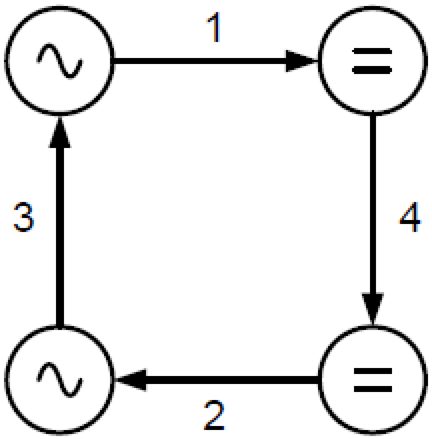
KOM3560
INDUSTRIAL ELECTRONICS

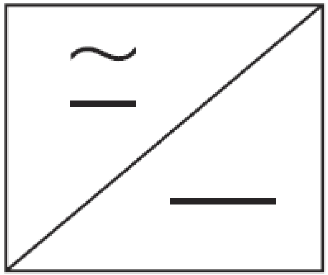
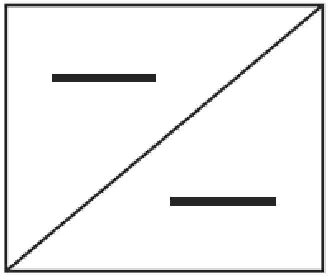
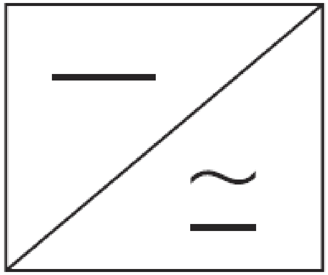
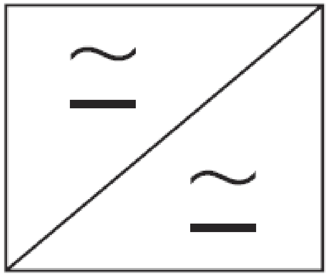
Spring : 2023

Lecture 3

Classification of Conversion Types

According to the power conversion type



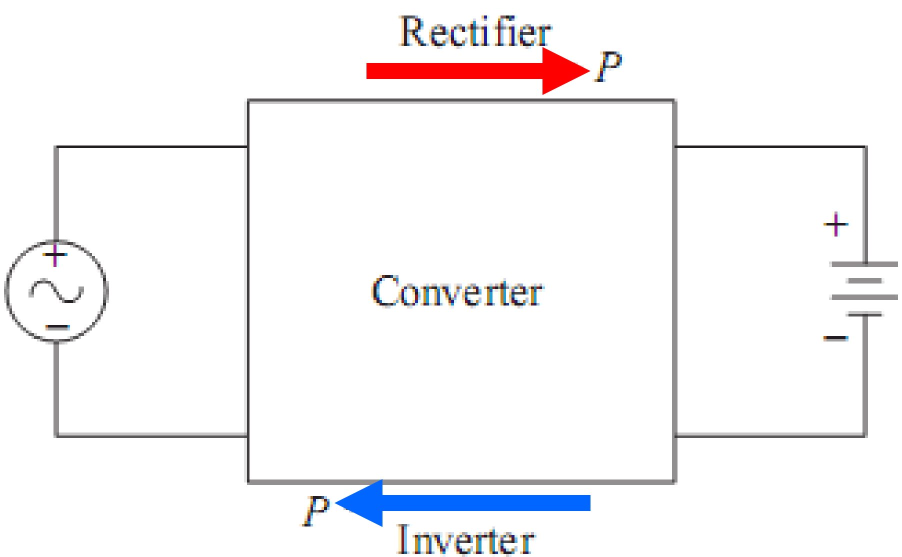
Conversion From/To	Converter Name	Converter Function	Converter Symbol
Ac to dc	Rectifier	Ac to unipolar (dc) current	
Dc to dc	Chopper	Constant dc to a variable dc or variable dc to a constant dc	
Dc to ac	Inverter	Dc to ac of desired output voltage and frequency	
Ac to ac	Ac voltage controller, Cycloconverter, Matrix converter	Ac of desired frequency and/or magnitude from generally line supply ac	

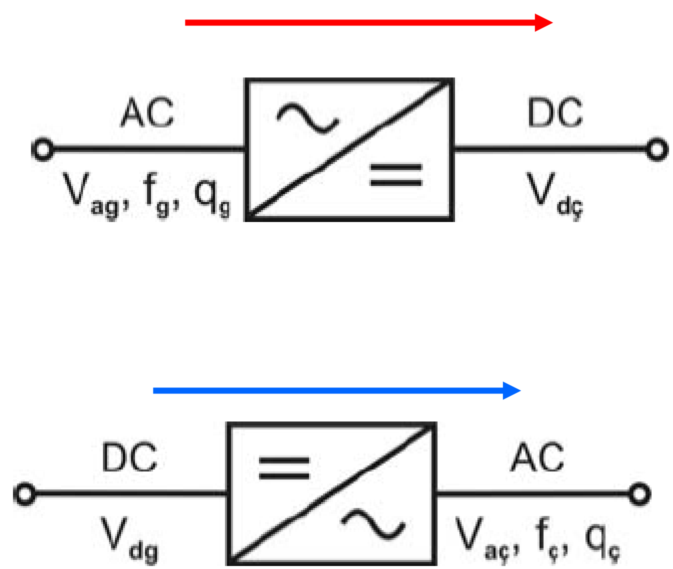
Classification of Conversion Types

According to the power flow direction

–Unidirectional
–Bidirectional

- The instantaneous power flow through the converter can be forward or backward direction at any instant of time.
- Rectifier operation: The power flows from AC source to the DC source in forward direction.
- Inverter operation: The power flows from DC source to the AC source in backward direction.

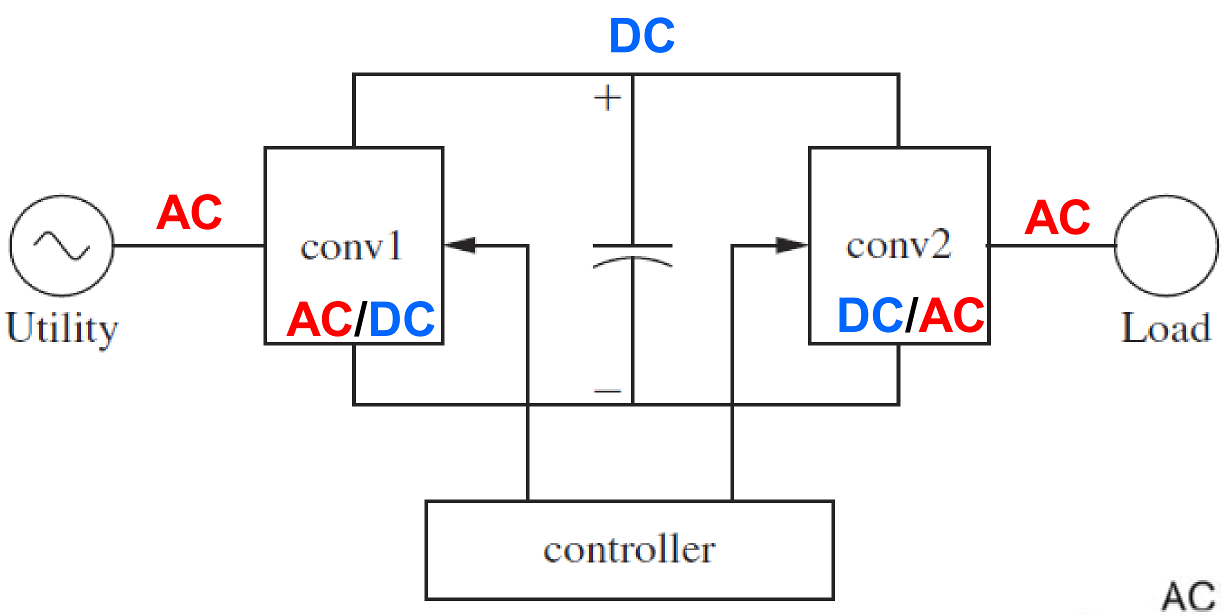




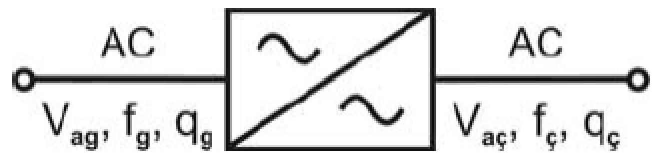
Multi-step Conversion

- Power conversion can be a multistep process involving more than one type of converter.
- For example, an **ac-dc-ac conversion** can be used to modify an ac source by first converting it to direct current and then converting the dc signal to an ac signal that has an amplitude and frequency different from those of the original ac source

Multi-step

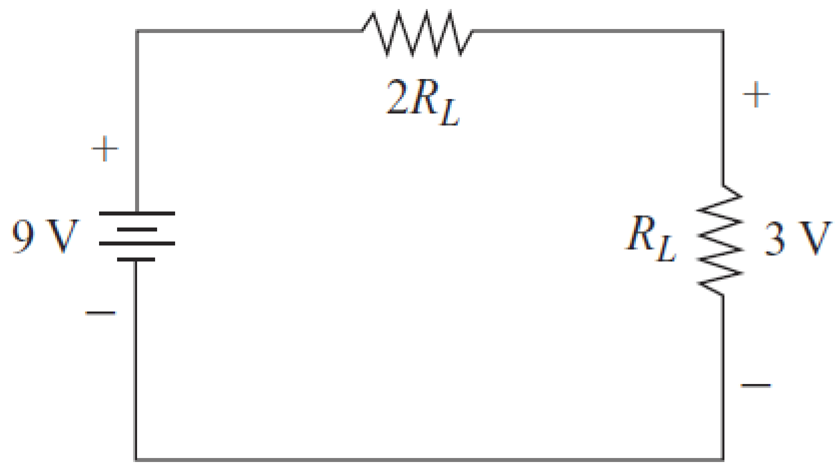


Single-step



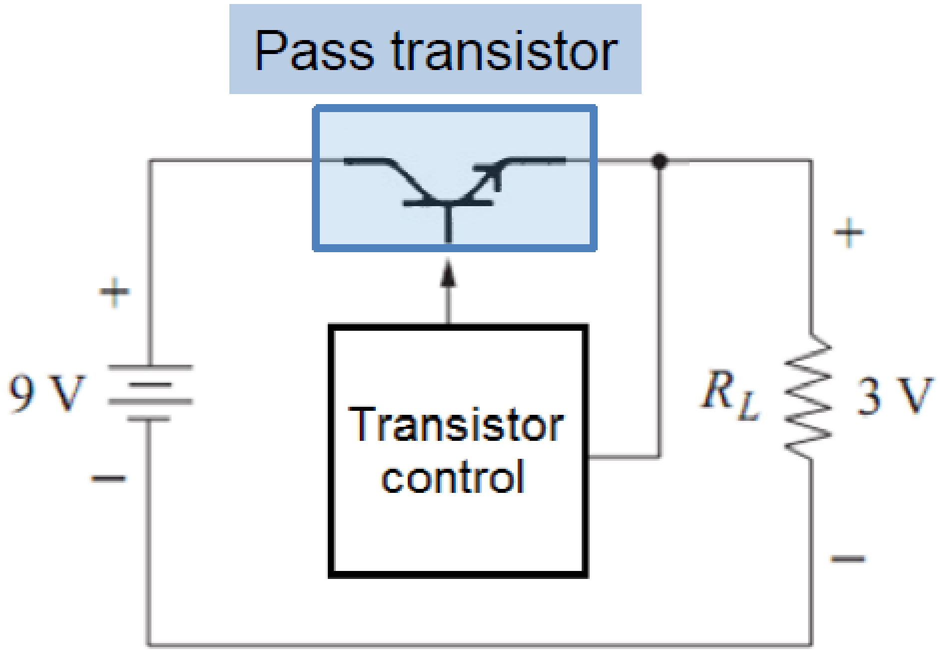
Power Conversion Concept

- The purpose is to supply 3 V to a load resistance.
- One simple solution is to use a voltage divider.
- **Problem 1** (regulation): if the value of the load resistance changes, the output voltage will change unless the $2R_L$ resistance changes proportionally.
- **Problem 2** (efficiency): the power absorbed by the $2R_L$ resistor is twice as much as delivered to the load and is lost as heat, making the circuit only 33.3% efficient.



Power Conversion Concept

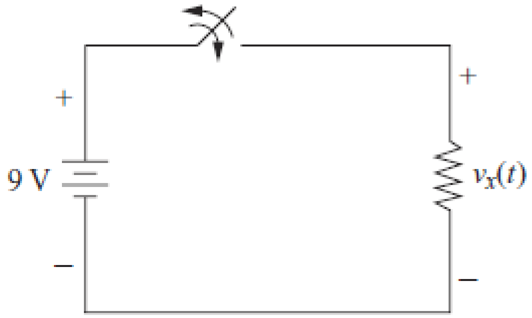
- **<u>One another solution is using pass transistor.</u>**
- The pass transistor behaves as a variable resistor.
- Problem 1 (regulation) can be solved by using a control system.
- The control system acts on the transistor to obtain fixed output voltage by varying the effective resistance of the pass transistor.
- This type of regulator is known as Linear Regulators.

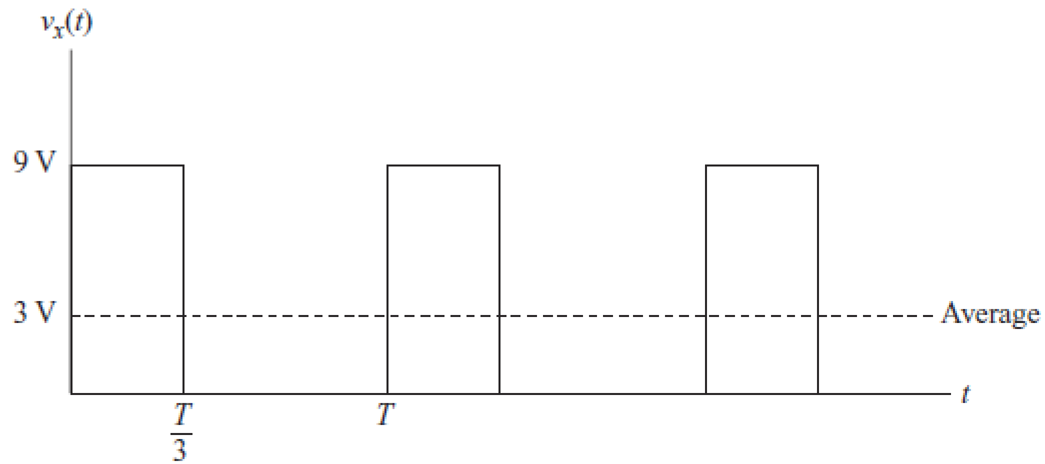


But problem 2 (low efficiency) still remains!!!!

Power Conversion Concept

- More desirable design solution is using an electronic switch instead of pass transistor
- The switch is opened and closed perodically.
- This type of regulator is known as Switching Regulator.
- If the switch is closed for one-third of the period, the average value of $v_x(t)$ (denoted as V_x) is one-third of the source voltage.





$$\text{avg}(v_x) = V_x = \frac{1}{T}\int_0^T v_x(t)\,dt = \frac{1}{T}\int_0^{T/3} 9\,dt + \frac{1}{T}\int_{T/3}^{T} 0\,dt = 3\text{ V}$$

Power Conversion Concept

What about the efficiency of the conversion???

- Instantaneous power absorbed by the switch is the product of its voltage and current.

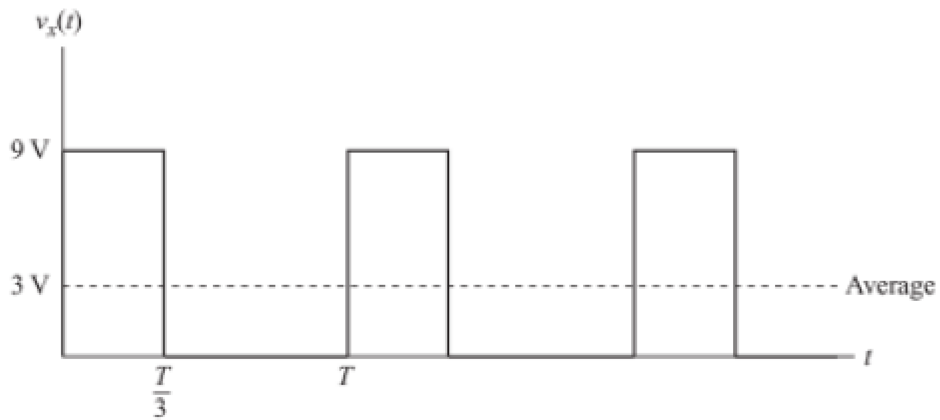
- When the switch is open, power absorbed by it is zero because the current in it is zero.

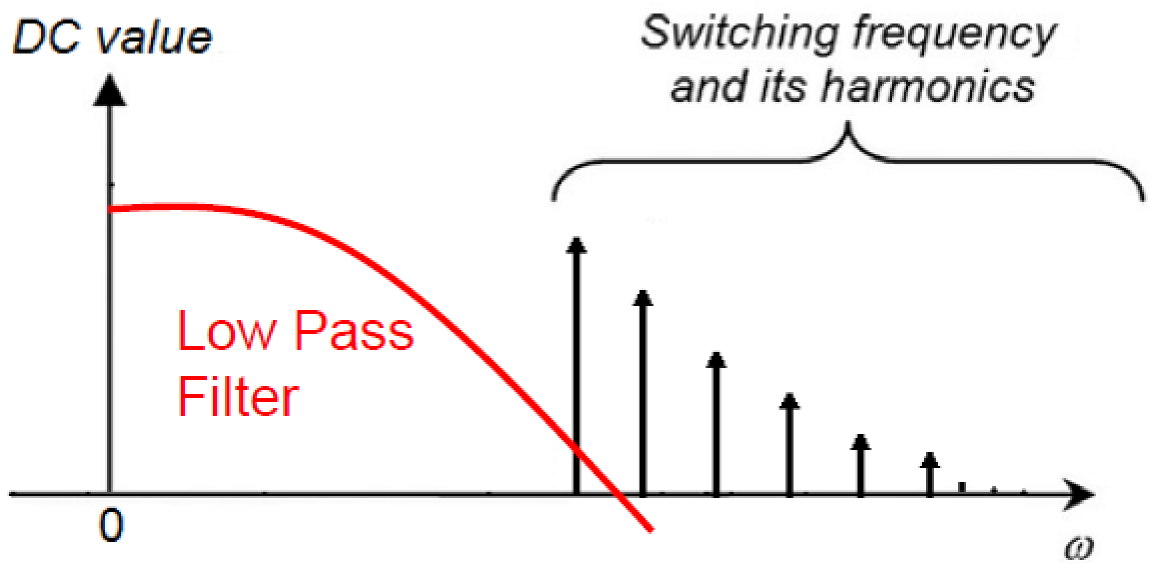
- When the switch is closed, power absorbed by it is zero because the voltage across it is zero.

- Since power absorbed by the switch is zero for both open and closed conditions, all power supplied by the 9V source is delivered to R_L, making **the circuit 100% efficient**.

Power Conversion Concept

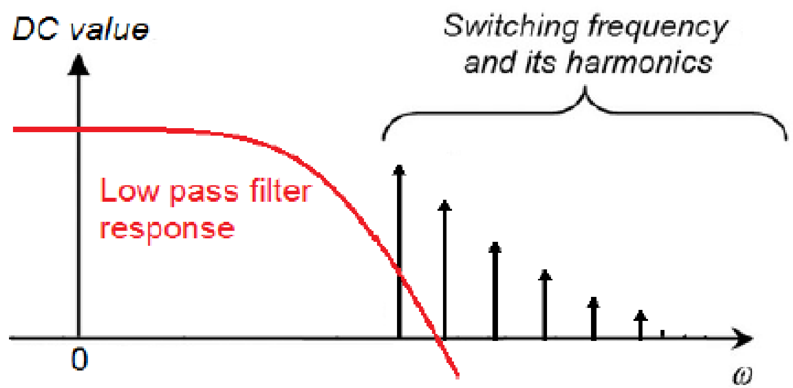
- But there is a serious problem**: the output voltage waveform is not pure DC!**
- However, the voltage waveform $v_x(t)$ can be expressed as a Fourier series

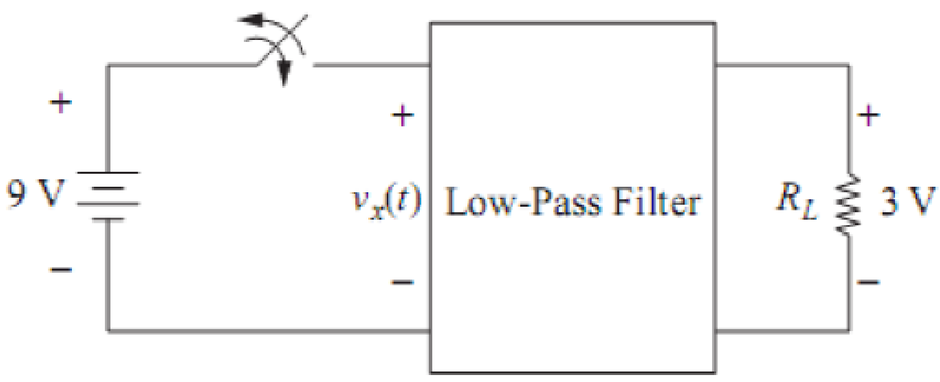


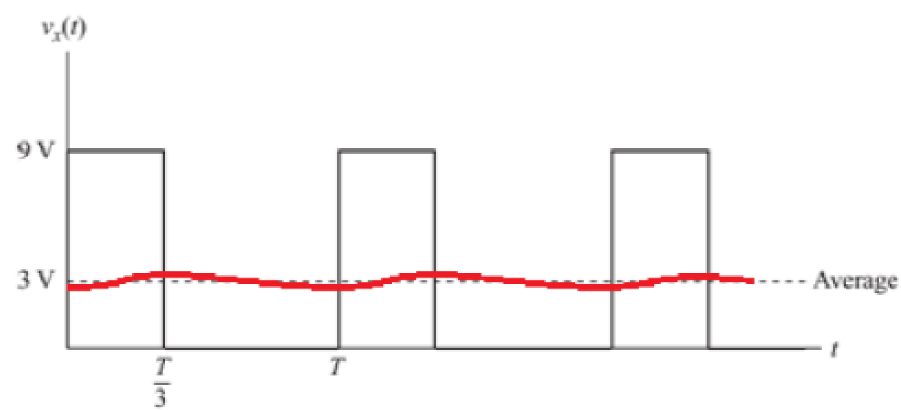


Power Conversion Concept

- To create a 3 Vdc voltage, $v_x(t)$ is applied to a low-pass filter.
- An ideal low-pass filter allows the dc component of voltage to pass through to the output while removing the ac terms, thus creating the desired dc output.



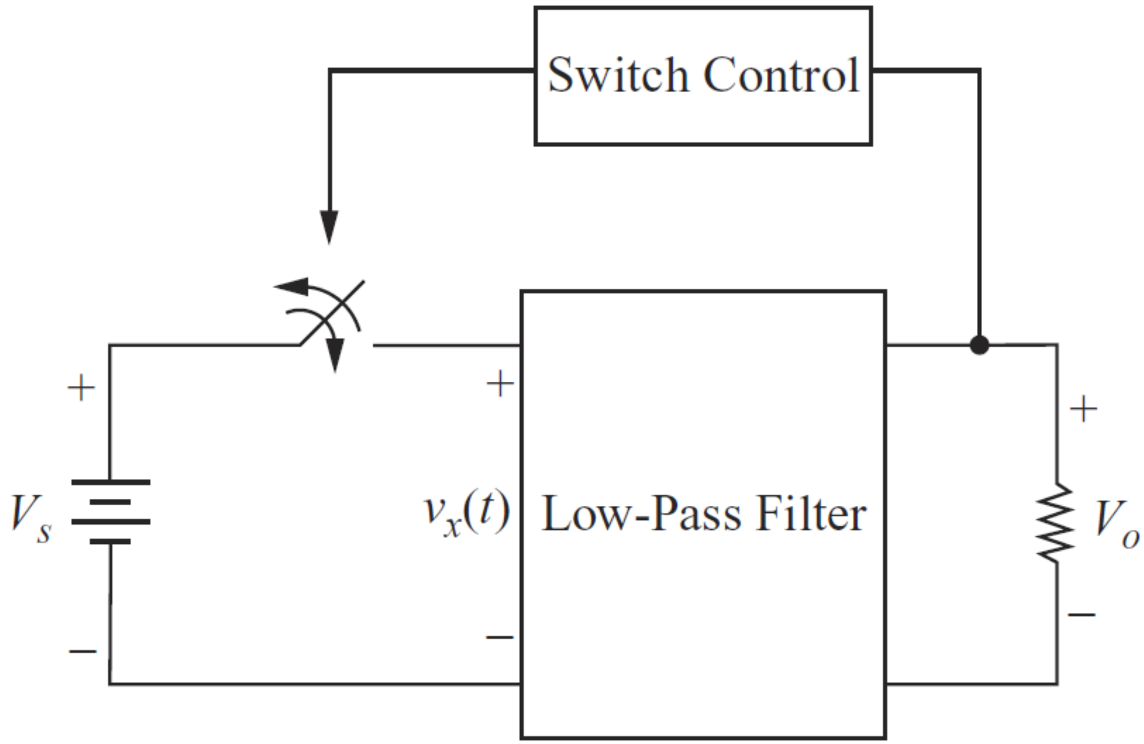




Power Conversion Concept

What about the output voltage regulation?

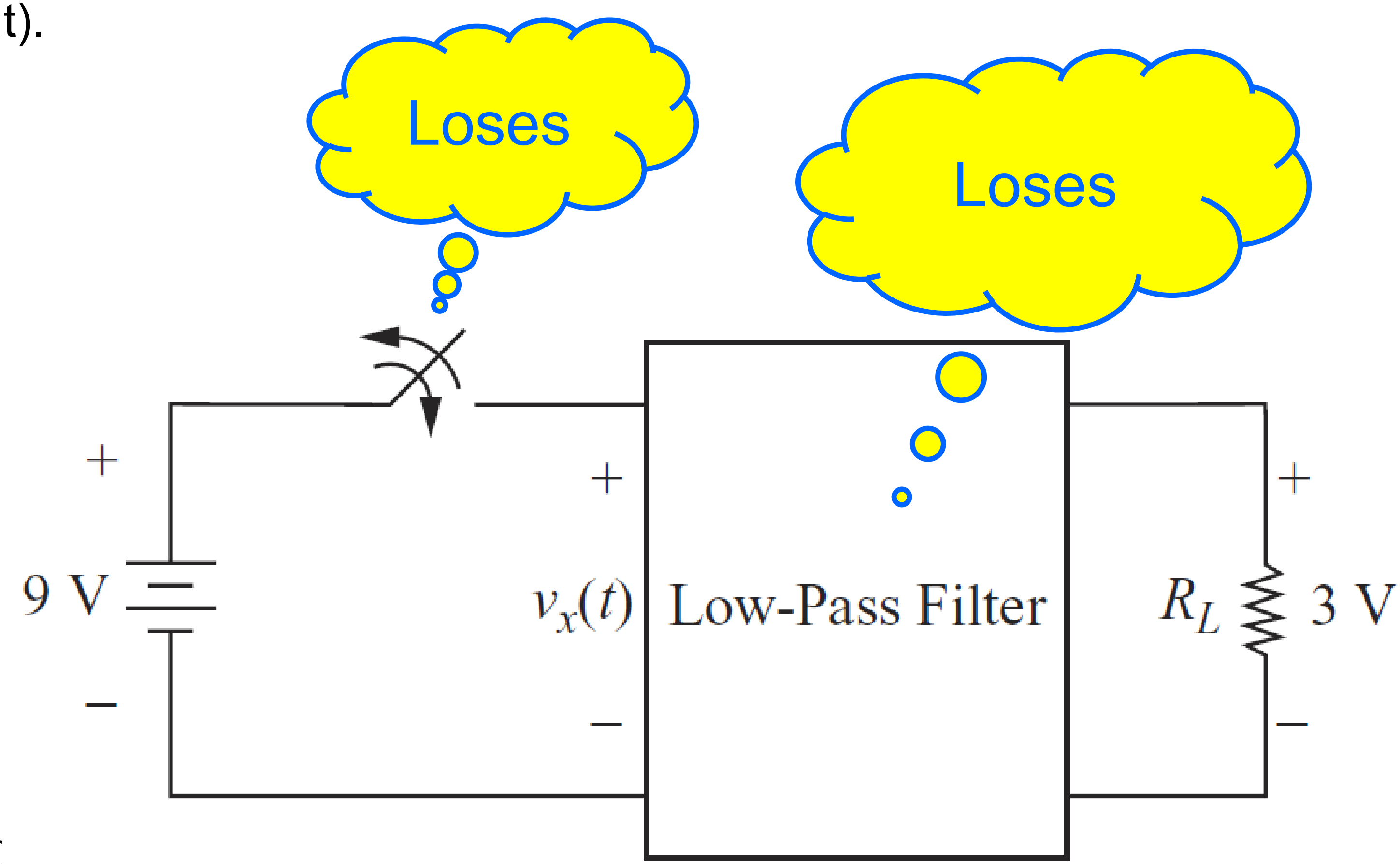
- The power conversion process usually involves system control.
- Converter output quantities such as voltage and current are measured, and operating parameters are adjusted to maintain the desired output.
- In our example, a feedback control system would detect if the output voltage were not 3 V and adjust the closing and opening of the switch accordingly



Power Conversion Concept

Regarding the switching regulators in practice:

- In practice, the filter will have some losses and will absorb some power.
- Additionally, the electronic device used for the switch will not be perfect and will have losses.
- However, the efficiency of the converter can still be quite high (more than 90 percent).



Power Electronic Devices

- In order to achieve high conversion efficiency in power electronic circuits, semiconductor switching devices are considered the heart of power electronic circuits!

- The control of power flow from the input to the output is done through a power processing switching network made of switching devices and energy storage elements!

- Power semiconductor switching devices are preferred with their two major desirable characteristics leading to the development of power electronic circuits:

  - Switching speed (turn-on and turn-off times)

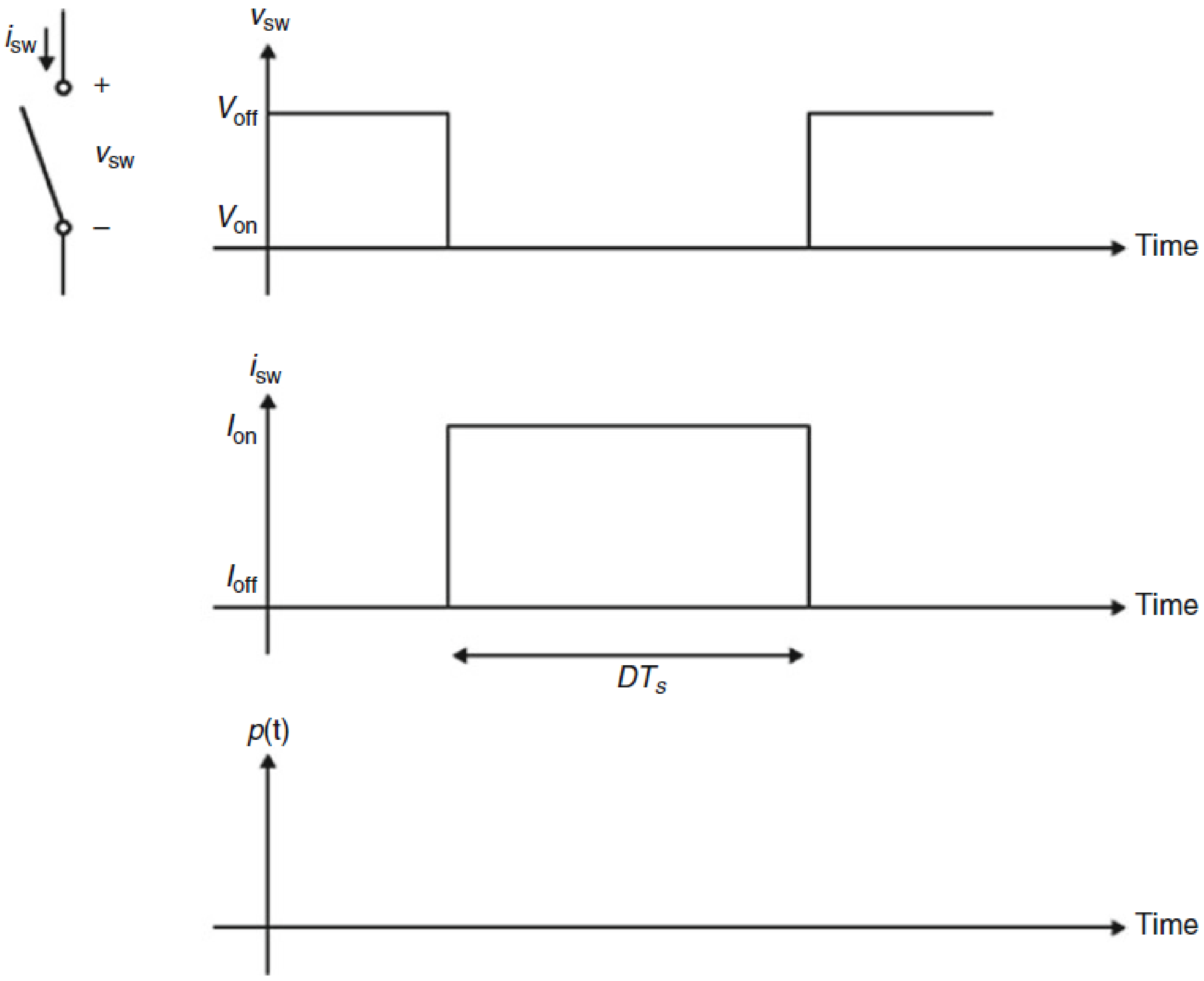
  - Power-handling capabilities (voltage blocking and current carrying capabilities)

Power Electronic Devices

It is always desired to have the power switches to perform as close as possible to the ideal case. For a semiconductor device to operate as an ideal switch, it must possess the following features:

- No limit on the amount of current (known as forward or reverse current) that the device can carry when in the conduction state (on-state)
- No limit on the amount of the device voltage (known as forward or reverse blocking voltage) when the device is in the nonconduction state (off-state)
- Zero on-state voltage drop when in the conduction state
- Infinite off-state resistance, i.e., zero leakage current when in the non-conduction state
- No limit on the operating speed of the device when it changes state, i.e., zero rise and fall times

Power Electronic Devices

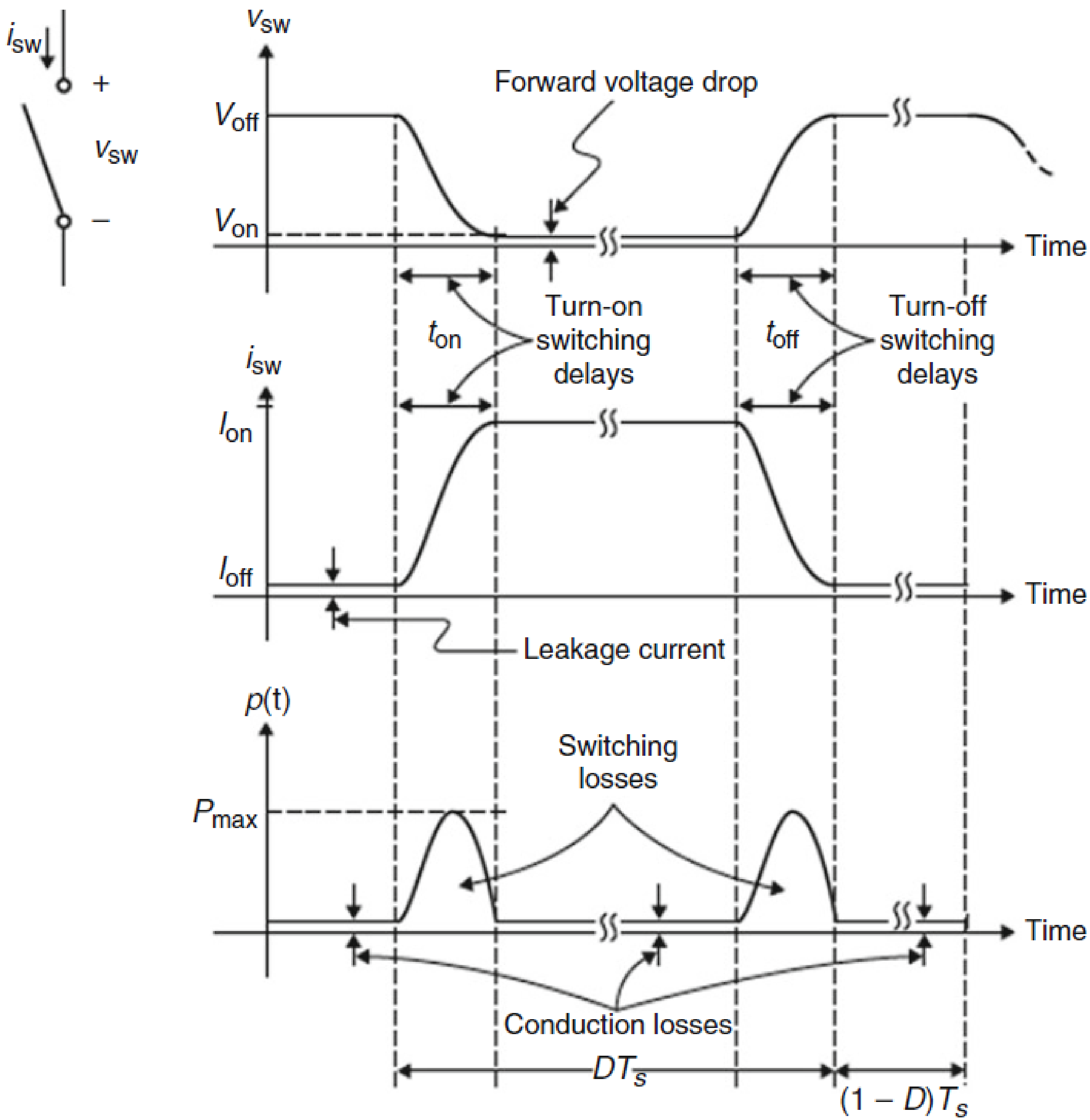


Power Electronic Devices

The practical switch has the following switching and conduction characteristics:

- Limited power-handling capabilities, i.e., limited conduction current when the switch is in the on-state and limited blocking voltage when the switch is in the off-state.
- Limited switching speed that is caused by the finite turn-on and turn-off times. This limits the maximum operating frequency of the device.
- Finite on-state and off-state resistances, i.e., there exists forward voltage drop when in the on-state and reverse current flow (leakage) when in the off-state.
- Because of characteristics 2 and 3 above, the practical switch experiences power losses in the on- and the off-states (known as conduction loss) and during switching transitions (known as switching loss).

Power Electronic Devices



Power Electronic Devices

The average power dissipation, P_{ave}, over one switching cycle is given by:

$$P_{\text{ave}} = \frac{1}{T_s}\int_0^{T_s} i_{\text{sw}} v_{\text{sw}}\, dt = P_{\text{ave,swit}} + P_{\text{ave,cond}}$$

where $P_{ave,\, swit}$ is the average switching losses and $P_{ave,\, cond}$ is the average conduction losses

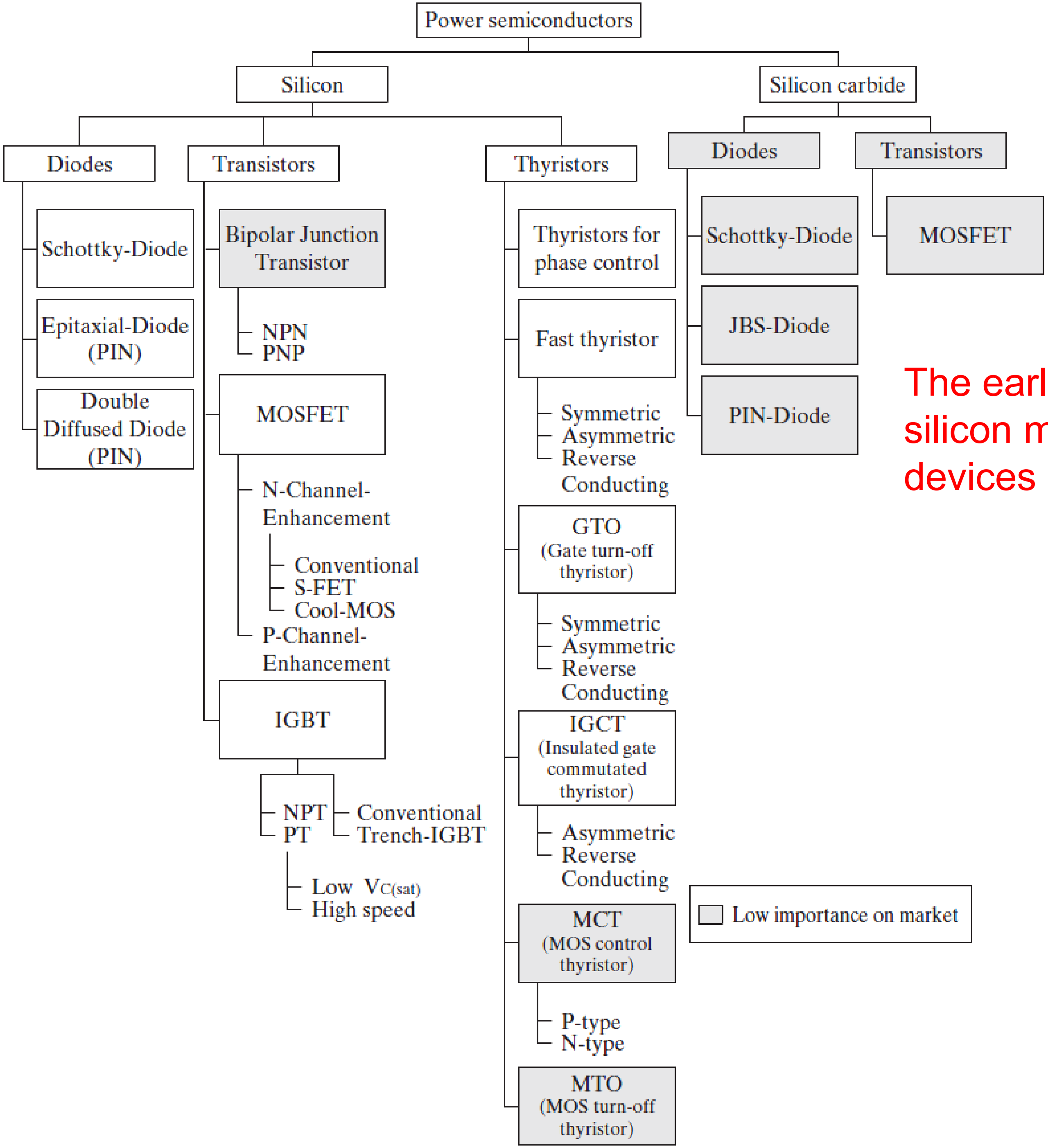
$$P_{\text{ave, swit}} = \frac{1}{T_S}\left[\underbrace{\int_0^{t_{\text{on}}} i_{SW} v_{SW} dt}_{\text{on switching losses}} + \underbrace{\int_{DT_s - t_{\text{off}}}^{DT_s} i_{SW} v_{SW} dt}_{\text{off switching losses}}\right]$$

$$P_{\text{ave, cond}} = \frac{1}{T_S}\left[\int_{t_{\text{on}}}^{DT_s - t_{\text{off}}} I_{\text{on}} V_{\text{on}} dt + \int_{DT_s}^{T_s} I_{\text{off}} V_{\text{off}} dt\right]$$

$$= I_{\text{on}} V_{\text{on}}\left(D - \frac{(t_{\text{on}} + t_{\text{off}})}{T_s}\right) + I_{\text{off}} V_{\text{off}}(1 - D)$$

If we assume the on and off times are small compared to T_s, then we have

$$P_{\text{ave,cond}} \approx \underbrace{I_{\text{on}} V_{\text{on}} D}_{\text{on conduction loss}} + \underbrace{I_{\text{off}} V_{\text{off}}(1 - D)}_{\text{off conduction loss}}$$



The earlier devices were made of silicon materials and the new devices are made of silicon carbide.

Power Electronic Devices

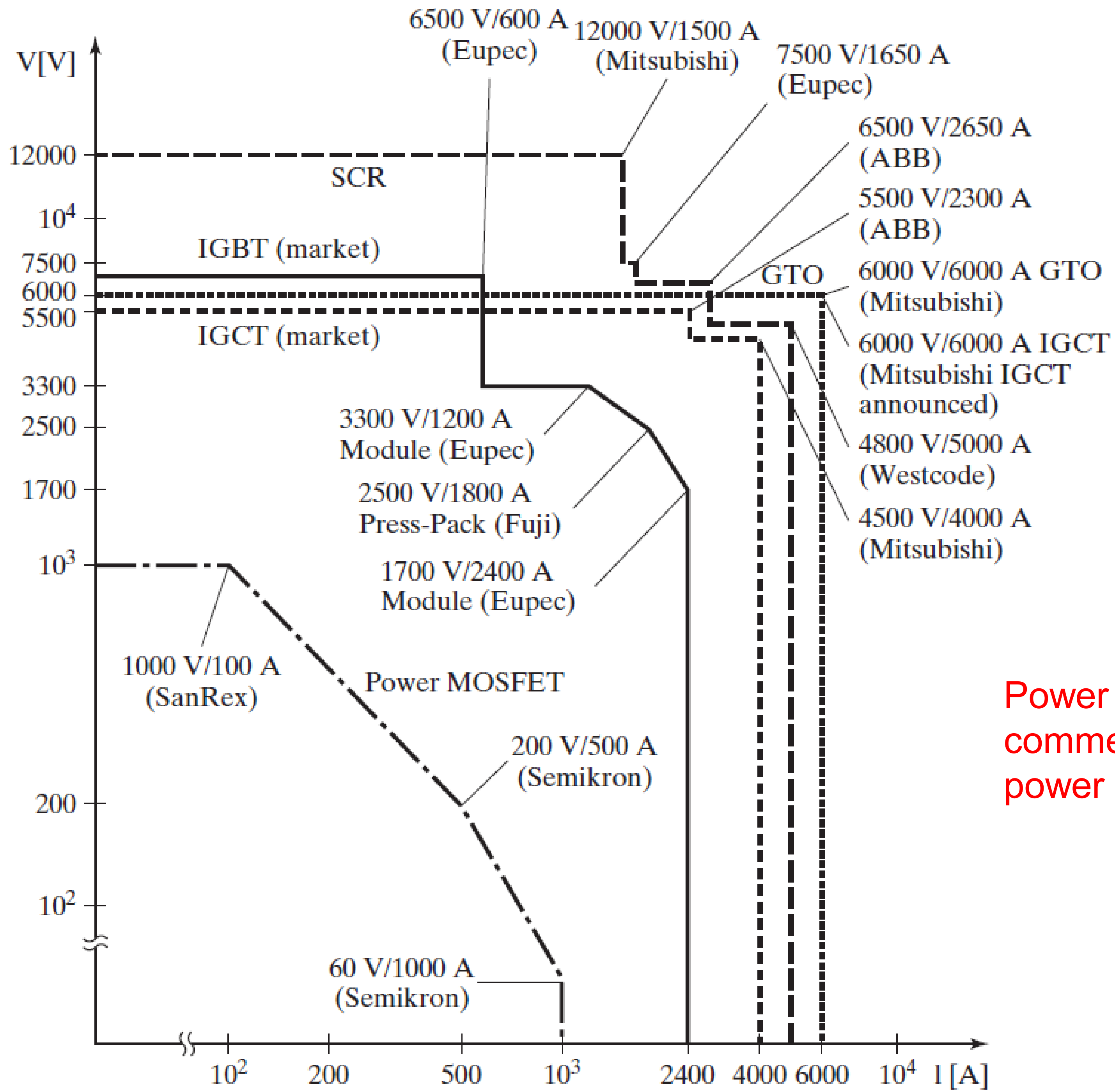
- Silicon carbide electrons need almost three times more energy to reach the conduction band as compared to silicon.

- As a result, SiC-based devices withstand far higher voltages and temperatures than their silicon counterparts.

- A SiC-based device can have the same dimensions as a silicon device but can withstand 10 times the voltage.

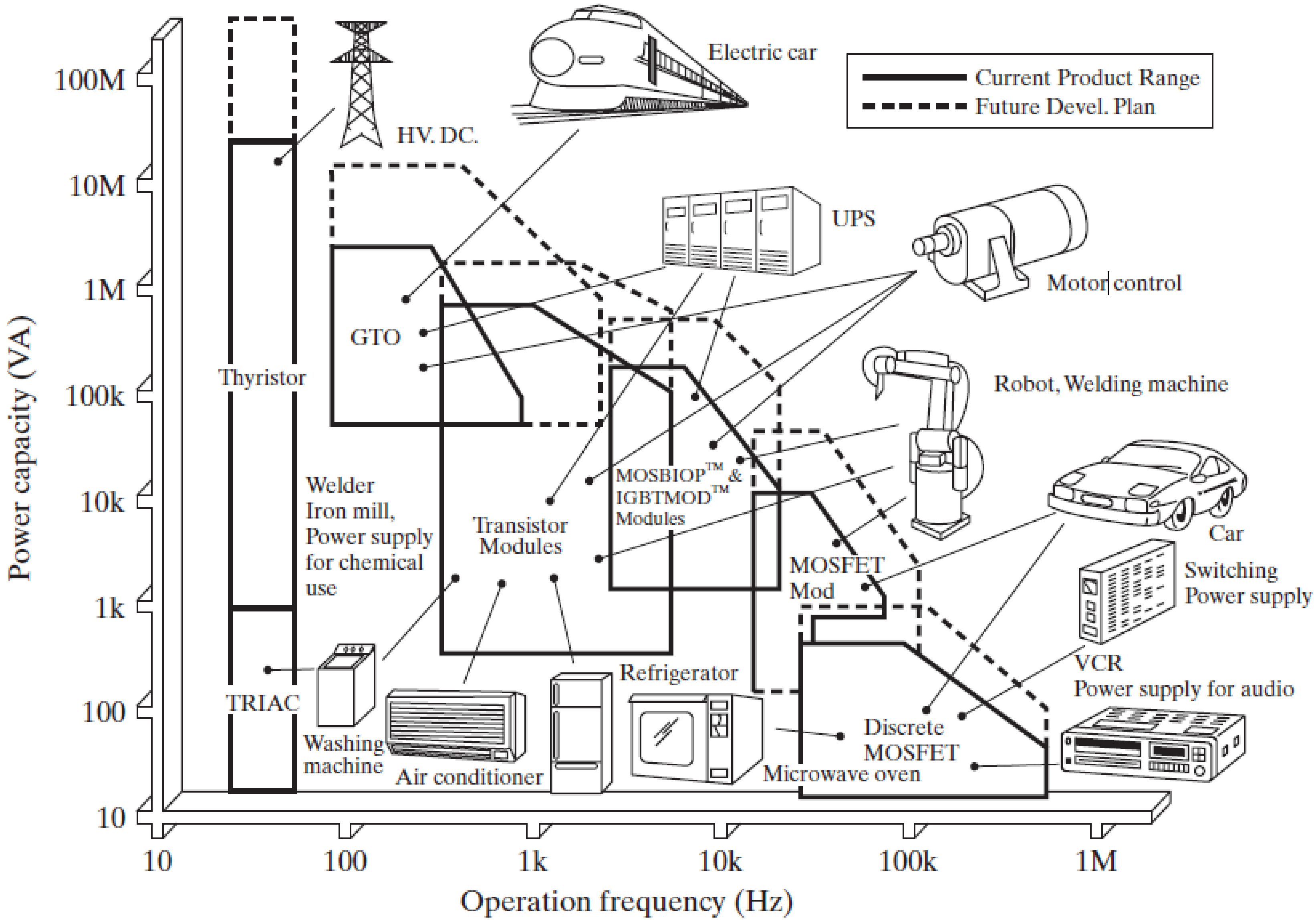
- Also, a SiC device can be less than a tenth the thickness of a silicon device but carry the same voltage rating.

- These thinner devices are faster and boast less resistance, which means less energy is lost to heat when a silicon carbide diode or transistor is conducting electricity.



Power ranges of commercially available power semiconductors

Power Electronic Devices



Power Electronic Devices

The power semiconductor switching devices can be classified on the basis of:

1. Uncontrolled turn-on and turn-off (e.g., diode);
2. Controlled turn-on and uncontrolled turn-off (e.g., SCR);
3. Controlled turn-on and -off characteristics (e.g., BJT, MOSFET, GTO, SITH, IGBT, SIT, MCT);
4. Continuous gate signal requirement (BJT, MOSFET, IGBT, SIT);
5. Pulse gate requirement (e.g., SCR, GTO, MCT);
6. Bipolar voltage-withstanding capability (SCR, GTO);
7. Unipolar voltage-withstanding capability (BJT, MOSFET, GTO, IGBT, MCT);
8. Bidirectional current capability (TRIAC, RCT);
9. Unidirectional current capability (SCR, GTO, BJT, MOSFET, MCT, IGBT, SITH, SIT, diode).

Power Electronic Devices

Switching Characteristics of Power Semiconductors

Device Type	Device	Continuous Gate	Pulse Gate	Controlled Turn-On	Controlled Turn-Off	Unipolar Voltage	Bipolar Voltage	Unidirectional Current	Bidirectional Current
Diodes	Power diode					x		x	
Transistors	BJT	x		x	x	x		x	
	MOSFET	x		x	x	x			x
	COOLMOS	x		x	x	x			x
	IGBT	x		x	x	x		x	
	SIT	x		x	x	x		x	
Thyristors	SCR		x	x			x	x	
	RCT		x	x			x		x
	TRIAC		x	x			x		x
	GTO		x	x	x		x	x	
	MTO		x	x	x		x	x	
	ETO		x	x	x		x	x	
	IGCT		x	x	x		x	x	
	SITH		x	x	x		x	x	
	MCT	x		x	x		x	x	

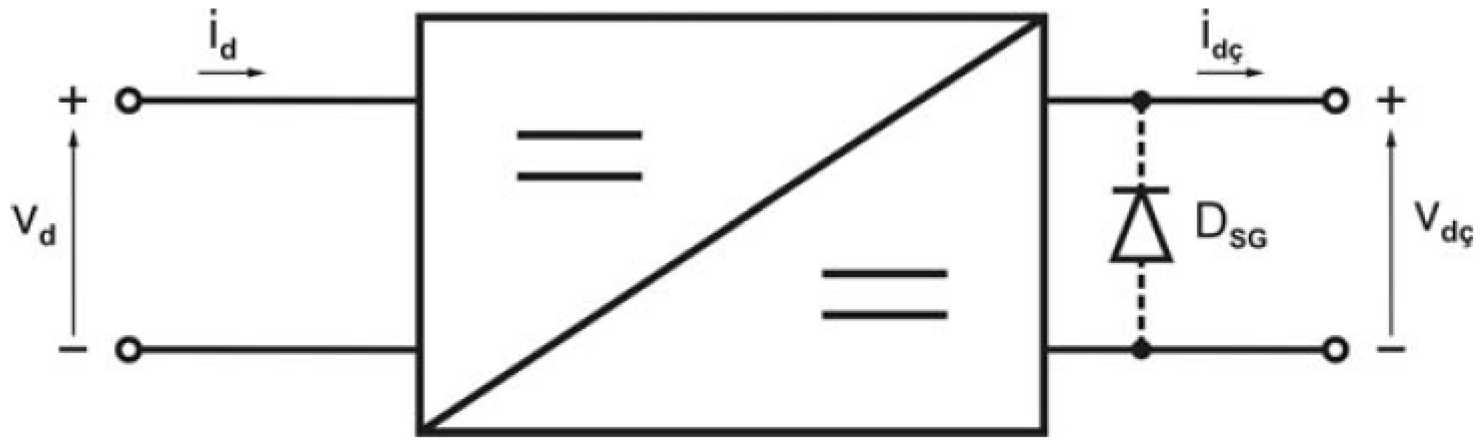
Power Electronic Devices

Device Choices for Different Power Levels

Choices	Low Power	Medium Power	High Power
Power Range	Up to 2 kW	2 to 500 kW	More than 500 kW
Usual Converter Topologies	ac-dc, dc-dc	ac-dc, dc-dc, dc-ac	ac-dc, dc-ac
Typical Power Semiconductors	MOSFET	MOSFET, IGBT	IGBT, IGCT, thyristor
Technology Trend	High power density High efficiency	Small volume and weight Low cost and high efficiency	High nominal power of the converter High power quality and stability
Typical Applications	Low-power devices Appliances	Electric vehicles Photovoltaic roofing	Renewable energy Transportation Power distribution Industry

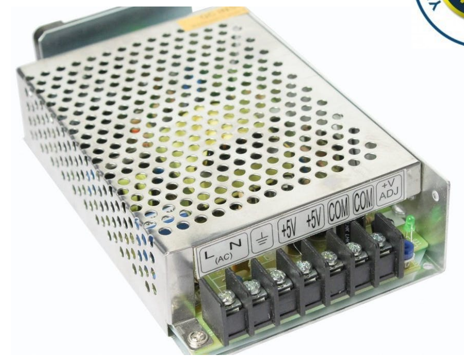
DC Choppers – DC 2 DC Converters

A dc-to-dc converter, also known as dc chopper, is a static device which is used to obtain a variable dc voltage from a constant dc voltage source. Dc converters are widely used for traction motor control in electric automobiles, trolley cars, marine hoists, forklift trucks, and mine haulers. They provide smooth acceleration control, high efficiency, and fast dynamic response.



v_d : DC input voltage
i_d :DC input current
D_{SG}: Free-wheeling Diode
$v_{dç}$: DC output voltage
$i_{dç}$: DC output current

DC Choppers – DC 2 DC Converters



Main application areas of DC-DC converters

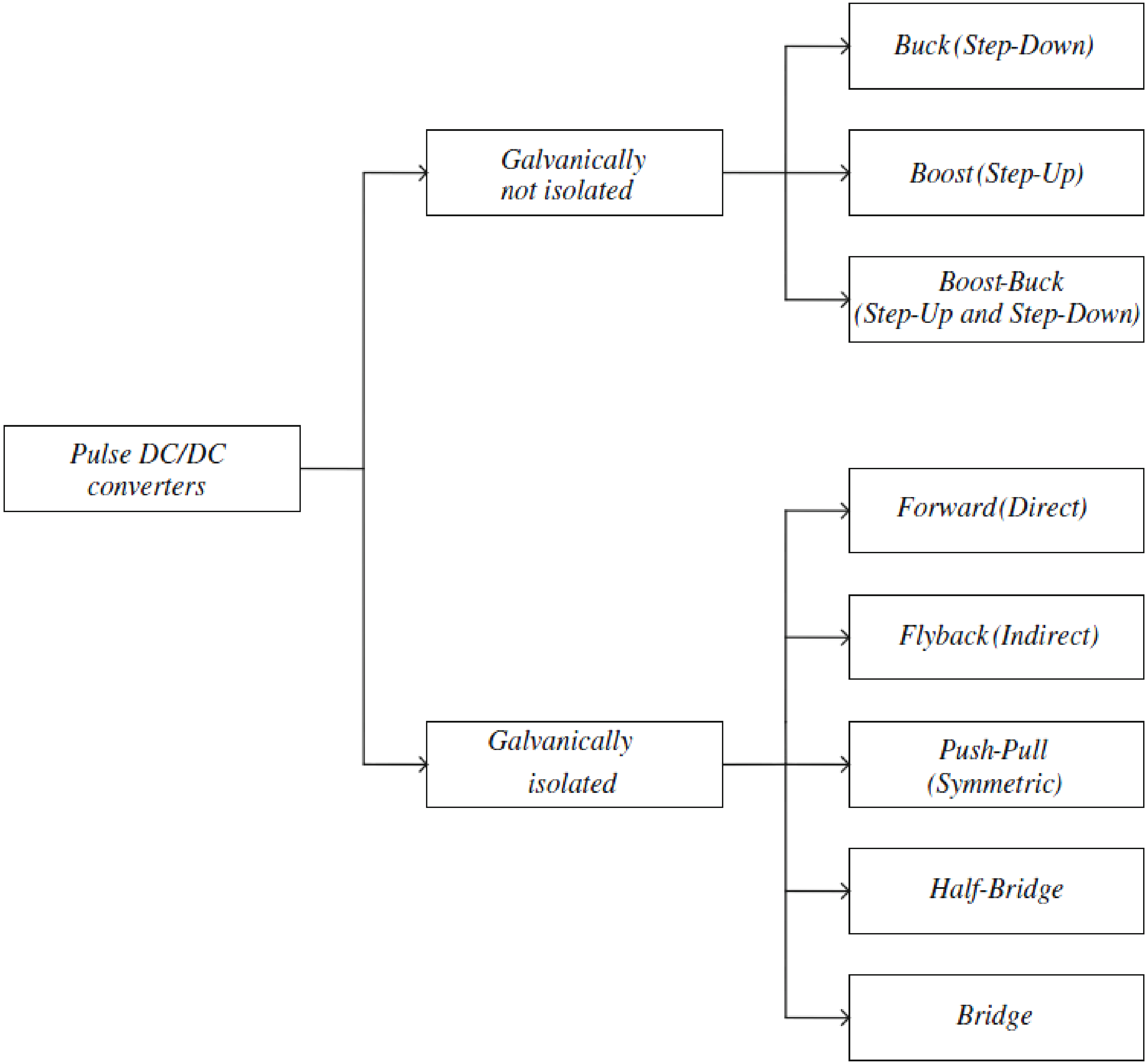
- DC motor control
- SMPS – Switching mode power supply
- UPS – Uniterruptible power supply
- Battery chargers
- Whelding machines
- Static VAR control
- …

Main features of DC-DC converters:

→It is forced commutated.
→It is realized with fully controlled switching devices.
→It is controlled by DC - PWM control method.
→A fixed or regulated and non-insulated or isolated DC voltage is generated
→Depending on the control technique, fluctuations may occur in the DC output voltage.
→Significant fluctuation may also occur in the DC input source current.

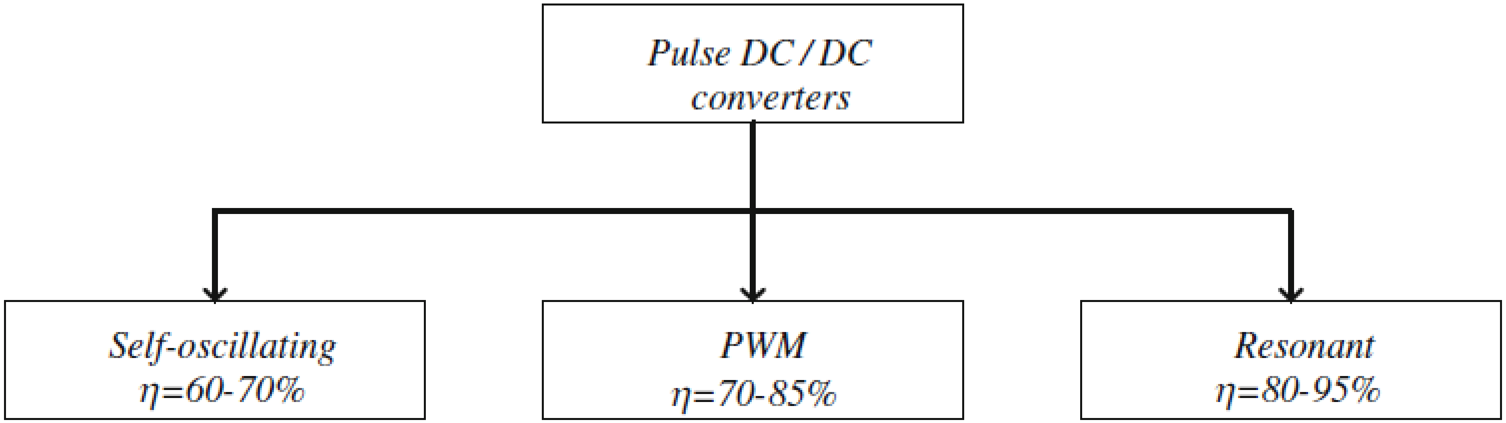
DC Choppers – DC 2 DC Converters

Classification of pulse DC/DC converters according to the topology of the basic circuit;



DC Choppers – DC 2 DC Converters

Classification according to the mode of control

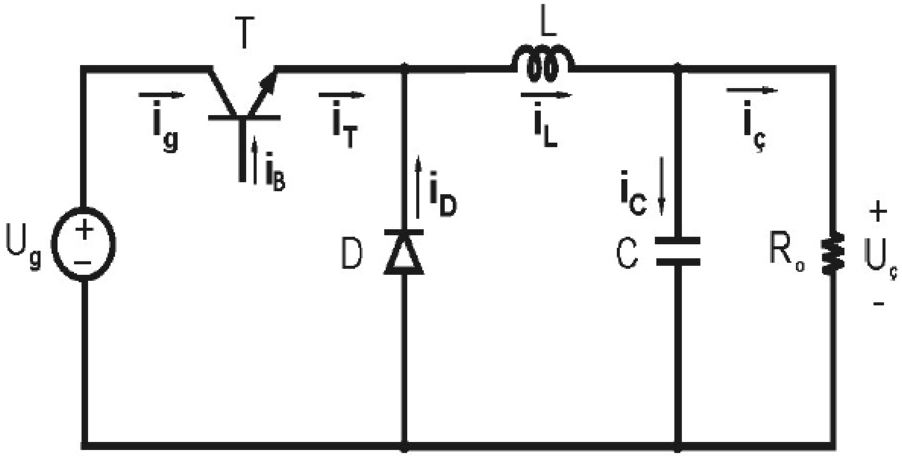


The self-oscillating converters are simple from the design point of view, but their efficiency factor η is the lowest. They are mainly used for supplying small loads (up to several tens of watts).

The widest application today finds DC/DC converters using pulse width modulation (PWM). The output voltage is controlled by varying the ratio of the on and off times of the switch with a constant frequency of switching.

Over the past 10 years an ever increasing attention has been paid to the resonant converters. It is considered that the future in the design of efficient power supplies belongs to this type of converter. The essential difference of resonant power converters compared to other converter types is that the state of the switch is changed at the zero crossing of the current or voltage.

THE BUCK (STEP-DOWN) CONV

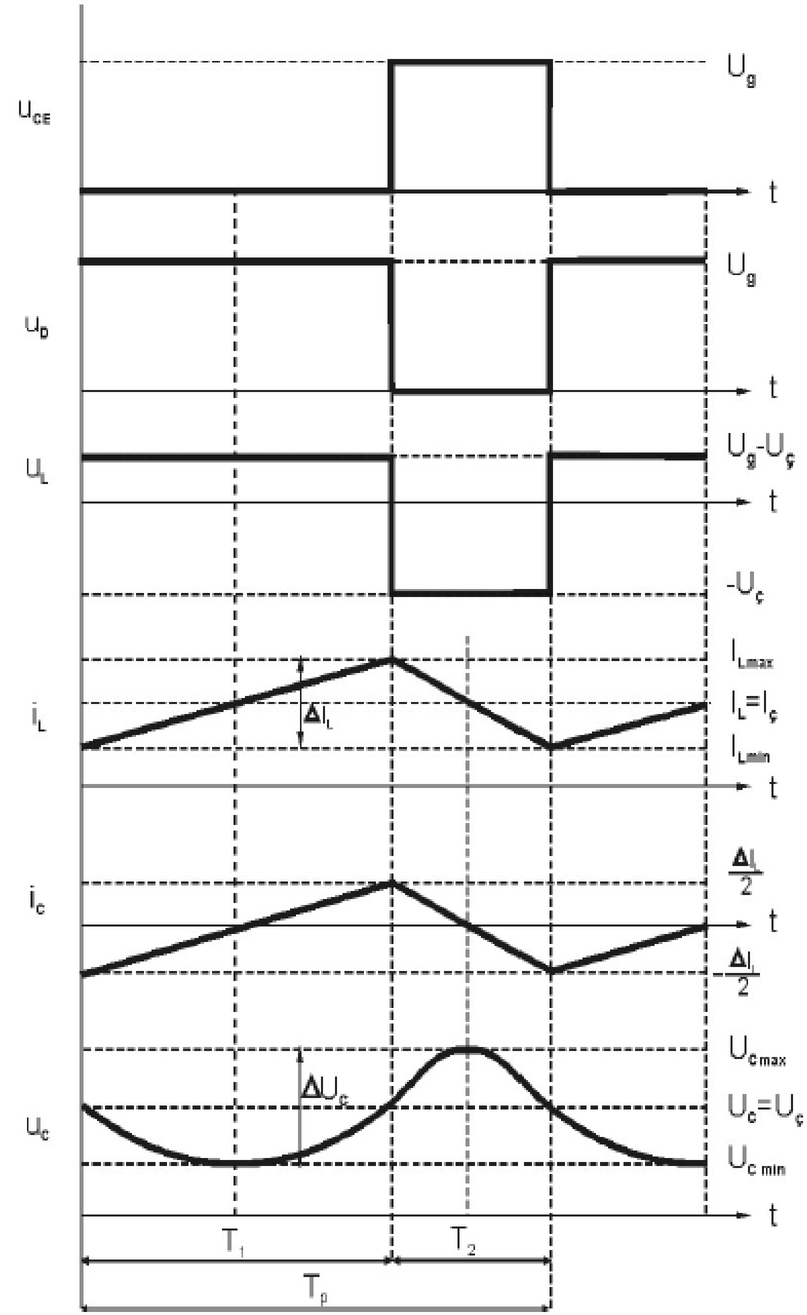


$$T_p = T_1 + T_2$$

T_1 : Transistorün iletim süresi
T_2 : Diyodun iletim süresi
T_p : Anahtarlama (Darbe) peryodu

$$I_L = I_T + I_D$$

I_T : Transistör akımı
I_D : Diyot akımı
I_L : Endüktans akımı



THE BUCK (STEP-DOWN) CONVERTER

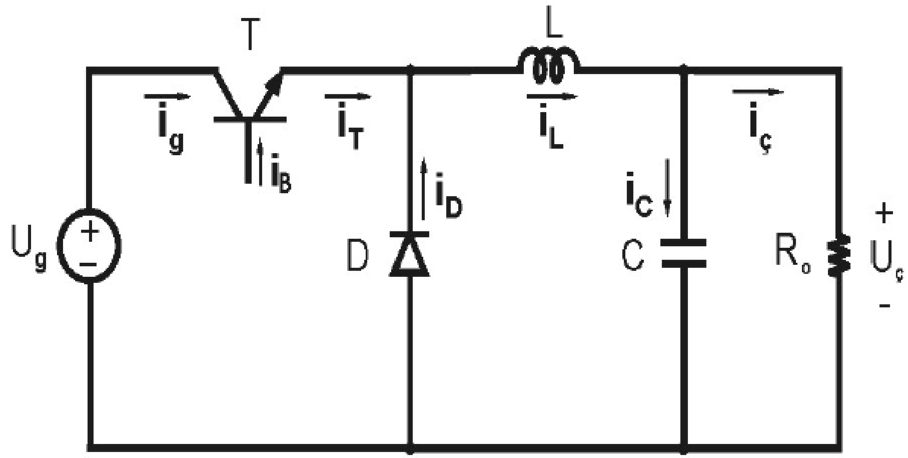
$$\lambda = \frac{T_1}{T_P} = \frac{I_T}{I_L}, \qquad f_P = \frac{1}{T_P}$$

$$T_1 = \lambda T_P, \quad T_2 = (1-\lambda)T_P$$

$$I_T = \lambda I_L, \quad I_D = (1-\lambda)I_L$$

f_p : Anahtarlama (Darbe) Frekansı

λ : Bağıl İletim Süresi



i_L : Sürekli, kesintisiz

$U_g, U_ç$ ve $I_ç$: Sabit

Assumptions

$\lambda = 2/3$ için,

U_g ve $I_ç$: 3 birim

$U_ç$ ve I_g : 2 birim

$$I_L = I_Ç$$

$$U_ç = \lambda U_g$$

$$I_g = \lambda I_ç$$

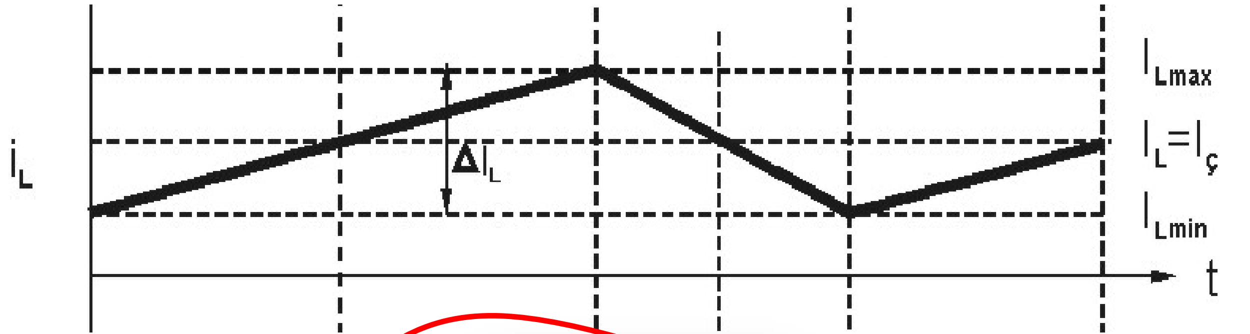
General definitons

THE BUCK (STEP-DOWN) CONVERTER

Calculation of Fluctuation in Inductance Current

T1: $$\frac{\Delta I_L}{T_1} = \frac{U_g - U_ç}{L}$$

T2: $$\frac{\Delta I_L}{T_2} = \frac{U_ç}{L}$$



$$U_ç = L\frac{\Delta I_L}{T_2} \Rightarrow \Delta I_L = \frac{T_1 U_g}{L} - \frac{T_1}{T_2}\Delta I_L$$

$T_p = T_1 + T_2$
$\lambda = T_1 / T_p$
$T_1 = \lambda T_p$
$T_2 = (1-\lambda) T_p$
$f_P = 1/T_P$

$$\Delta I_L = \lambda(1-\lambda)\frac{U_g}{f_p . L}$$

Max current comes out when

$$\frac{d\Delta I_L}{d\lambda} = 0$$

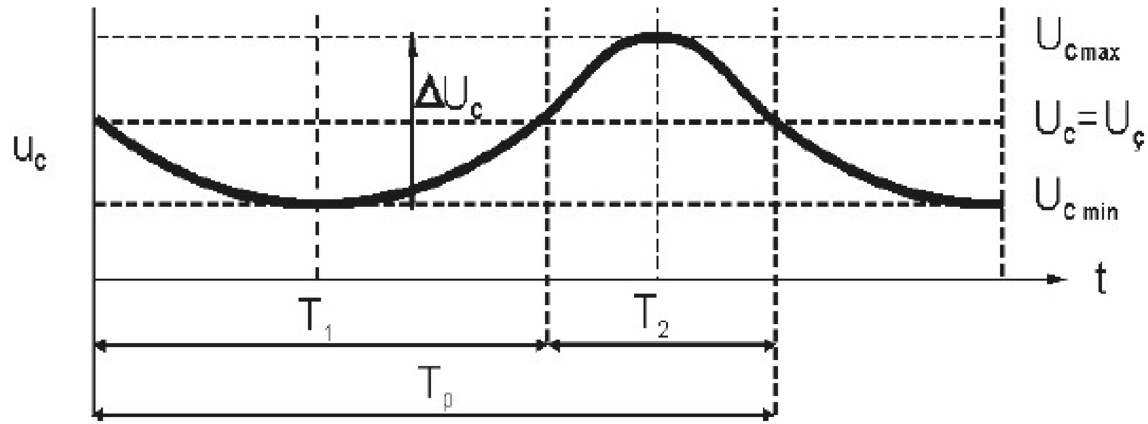
$$\frac{d\Delta I_L}{d\lambda} = [(1-\lambda)-\lambda]\frac{U_g}{f_p L} \Rightarrow 1\text{-}2\lambda=0 \quad \Rightarrow \lambda = 1/2$$

$$\boxed{\Delta I_{L\,max} = \frac{U_g}{4 f_p L}}$$

THE BUCK (STEP-DOWN) CONVERTER

Calculation of Capacitor Voltage Ripple

$$U_c = \frac{1}{C}\int i_c . dt$$



$$C.\Delta U_c = I_c . \Delta t$$

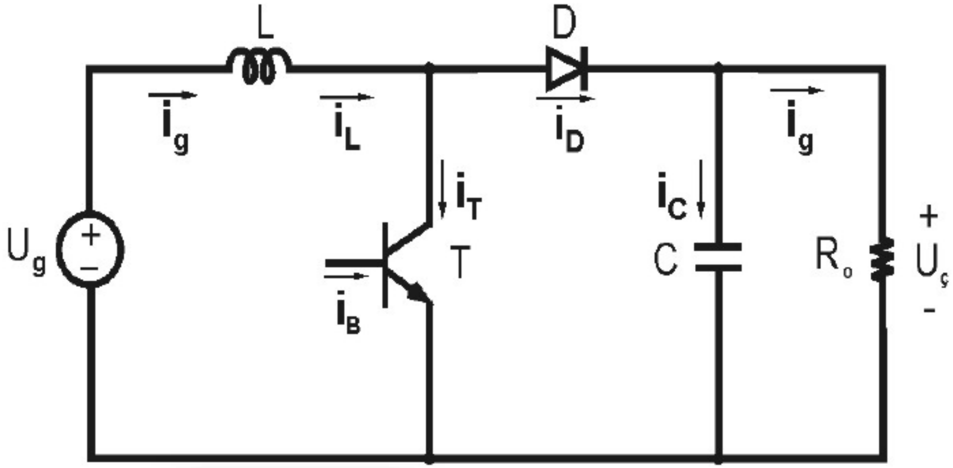
$$\Delta U_c = \frac{1}{C}\left[\int_0^{T_1/2} \frac{\Delta I_L/2}{T_1/2} t.dt + \int_0^{T_2/2} \frac{\Delta I_L/2}{T_2/2} t.dt\right]$$

$$\Delta U_c = \frac{\Delta I_L}{8 f_p C}$$

For maximum ripple in voltage

$$\Delta U_{C\,max} = \frac{\Delta I_{1\,max}}{8 f_p C}$$

THE BOOST CONVERTER



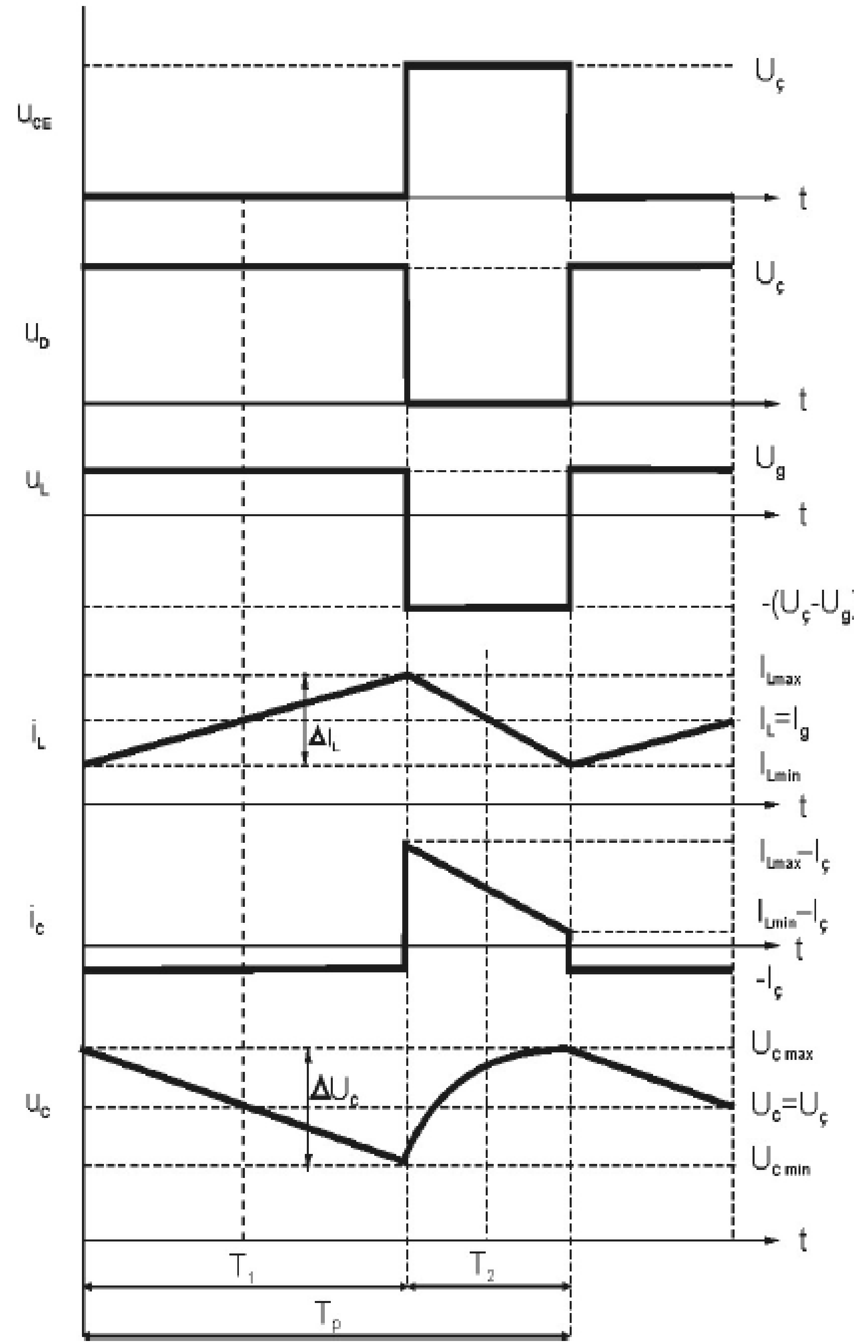
T1: $$\frac{di_L}{dt} = \frac{U_g}{L}$$

T2: $$\frac{di_L}{dt} = -\frac{U_ç - U_g}{L}$$

$$U_ç = \frac{1}{1-\lambda} U_g$$ Output voltage

$$I_g = \frac{1}{1-\lambda} I_ç$$ Input current

λ=2/3 için Temel Dalga Şekilleri



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