Topologies

Voltage Regulation

Ferro-resonant Regulation

Ferro-resonant techniques generate a line regulation by means of a resonant tank circuit and provide inherent isolation between primary and secondary windings.

Ferro-resonant regulation is derived from a specially designed constant-voltage transformer. The semi-square wave output voltage of the transformer is well suited to rectification and filtering.

The inherent current limitation in ferro-resonant regulated power supplies results from the collapse of output voltages as load current becomes excessive.

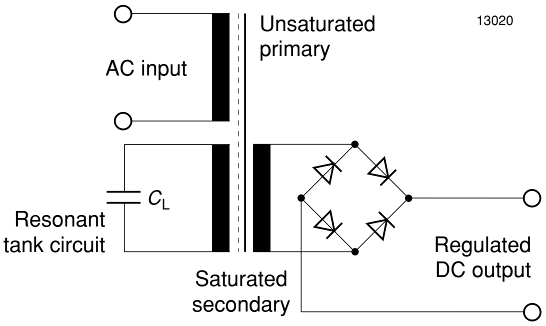


Fig. 1
Ferro-resonant regulator, input to output isolated

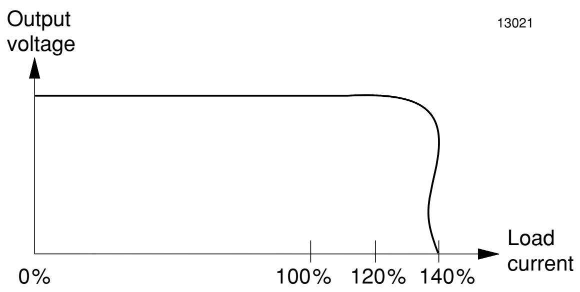


Fig. 2
Inherent current limitation

Linear Regulation

Linear regulation is accomplished by the control of a voltage drop across a variable resistance element, the pass transistor. The difference between the unstable input voltage and the stabilized output voltage is generated across this pass transistor. The power loss is the product of its collector-emitter voltage and the input current. The input current and the output current are approximately equal.

Linear regulators do not provide any isolation between the input and output circuits.

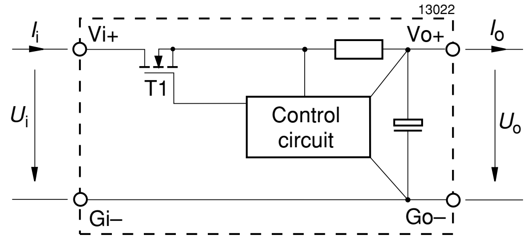


Fig. 3
Linear regulator without input to output isolation

Switching Regulation

Switching regulation is accomplished by the control of the on-time to off-time ratio of the pass transistor but in a fast switching technique. Advantages are a high efficiency and reliability and minimum heat generation.

This control technique is known as Pulse Width Modulation (PWM) and is commonly working at switching frequencies far above 20 kHz.

The active pulse width is narrow at high input voltage and is wide for low input voltage, but always remains within the envelope of the almost constant switching frequency.

Switching regulators do not provide any isolation between the input and output circuits.

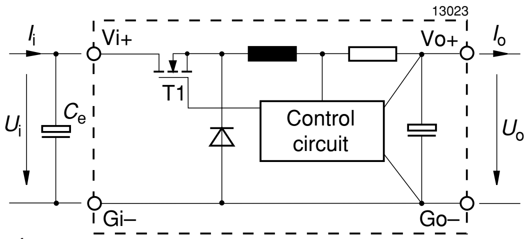


Fig. 4
Switching regulator without input to output isolation

Efficiency

(calculated for regulators without input to output isolation).

a) Linear regulator

$$\eta = \frac{P_o}{P_i} = \frac{U_o \cdot I_o}{U_i \cdot I_i}$$

b) Switching regulator
1 V collector-emitter saturation voltage, switching losses are not considered.

$$P_{loss} \approx I_o \cdot 1\,\text{V}$$

$$\eta = \frac{P_o}{P_i} \approx \frac{U_o}{(U_o + 1)}$$

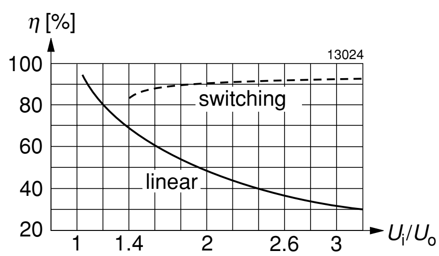


Fig. 5
Efficiency versus input voltage

Basic Switching Configurations

Buck Converter

Advantages:
FET drain-source $U_{DS} \approx U_i$, simple choke. No problems with magnetic coupling. Low loading of output capacitor. Duty cycle of T_{ON} / T = 1 is possible.

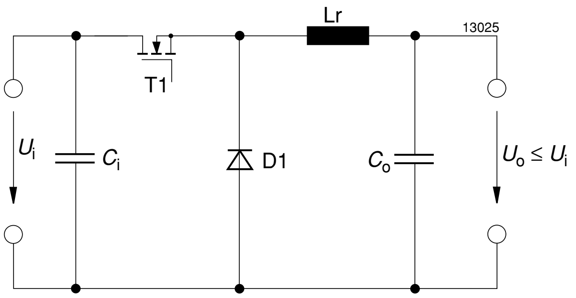
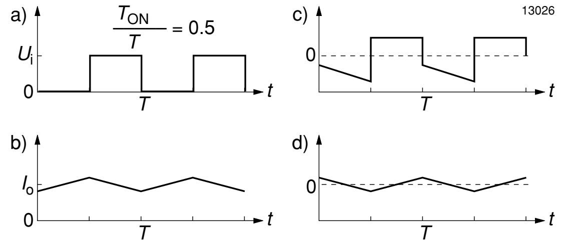


Fig. 6
Buck converter

Disadvantages:
No isolation between input and output. The gate drive circuit must be in a floating configuration.



a) Voltage across the transistor T1
b) Choke current
c) Current across the input capacitor C_i
d) Current across the output capacitor C_o

Boost Converter

Advantages:
Simple choke. No problems with magnetic coupling. Duty cycle T_{ON} / T = 0 is possible ($U_0 \approx U_i$).

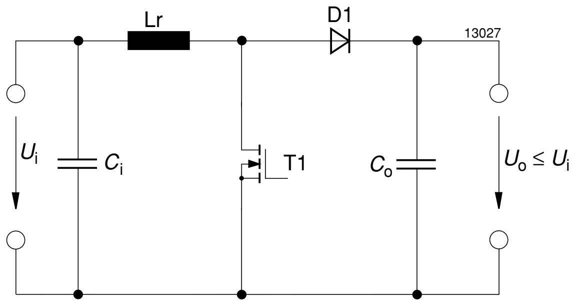
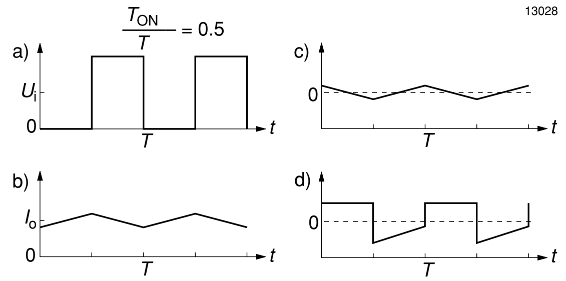


Fig. 7
Boost converter

Disadvantages:
No isolation between input and output is provided. Medium loading of the output capacitor. High input start-up current.



a) Voltage across the transistor T1
b) Choke current
c) Current across the input capacitor C_i
d) Current across the output capacitor C_o

Buck-Boost Converter

Advantages:
Simple choke. No problems with magnetic coupling.

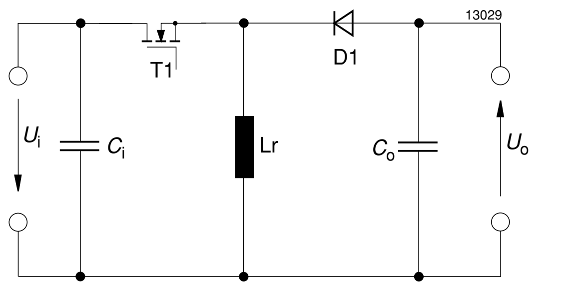
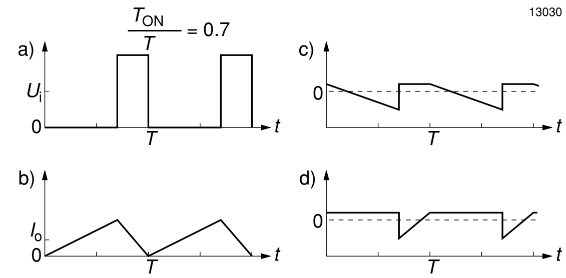


Fig. 8
Buck-Boost converter

Disadvantages:
Power transistor drain-source voltage achieves approximately $U_{DS} \approx U_i + U_o$. No input to output isolation. Heavy loading of output capacitor. The gate drive circuit must be in a floating configuration. The polarity of the output voltage is negative in relation to the input voltage.



a) Voltage across the transistor T1
b) Choke current
c) Current across the input capacitor C_i
d) Current across the output capacitor C_o

Continuous Flyback Converter

Advantages:
Input to output isolation. Several output voltages can be regulated simultaneously. Wide control range for operation voltage changes (continuous transformer ratio).

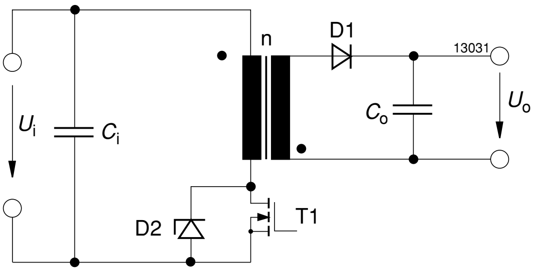
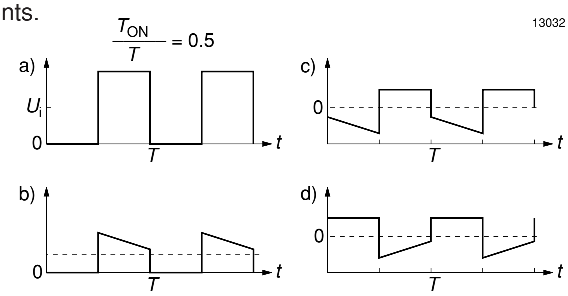


Fig. 9
Continuous flyback converter

Disadvantages:
Power transistor drain-source voltage $U_{DS} > U_i + n \cdot U_o$. Heavy loading to output capacitor and diode. Very good magnetic coupling necessary. Large core cross section with air gap required. Problems with stability and eddy currents.



(Trapezoidial current flow in transistor or primary winding)

a) Voltage across the transistor T1
b) Current across D1
c) Current across the input capacitor C_i
d) Current across the output capacitor C_o

Discontinuous Flyback Converter

Advantages:
Galvanic isolation between input and output. Good stability and response times. Several output voltages can be regulated simultaneously.

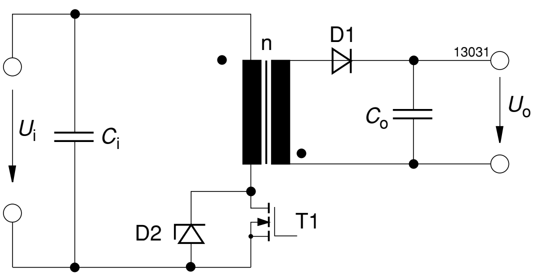
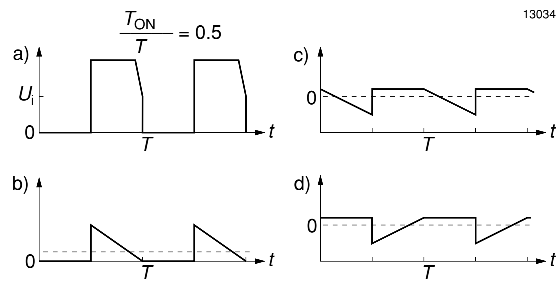


Fig. 10
Discontinuous flyback converter

Disadvantages:
Power transistor drain-source voltage $U_{DS} > U_i + n \cdot U_o$. Heavy loading to output capacitor and diode. Very good magnetic coupling necessary. Large core cross section with air gap required. Problems with eddy currents.



(Sawtooth current flow in transistor or primary winding)

a) Voltage across the transistor T1
b) Current across D1
c) Current across the input capacitor C_i
d) Current across the output capacitor C_o

Single-Transistor Forward Converter

Advantages:
Core demagnetization is no problem. Simple design. Low output ripple current.

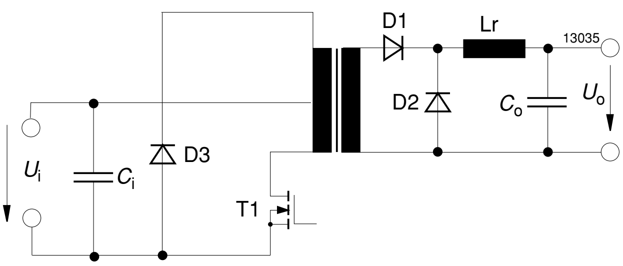
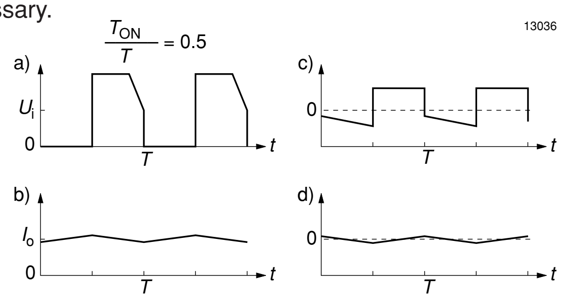


Fig. 11
Single transistor forward converter

Disadvantages:
Power transistor drain-source voltage $U_{DS} > 2 \cdot U_i$. A demagnetization winding is necessary. Good magnetic coupling between primary and demagnetization winding is necessary.



a) Voltage across the transistor T1
b) Current across the choke Lr
c) Current across the input capacitor C_i
d) Current across the output capacitor C_o

Push-Pull Converter

Advantages:
Small transformer. Low output ripple current.

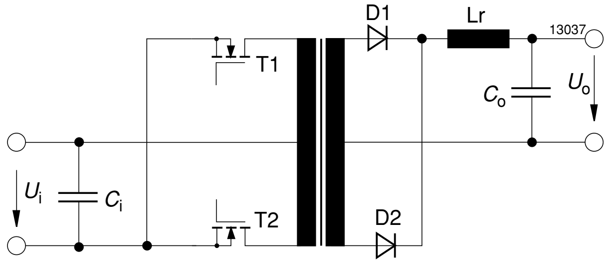
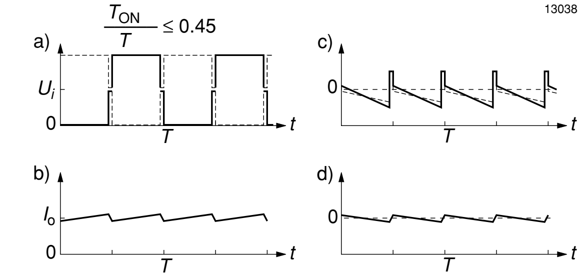


Fig. 12
Push-pull converter

Disadvantages:
Power transistor drain-source voltage $U_{DS} > 2 \cdot U_i$. Correction of the symmetry may cause problems. Good magnetic coupling between the two primary windings is necessary. Danger that both transistors may conduct simultaneously.



a) Voltage across the transistor T1
b) Current across the choke Lr
c) Current across the input capacitor C_i
d) Current across the output capacitor C_o

Half Bridge Push-Pull Converter

Advantages:
FET drain-source voltage $U_{DS} \approx U_i$. The transformer is very small and may have a high level of stray inductance. Low output ripple current.

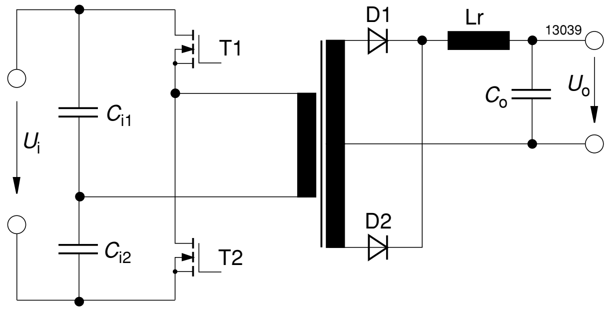
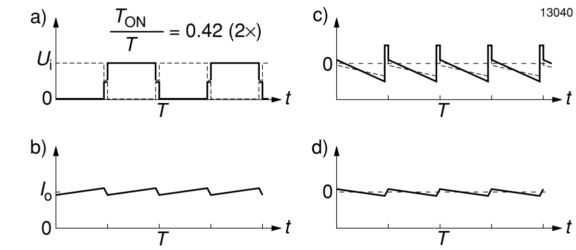


Fig. 13
Single-ended push-pull converter

Disadvantages:
Danger that both transistors may conduct simultaneously. One galvanically isolated drive circuit is required.



a) Voltage across the transistor T1
b) Current across the choke Lr
c) Current across the input capacitor C_{i1}
d) Current across the output capacitor C_o

Two-Transistor Forward Converter

Advantages:
FET drain-source voltage $U_{DS} \approx U_i$. Core demagnetization is not a problem. The transformer may have a high level of stray inductance. High efficiency. For higher input voltages. Low output ripple current.

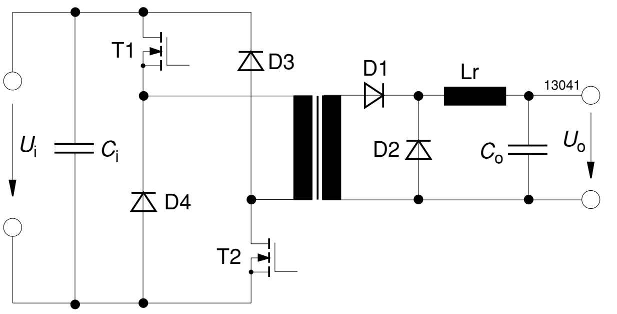
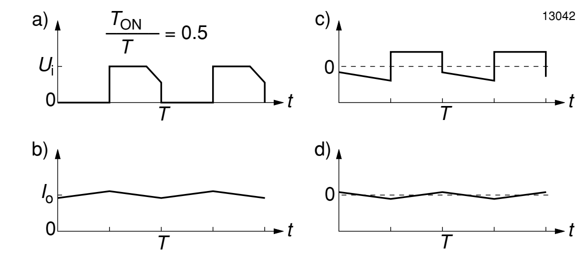


Fig. 14
Two-transistor forward converter

Disadvantages:
One galvanically isolated drive circuit is required. Large transformer size.



a) Voltage across the transistor T1
b) Current across the output choke Lr
c) Current across the input capacitor C_i
d) Current across the output capacitor C_o

Full-Bridge Push-Pull Converter

Advantages:
FET drain-source voltage $U_{DS} \approx U_i$. The transformer may have a high level of stray inductance. For high power. Low output ripple current.

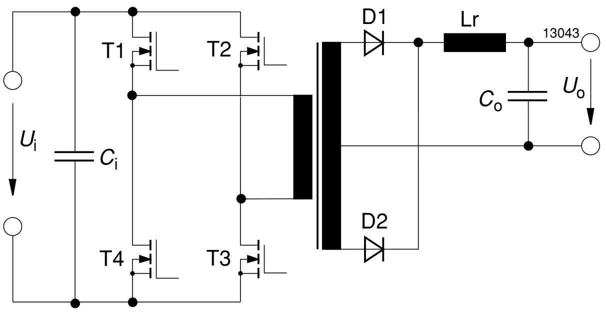
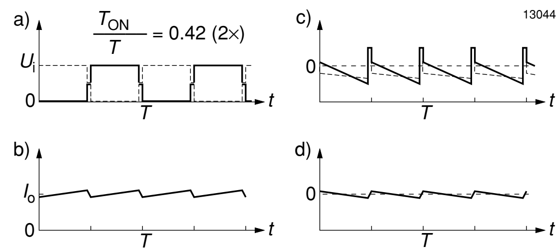


Fig. 15
Full bridge push-pull converter

Disadvantages:
Correction of symmetry may cause problems. Danger that two series transistors may conduct simultaneously. Two galvanically isolated drive circuitries are required. High component count.



a) Voltage across the transistor T1
b) Current across the choke Lr
c) Current across the input capacitor C_i
d) Current across the output capacitor C_o

Some Advanced Topologies

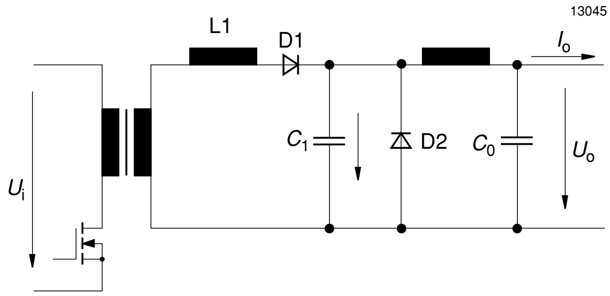


Fig. 16
Pseudo-resonant forward converter. High frequency variations.

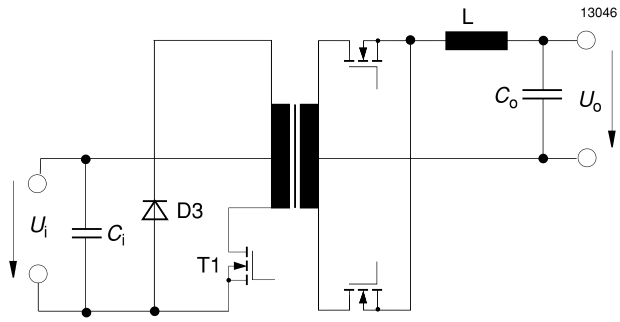


Fig. 17
Synchronous rectifier (for low input voltages and high efficiency)

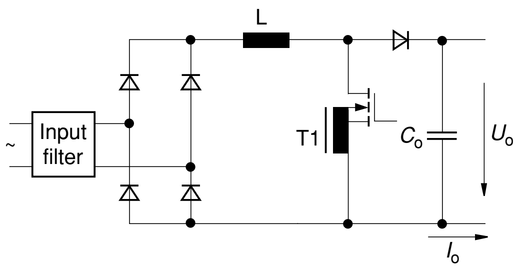


Fig. 18
Boost converter (acting as power factor corrector)