



# **EEE 5451 Power Electronics**

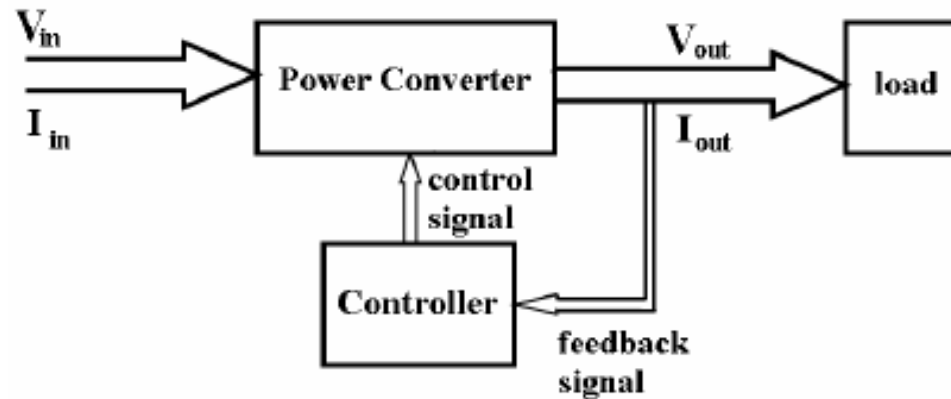
## **Lecture 2: Power Semiconductor Devices**

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# 2.1 Introduction

Fig. 2.1 - The block diagram shows the components of a Power Electronic system and how they are interlinked.



➤ A power electronic system converts electrical energy from one form to another and ensures the following is achieved –

1. Maximum efficiency

2. Maximum reliability

3. Maximum availability

4. Minimum cost

5. Least weight

6. Small size

- Applications of Power Electronics are classified into two types – Static Applications and Drive Applications.

## 2.1.1 Static Applications

- This utilizes non-moving and/or rotating mechanical parts such as welding, heating, cooling, and electro-plating and DC power supply.



**Fig. 2.2 - DC Power Supply**

## 2.1.2 Drive Applications

- Drive applications have rotating parts such as motors. Examples include compressors, pumps, conveyer belts and air conditioning systems.

### Air Conditioning System

- Power electronics is extensively used in air conditioners to control elements such as compressors.

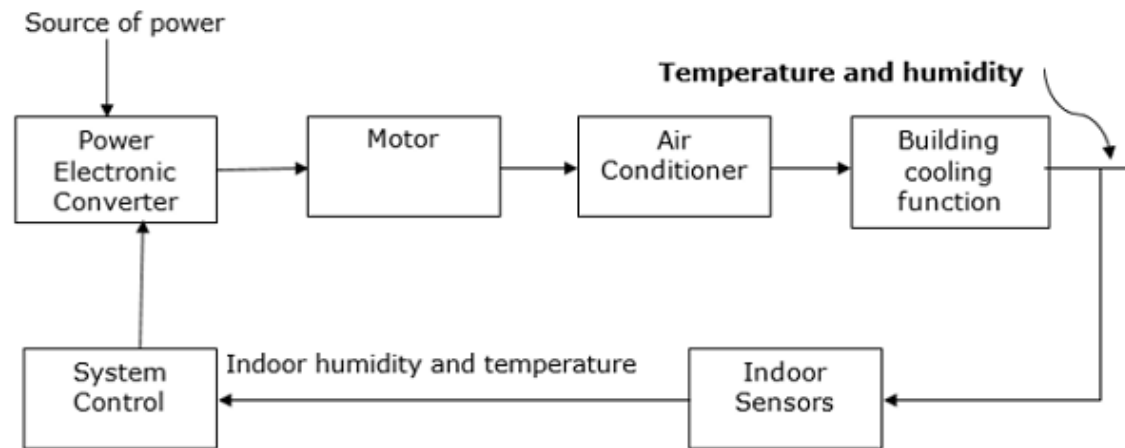


Fig. 2.3 - A schematic diagram that shows how power electronics is used in air conditioners is shown below.

# 2.2 Power Semiconductor Switches

❖ The main power semiconductor devices of interest are Diode, SCR, TRIAC, BJT, IGBT and MOSFET.

## 2.2.1 Diode

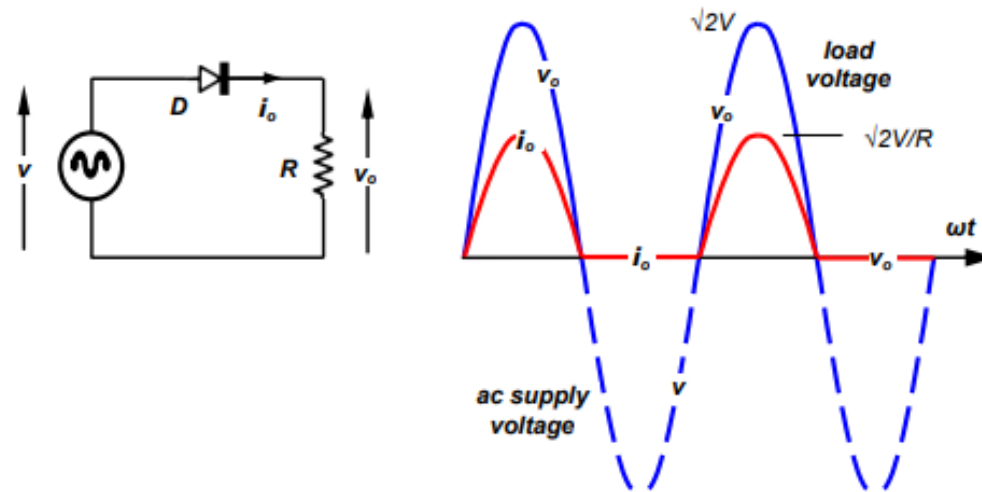


Fig. 2.4 - Application in a half-wave rectifier

# Diode

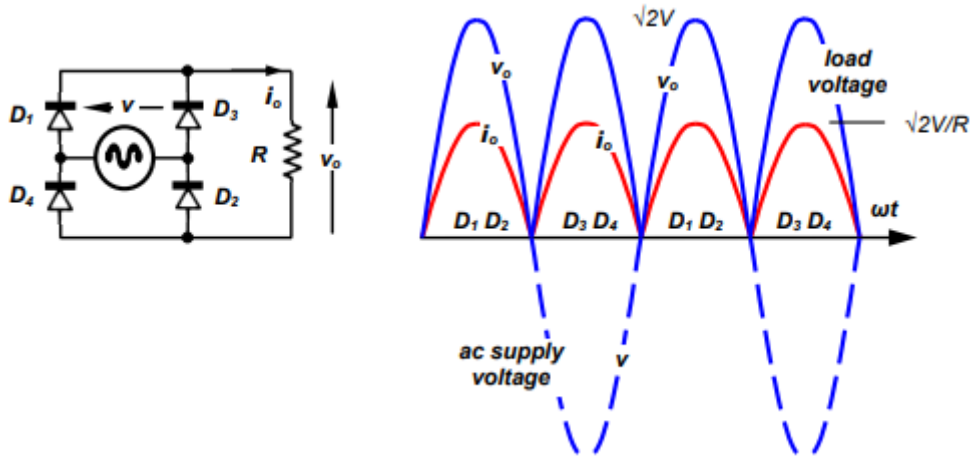


Fig. 2.5(a) - Application in a full-wave rectifier

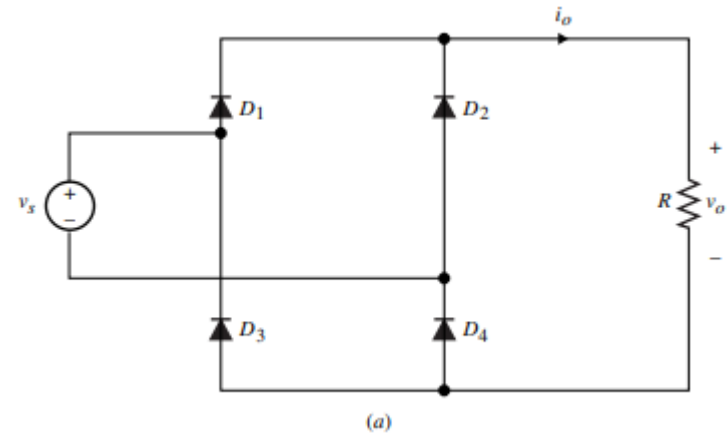


Fig. 2.5(b) – Alternative form of circuit (a)

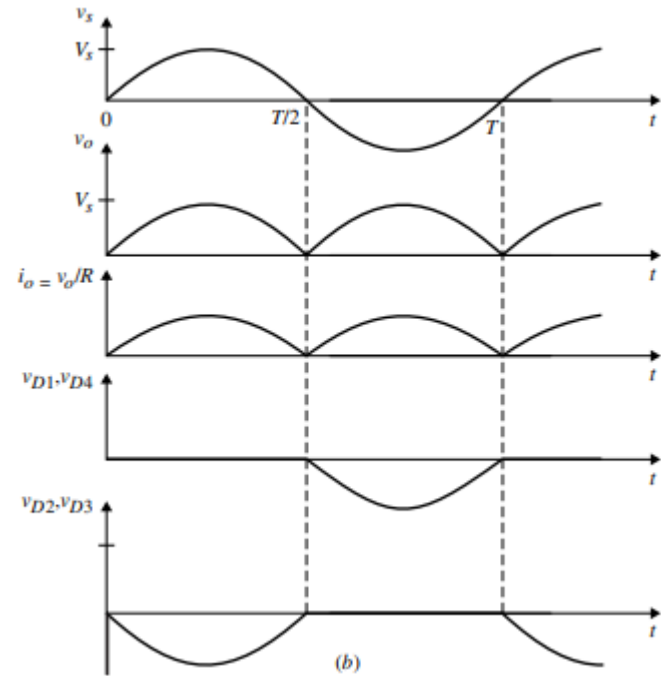
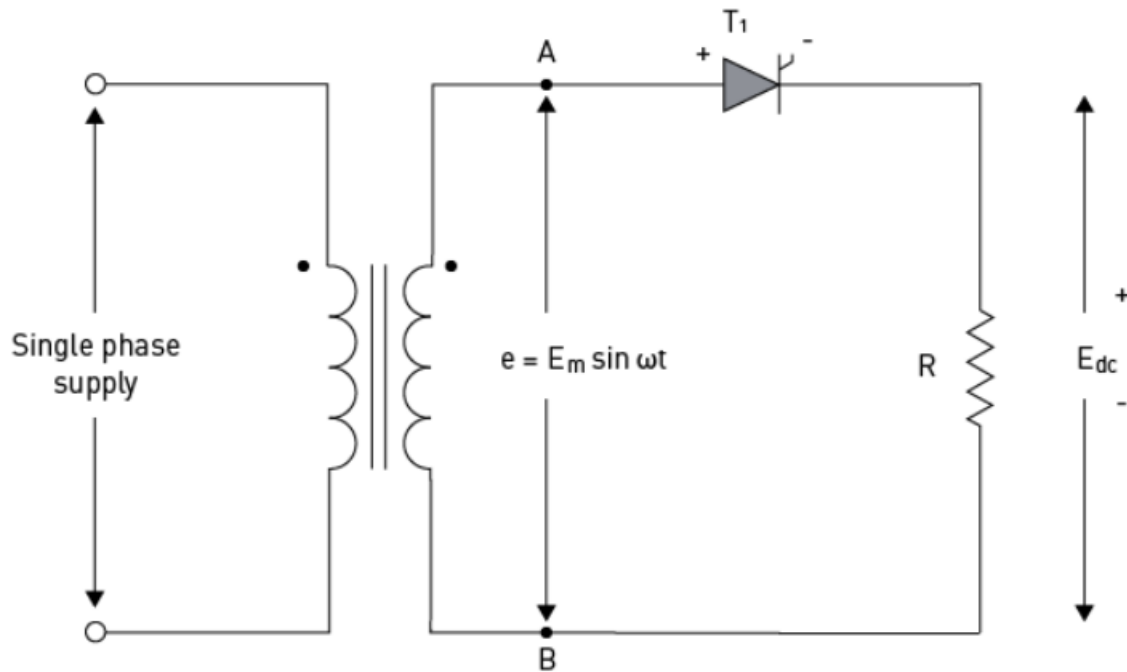


Fig. 2.5(c) – Output waveforms

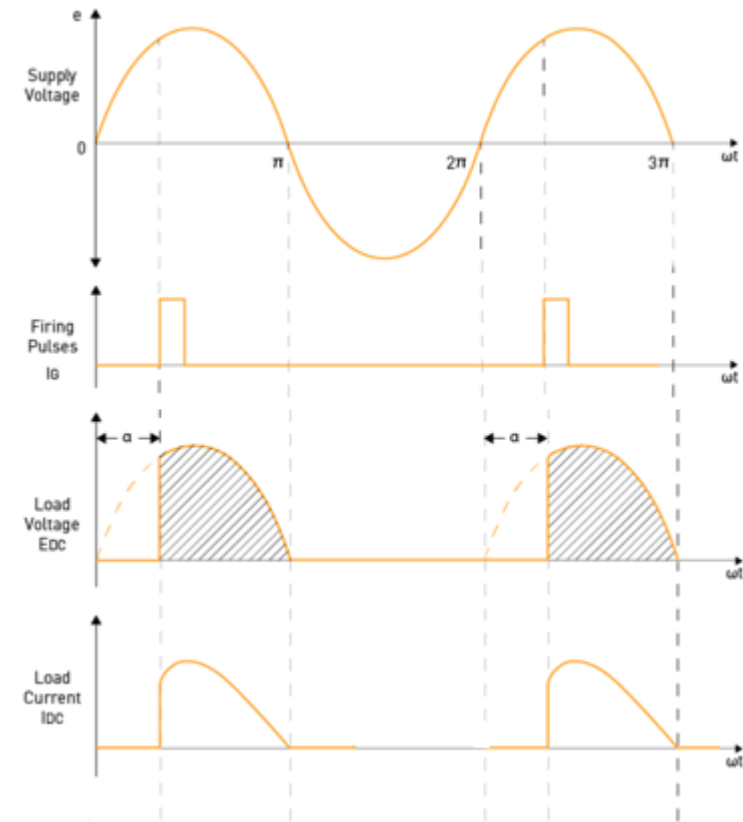
## 2.2.2 Silicon Controlled Rectifier

- A silicon controlled rectifier or semiconductor-controlled rectifier is a four-layer solid state current-controlling device.
- The name "silicon controlled rectifier" is General Electric's trade name for a type of thyristor.
- SCRs are mainly used in electronic devices that require control of high voltage and power.
- This makes them applicable in medium and high AC power operations such as motor control function.



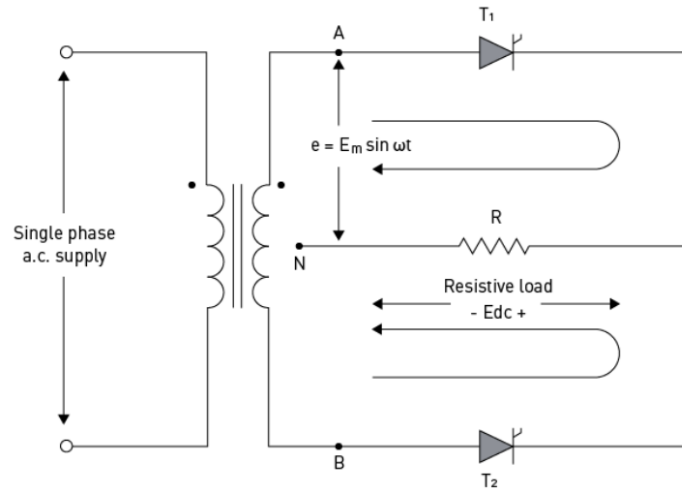


**Fig. 2.6 - Half-wave Controlled Rectifier Circuit**

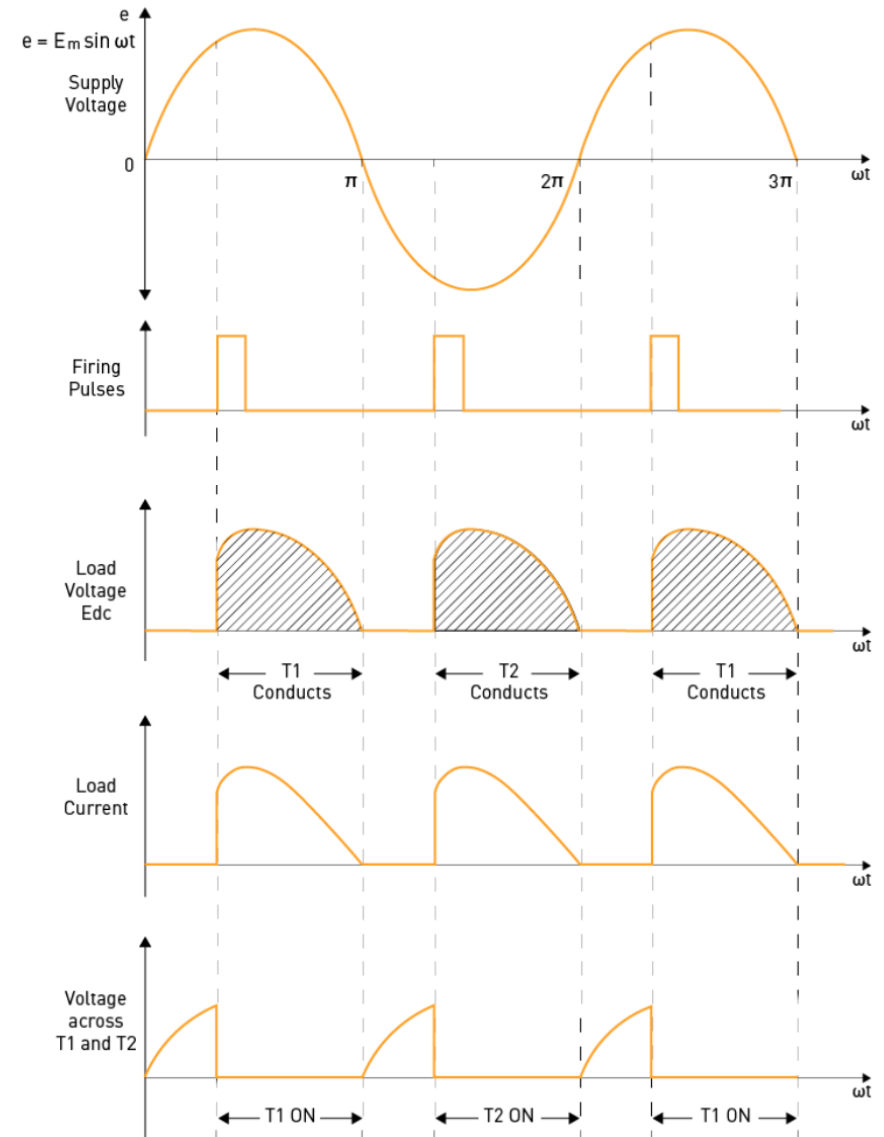


**Fig. 2.7 - Output characteristics**



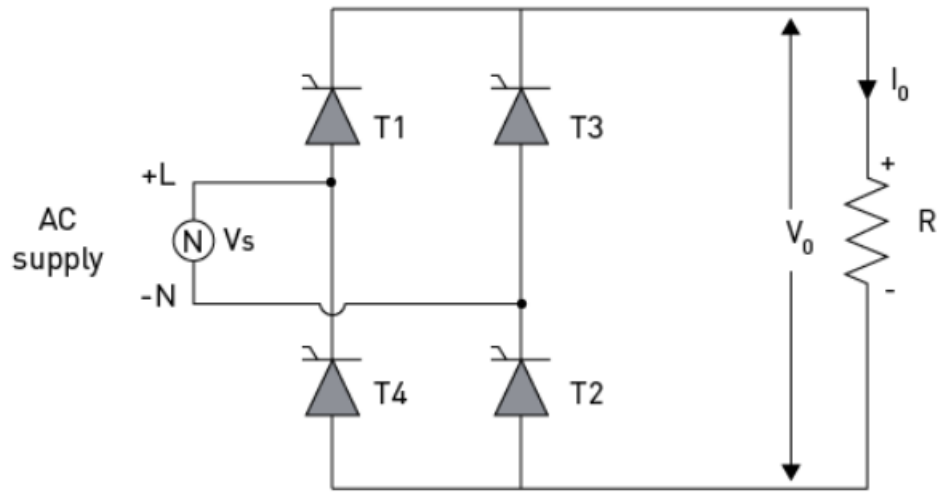


**Fig. 2.8 - Full-wave Controlled Center-tap Rectifier Circuit**

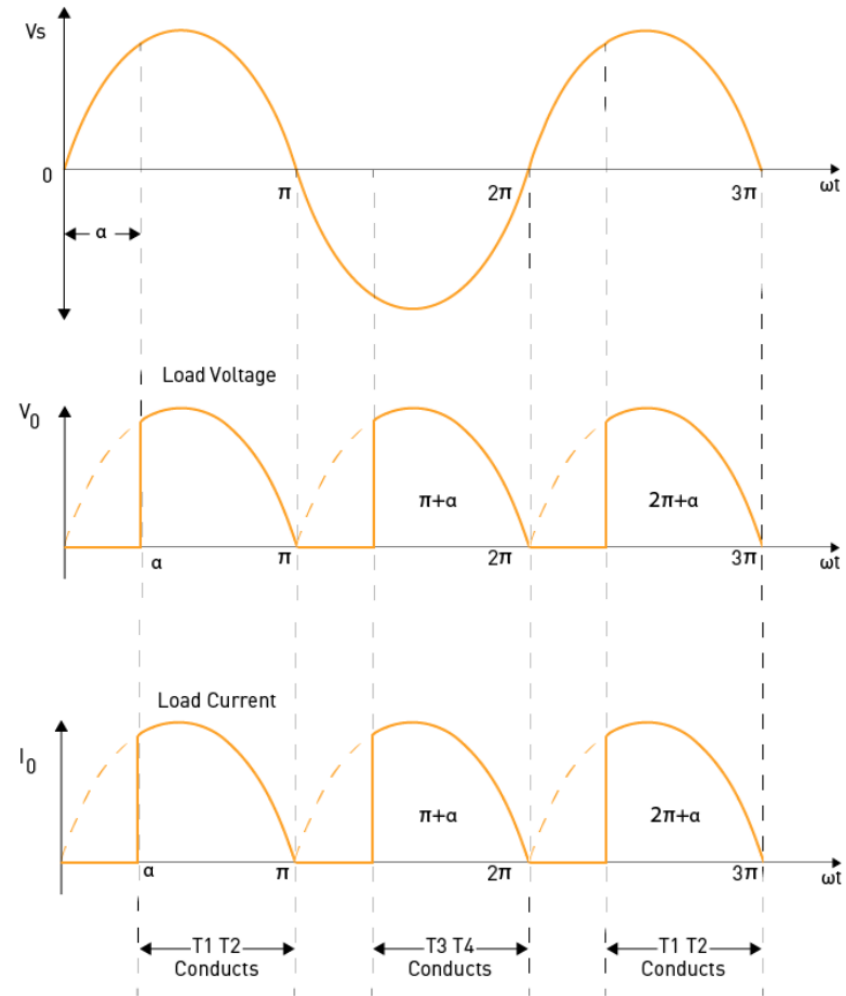


**Fig. 2.9 – Output waveforms**





**Fig. 2.10 - Full-wave Controlled Rectifier Circuit**

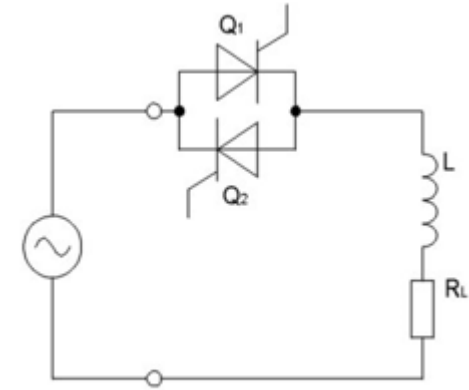


**Fig. 2.11 – Output waveforms**

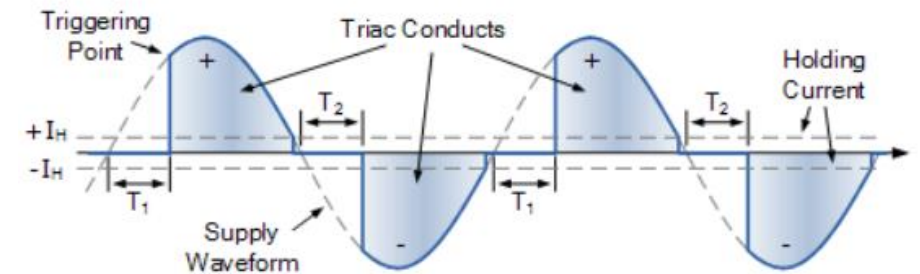


## 2.2.3 TRIAC

- The acronym TRIAC stands for Triode for Alternating Current.
- A TRIAC is a semiconductor device with three terminals that control the flow of current, thus the name Triac.
- Unlike an SCR, a TRIAC is bi-directional while an SCR is unidirectional.
- It is ideal for operation utilizing AC power for switching purposes since it can control current flow for both halves in an alternating current cycle.



**Fig. 2.12 – Circuit application**



**Fig. 2.13 – Output characteristics**

# TRIAC Operation

- The operation of the TRIAC is based on the thyristor. It facilitates the switching function in AC electrical components and systems.
- TRIACs are normally used in applications that do not require very high power because they exhibit non-symmetrical switching in their operation.
- As a result, TRIACs are used in motor controls, light residential light dimmers and small electric fans to control speed.

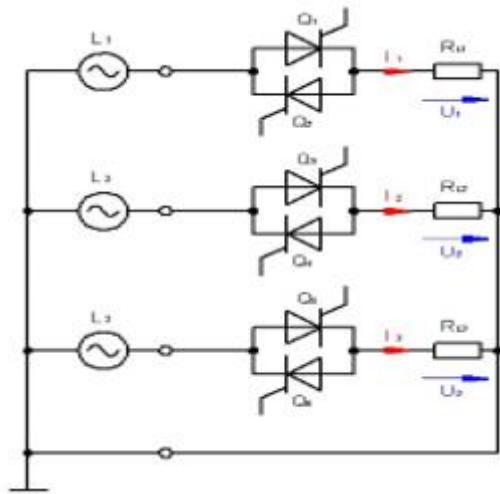


Fig. 2.14 – Three-phase circuit application

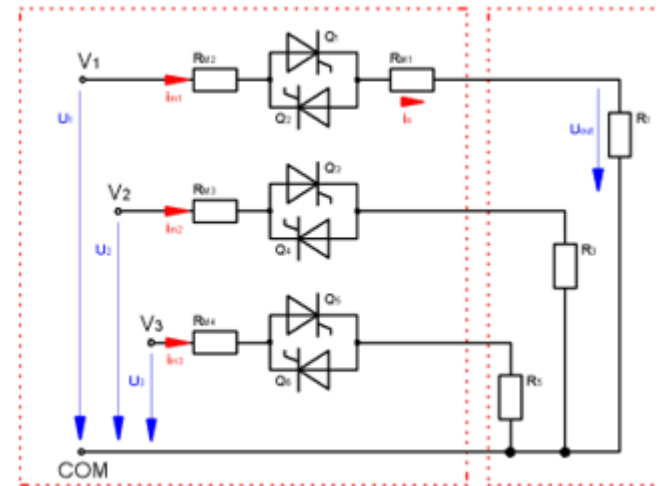


Fig. 2.15 – Alternative circuit

## 2.2.4 BJT

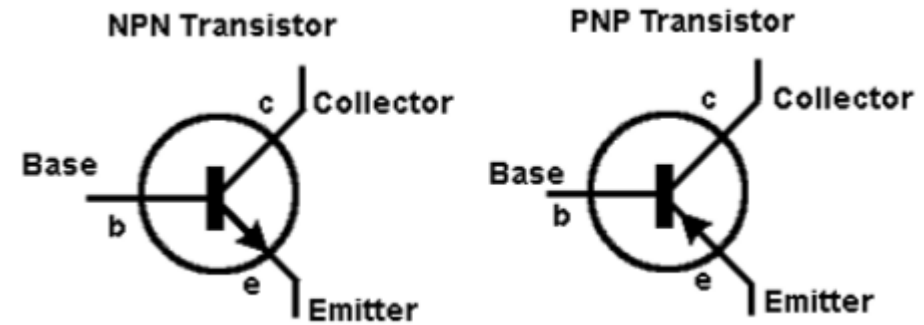


Fig. 2.16 – Device symbols

- A Bipolar Junction Transistor (BJT) is a transistor whose operation depends on the contact made by two semiconductors.
- It can act as a switch, amplifier or oscillator.
- It is known as a bipolar transistor since its operation requires two types of charge carriers (holes and electrons).
- Holes constitute the dominant charge carriers in P-type semiconductors whereas electrons are the main charge bearers in N-type semiconductors.

## 2.2.5 IGBT

- The insulated gate bipolar transistor (IGBT) is a semiconductor device with three terminals and is used mainly as an electronic switch.
- It is characterized by fast switching and high efficiency, which makes it a necessary component in modern appliances such as lamp ballasts, electric cars and variable frequency drives (VFDs).
- Its ability to turn on and off, rapidly, makes it applicable in amplifiers to process complex wave-patterns with pulse width modulation.
- IGBT combines the characteristics of MOSFETs and BJTs to attain high current and low saturation voltage capacity respectively.



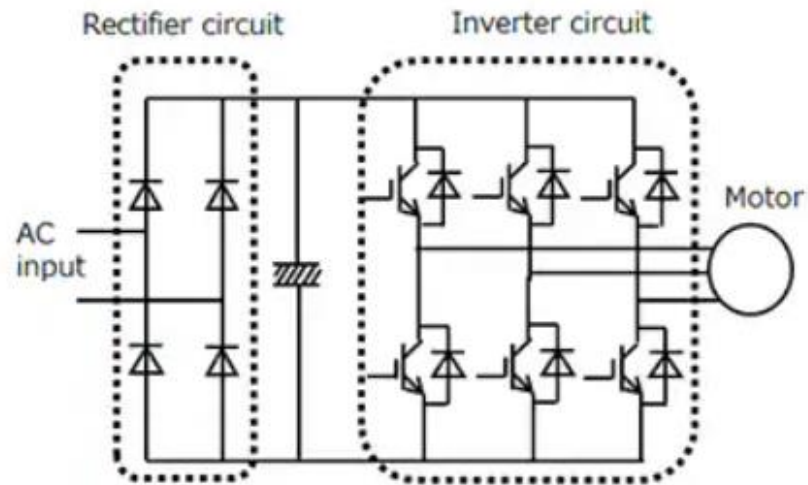


Fig. 2.17 - Motor drive circuit

- IGBTs for inverter applications are used in home appliances such as air conditioners and refrigerators, industrial motors, and automotive main motor controllers to improve their efficiency.

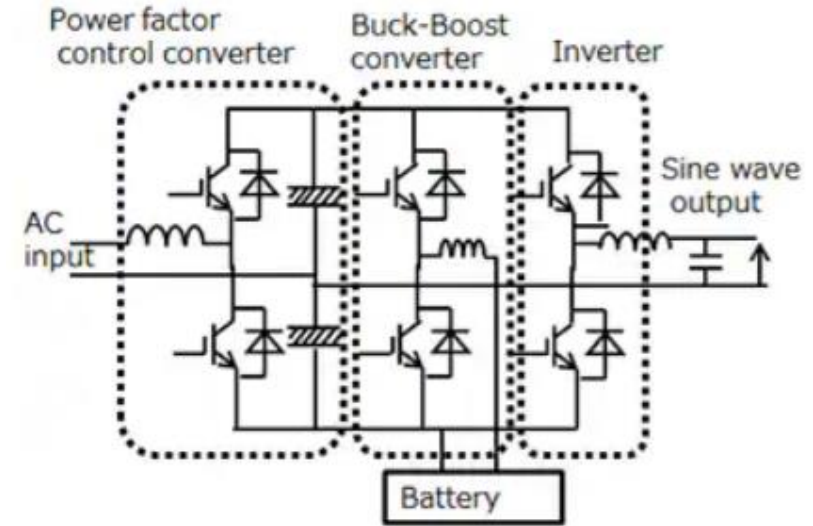
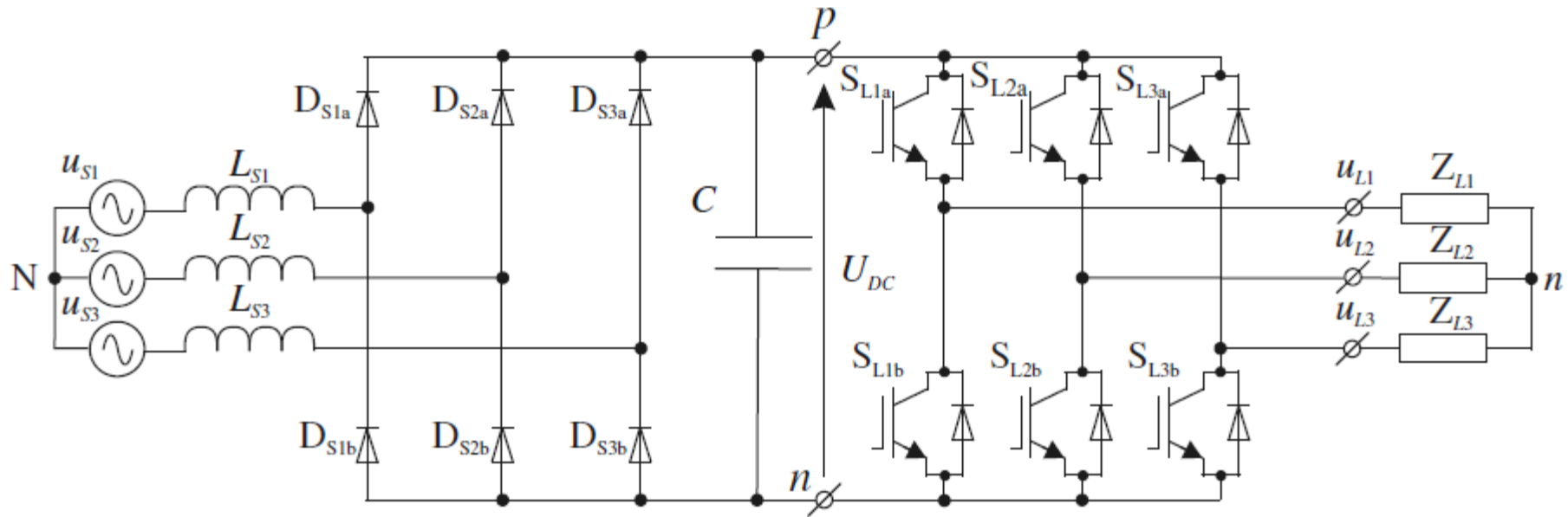


Fig. 2.18 - UPS circuit

**Figure (b) shows an example of a UPS circuit. IGBTs are in middle- and large-capacity (several kVA or higher-capacity) models, contributing to high efficiency and space saving.**



**Fig. 2.19 - Two-level indirect frequency converter with voltage source inverter and diode bridge rectifier**

- The DC-link capacitor decouples two AC power conversion stages and ensures the independent control of the two stages.

➤ The control of the output is achieved by modulating the duty cycles of the devices in the inverter stage so as to produce near-sinusoidal output currents in the inductive load, at a desired amplitude and frequency.

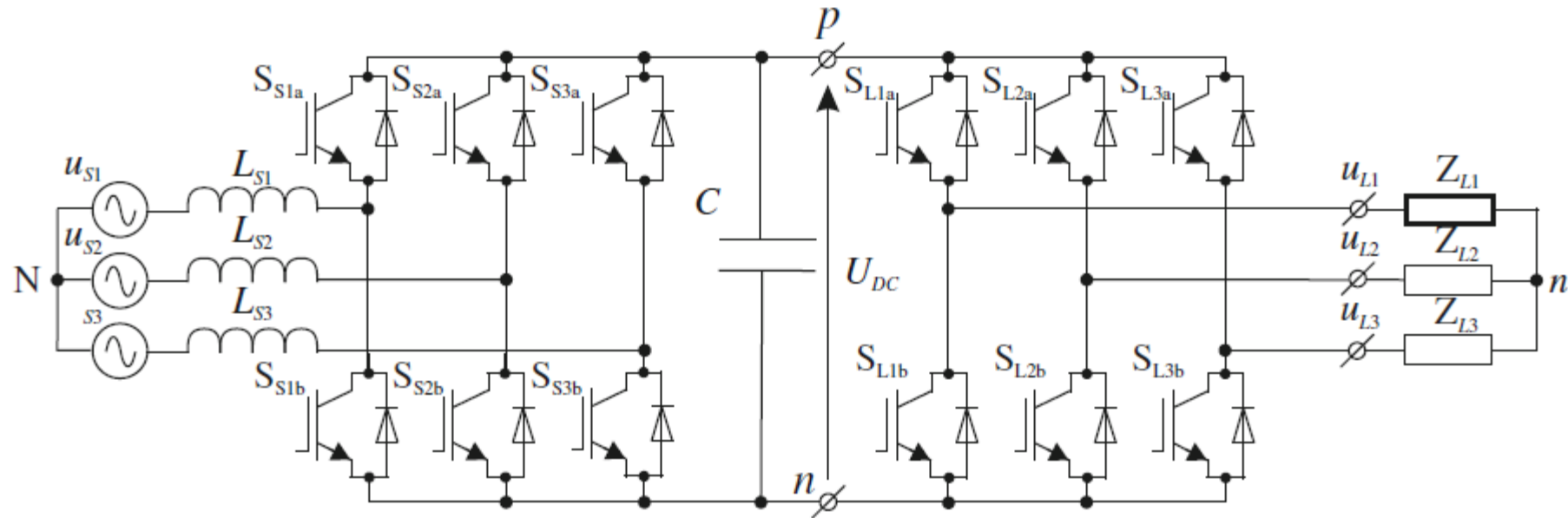
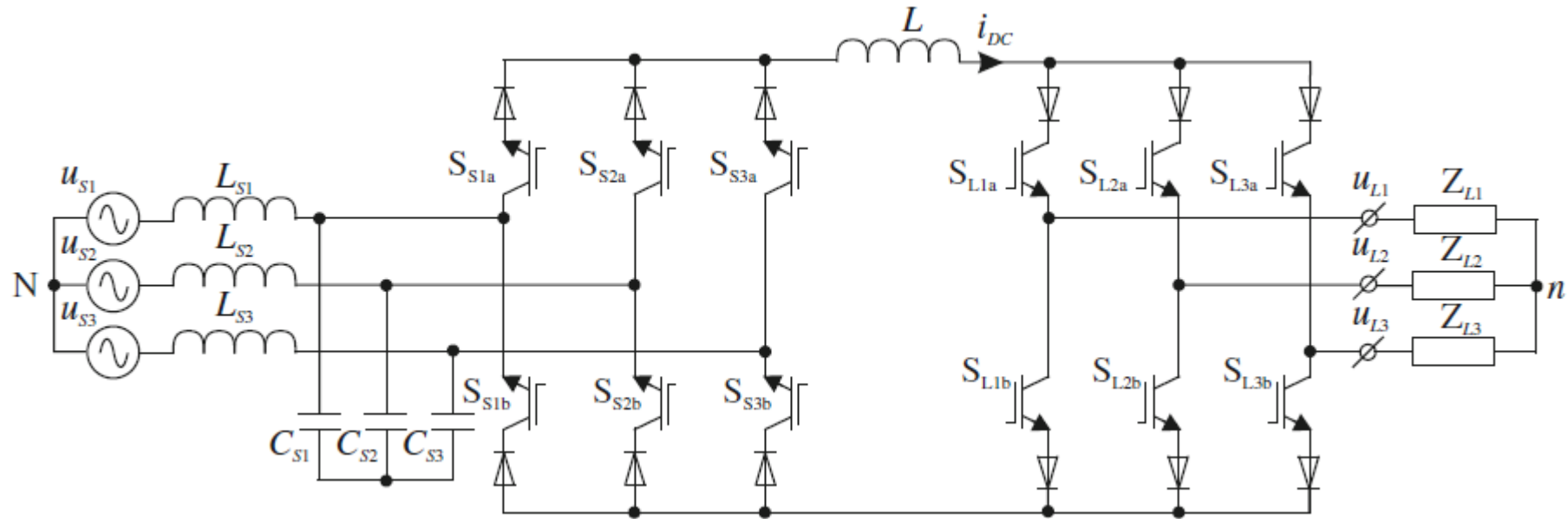


Fig. 2.20 - Back-to-back converter (BB-VSI), an improvement on Fig. 2.19

- An alternative solution to a frequency converter with voltage source inverter is the solution with PWM current source inverter (CSI), presented in Fig. 2.21. The CSI produces sinusoidal supply current waveforms similar to the back-to-back VSI.



**Fig. 2.21** - Two-level indirect frequency converter with current source inverter

# Applications of IGBTs

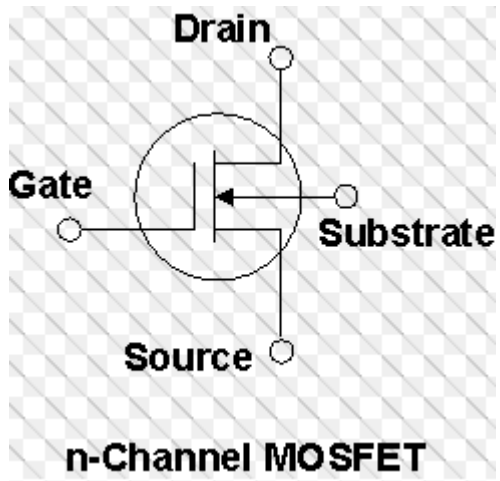
- The IGBT is used in medium to ultra-high power applications, for example traction motor.
- In large IGBTs, it is possible to handle high current in the range of hundred amperes and blocking voltages of up to 6 kV.
- IGBTs are also used in power electronic devices such as converters, inverters and other appliances where the need for solid state switching is necessary.
- Bipolars are available with high current and voltage. However, their switching speeds are low.
- On the contrary, MOSFETs have high switching speeds although they are expensive.



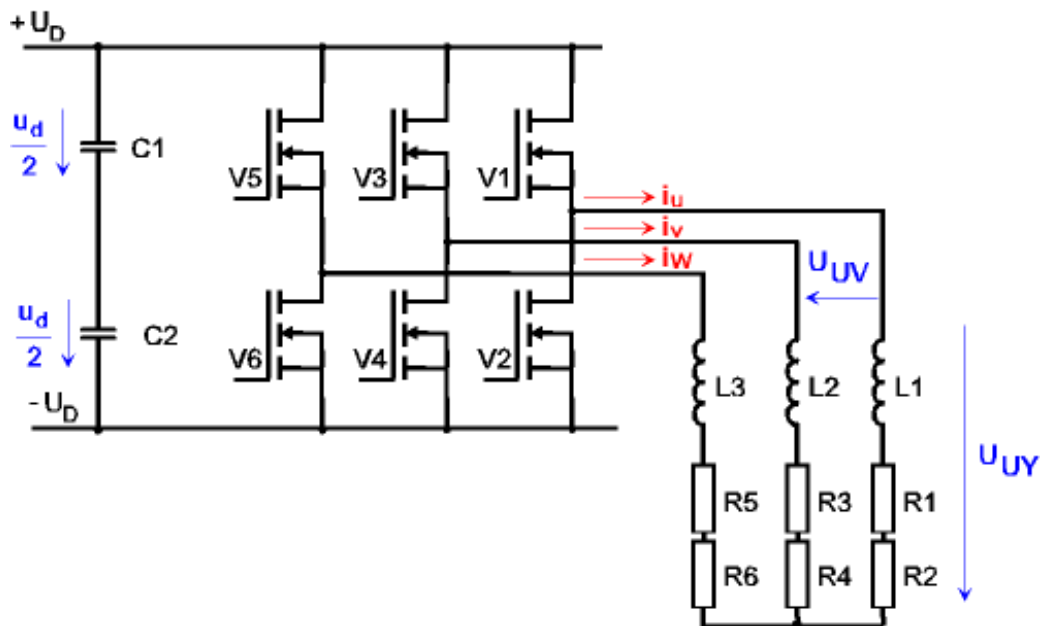
## 2.2.6 MOSFET

- A Metal Oxide Semiconductor Field Effect Transistor (MOSFET) is a type of transistor used to switch electronic signals.
- It has four terminals namely; source (S), Drain (D), Gate (G) and Body (B).
- The MOSFET's body is normally connected to the terminal of the source(S), which results into a three-terminal device similar to other field effect transistors (FET).
- Since these two main terminals are usually interconnected via a short circuit, only three terminals are visible in electrical diagrams.
- It is the most common device in circuits that are both digital and analogue.

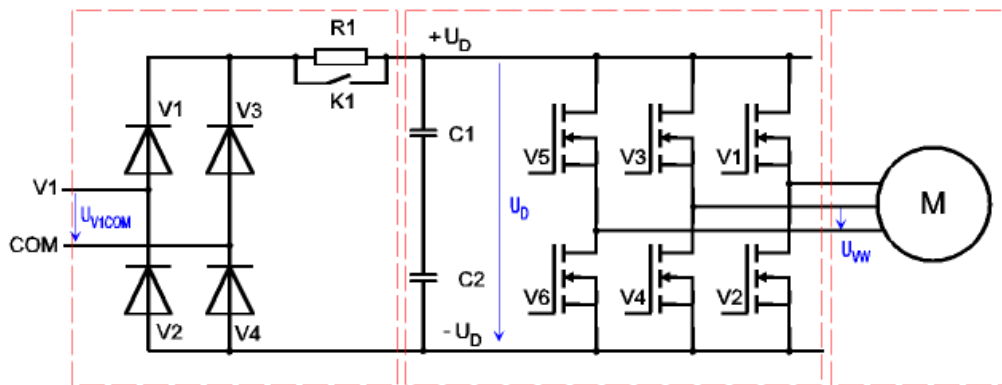




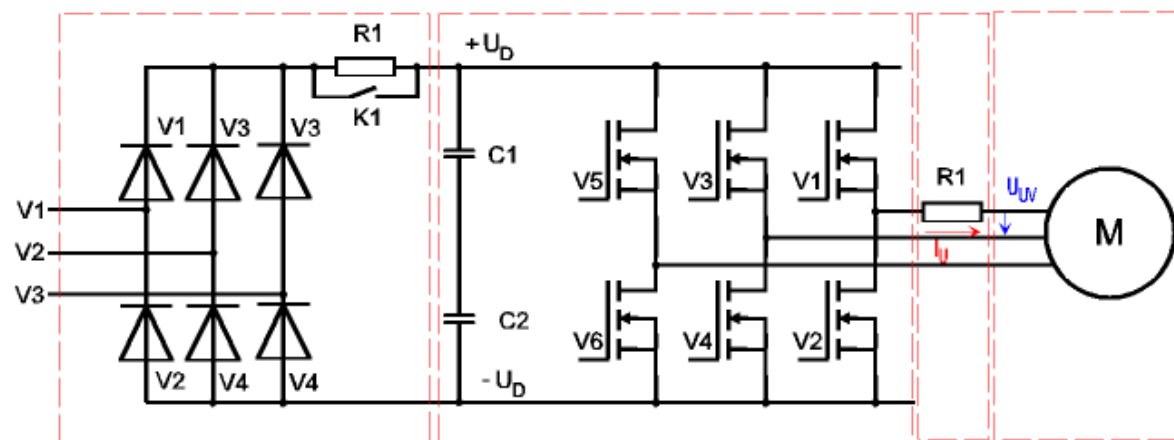
**Fig. 2.22 - MOSFET symbol**



**Fig. 2.23 – Three-phase inverter**



**Fig. 2.24 – MOSFET Application in a motor drive circuit with 1-Phase input**



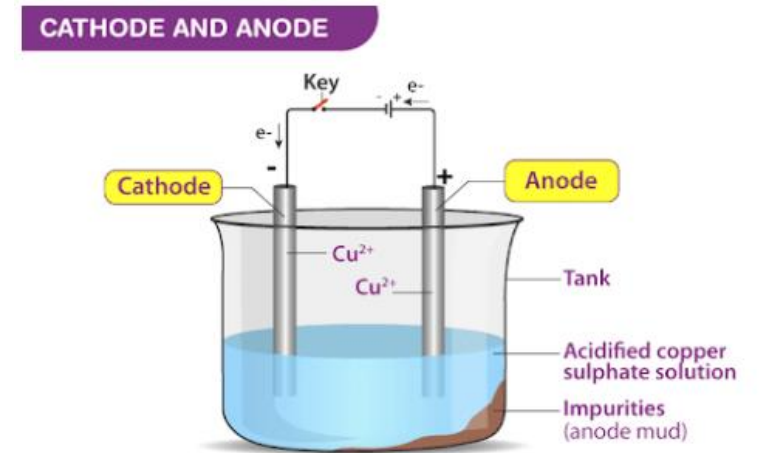
**Fig. 2.25 – MOSFET Application in a motor drive circuit with 3-Phase input**

# Conclusion

- Power electronics is the technology associated with the efficient conversion, control and conditioning of electric power by static means from its available input form into the desired electrical output form.
- Power electronic converters can be found wherever there is a need to modify the electrical energy form (i.e. modify its voltage, current or frequency.)
- With "classical" electronics, electrical currents and voltages are used to carry information, whereas with power electronics, they carry power.
- Some examples of uses for power electronic systems are DC/DC converters used in many mobile devices, such as cell phones or PDAs, and AC/DC converters in computers and televisions.



- Large scale power electronics are used to control hundreds of megawatt of power flow across a power system.
- Research in this area includes power electronics applications to control large scale power transmission and distribution as well as the integration of distributed and renewable energy sources into the grid.
- There is need for universities around the world to have a strong program on the emerging applications of wide band-gap semiconductor devices that offer high operating temperatures, higher efficiency and higher power density.



**Fig. 2.26 - Copper Cathode Production**

*End of Lecture 2!*