ECOSIGN

Ecodesign of Electronic Devices

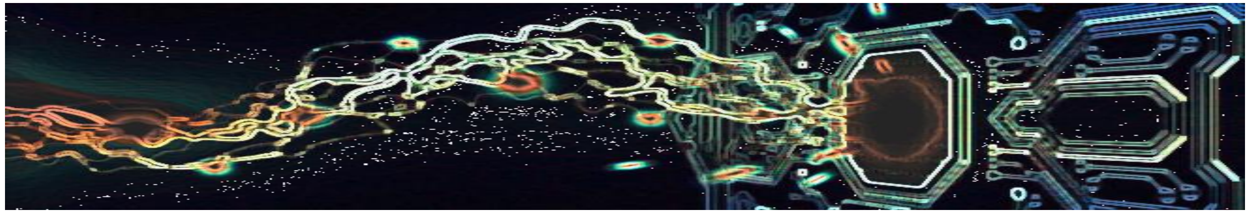
UNIT 10: Power Electronics

Funded by the Erasmus+ Programme of the European Union

Ecoinnovation Skills for European Designers, Project number: 562573-EPP-1-2015-1-SI-EPPKA2-SSA.

Power Electronics

- Electrical power engineering is part of electrical engineering that covers conversion and saving of electrical energy. All electronic appliances are powered by different sources. These sources can be autonomous and portable or stationary.
- Autonomous sources are all battery systems and devices that power portable and autonomous devices. Generally, battery systems are only a way of saving the energy that we supply from stationary systems, such as electrical network. Completely autonomous energy sources are systems that are not dependent on energy from electrical networks and do the conversion of non-electrical energy into electrical on the given spot. Such sources are different solar cells, wind power plants, etc.
- Capacity and flexibility of modern electronics have to be accepted as new challenges for efficient use of energy. It is crucial to think how electronic circuits and systems can be used for conversion and energy management.



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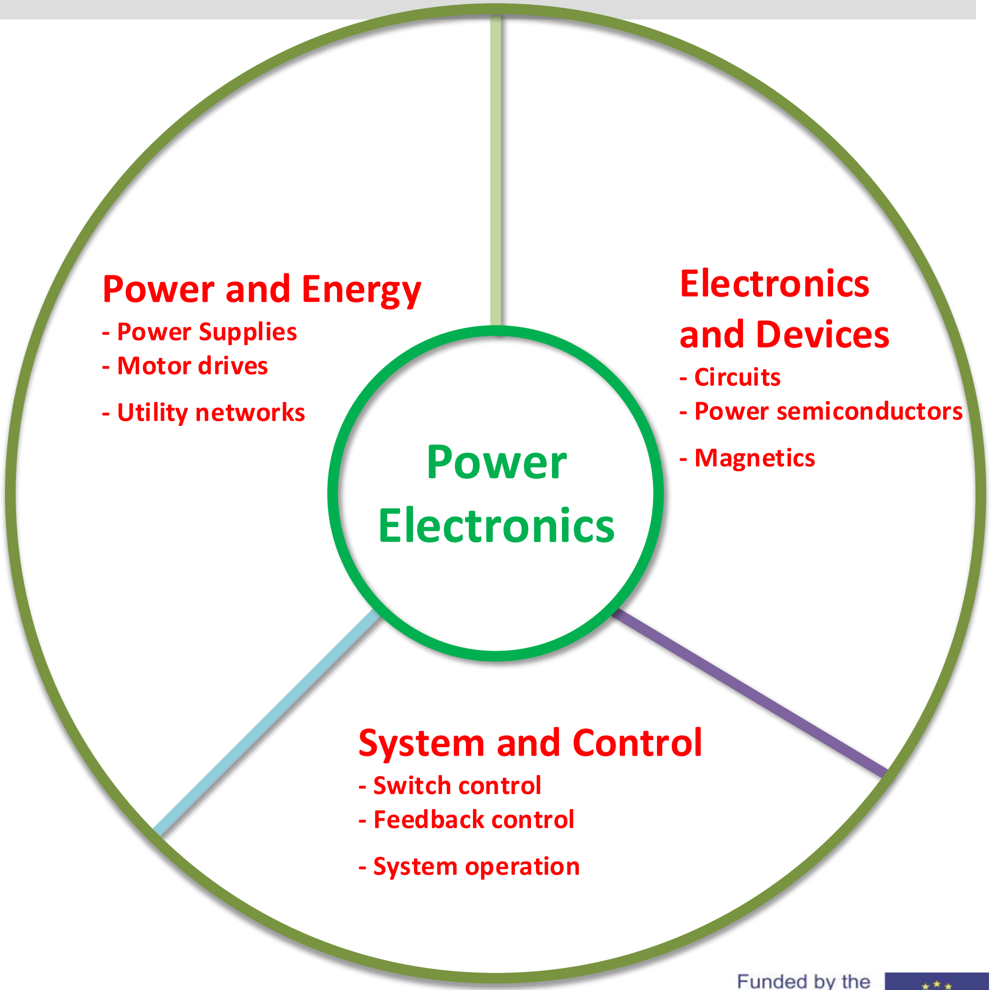
Power Electronics

History of electrical power engineering is closely related to the improvements of electronic components that provide functioning with higher powers. Since 1990 the components and devices became so sophisticated that the transition from physical devices to program applications has begun. This transition was based on two key factors:

- For almost every application exist advanced semiconductors with suitable powers that are widely accessible.
- The main tendency for component miniaturization increases with the number of electrical devices and products.



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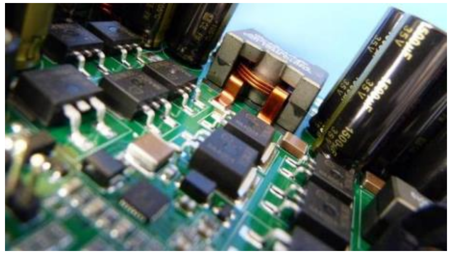
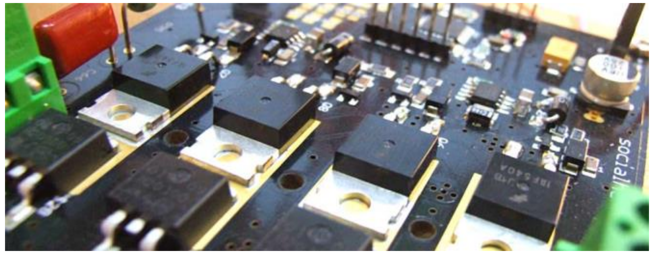
Power Electronics

- All electronic circuits regulate electrical energy current between electrical source and load. Components in circuit need to direct to electrical currents and not interfere with them. The general power conversion system is presented on a picture. The function of power converter, is control an energy current between source and load. In our case, the power conversion will be executed with the electronic circuit.

Electrical energy source → **Power converter** → **Electrical load**





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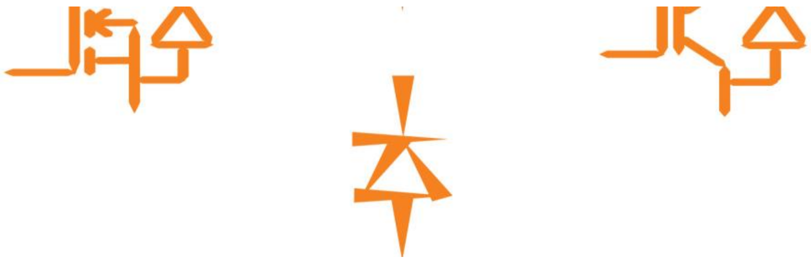
Switch-mode functioning

- Functioning of switch converters is based on low-loss switches which are extreme requirements for electrical power engineering.
- In the ideal case, when the switch is on, it has a zero drop in voltage and will transmit full energy to the load without any additional losses. If the switch is off, it has unlimited resistance, meaning that no current will go through the switch.
- The power of switch is a product of voltage and current, meaning that the desired product of both values equals zero. If the power is equal to zero, we do not have any energy use on the switch element in the given time. The switch, therefore, regulates energy current without loss, where switch reliability is crucial.
- Household mechanical switches perform maybe even more than 100.000 switches in one decade of use..



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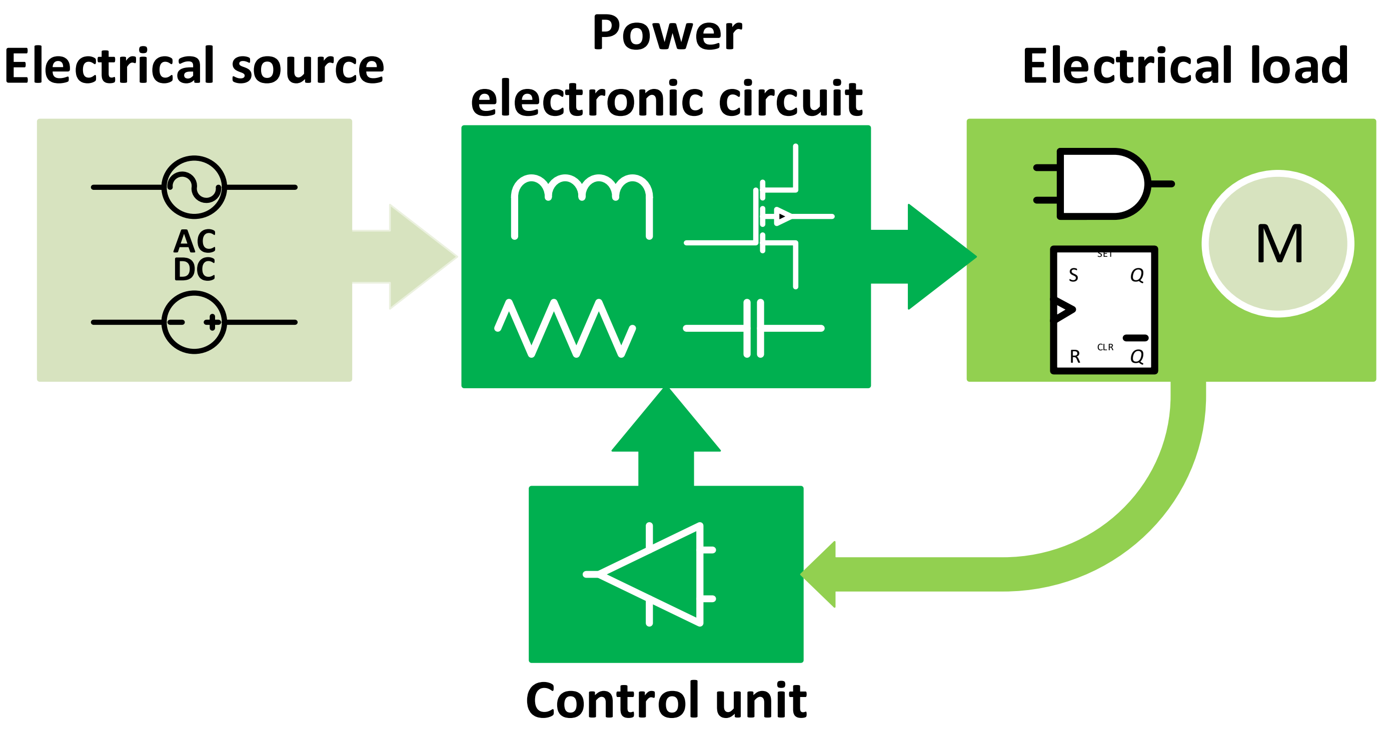
Energy conversation

- Conversion system consists of four separate units, which are: Energy source, power circuit, control unit and load.



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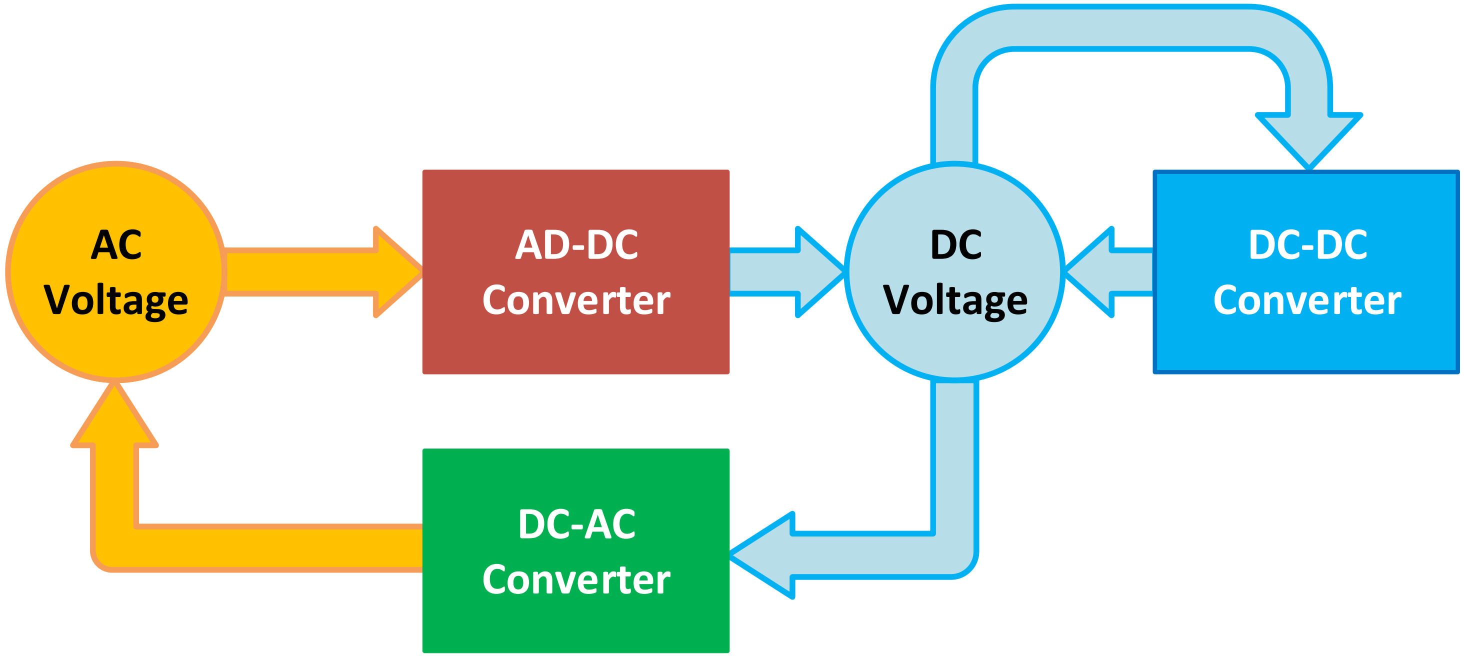
Energy conversation

- The power circuitry varies according to the converter type. The converter type is distinguished from the input and output voltages.



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Converter design

The design of power converters can be identified by three major challenges:

- The first challenge is the reliability of power electronic circuits. It is necessary to strictly consider the nominal voltages, currents and output power of the device, but these should always remain within the limit values. This is particularly important in the management of high power.
- The second challenge is the simplicity of the circuit. For electronic circuits, it is known that as many elements contain the greater the possibility of error or failure of the entire system. Powerful electronic circuits usually have some parts, especially in the main power supply. In order to achieve the efficiency of the converter, it is very important to rationalize the main components. This often means that sophisticated management strategies are implemented with simple electronic circuits.
- The third challenge is integration. One way to avoid the compromise of reliability and complexity is to integrate multiple components and functions into one single substrate. For example, a microprocessor can contain millions of ports. All interconnections and signals run within one chip, and reliability depends on a single part.

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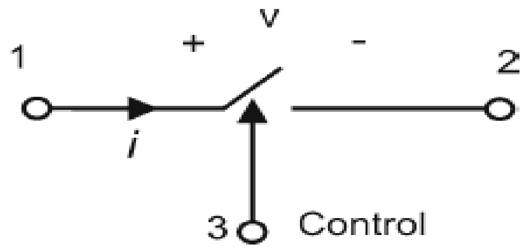
Switching elements

- Electronic switches that are capable of managing high voltages and currents in high-frequency range are the most important elements in designing systems for energy conversion.
- So, which switch is ideal? Ideal electronic switch can be a device with three connectorsIdealno stikalo pomeni, da v odprtem stanju nima upornosti v zaprtem stanju ima neskončno upornost. Idealno stikalo spremeni stanje takoj, kar pomeni, da je potrebno ničelni čas, da preklopite iz ON-v-OFF ali OFF-v-ON.
- Actual switches have limitations in all characteristics that have been mentioned at the ideal switch. For example, when the switch is on, we have a drop of voltage, meaning it has a certain resistance. When switched off, some current can be leaked, meaning it does not have infinite resistance. The switch time is also not infinitely fast. As a consequence of given non-ideal switch characteristics, voltage and current are always present in the switch, and consequently, there are two types of losses.



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Switching elements

- The concept of the ideal switch is important for circuit evaluation. Assumptions on zero voltage drop, current leak and switching occurrences ease simulation and modeling on different converter switch behavior. Depending on characteristics of the ideal switch are three classes of power switches:
  - **Uncontrolled switch:** The switch does not have control connector. Switch mode is determined by an external voltage or current circuit conditions in which the switch is in. An example of such switch is a diode.
  - **Half-controlled switch:** In this case, the circuit designer has limited control over the switch. For example, the switch can be turned on with control connector, but when it is closed, it cannot be unlocked with the control signal. The switch can be turned off depending on current circuit state or with added control electronics that forces the switch to turn off. An example of this switch ist thyristor.
  - **Fully controlled switch:** The switch can be turned on or off through control connector. Examples of this switch are bipolar transistor BJT, MOSFET transistor, and IGBT transistor.

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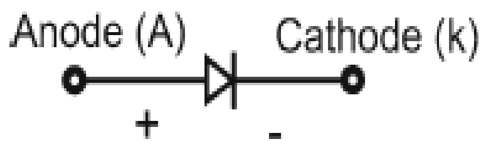
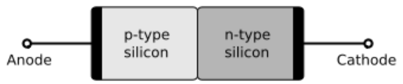
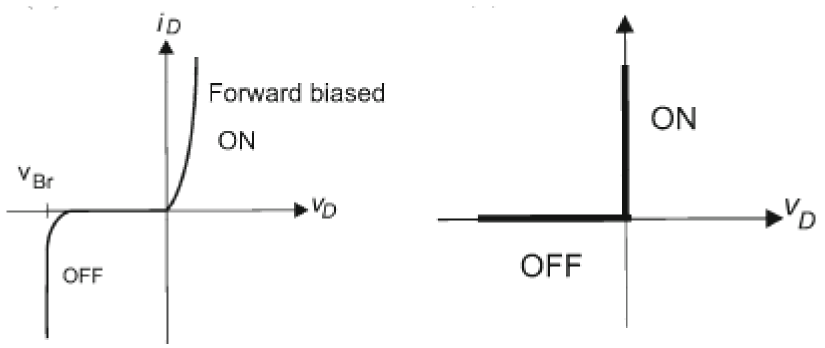
Uncontrolled switch

- Diode is also known as a rectifier and is an uncontrolled switch. It is an element with two connectors, seen in image 9. The connectors are anode (A) and cathode (K). In the ideal case, diode current (id) is one-way, meaning current is only going from anode to cathode.





- Diode voltage V_d is measured as the voltage between anode and cathode. U-I diode characteristics are presented in the right image. In the first quadrant, the diode is in open mode, meaning it is conducting. On diode, we have a small drop of voltage that is dependent on semiconductor type that is used in the diode. Voltage drop on silicon diode is 0.7V and in germanium diode approximately 0.3V. . In the third quadrant, diode is closed, meaning there is no minimal current or current leakage.



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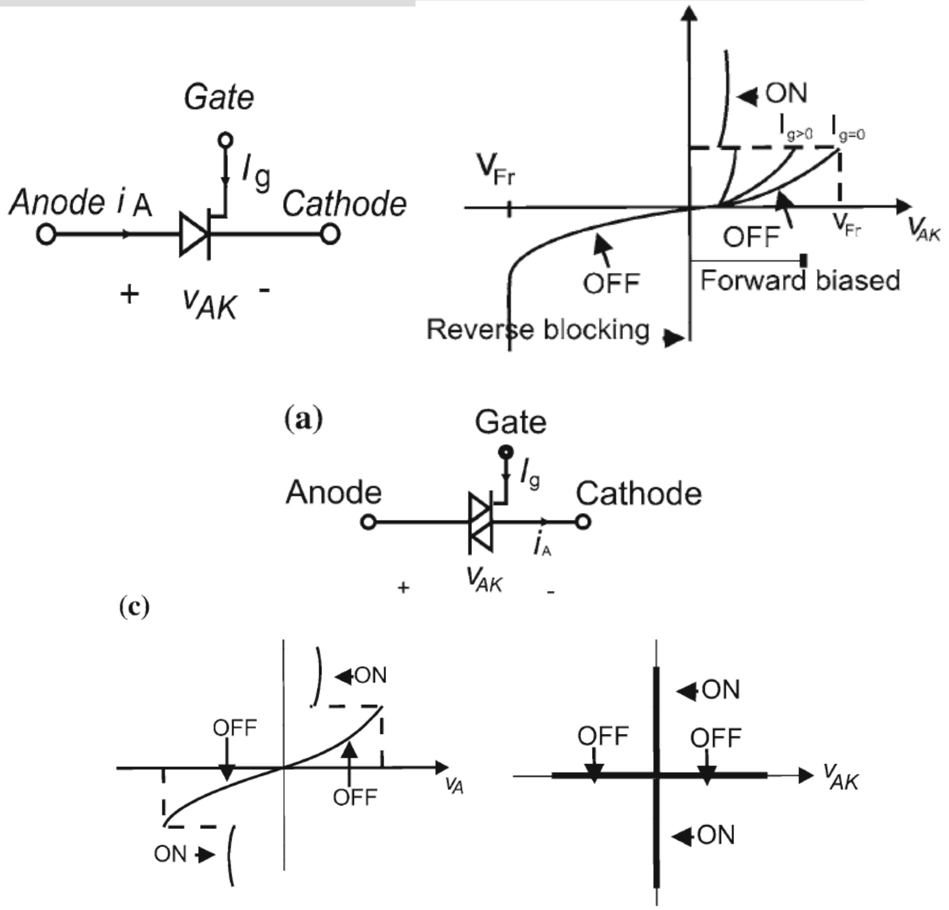
Half-controlled switch

- Thyristor or SCR is semiconductor switch which can be opened with control clamp gate.
- When the switch is on, it cannot be turned off through control clamp and thyristor works similar as a diode. This means thyristor is classified as a half-controlled switch.
- Even though there are certain similarities between thyristor and diode, thyristor is working differently. Thyristor current is running from the anode to cathode, and thyristor voltage U_{AK} is positive, which is presented in U-I characteristic.



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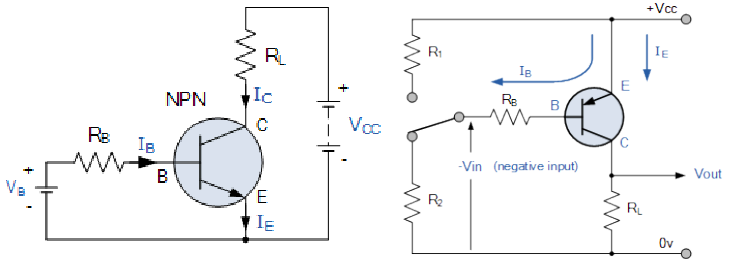
Fully controlled switches

In fully controlled switches, the modes open/closed can be activated through control connector.

- **Bipolar transistor**–BJT (bipolar junction transistor) is a fully controlled switch, where we use base (B) to open the switch. The current in it goes from the collector (C) to emitter E) and in the reverse direction, the transistor is non-conductive
- **MOSFET transistor** MOSFET (metal oxide semiconductor field effect transistor) has been named after operating principle. Similarly as a transistor, it has three connectors (G),(D) and (S). Channel openness is controlled through a connector (G), which uses electric field between the reverse polarized substrate for its functioning
- **IGBT transistor** is hybrid between BJT and MOSFET transistor. IGBT contains good characteristics of MOSFET, such as fast switching and low conducting resistance of BJT transistor. IGBT is Darlington connection, made of MOSFET and BJT transistor. MOSFET controls base current in BJT transistor.



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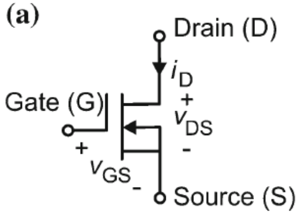

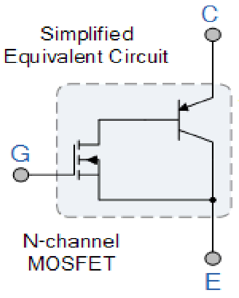

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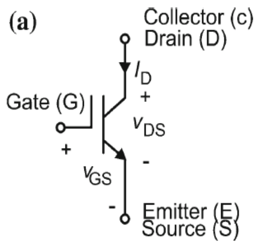

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Fully controlled switches

- Comparison between fully controlled switches:

Property	***BJT***	***MOSFET***	***IGBT***
Voltage rating	High<1kV	High <1kV	Very High >1kV
Current rating	High<500A	Low<200A	High>500A
Input drive	h_{FE} 20-200	3-10V	4-8V
Input impendance	Low	High	High
Output impendance	Low	Medium	Low
Swithing speed	Slow	Fast	Medium
Cost	Low	Medium	High

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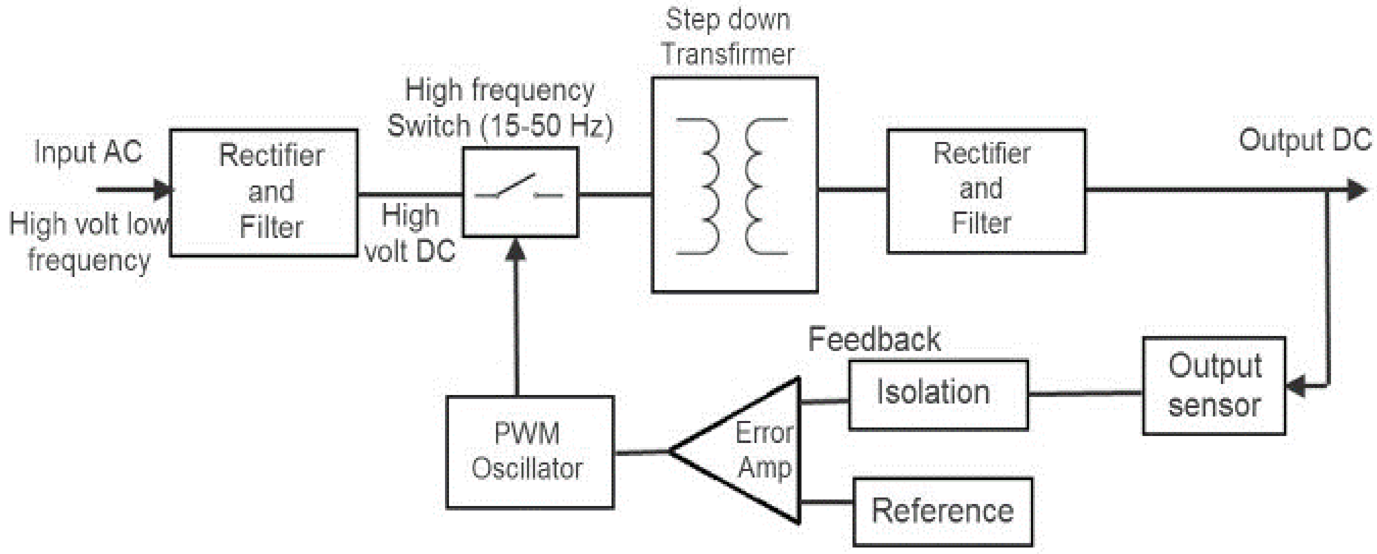
AC-DC switch converters – rectifiers

- AC-DC converters are power circuits that convert alternating voltage into one-way.
- AD-DC converters are part of most electronic devices. The reason for this are their efficiency and yield that are both very important.
- The advantage of switch AC-DC rectifier in comparison to the ordinary one is higher efficiency and smaller dimensions with the same powers.



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AC-DC switch converters – rectifiers

- The AC-DC converter operates in such a way that, in the first block, the alternating input voltage is immediately directed by a half-wave or full-wave diode rectifier. Many AC-DC converters in the first stage contain various low-pass filters to eliminate interference and noise from the network.
- In the second phase, the rectified voltage is passed through a high frequency switch that is guided according to the desired output voltage. The switching frequency is usually 10-100kHz depending on the type of converter.
- From the switch, we get a train of pulses that have the same frequency as a switch. We drive the pulse train to a transformer that reduces the voltage.
- At the output of the transformer, a low pass smoothing filter or a DC-DC switching converter can be used. Depending on the desired DC output, the switching speed of the switch is controlled.

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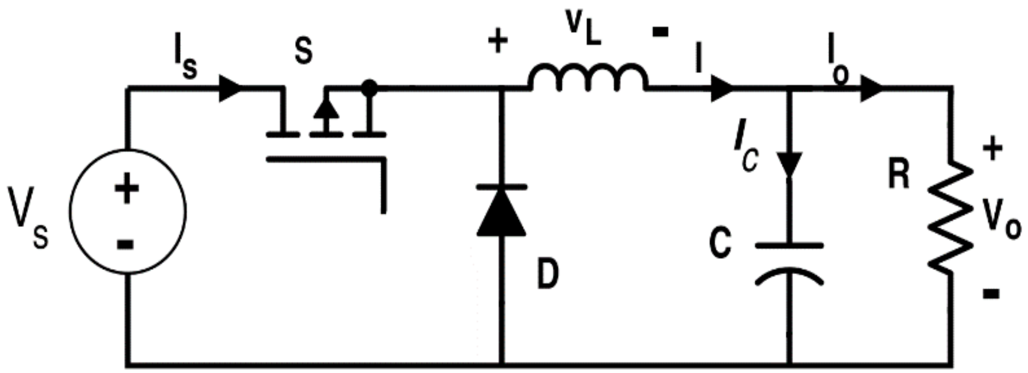
DC-DC switch converters - step down

- **Converter step-down,** as the name suggests, lowers DC input voltage. Operating principle of the converter is simple; we control the switch by leading input voltage to LC circuit.
- When the switch is closed, the current is going to LC circuit and powers the load. In case the switch is not closed, diode itself closes secondary circuit that is the consequence of own induction in the coil. The switch is usually controlled by PWM signal. LC circuit is a low-frequency sieve that smooths corrugations of the output voltage due to the switching. For controlled switch depending on the power, we can use BJT, MOSFET or IGBT transistor.



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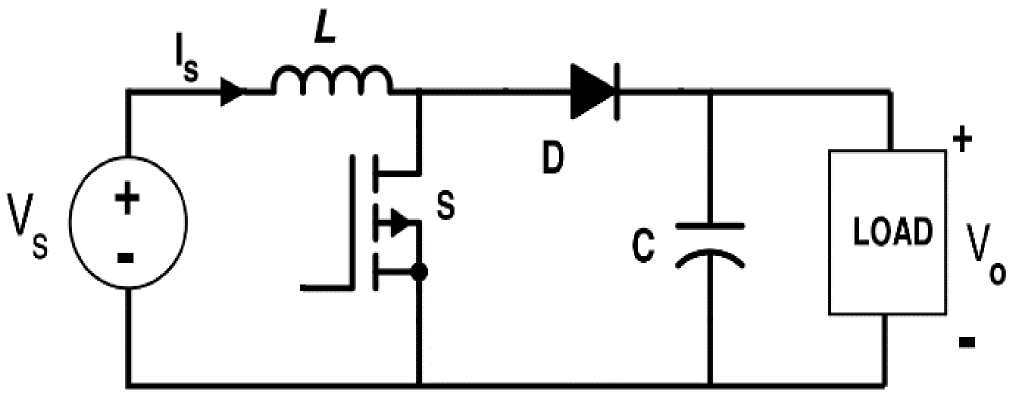
DC-DC switch converters – Step up

- **Step-up converter** is used for one-way consumers that need a higher voltage than is connected.
- The operating principle is based on own induction of the input coil. With fast switching, the switches cause voltage edges in coil L. In case the switch is concluded, the current is going through the coil back into the power supply. In this phase, we cause coil's own induction, meaning we save energy in L. When the switch is not closed due to own induction, the coil redirects saved energy through the diode into a capacitor that acts as energy storage in secondary circle and smoothener of the output voltage. Size of voltage edges depends on switching speed.



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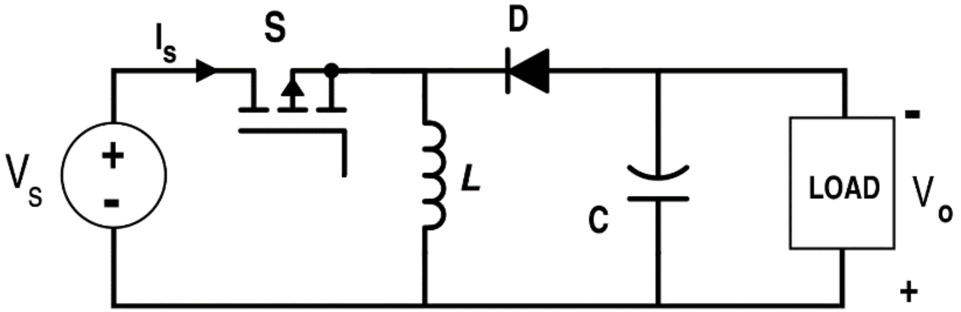
DC-DC switch converters – Step-down/up

- Depending on the common connector in an electronic circuit, there often appears a need for negative voltage on converter output. For this cases, step-down/up is used.
- Step-down/up converter consists of cascade converter step-down and step-up. The presented scheme shows realization of both converters with half-set of elements. The converter can generate lower or higher voltage depending on connected potential. The operating principles are following: when the switch is closed, the current goes through the coil L. When the switch is open due to own induction of coil L and negatively polarized diode, the current goes in the reverse direction. On capacitor C we get negative voltage, depending on connected voltage. The ratio between output and input voltage is given with duty cycle of PWM signal (V_0/V_s=D (1/(1-D))).



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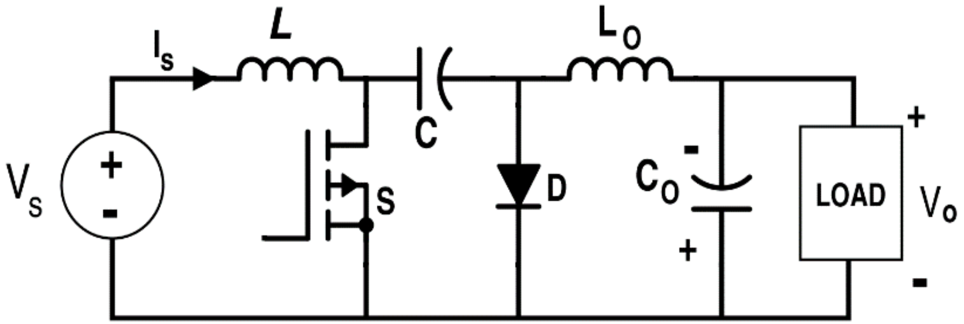
DC-DC switch converters – Ćuk converter

- Ćuk converter was named after Slobodan Ćuk, who has been the first to develop such circuit.
- Ćuk converter is basically step-down/up converter that can generate a negative voltage in output. The main difference is that capacitor and coil is responsible for energy transfer, in comparison to previous examples. For Ćuk converter it is typical that the energy is being transmitted in both switch modes (ON and OFF). In classical converter, the energy is only transmitted when the switch is in one state open or closed.



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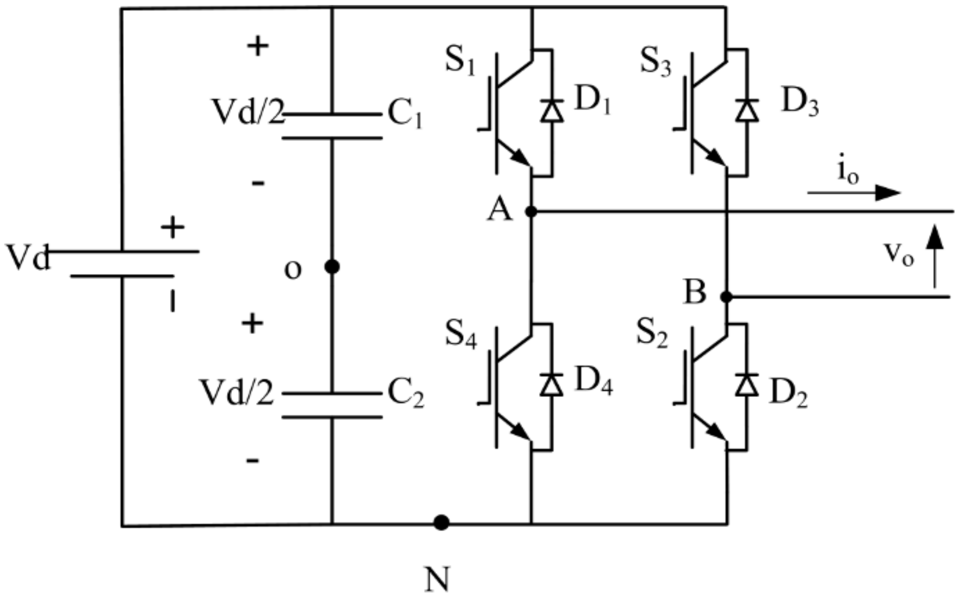
DC-AC switch converters – inverters

- DC-AC converters are electrical power engineering circuits that convert the output of the one-way voltage source, such as batteries, solar cells or fuel cells into alternating AC voltage. Inverters are often used for propulsion of electrical motors or voltage generators. Inverters are key in systems of uninterruptible power supplies system UPS. Inverters can often be classified depending on their output power and number of phases (single or three-phase) and depending on conversion type (half-wave or full-wave).
- The operating principle of the circuit is based on electronic control of switches S_1-S_4. The switches are switched diagonally S_1S_2 and S_3S_4, where we need to be careful not to close S_1S_4 or S_3S_2.



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