C6: POWER CIRCUITS (2)

- DC-DC converters
- AC-AC converters
- Power inverters

Switching DC-DC converters

- ***Functions of DC-DC converters:***

  - conversion of the DC input voltage (U_{in}) into a DC output voltage.(U_o);
  - stabilization of the continuous output voltage in relation to line and load variations;
  - reduction of AC voltage ripples at the exit below the imposed level;
  - ensuring isolation between input source and load (isolation is not always necessary);
  - protecting the system from electromagnetic interference (EMI);
  - the fulfillment of various national and international safety standards.

- ***Classification of d.c.-d.c. converters*** :

  - converters controlled with pulses width modulation (PWM) with hard switching *:*

    - **buck)**
    - **boost;**
    - **buck-boost;**
    - **Cuk; Zeta; SEPIC.**

  - soft switching and resonant converters.

Classification of DC-DC converters *from a constructive point of view*

- non-isolated power converter (with direct transfer) - limited use (eg: dc/dc converters with a single output size). The output range is limited by the input magnitude and the duty cycle of the converter.
- Isolated power converters (with transformer).

▪ *The introduction of a transformer removes many of the shortcomings of a converter without isolation, offering the following advantages:*

- ***Isolation between input and output.***
- ***Wide range of output voltages*** *(*output range approx. 5 times larger than in the case of non-isolated converters; the duty cycle of the conv. can be optimized, reducing its overload; the polarity of the voltage on each output is also selectable).
- ***Multiple outputs*** *(*by adding more windings in the secondary of the transformer).

▪*Disadvantages related to the introduction of the transformer in the converter structure:*

- *increasing the size and weight of the assembly;*
- *increase in power losses;*
- *the problem of generating voltage pulses due to leakage inductance.*

CONCLUSION isolated vs non-isolated converters

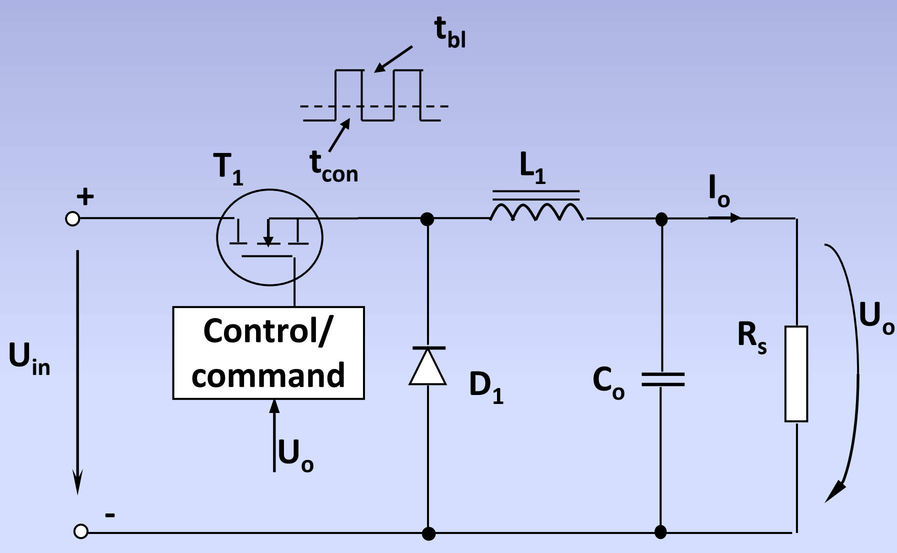
- Isolation is a very useful feature within power solutions as it is able to provide safe operation, reduce noise / ground loops and allow flexibility in how the voltage rails are configured with respect to one another.

- However, where non-isolated converters are able to be used, designers are able to take advantage of smaller size, better efficiency and lower costs.

- The intermediate bus architecture has been popular for several decades and, until recently, the IBC has been an isolated device. However, as this approach is finding new applications such as high-performance computing and datacoms, isolation is not required in the IBC as it is already present in the front-end SMPS (switch mode power supply).

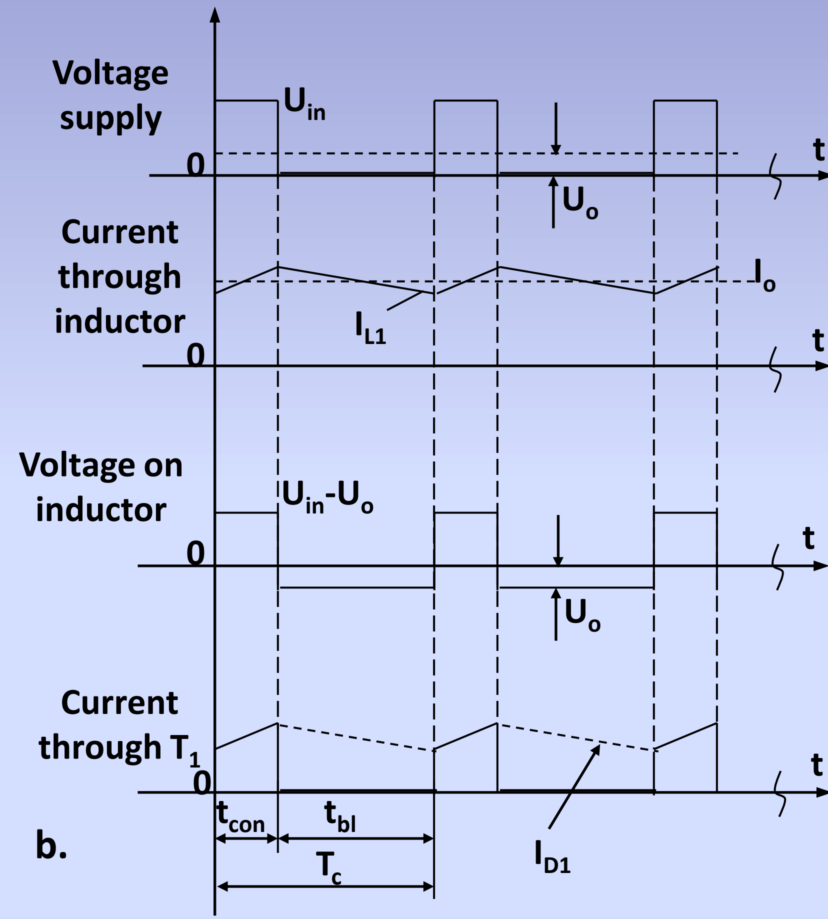
NON ISOLATED DC-DC CONVERTERS

❑ BUCK CONVERTER



a.

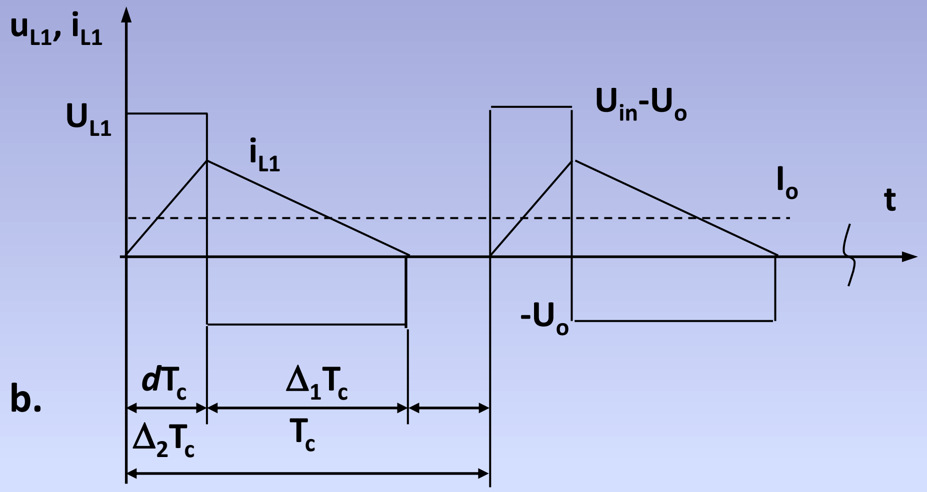
$$\frac{U_o}{U_{in}} = d, \qquad d = \frac{t_{con}}{T_c}$$



b.

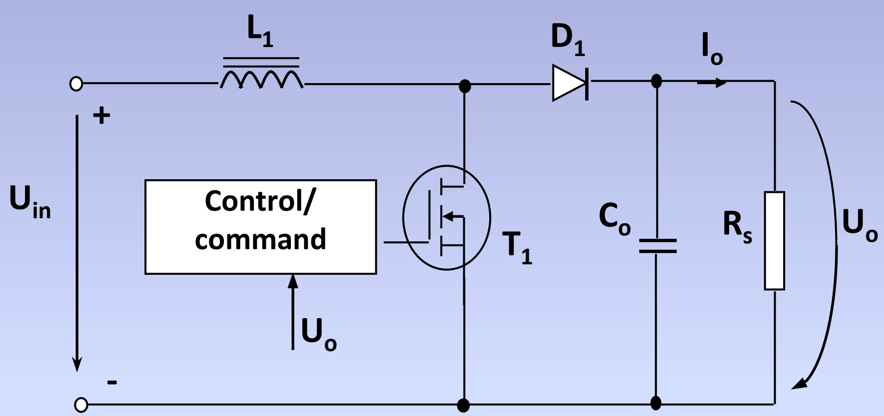
Buck converter: **a.** structure;
b. Waveforms to the specific continuous conduction mode.

discontinuous conduction mode



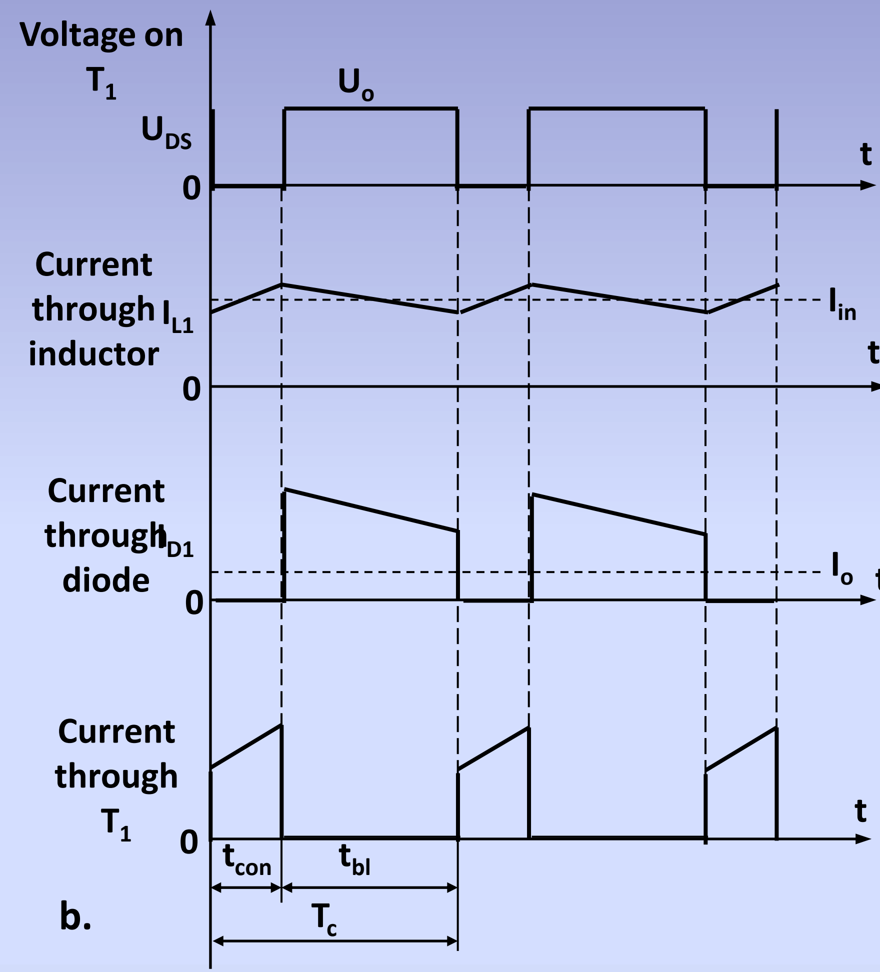
The average voltage at the coil terminals during a complete switching cycle must be equal to zero - at idle operation (no consumption).

❑ BOOST CONVERTER



a.

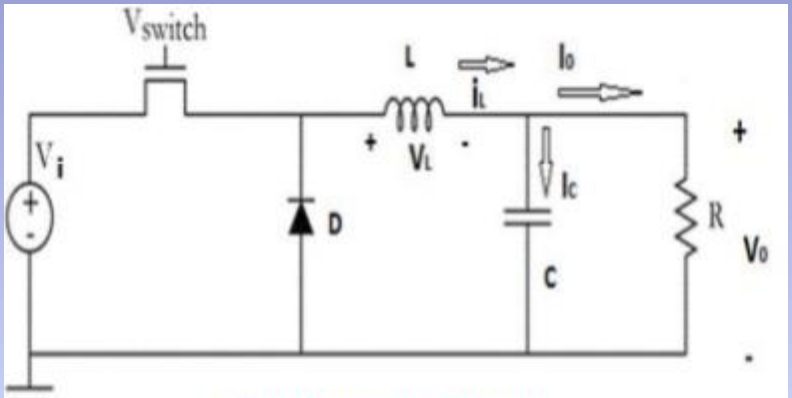
$$\frac{U_o}{U_{in}} = \frac{1}{1-d}$$



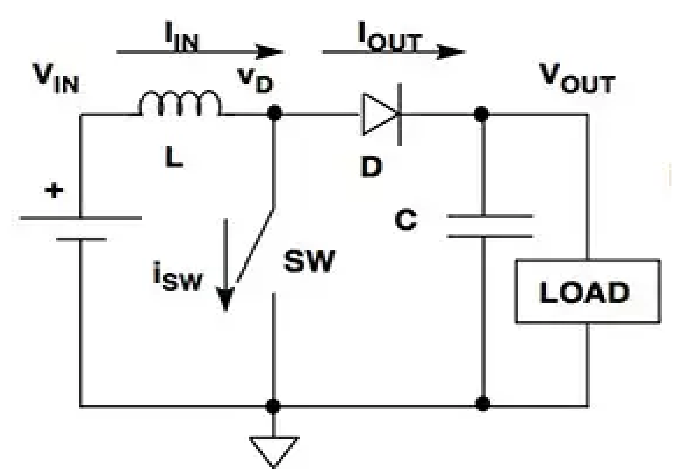
b.

Boost converter: **a.** structure; **b.** Waveforms to the specific continuous conduction mode

Difference between Buck converter and Boost converter



Buck Converter Circuit



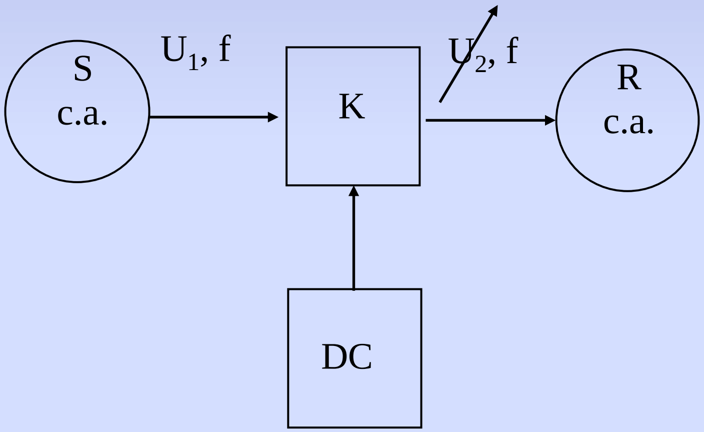
Boost Converter Circuit

- A buck converter is known as step down converter.
- The figure-1 depicts circuit of buck converter.
- It steps down input voltage and steps up input current.
- Hence, Vin > Vout and Iin < Iout

- A boost converter is known as step up converter.
- The figure-1 depicts circuit of boost converter.
- It steps up input voltage and steps down input current.
- Hence, Vin < Vout and Iin > Iout

AC-AC CONVERTERS (AC VOLTAGE REGULATOR)

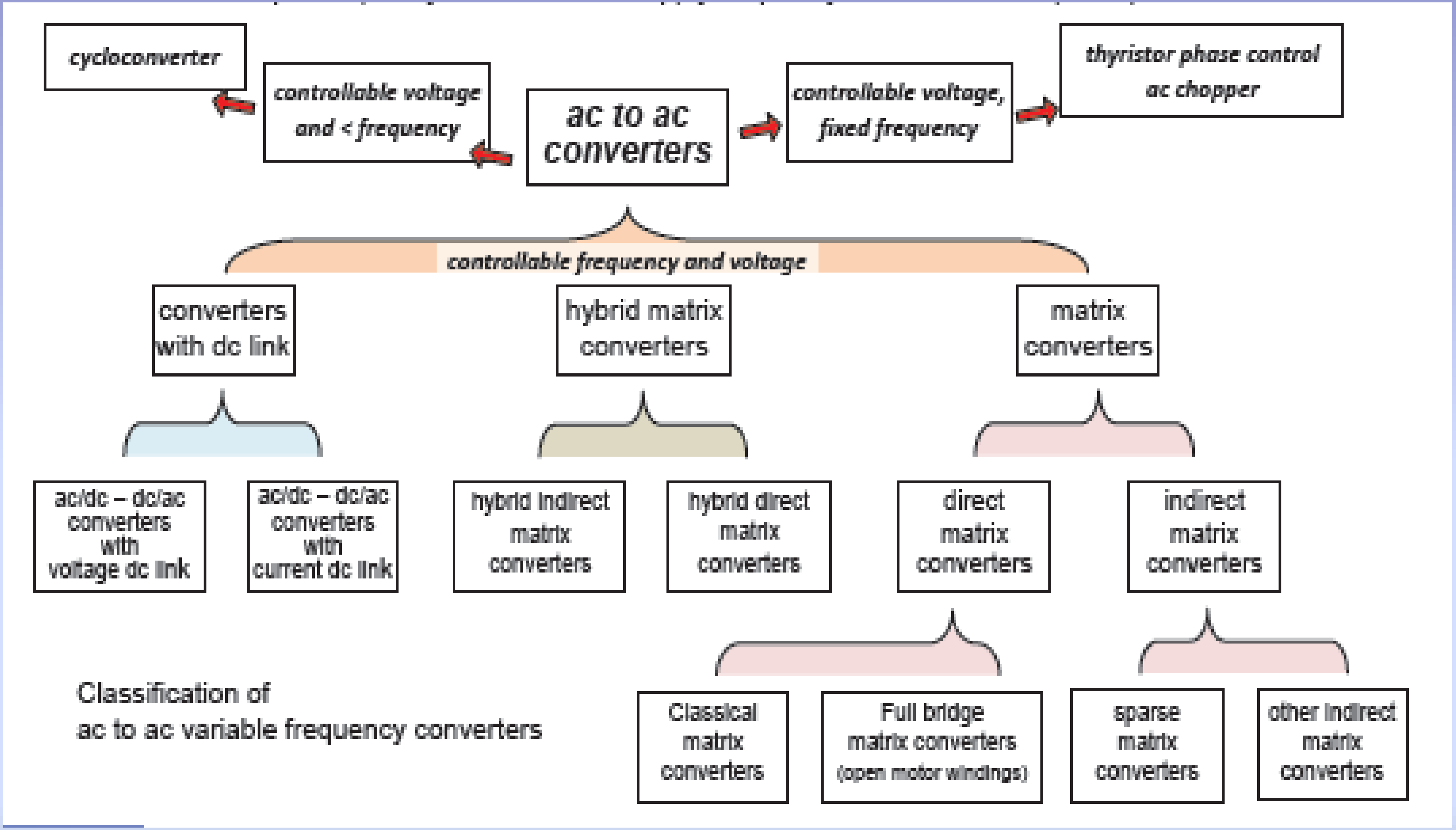
- are widely used to obtain an alternating voltage with variable effective value from an alternating current source (at the same frequency);
- Allow changes of the voltage and power control in circuits with alternating current sources and receivers. It changes the amplitude of the voltage but does not change the frequency.



Structure of AC voltage regulator.:
K-switch; DC- device of control/ command;
S c.a.-sourse of AC voltage;
R c.a.-receiver of AC voltage.

The output voltage is maintained for changes in input voltage, output load current, and load power factor.

Clasification of AC voltage regulator



Classification of AC voltage regulator

1st type of calssification

There are three basic ac regulator categories, depending on the relationship between the input supply frequency f_s, which is usually assumed single frequency sinusoidal, possibly multi-phased, and the output frequency f_o. Without the use of transformers (or boost inductors), the output voltage rms magnitude V_o rms is less than or equal to the input voltage rms magnitude V_s , V_o rms ≤ V_s .

- output frequency increased, $f_o > f_s$, for example, the matrix converter
- output frequency decreased, $f_o < f_s$, for example, the cycloconverter
- output frequency fundamental = supply frequency, $f_o = f_s$, for example, a phase controller

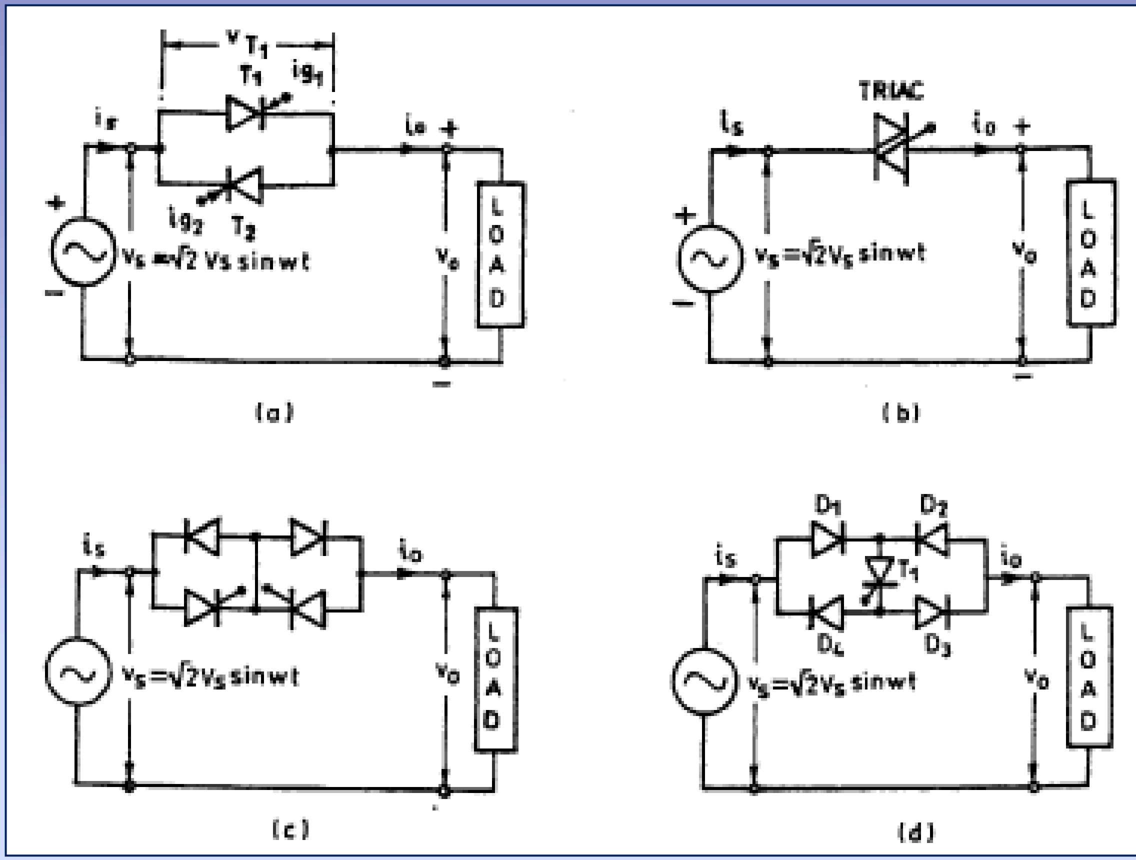
2nd type of classification

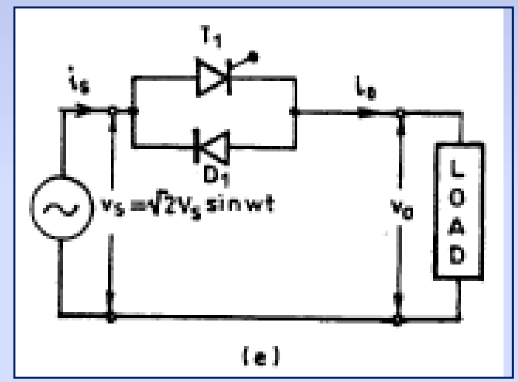
- by the number of phases:
  - single-phase AC voltage regulator;
  - three-phases AC voltage regulator.
- by control/ command mode:
  - Phase control ac voltage regulator;
  - Integral Cycle Control;
  - PWM ac voltage control (chopper).
    - buck;
    - boost;
    - buck-boost;
    - Cuk; Zeta; SEPIC.

Working Principle of AC Voltage Controller

In ***Phase Control method***, the phase relationship between the start of load current and the input supply voltage is controlled by controlling the firing angle of the thyristor.

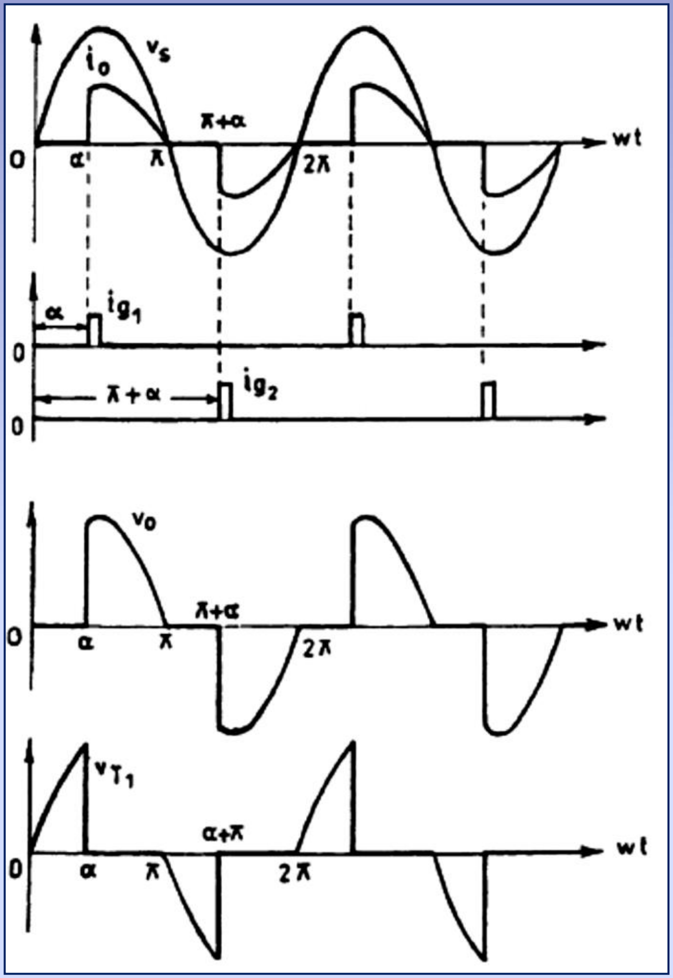
In ***Integral Cycle Control***, the AC input supply is switched ON for some integral cycles and turned OFF for further number of integral cycles.
Integral cycle control is mainly used for applications where the mechanical time constant or thermal time constant is quite high of the order of some seconds.
For example, mechanical time constant for many of the speed control drives, or the thermal time constant of the heating loads is usually quite high. For such applications, almost no variation in speed or temperature will be noticed if the control is achieved by connection the load to the source for some on-cycles and then disconnecting the load for some off-cycles. This form of power control is the integral cycle control.



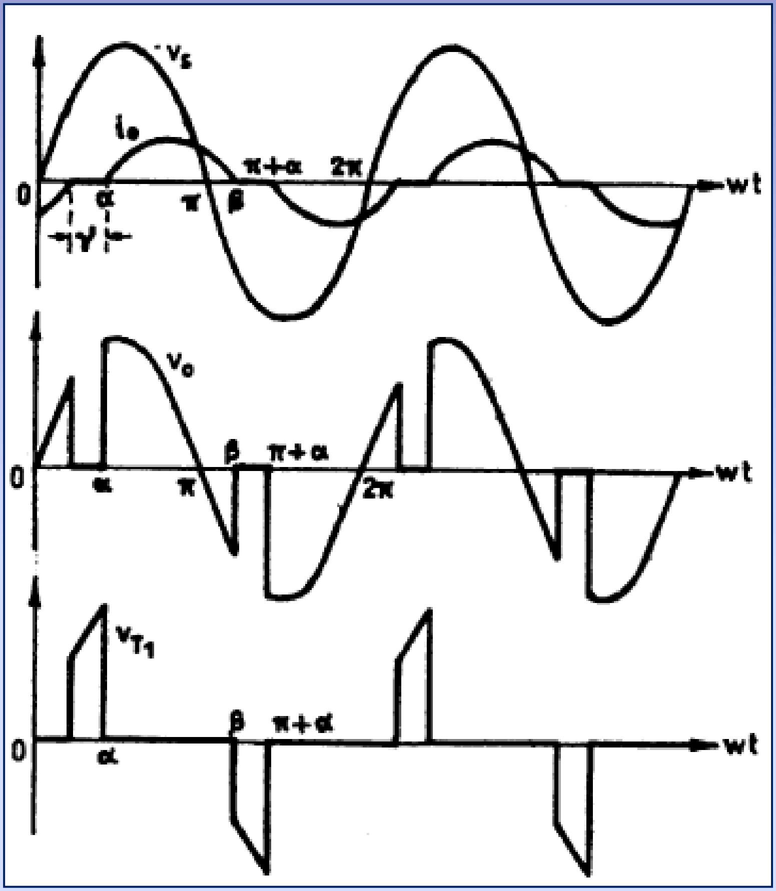


AC voltage regulator: (a) full wave with 2 thyristors; (b) full wave with triac; (c); full wave with thyristors and 2 back to back diodes; (d) full wave with 1 thyristor and 4 diodes; (e) half wave with back to back thyristor and diode

Wave forms in Phase Control method



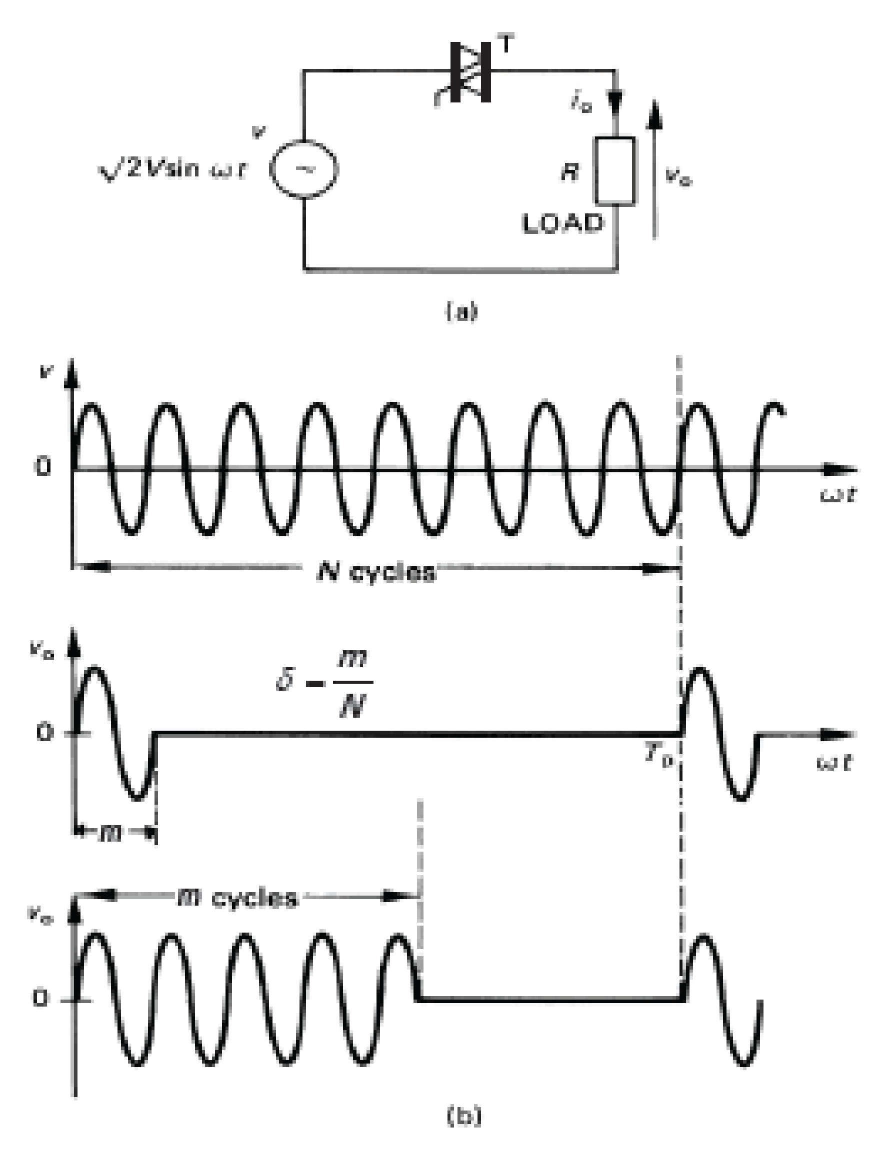
Wave forms of AC voltage regulator single phase, full wave, resistive load



Wave forms of AC voltage regulator single phase, full wave and load of RL.

Single-phase ac regulator – integral cycle control - line commutated

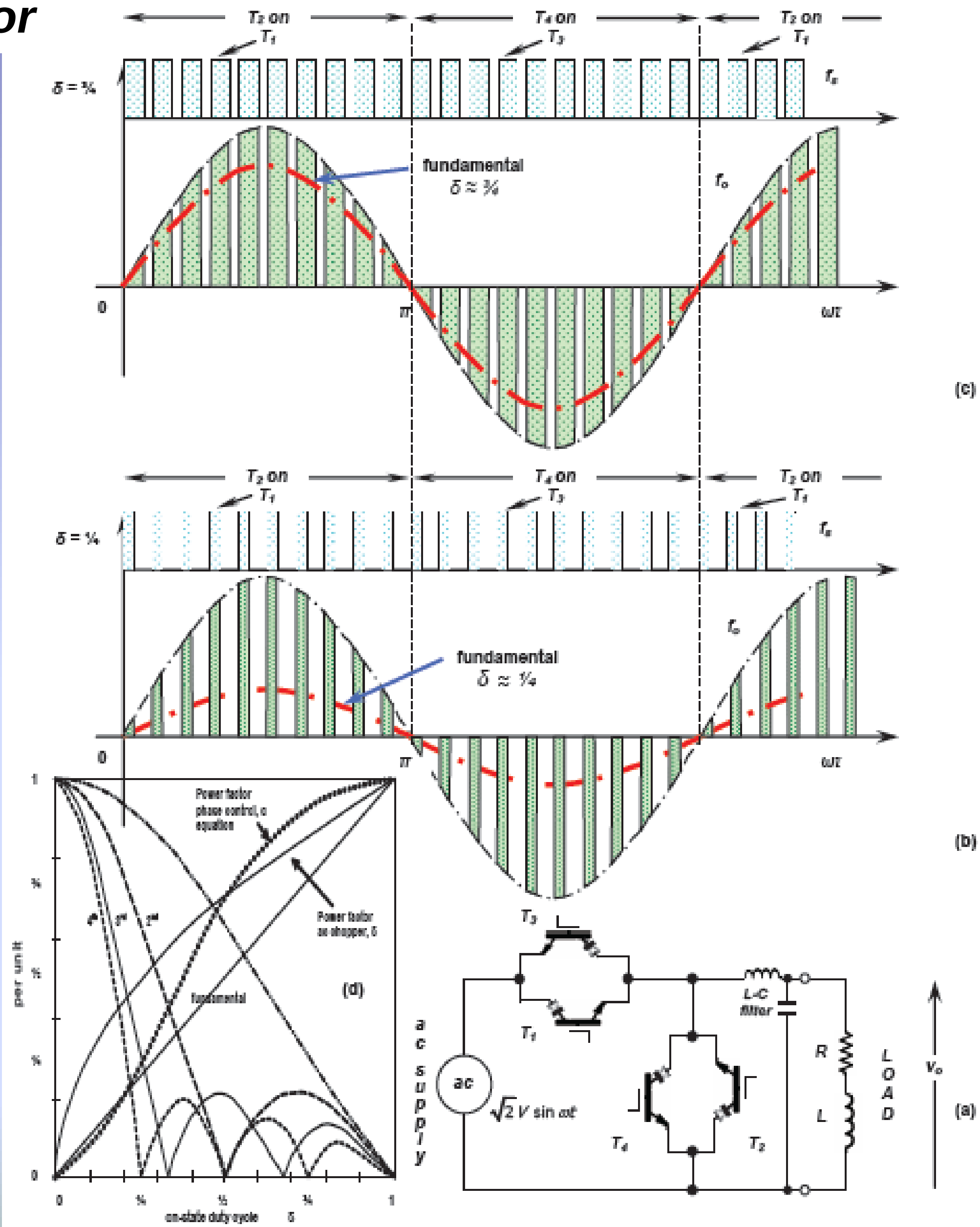
Figure shows the regulator when a triac is employed and the output voltage indicating the regulator's operating principle.

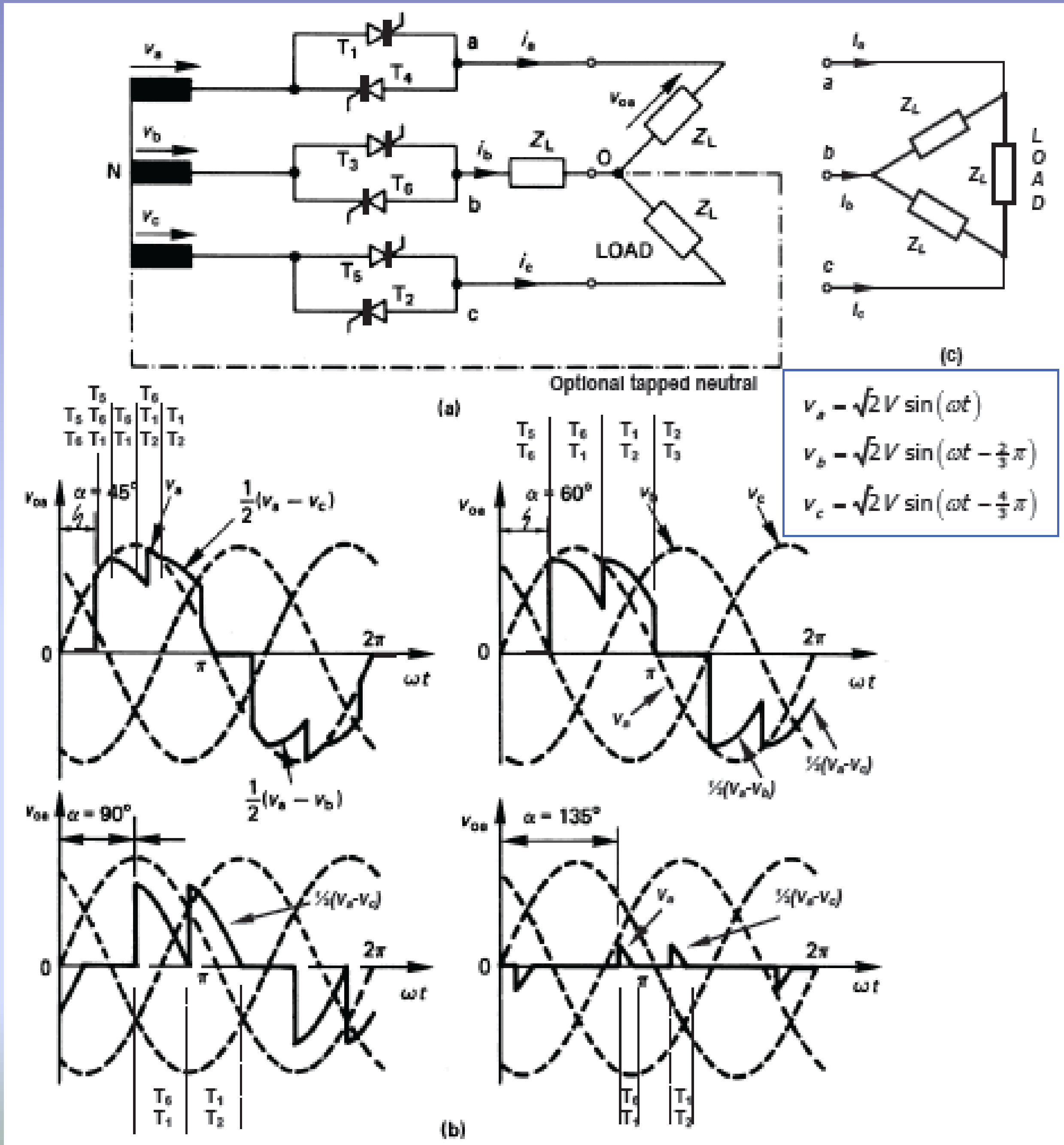


Single-phase ac chopper regulator

An ac step-down chopper is shown in figure.

- The switches T1 and T3 (shown as reverse blocking IGBTs) impress the ac supply across the load while T2 and T4 provide load current freewheel paths when the main switches T1 and T3 are turned off.
- In order to prevent the supply being shorted, switches T1 and T4 can not be on simultaneously when the ac supply is in a positive half supply cycle, while T2 and T3 can not both be on during a negative half cycle of the ac supply





$$v_a = \sqrt{2}V\sin(\omega t)$$
$$v_b = \sqrt{2}V\sin\left(\omega t - \tfrac{2}{3}\pi\right)$$
$$v_c = \sqrt{2}V\sin\left(\omega t - \tfrac{4}{3}\pi\right)$$

Exemple of three phase ac voltage regulator: *Three-phase ac full-wave voltage controller*

Application of AC Voltage Controller

Some of the main application of AC Voltage Controller are for the following:
- Domestic and industrial heating
- Transformer tap changing
- Lighting control
- Speed control of single phase and three phase AC drives
- Starting of Induction Motors

Earlier the devices were used for the above applications were auto-transformers, tap-changing transformers, magnetic amplifiers, saturable reactors etc.

These devices are now replaced by thyristor and TRIAC based AC Voltage Controller because of their high efficiency, flexibility in control, compact size and less maintenance requirement. AC voltage controllers are also adaptable for closed-loop control system.
The main disadvantage of AC voltage controller is the introduction of objectionable harmonics in the supply current and load voltage waveform, particularly at reduced output voltage level.

Inverter/ power inverter

Inverters are also called AC Drives, or VFD (variable frequency drive). They are electronic devices that can turn DC (Direct Current) to AC (Alternating Current).

- It is also responsible for **controlling speed and torque for electric motors**.

- Intervers can become:

- voltage source;
- current source.

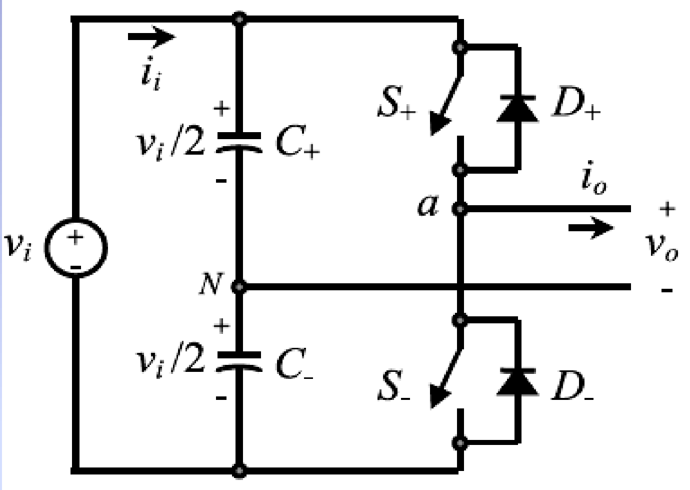
- Intervers can be:

- single phase;
- three phase.

Structurally, the inverters are made:

- *half bridge*
- *full bridge*

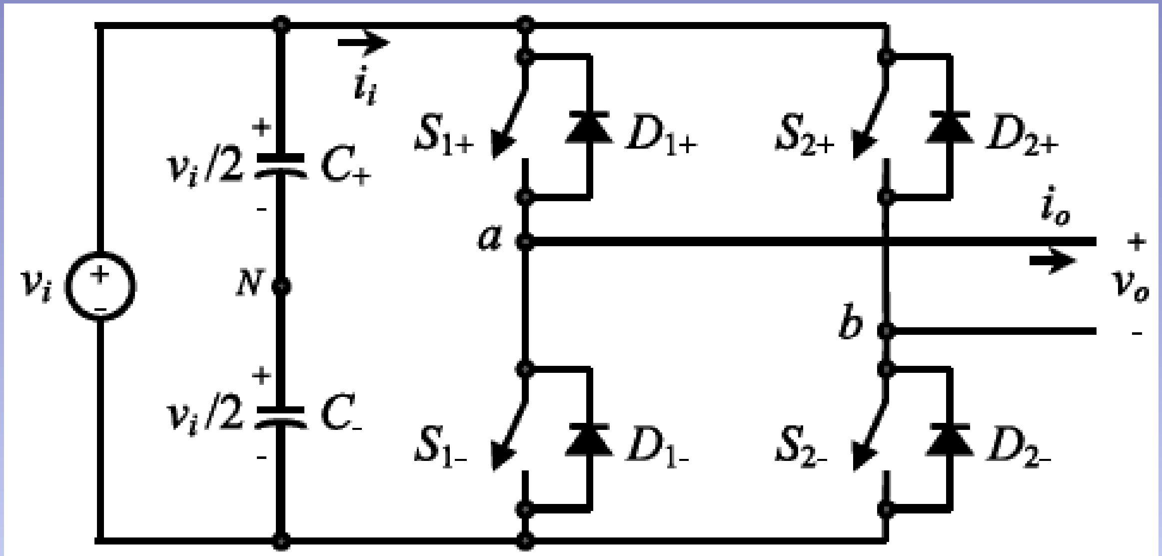
Half H-bridge is one of the inverter topologies which convert DC into AC. The typical Half-bridge circuit consists of two control switches, 3 wire DC supply, two feedback diodes, and two capacitors connecting the load with the source. Control switch can be anyelectronic switch i.e. MOSFET, BJT, IGBT, or thyristor, etc.



The circuit is designed in such a way that both switches must not turn-on at a single time & only one of the two switches will conduct. Each switch will operate for half period (T/2), providing half of the applied voltage the load ($\pm V_{dc}/2$). When both the switches are off, the reserved voltage across the load will be V_{dc} instead of $V_{dc}/2$. This is called a half-bridge inverter.

full bridge inverters

Single phase full bridge inverter has four controlled switches which control the direction of flow of current in the load.



The bridge has 4 feedback diodes that feedback the stored energy in the load back into the source. These feedback diodes function only when all thyristors are off and load is other than pure resistive load.

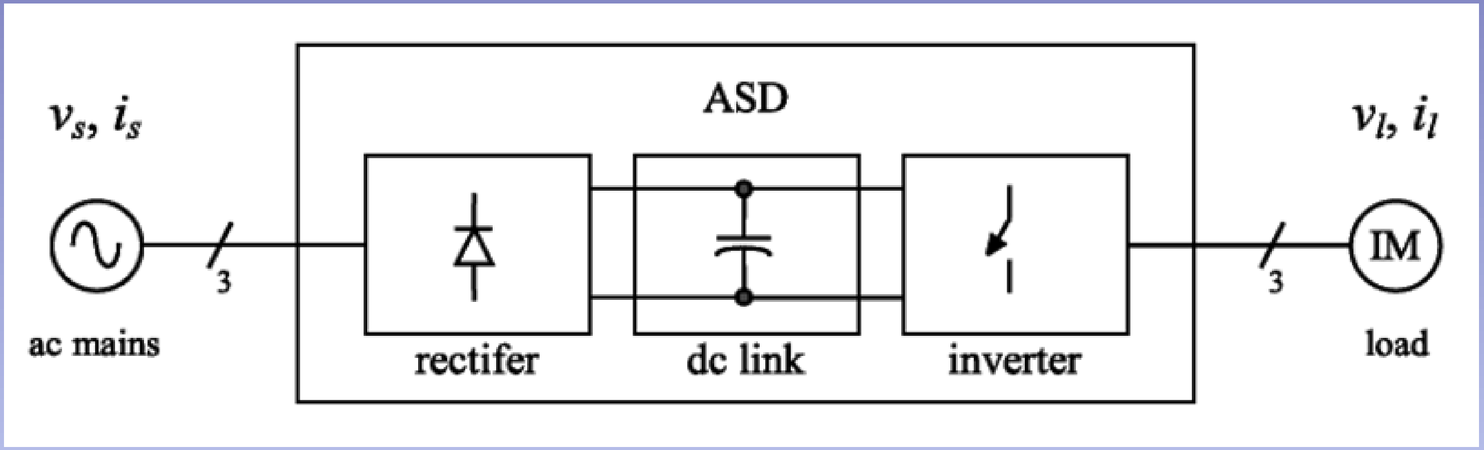
For any load, only 2 thyristors will work at a time.

Thyristors T1 and T2 will conduct in one period while T3 and T4 will conduct in another period.

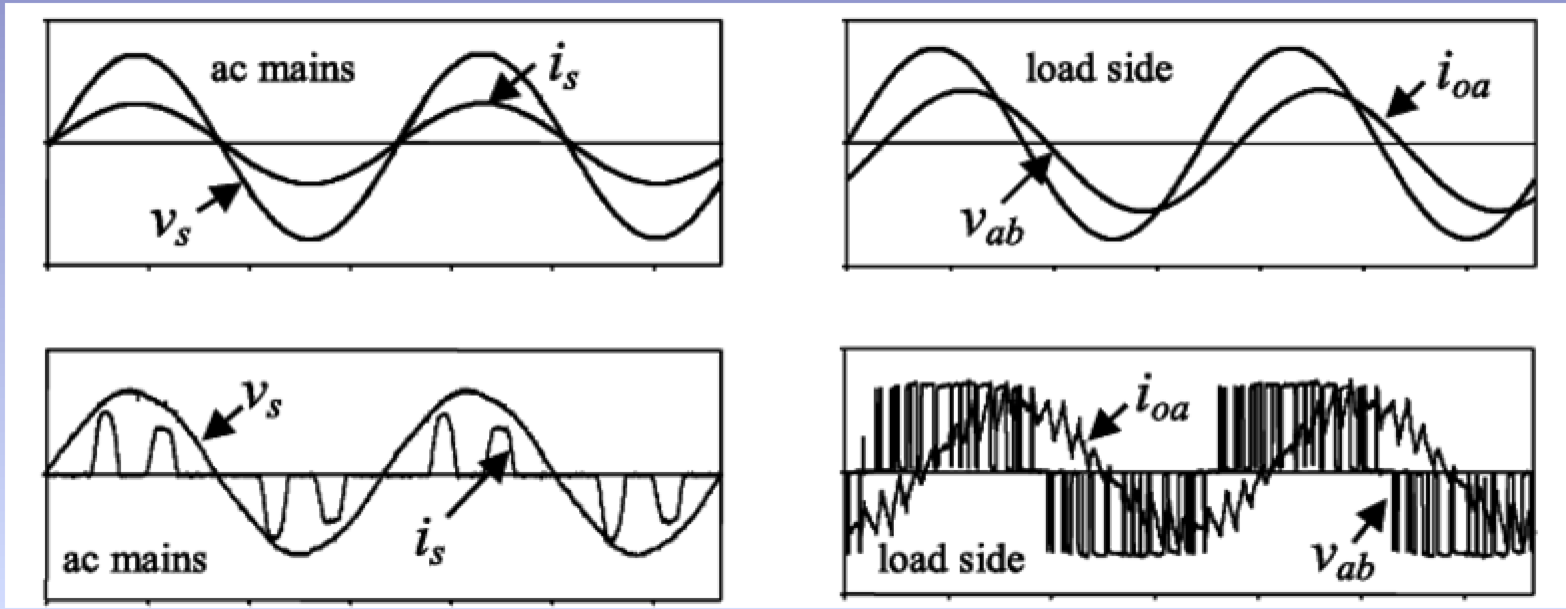
In other words, when T1 and T2 are in ON condition, T3 and T4 are off while when T3 and T4 are ON, then other two are OFF.

Turning ON more than two thyristors at a time will cause a short circuit which will produce excessive heat and immediately burning the circuit.

The construction of full bridge inverter is just like a half bridge inverter where full bridge inverter has an extra leg with it.



An AC drive works between a power supply and an electric motor. Power goes into the AC drive and regulates it. The regulated power is then sent to the motor.
An AC drive consists of a rectifier unit, a DC intermediate circuit, and an inverse conversion circuit. The rectifier unit inside an AC drive can be unidirectional or bidirectional.
A DC circuit will store the electrical power for the inverse conversion unit to use.
Before the regulated power is received by the motor, it undergoes a process inside the AC drive. The input power runs into a rectifier unit and the AC voltage is converted to DC voltage. The DC intermediate circuit smoothens the DC voltage. It then flows through the inverse conversion circuit to convert the DC voltage back into AC voltage.
This process allows the AC drive to adjust the frequency and voltage supplied to the motor depending on the demands of process.



Standard Speed Regulation Schematic and Associated Waveforms:
(a) the topology of the conversion structure; (b) ideal waveforms of the input (AC supply) and output (load) quantities; (c) in reality waveforms of the input (AC supply) and output (load) quantities.

***Benefits** when the inverters are used to control electric motors*

- Energy-saving
- Soft Starters
- Controlled Starting Current
- Reduced Power Line Disturbances
- Easily Changes the Direction of Rotation
- Simple Installation
- Adjustable Torque Limit
- Elimination of Mechanical Drive Components

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