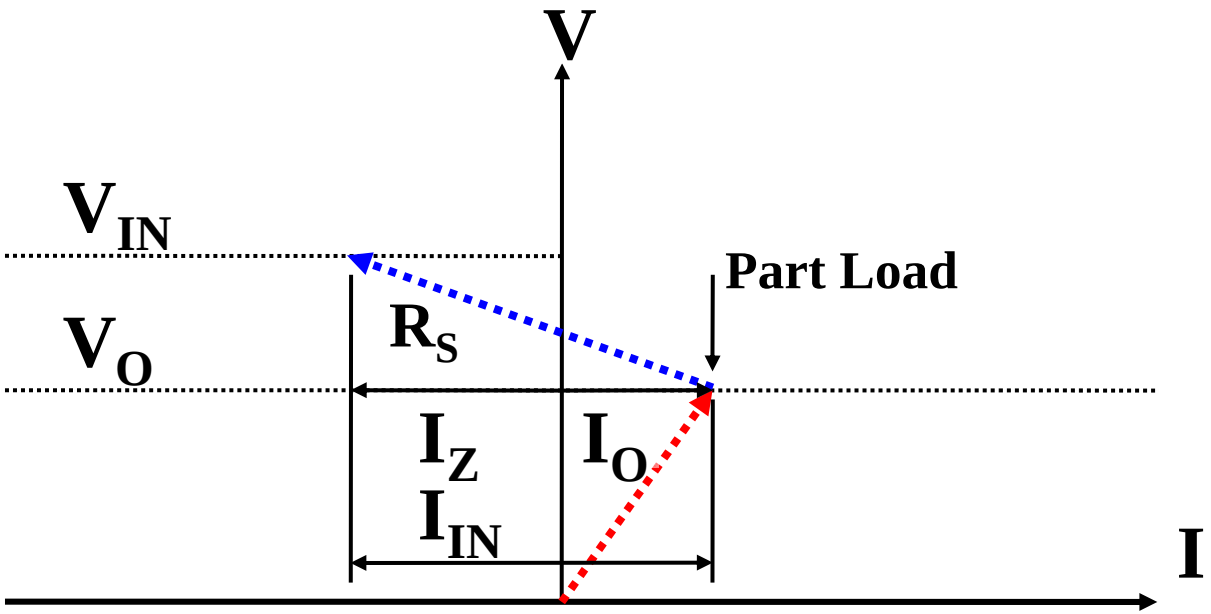


Shunt Controlled Converter

Typical Operating Point

Zener Regulator

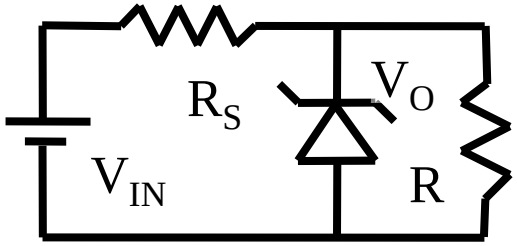


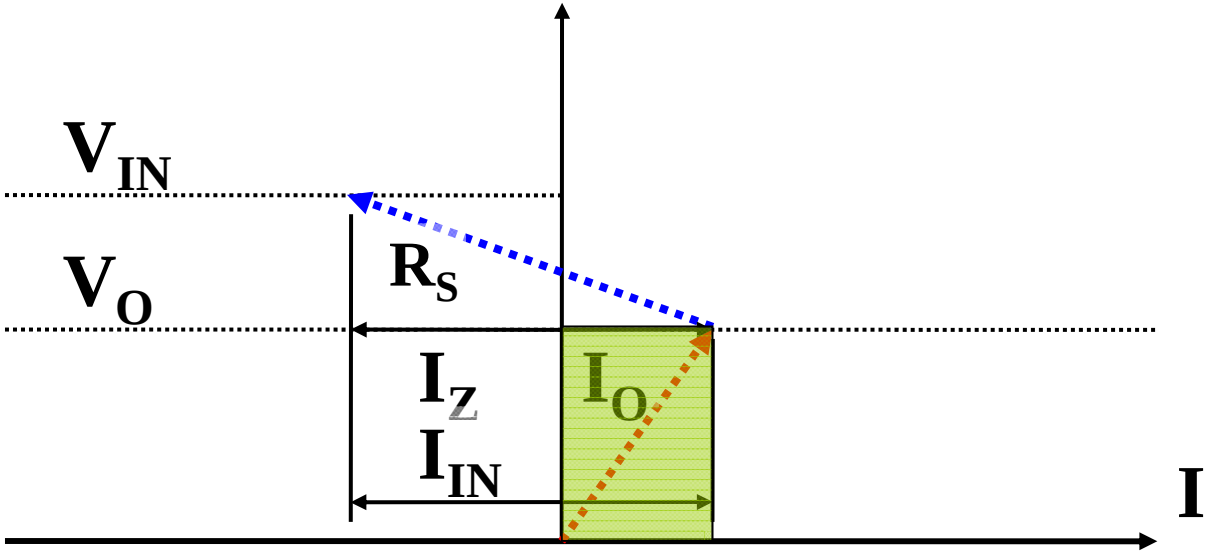


Shunt Controlled Converter

Output Power

Zener Regulator

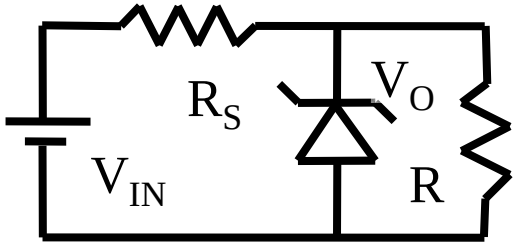


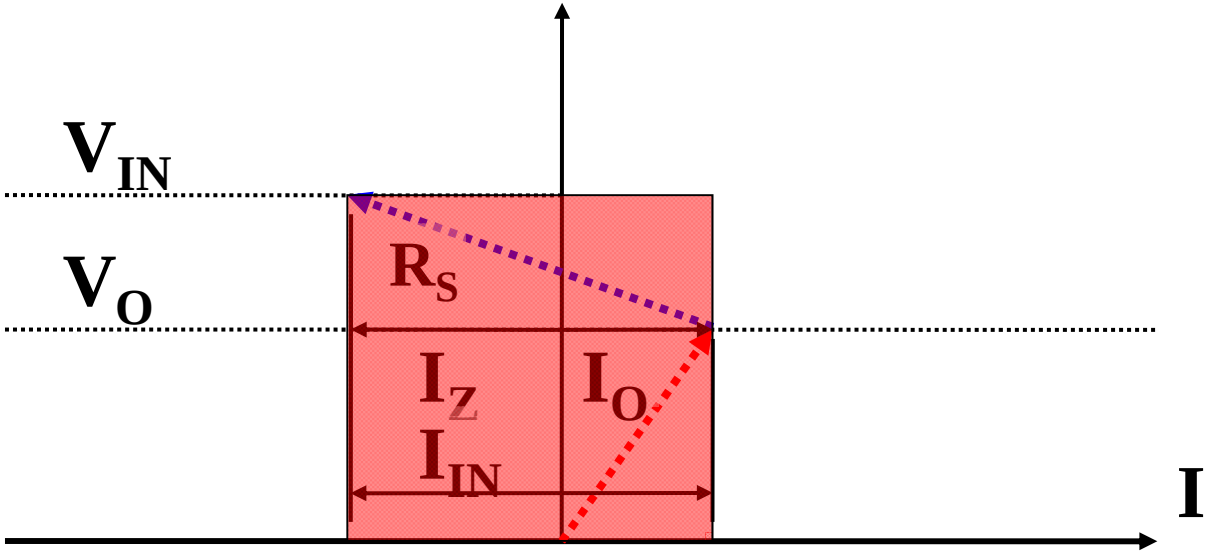


Shunt Controlled Converter

Input Power

Zener Regulator

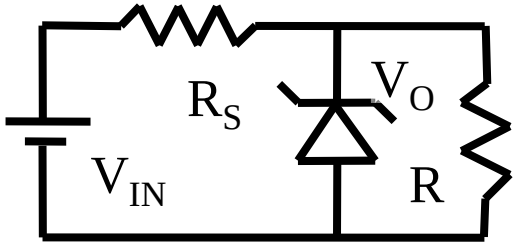


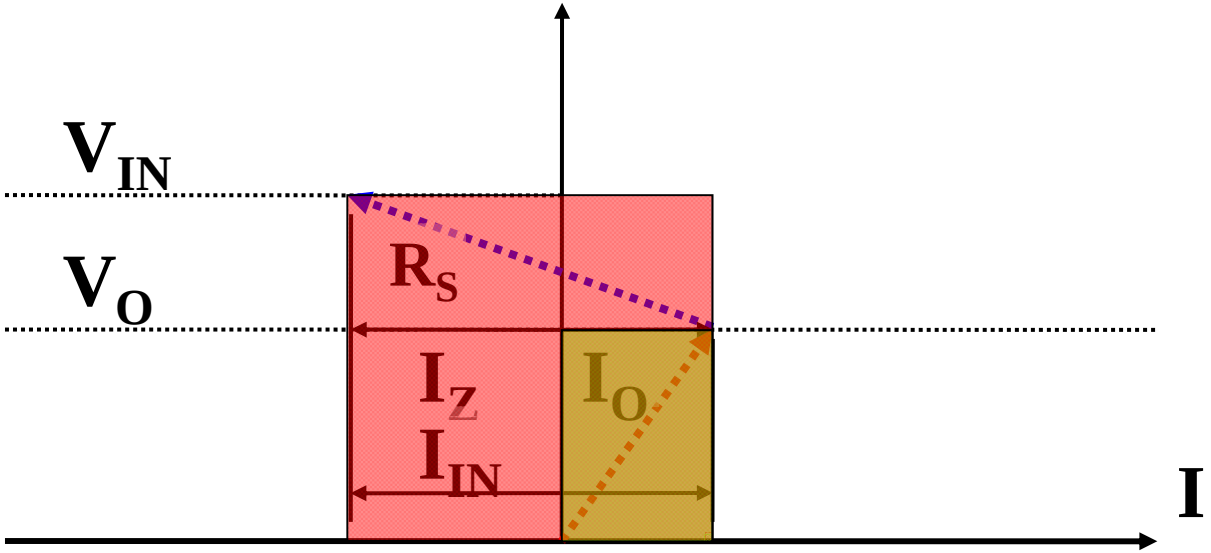


Shunt Controlled Converter

Efficiency

Zener Regulator

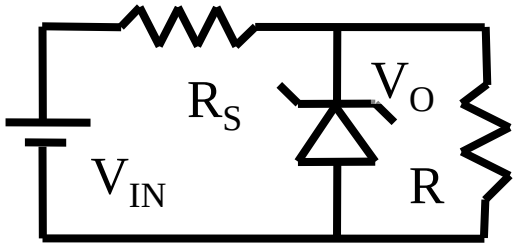


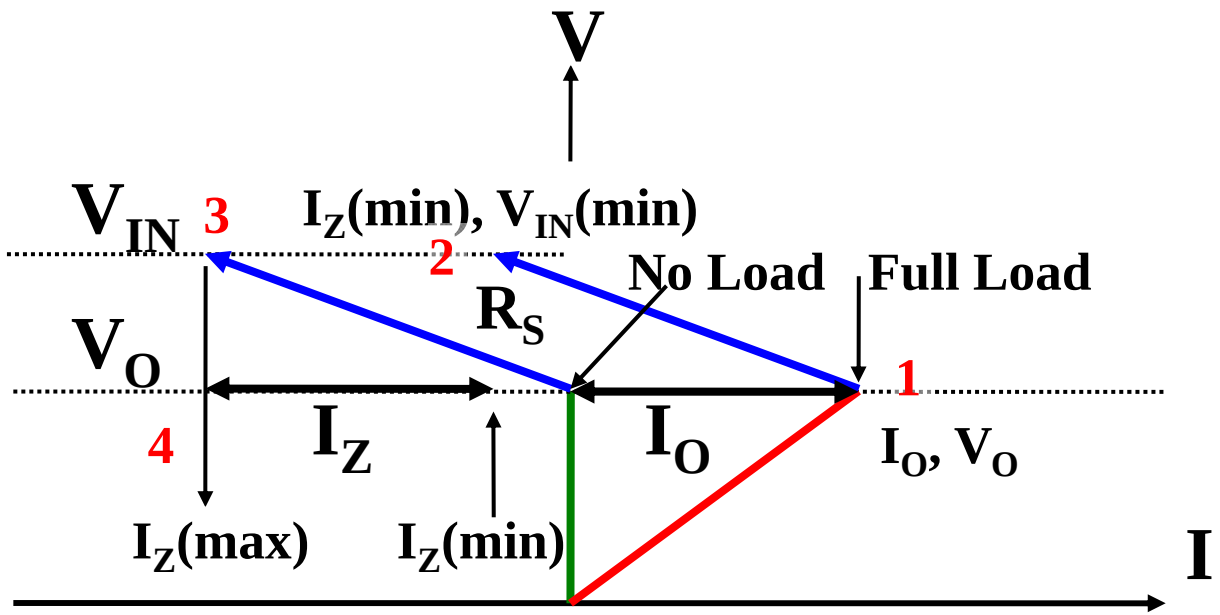


Shunt Controlled Converter

Design Sequence

Zener Regulator



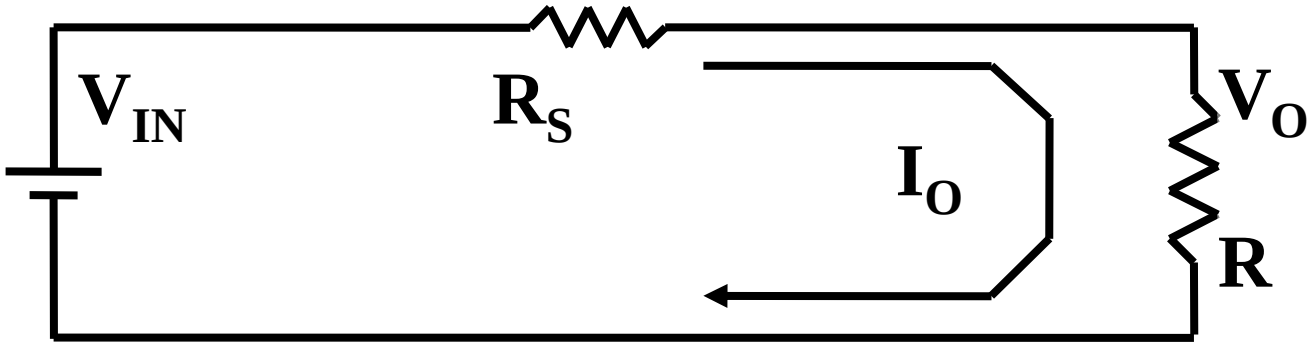


Switched Mode Power Conversion

Prior Art

DC-DC Converters

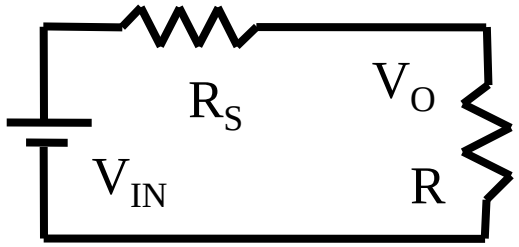
Series Controlled Converter



Prior art

Circuit Diagram

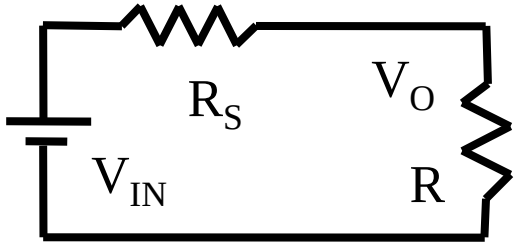
Series Controlled Converter

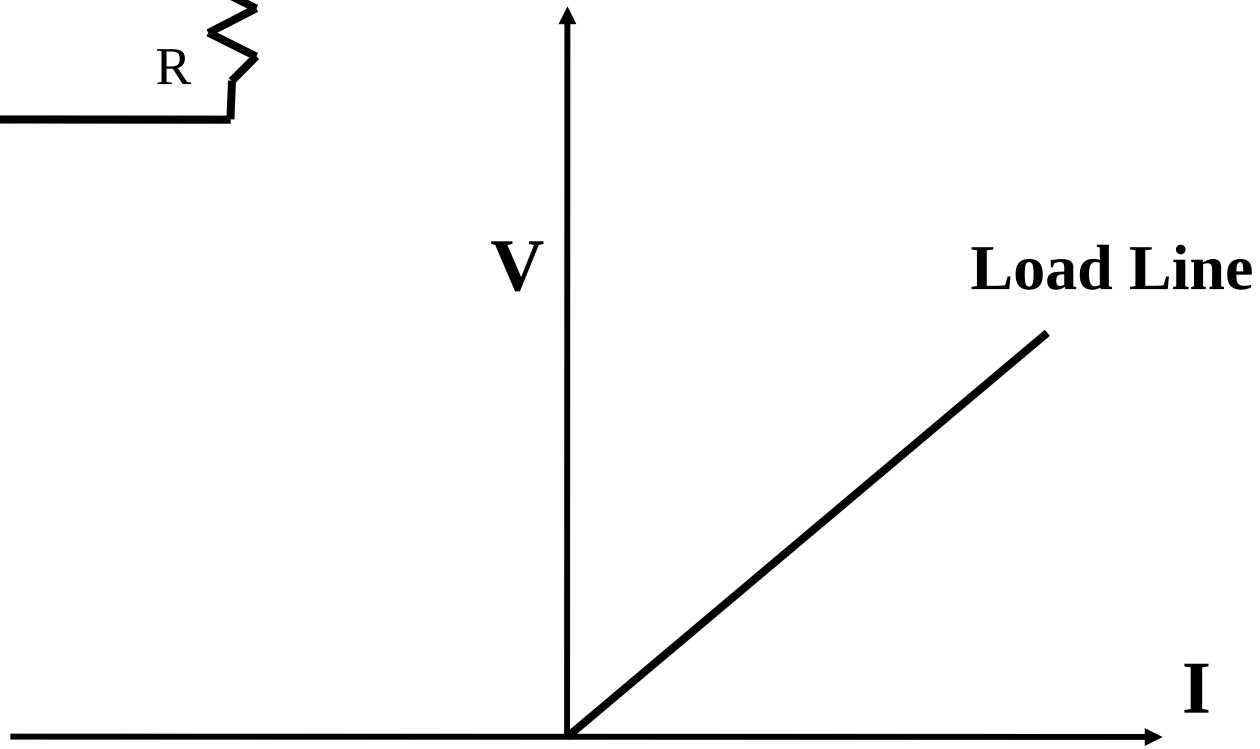


Prior Art

Load Line

Series Controlled Converter

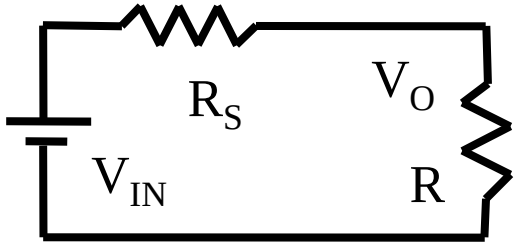


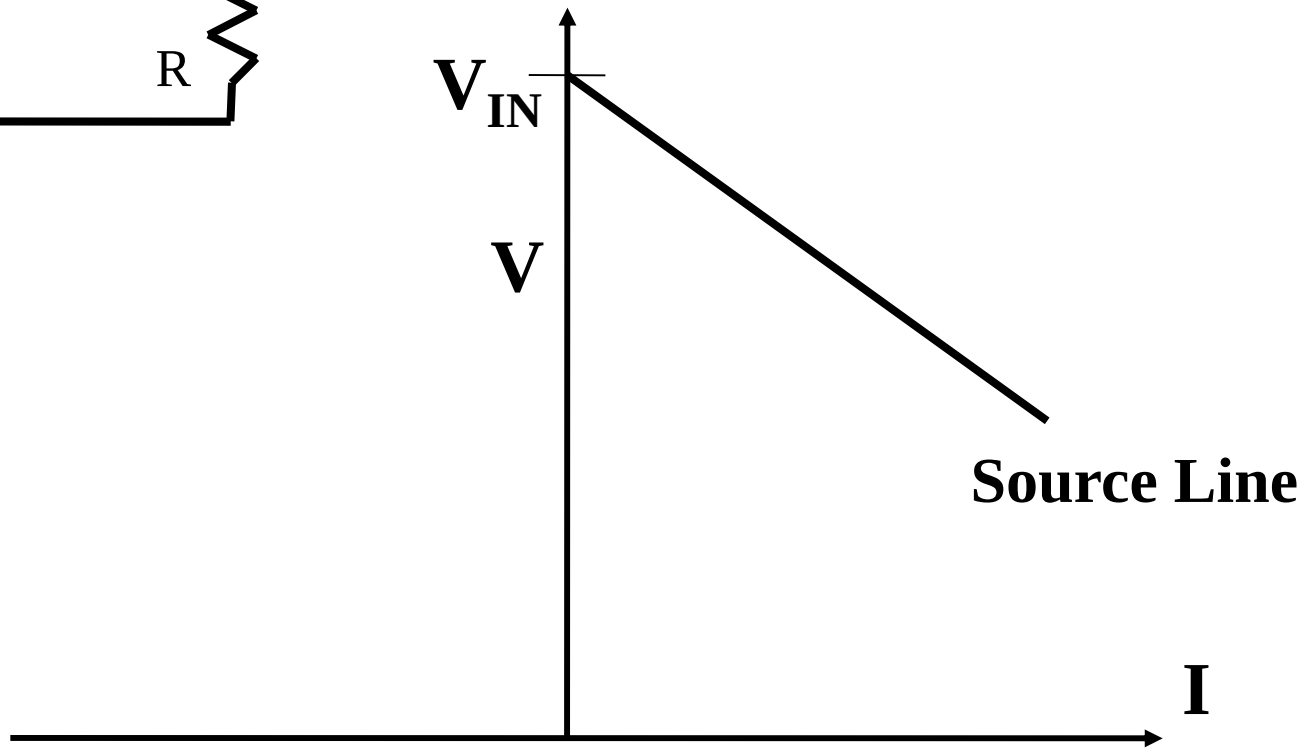


Prior Art

Source Line

Series Controlled Converter

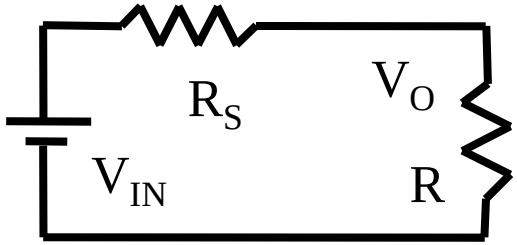


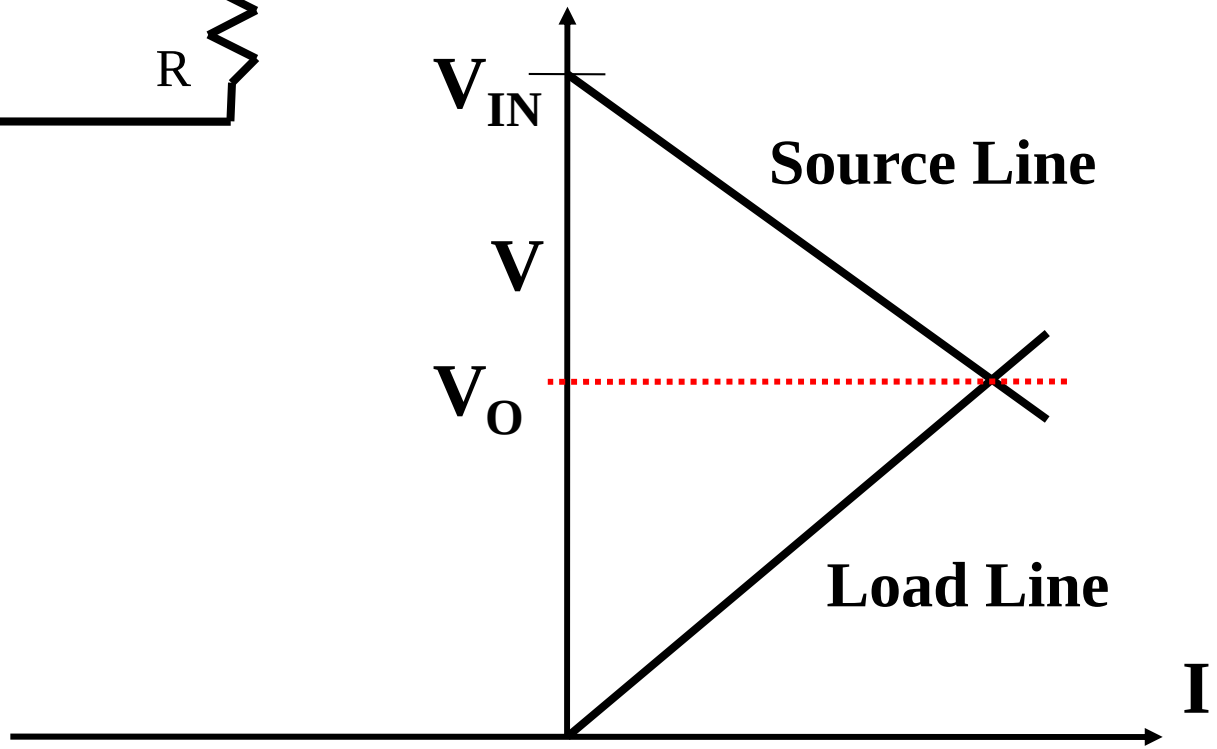


Prior Art

Output Voltage

Series Controlled Converter

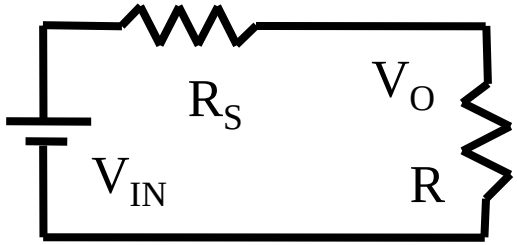


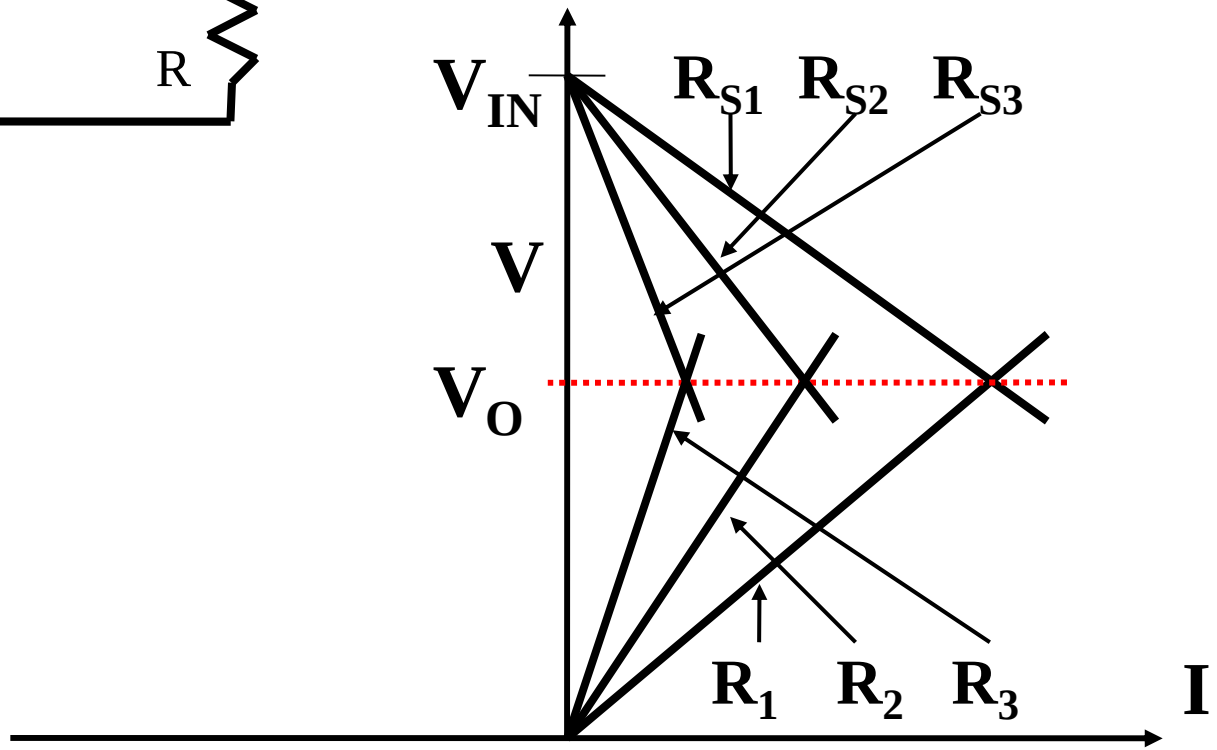


Prior Art

Control Strategy

Series Controlled Converter

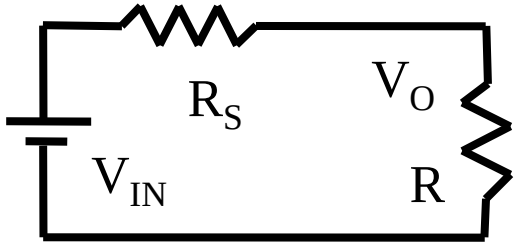


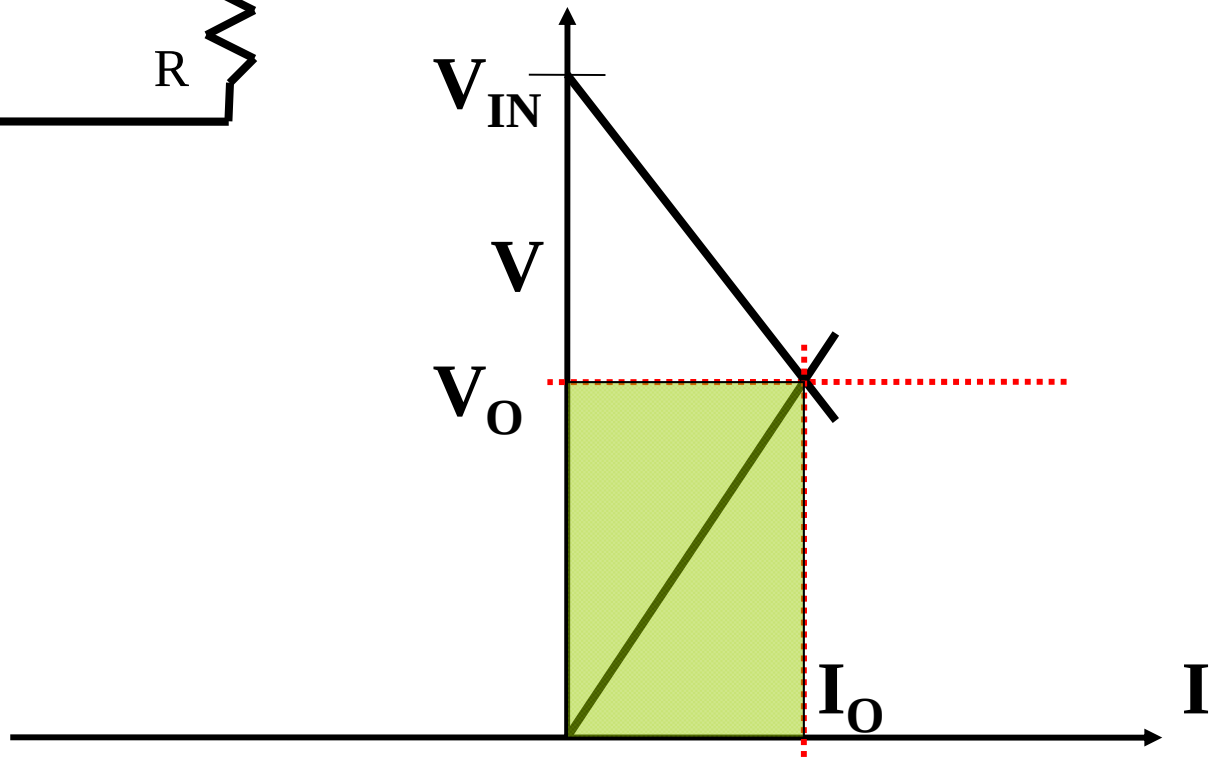


Prior Art

Output Power

Series Controlled Converter

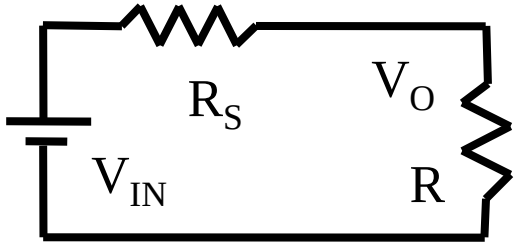


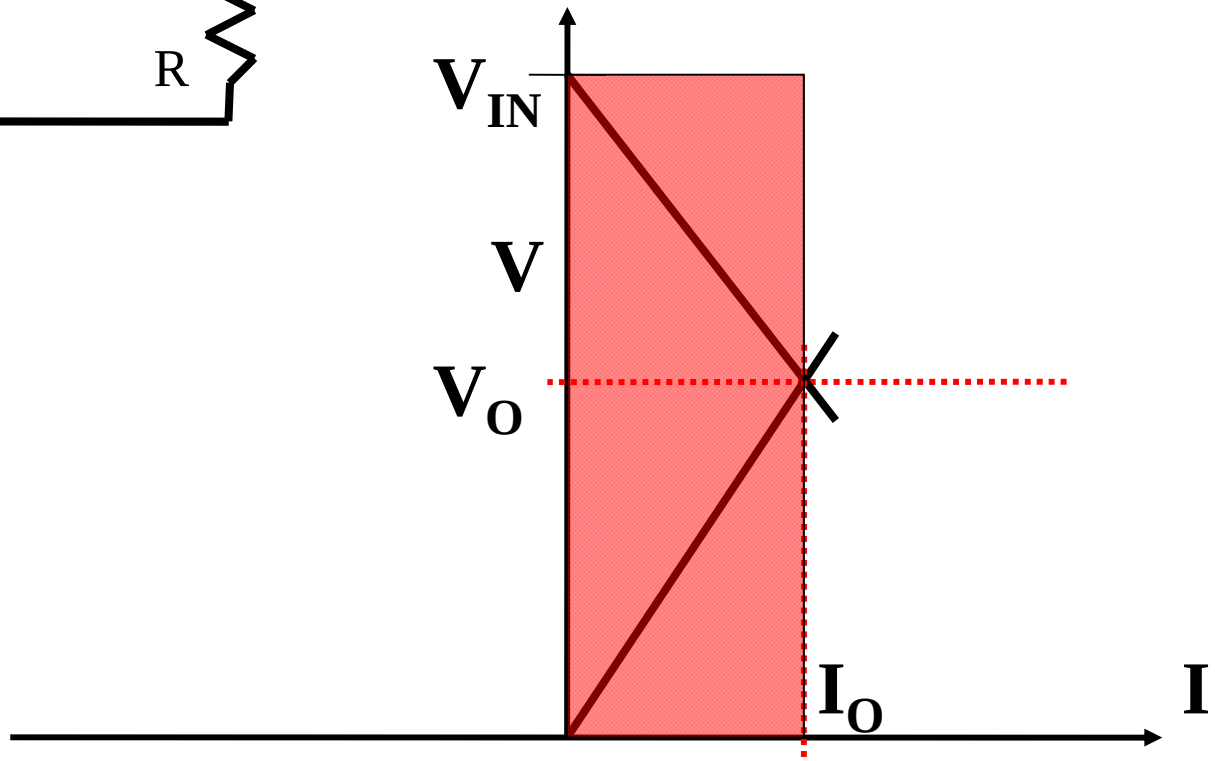


Prior Art

Input Power

Series Controlled Converter

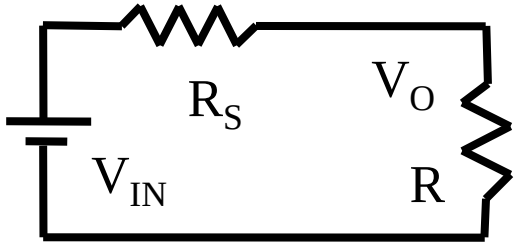


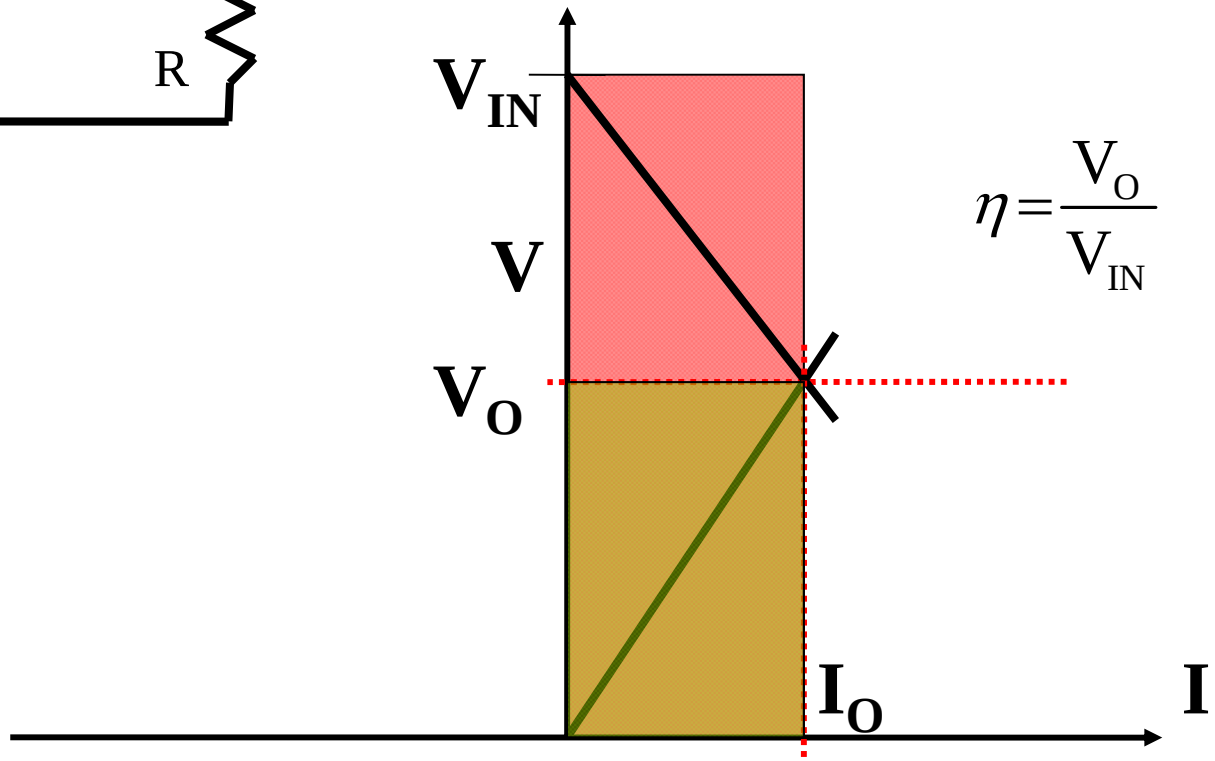


Prior Art

Efficiency

Series Controlled Converter



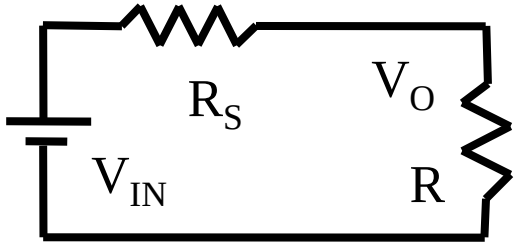


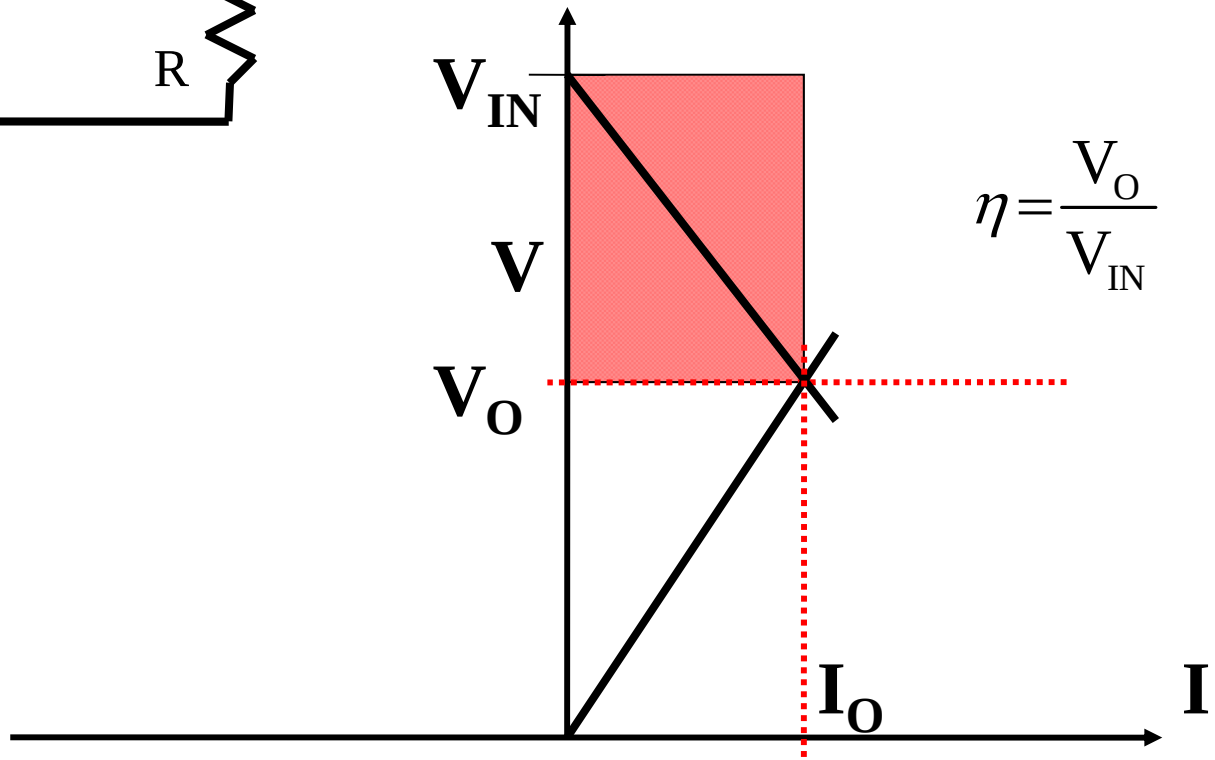
$$\eta = \frac{V_O}{V_{IN}}$$

Prior Art

Losses

Series Controlled Converter



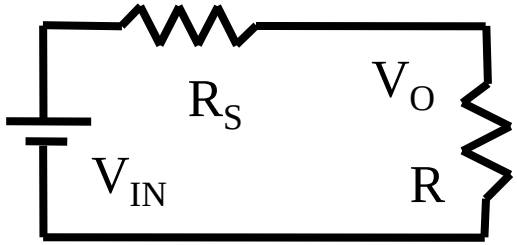


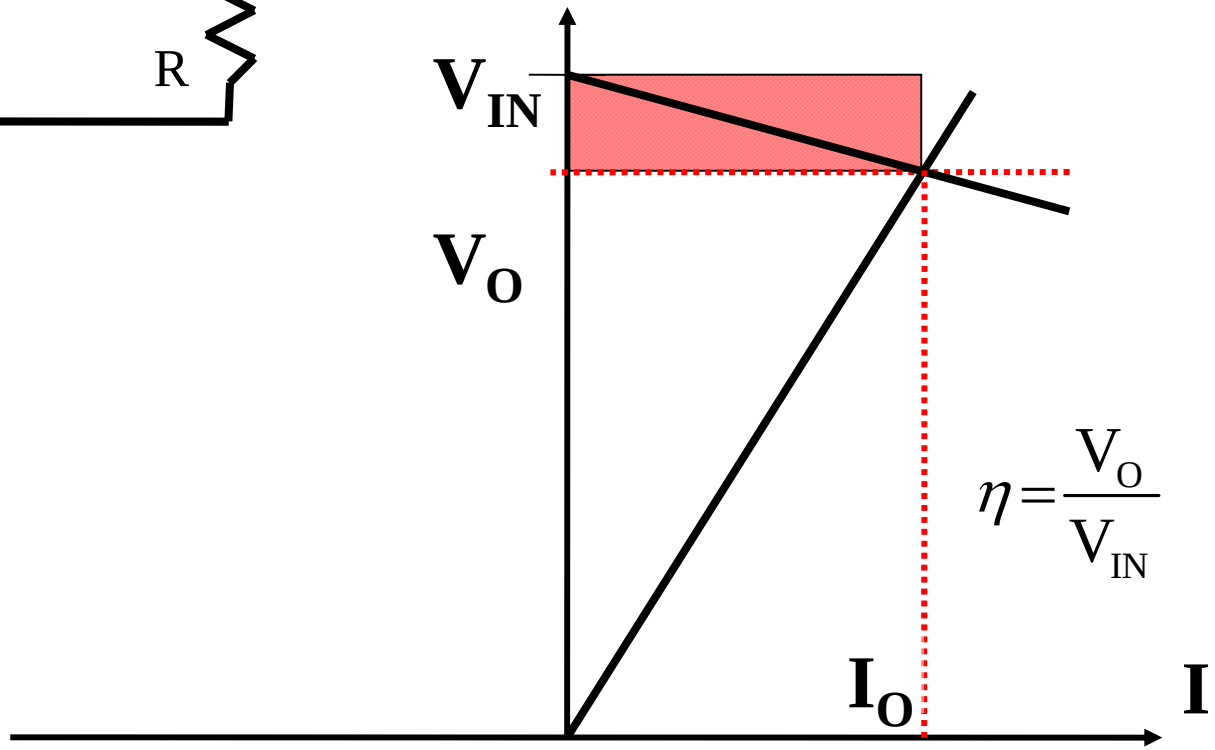
$$\eta = \frac{V_O}{V_{IN}}$$

Prior Art

Losses

Series Controlled Converter

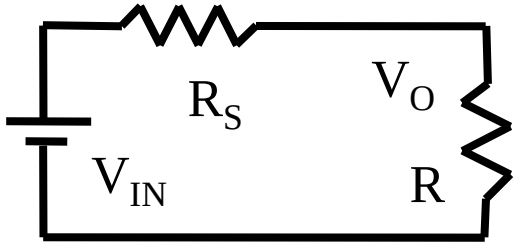


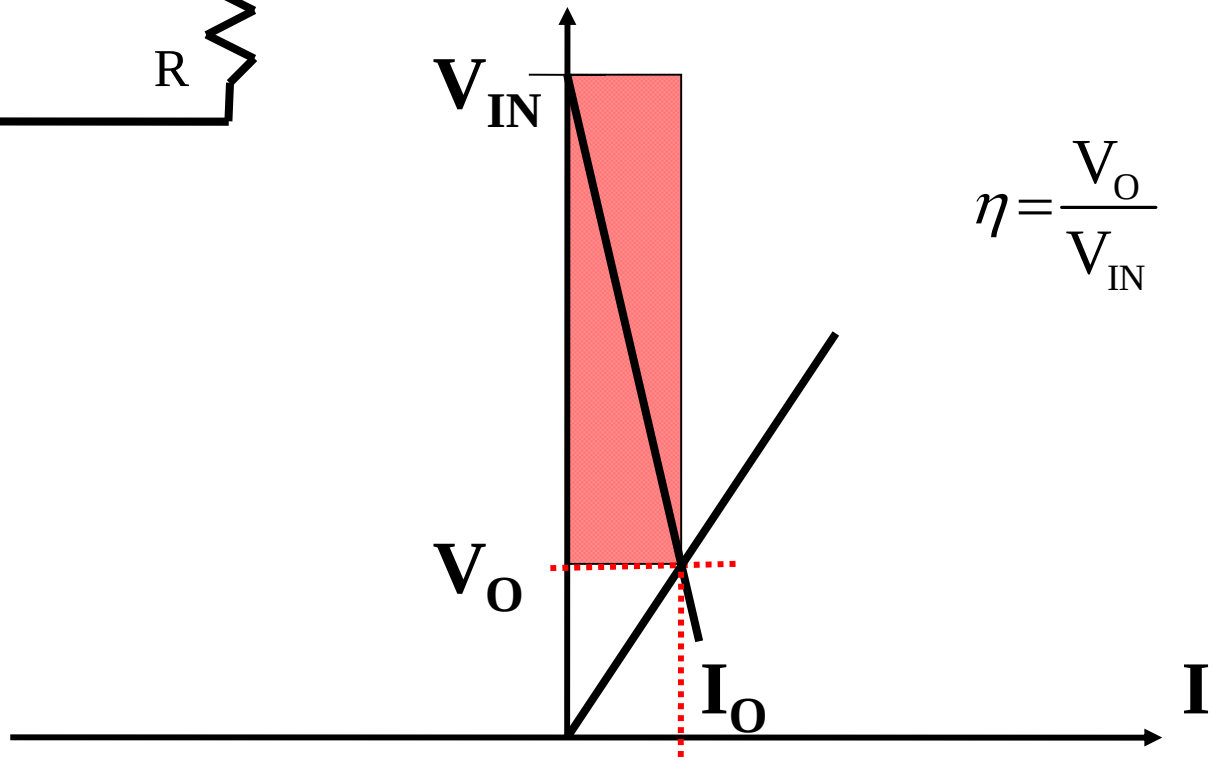


Prior Art

Losses

Series Controlled Converter



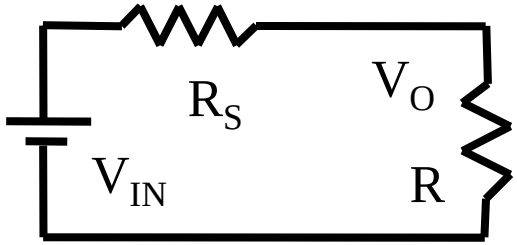


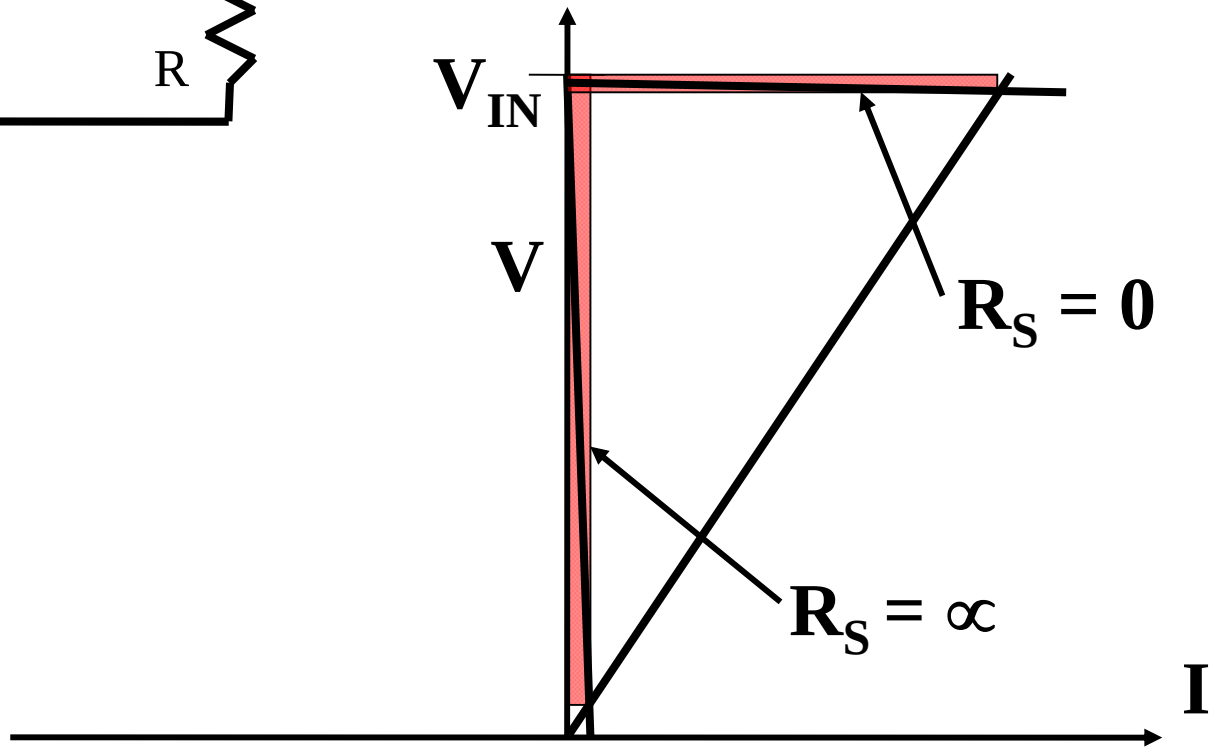
$$\eta = \frac{V_O}{V_{IN}}$$

Prior Art

Two Low-Loss Conditions

Series Controlled Converter

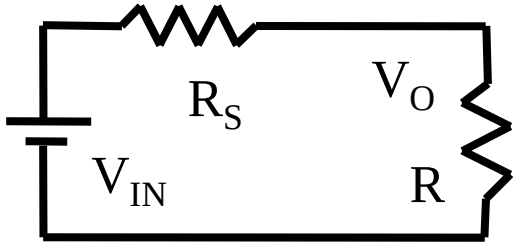


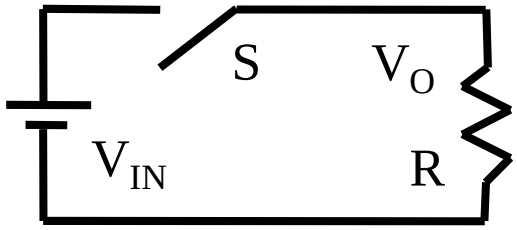


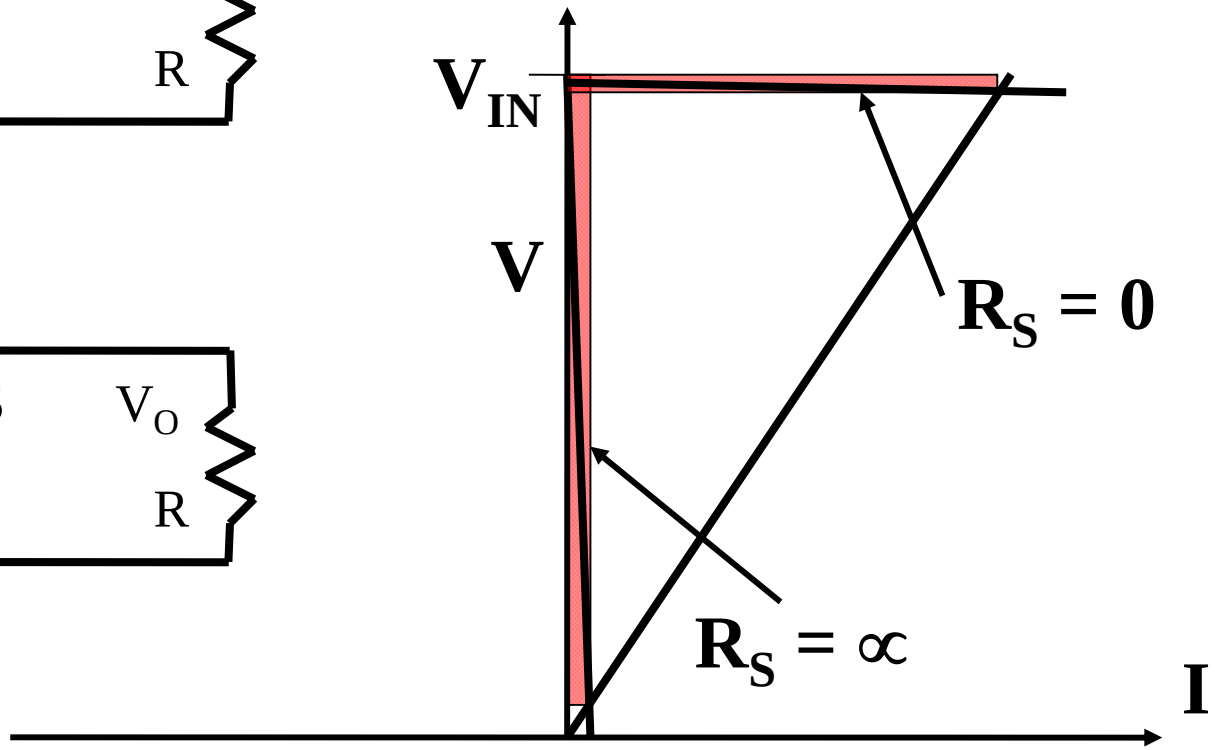
Prior Art

Central Idea of Switch Mode Power Conversion

Series Controlled Converter



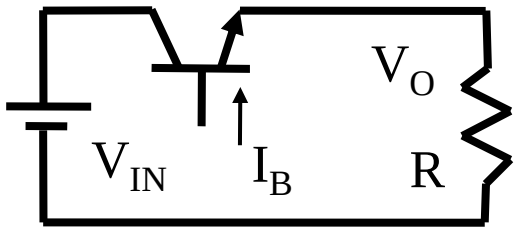


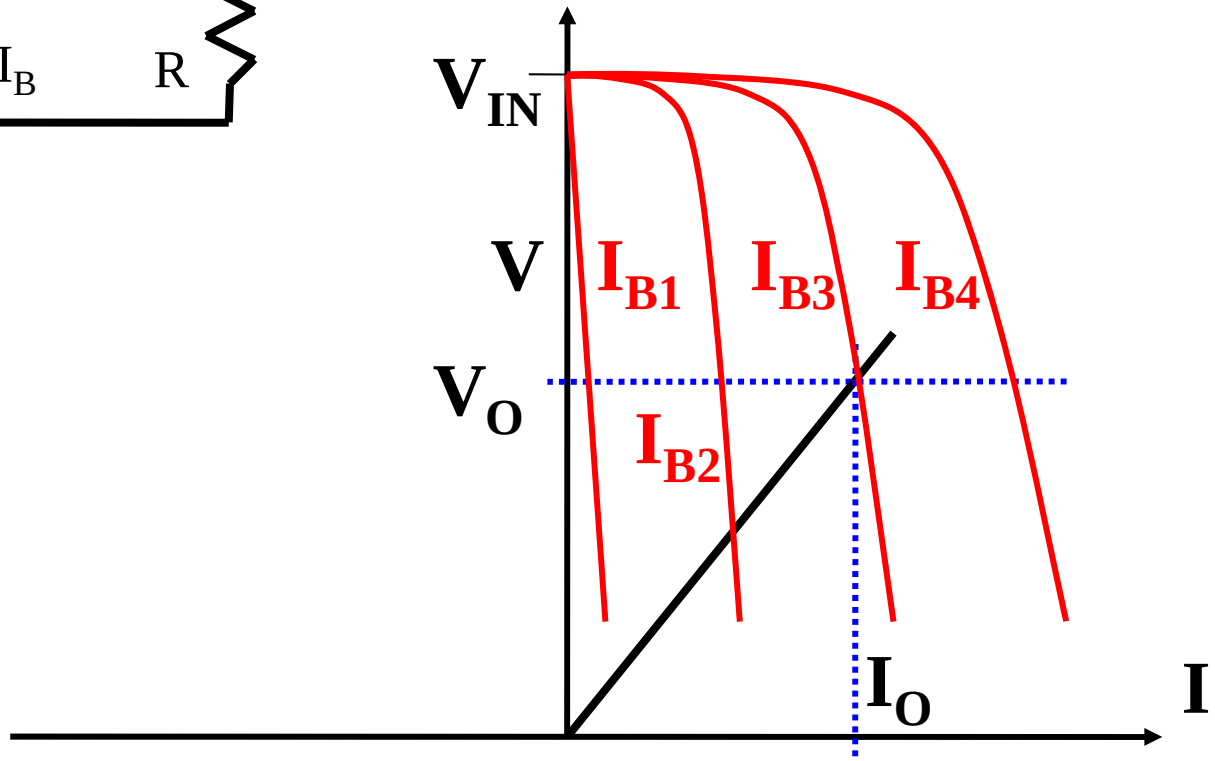


Prior Art

Another Version

Series Controlled Converter

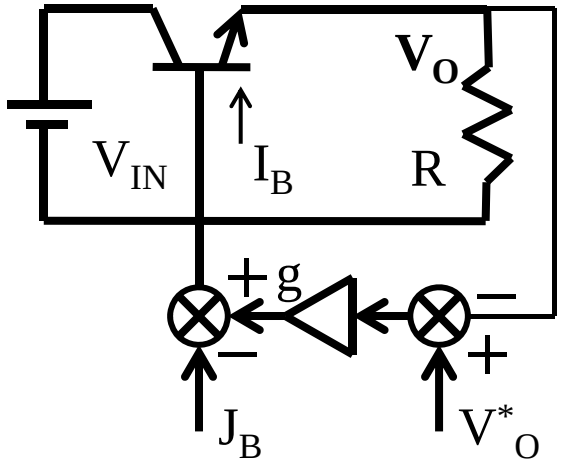


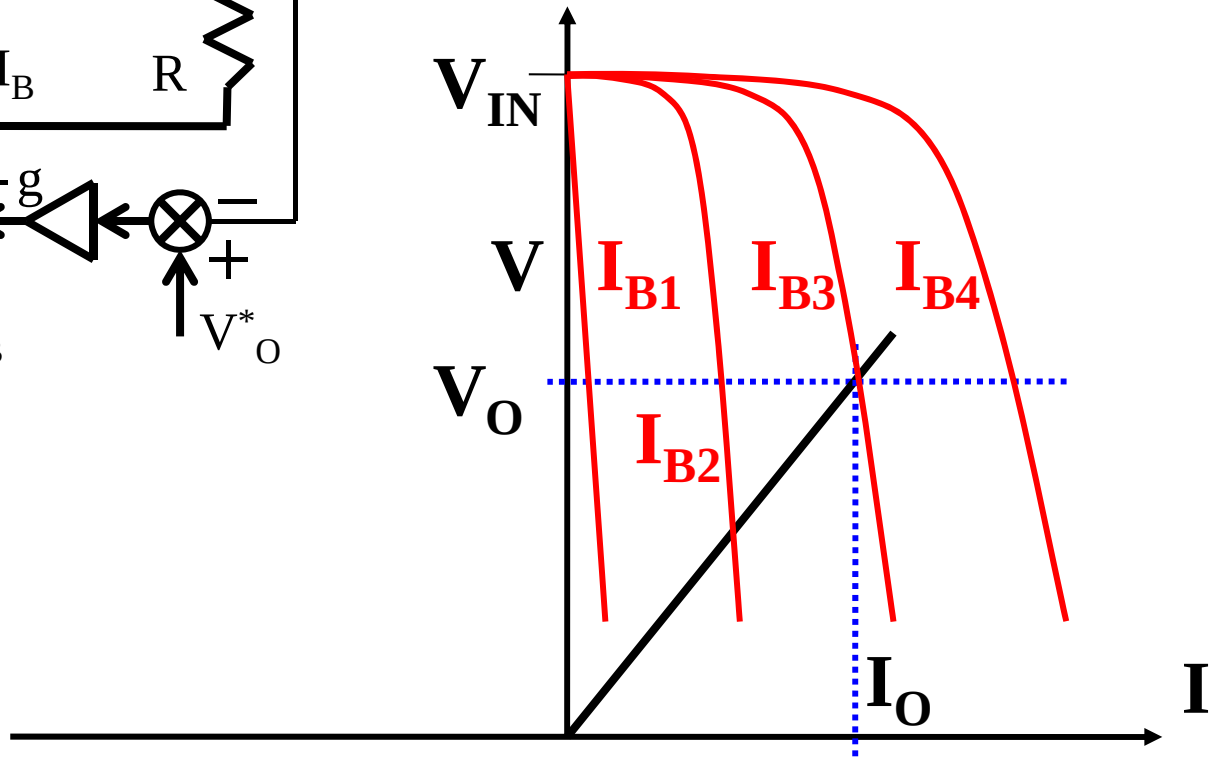


Prior Art

Closed Loop Control

Series Controlled Converter

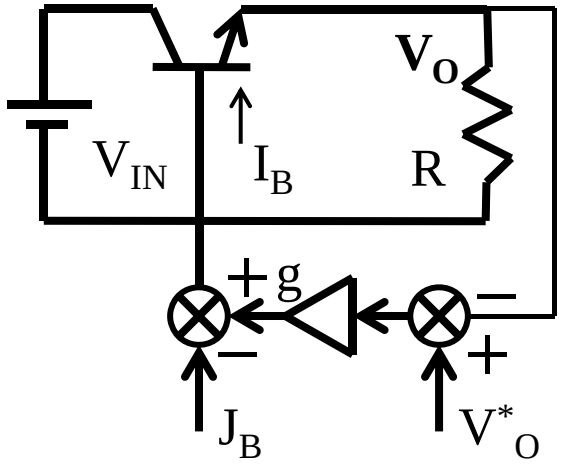




Prior Art

Output Voltage

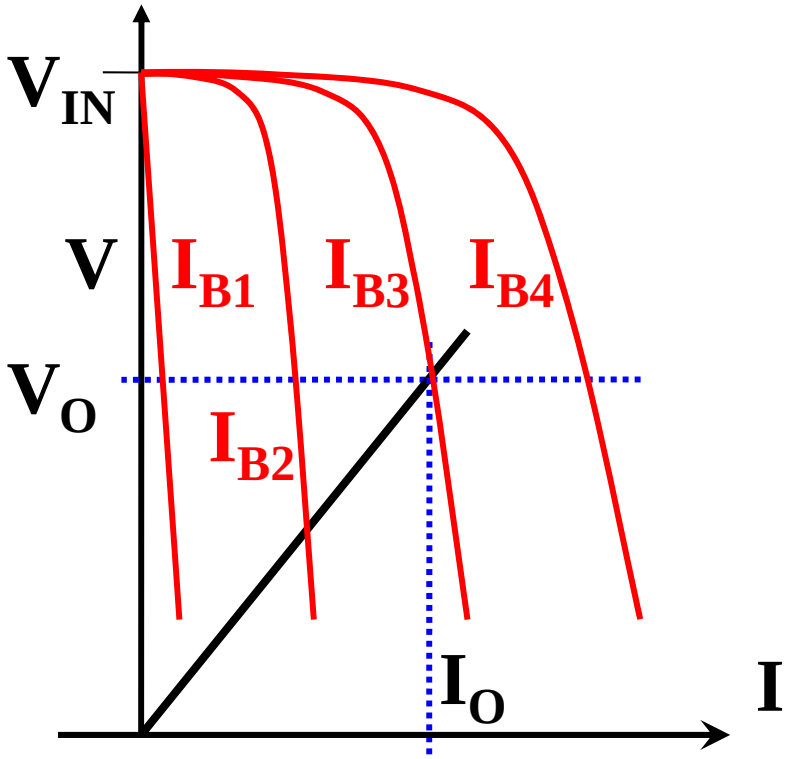
Series Controlled Converter



$$\left(g(V_O^* - V_O) - J_B\right)\beta R = V_O$$

$$V_O = V_O^* \frac{g\beta R}{1+g\beta R} + J_B \frac{\beta R}{1+g\beta R}$$

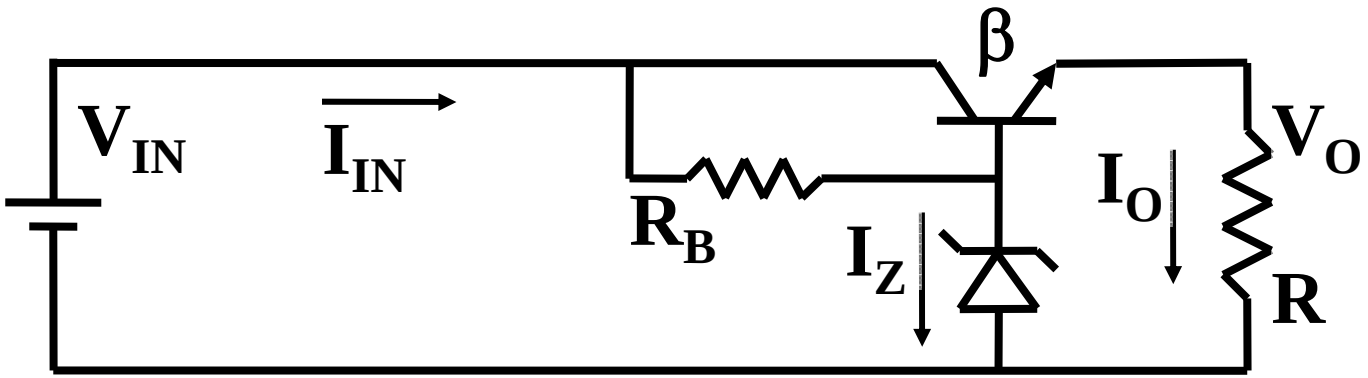
$$V_O \approx V_O^* \quad \text{for } g >>> 1$$



Shunt Controlled Power Converter

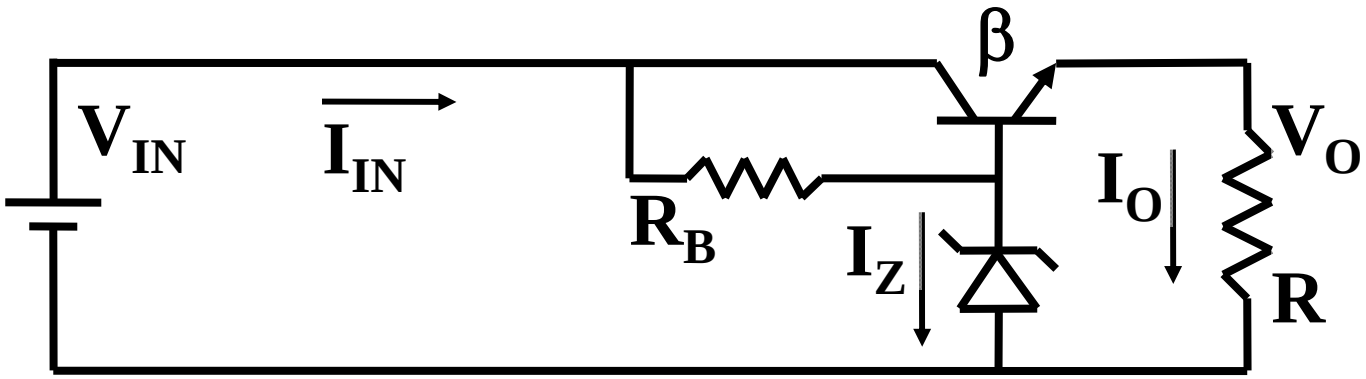
Zener Regulated Power Converter

A Sample Exercise



Shunt Controlled Power Converter

A Sample Exercise



$V_O = 10$ V ; $P_O = 10$ W ;

R = 10 Ω to 100 Ω ;

$V_{IN} = 15$ V to 18 V ;

$V_Z = 10$ V, 7 Ω, 1 W Zener ;

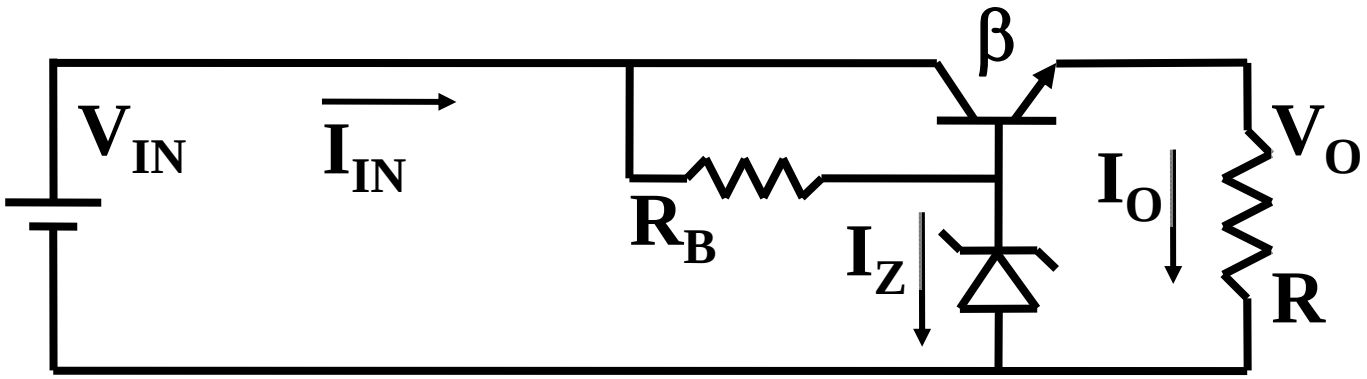
$\beta = 20$;

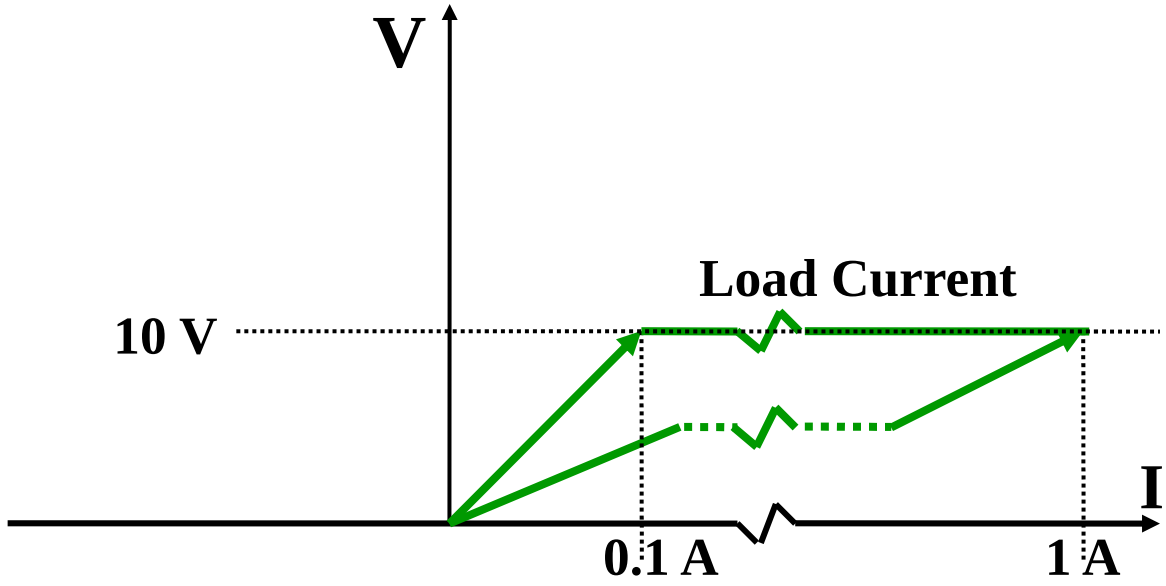
$R_B = ?$; $\eta = ?$;

$\Delta V_O = ?$;

Shunt Controlled Power Converter

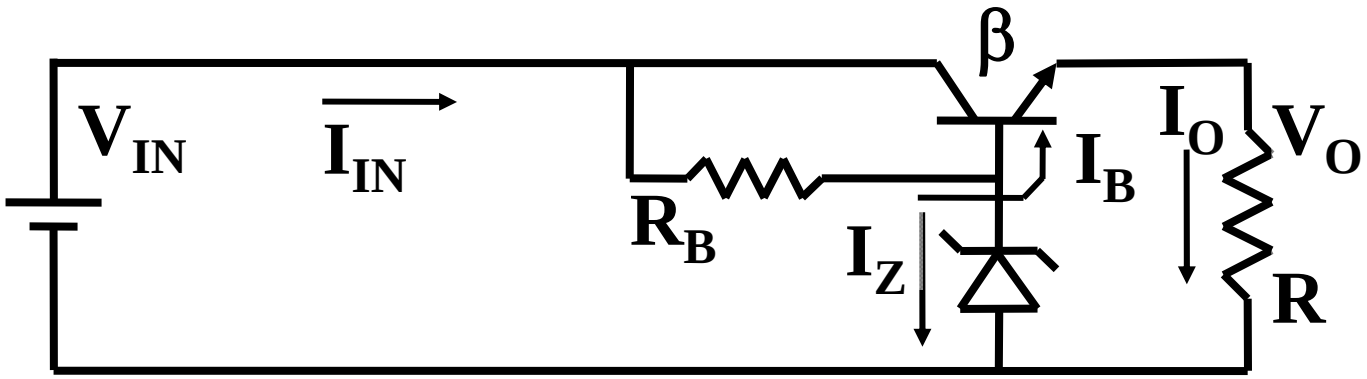
Load Current





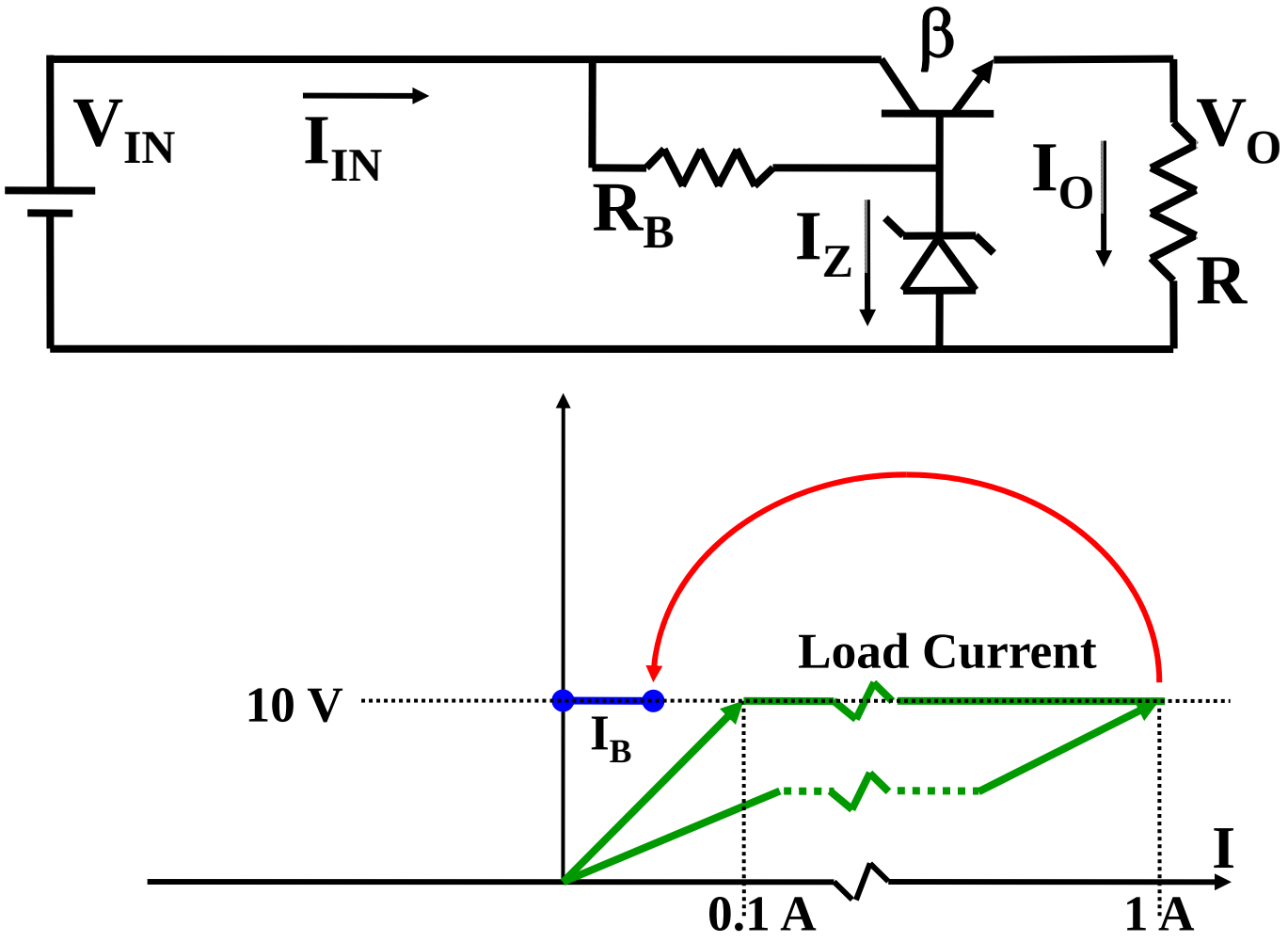
Shunt Controlled Power Converter

Base Current



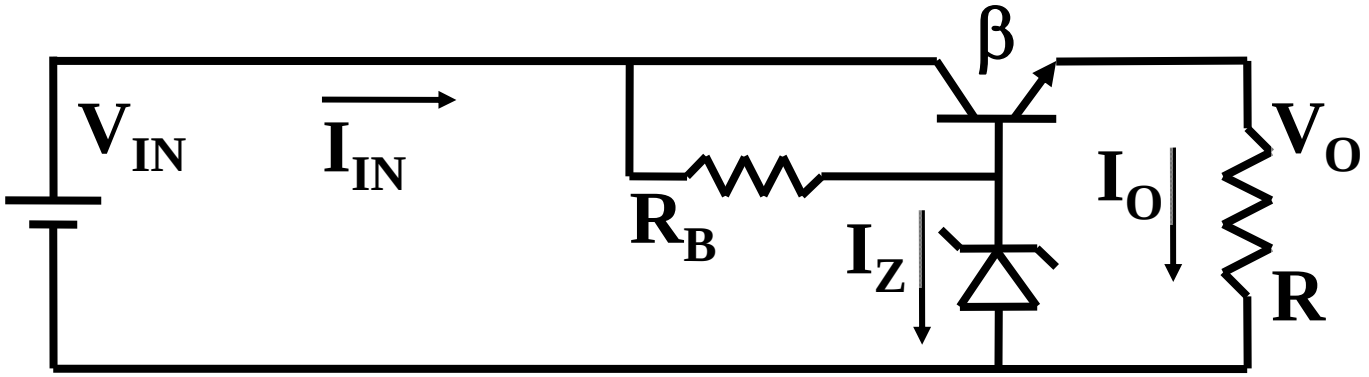
Shunt Controlled Power Converter

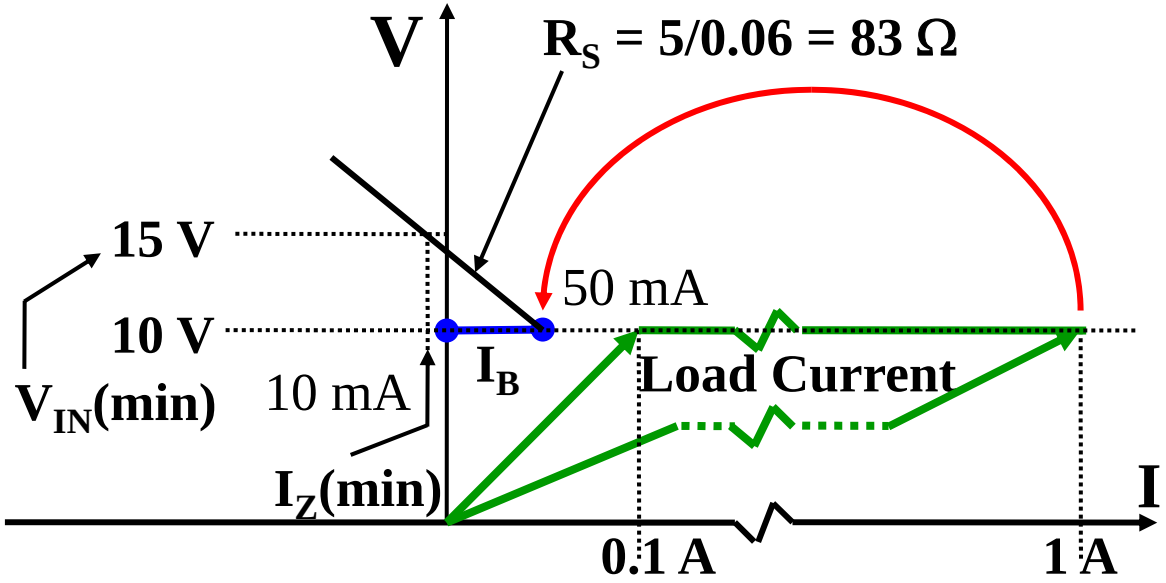
Base Current



Shunt Controlled Power Converter

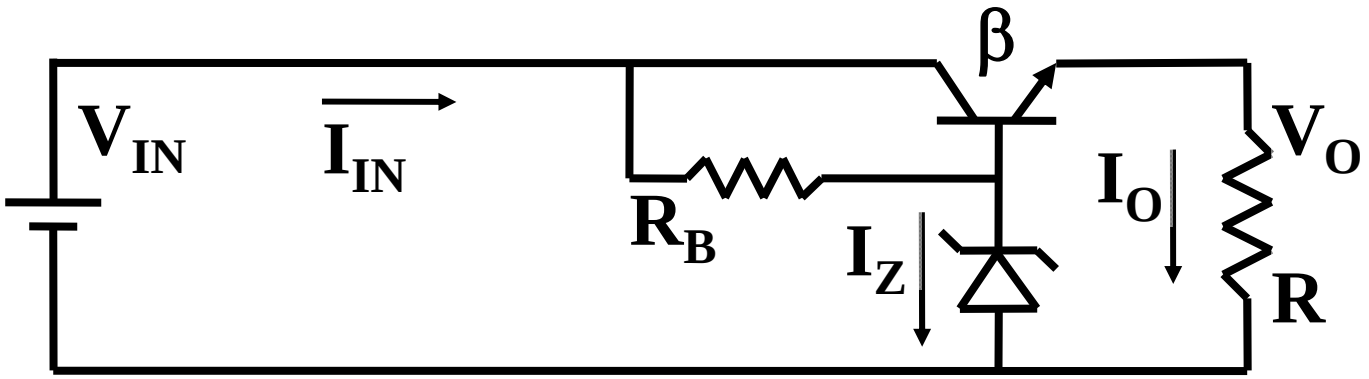
Selection of R_S

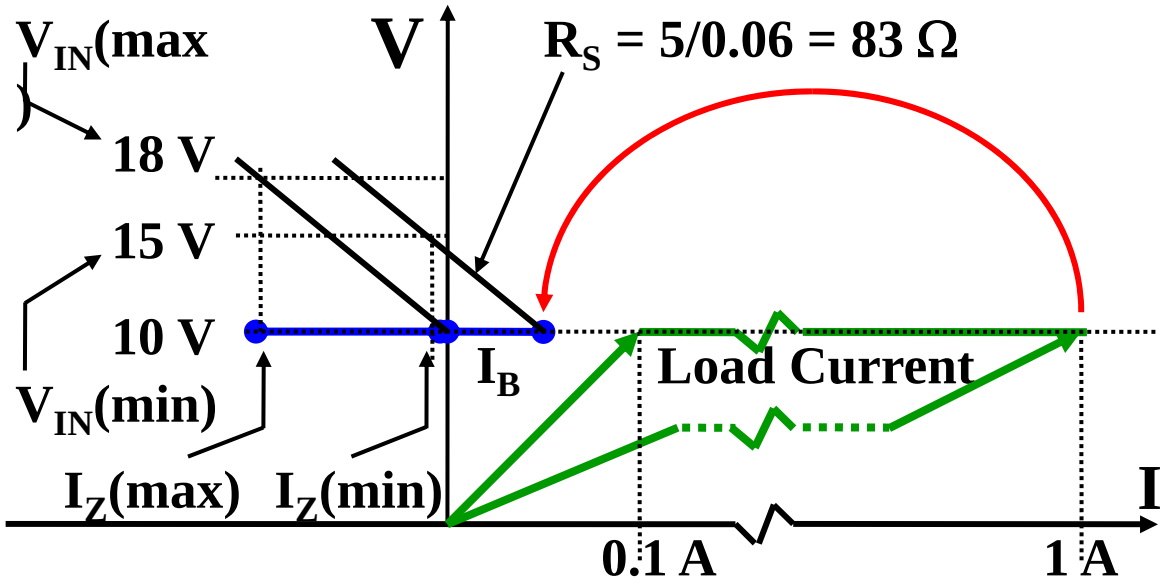




Shunt Controlled Power Converter

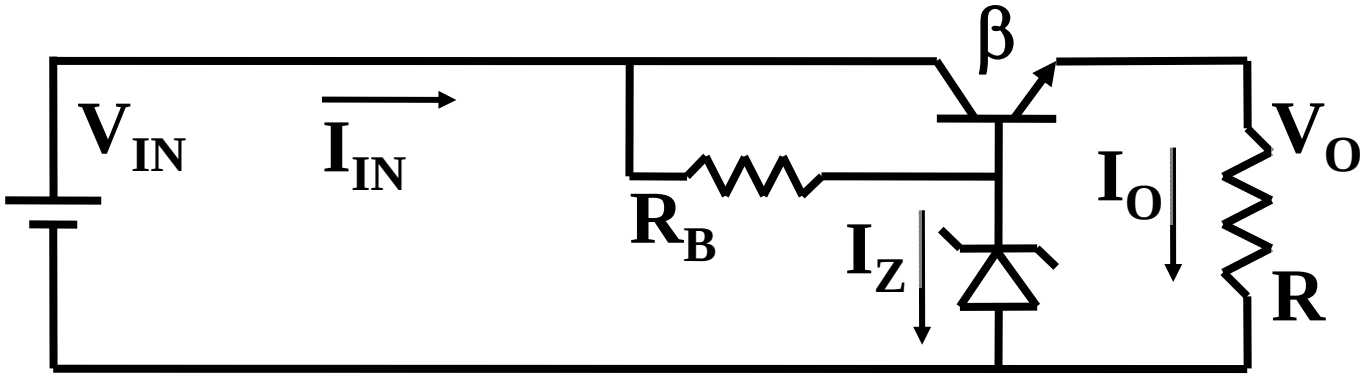
Spread of Zener Current

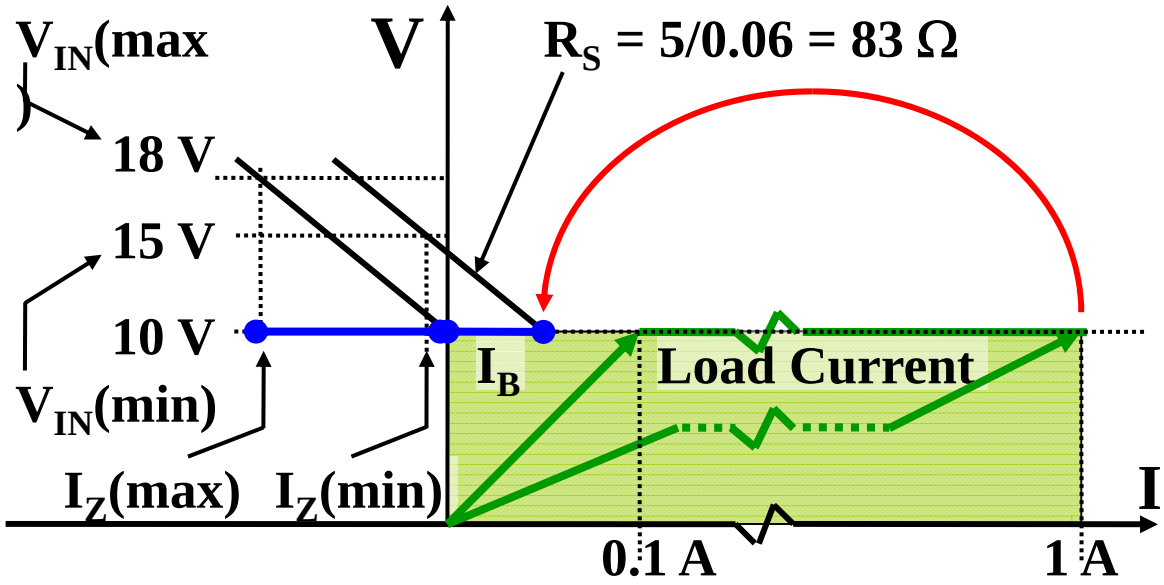




Shunt Controlled Power Converter

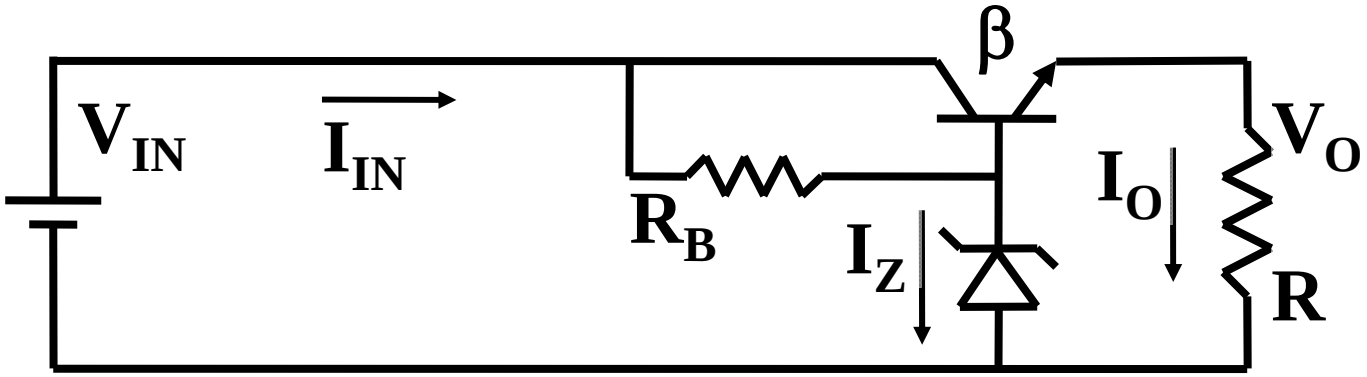
Output Power

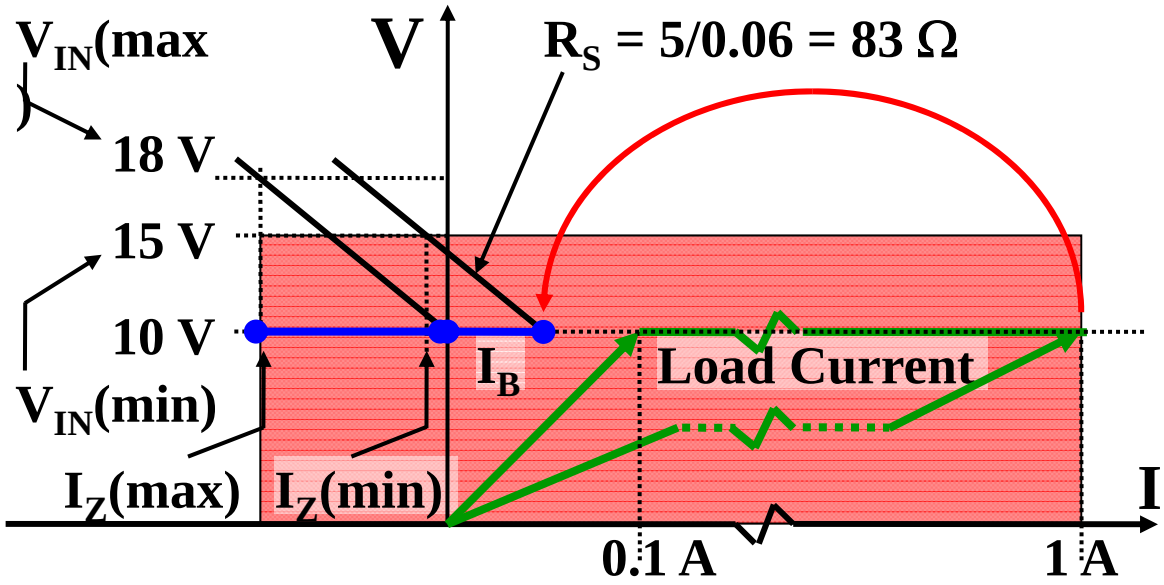




Shunt Controlled Power Converter

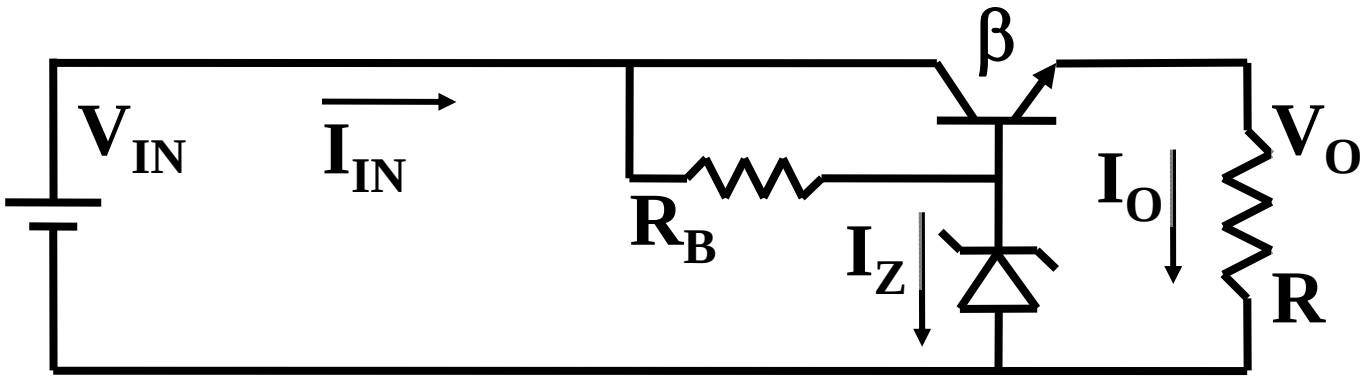
Input Power

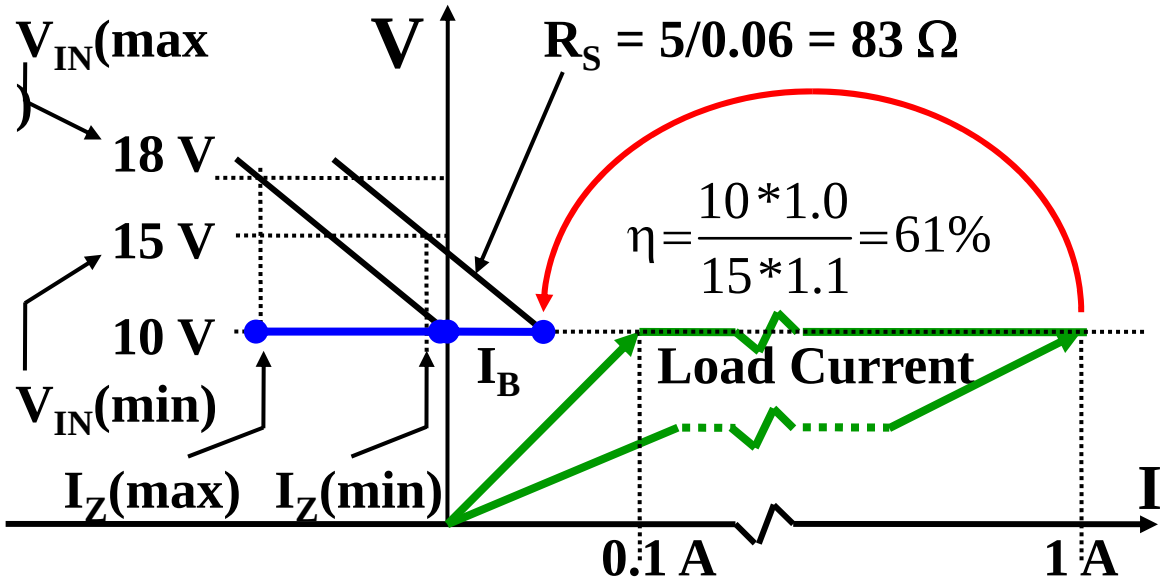




Shunt Controlled Power Converter

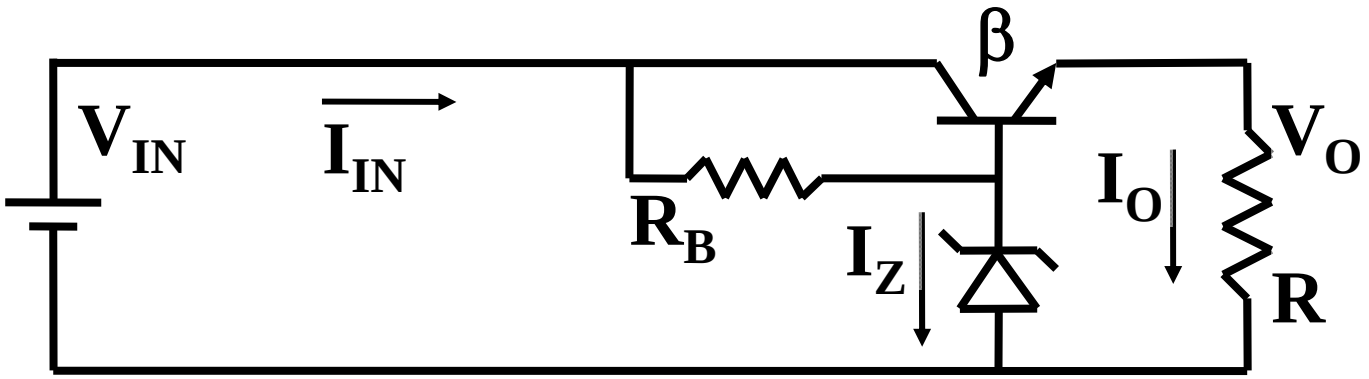
Efficiency

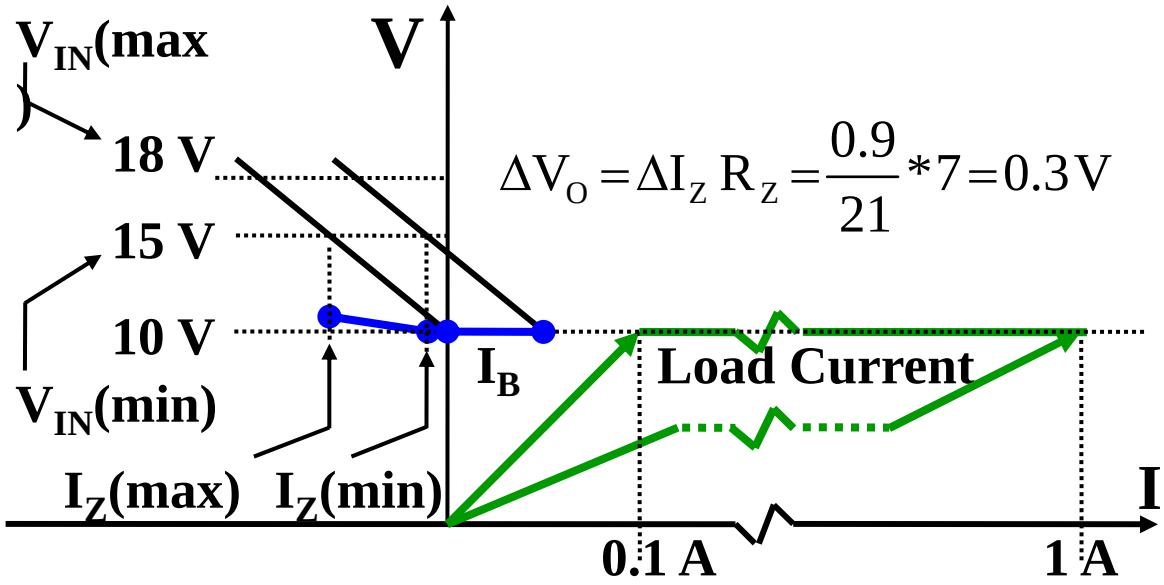




Shunt Controlled Power Converter

Load Regulation

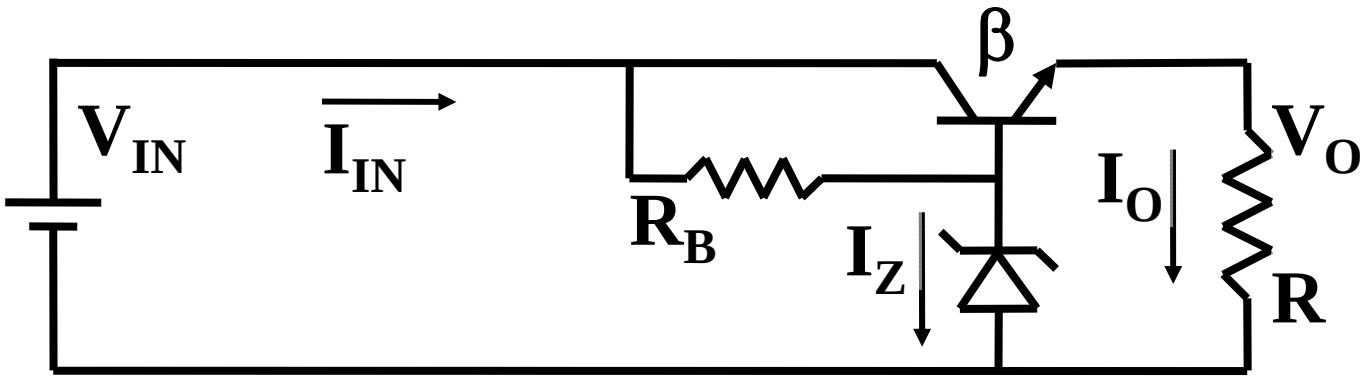


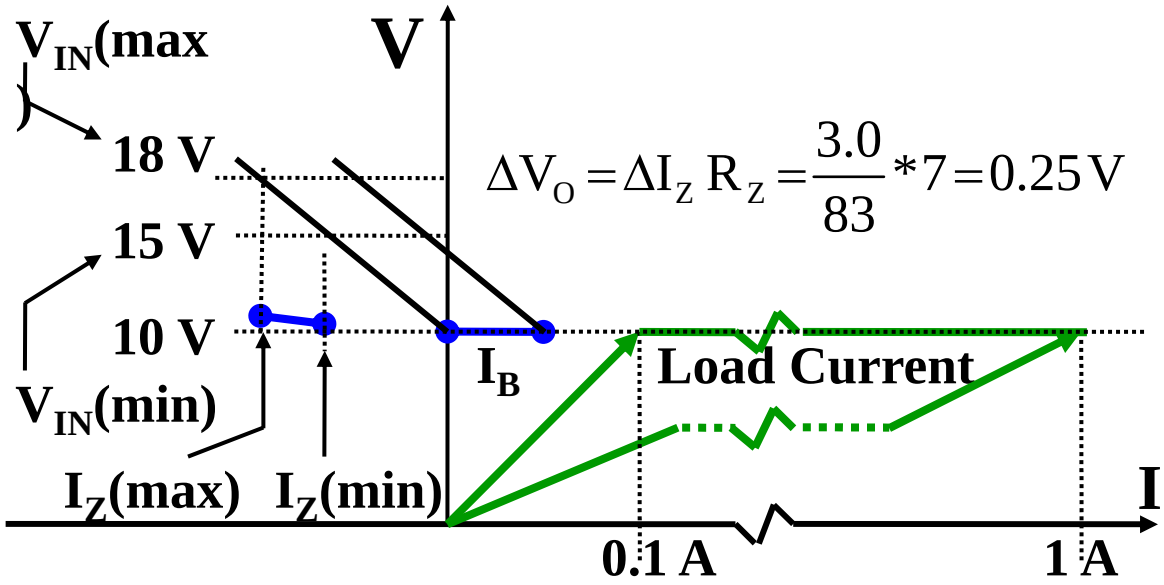


$$\Delta V_O = \Delta I_Z R_Z = \frac{0.9}{21} * 7 = 0.3\,V$$

Shunt Controlled Power Converter

Line Regulation

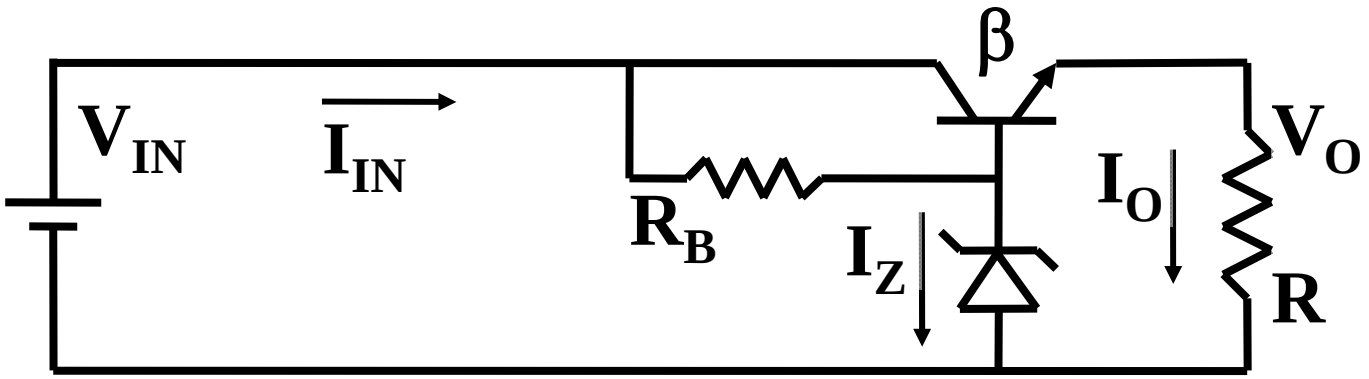


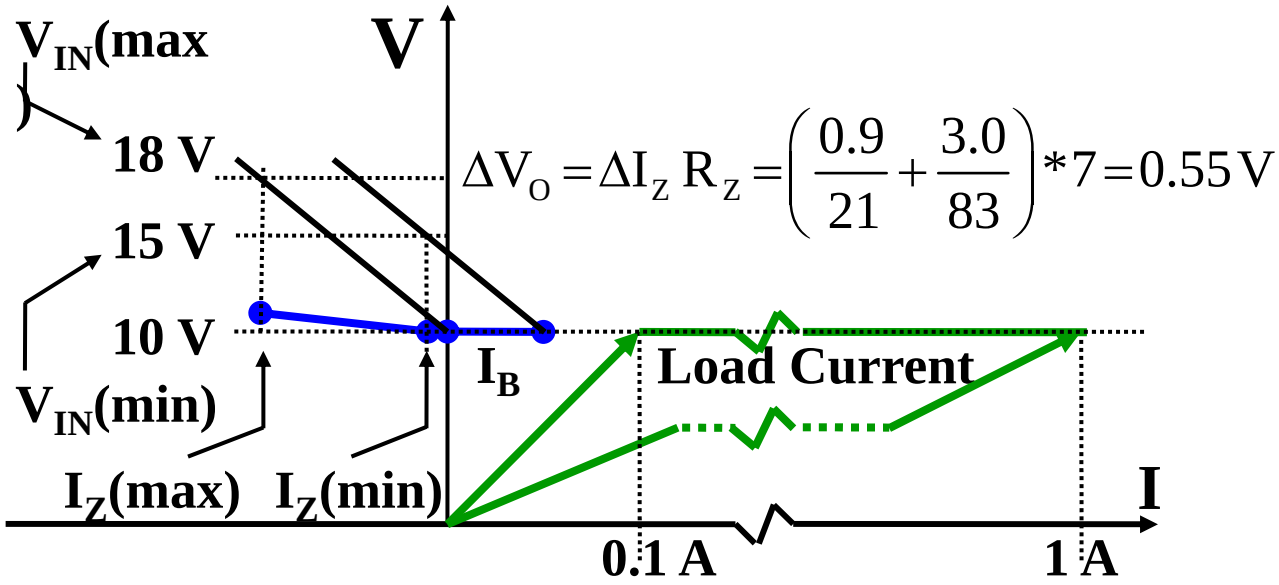


$$\Delta V_O = \Delta I_Z R_Z = \frac{3.0}{83} * 7 = 0.25\,V$$

Shunt Controlled Power Converter

Line & Load Regulation

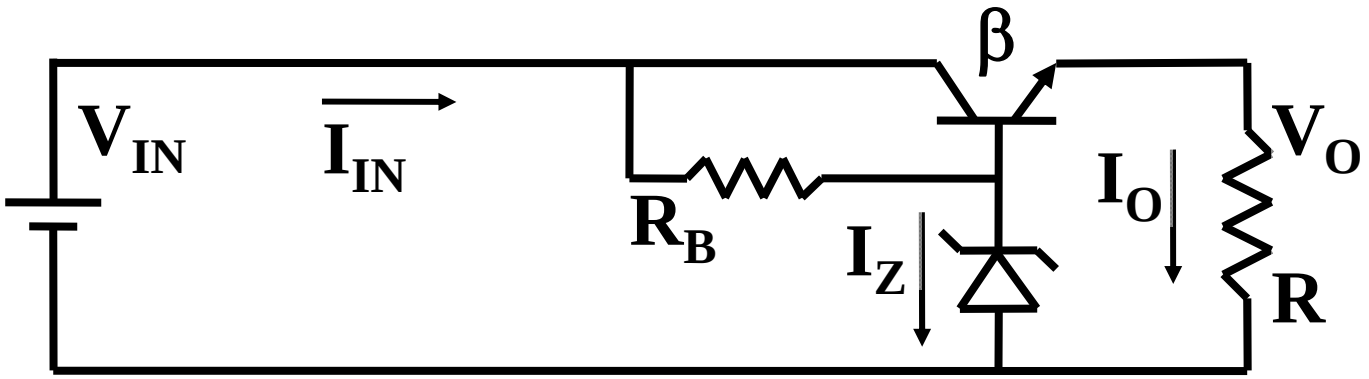


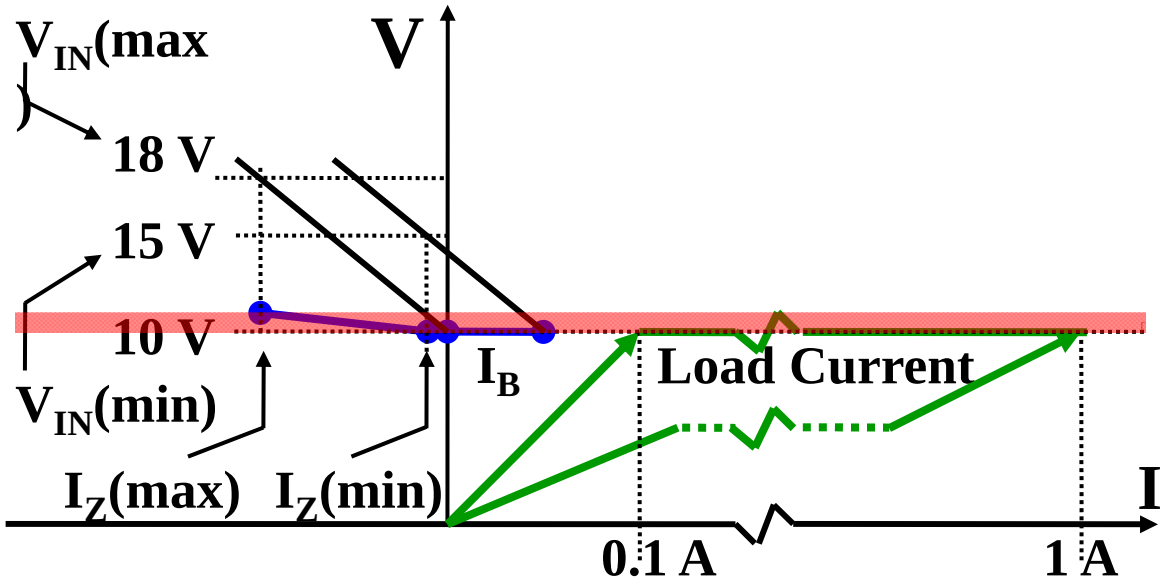


$$\Delta V_O = \Delta I_Z R_Z = \left(\frac{0.9}{21} + \frac{3.0}{83}\right) * 7 = 0.55\,V$$

Shunt Controlled Power Converter

Output Voltage Band



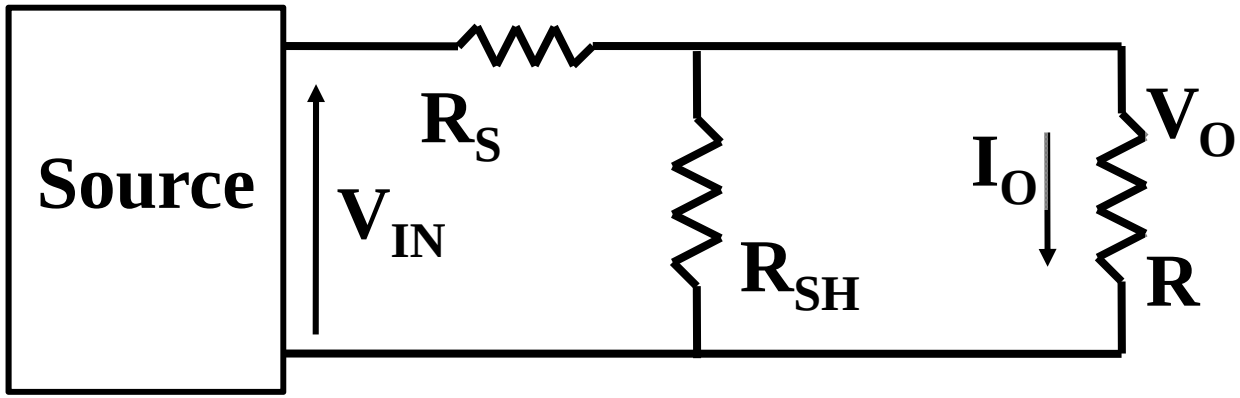


Prior Art

Summary

Series & Shunt Controlled Converters

General Linear Power Converter



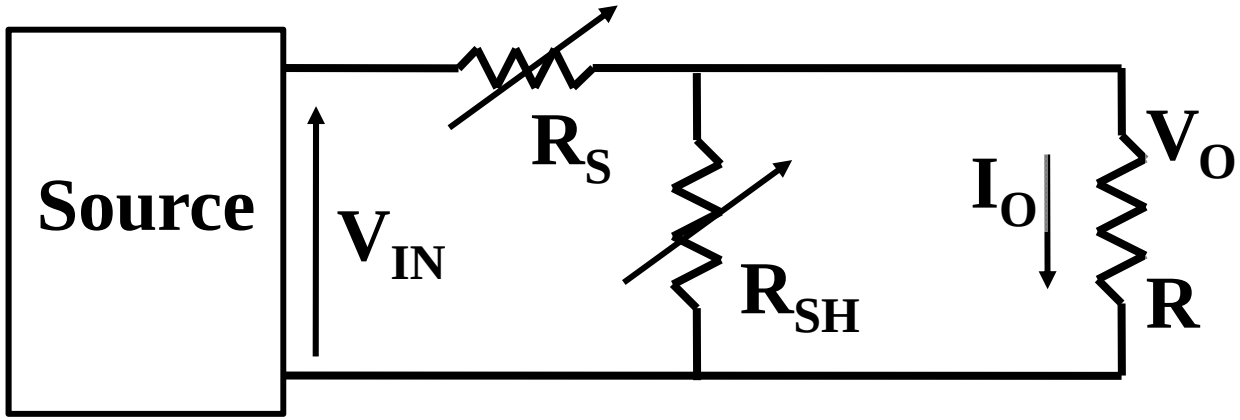
Prior Art

Summary

Series & Shunt Controlled Converters

Simple in Design

Poor Efficiency

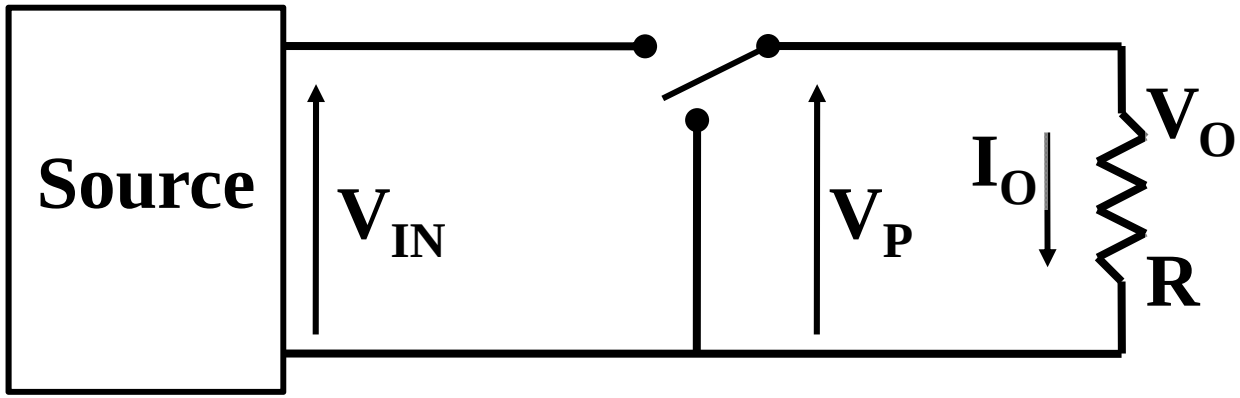


Loss is Low if R_S and R_{SH} are Replaced with Switches

Switched Mode Power Conversion

Central Idea of Loss-less Power Conversion

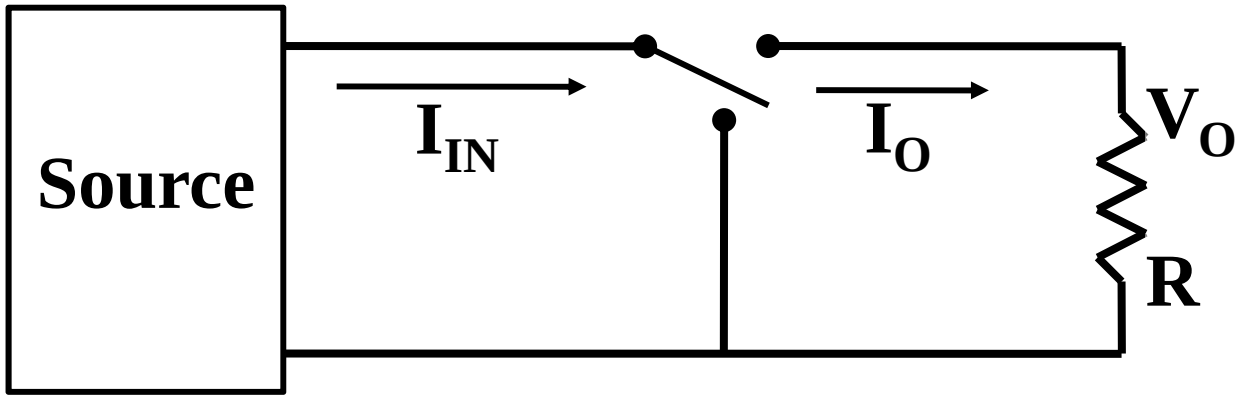
Switching Converter



Switched Mode Power Conversion

Central Idea of Loss-less Power Conversion

Switching Converter



Switched Mode Power Conversion

What Next?

Devices for Efficient Power Conversion

Switches

Inductors

Transformers

Capacitors