Power Electronics

Unit II, Chapter 05

Basic Electrical Engineering

Department of Electrical and Electronics Engineering

Title Slide

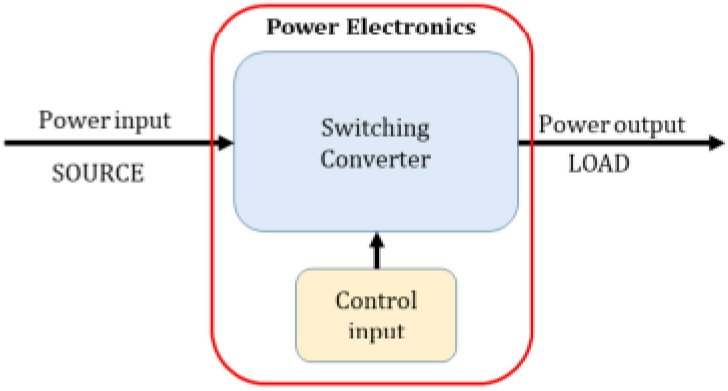
Chapter Outline:

- Introduction
- Semiconductor switches
- Power Electronic Converters
  1. Rectifiers
  2. DC-DC converters
  3. Inverters
  4. AC-AC Converters
- Summary

Chapter Outline:

In this chapter, we will discuss basics of Power Electronics and its application

Introduction to Power Electronics:

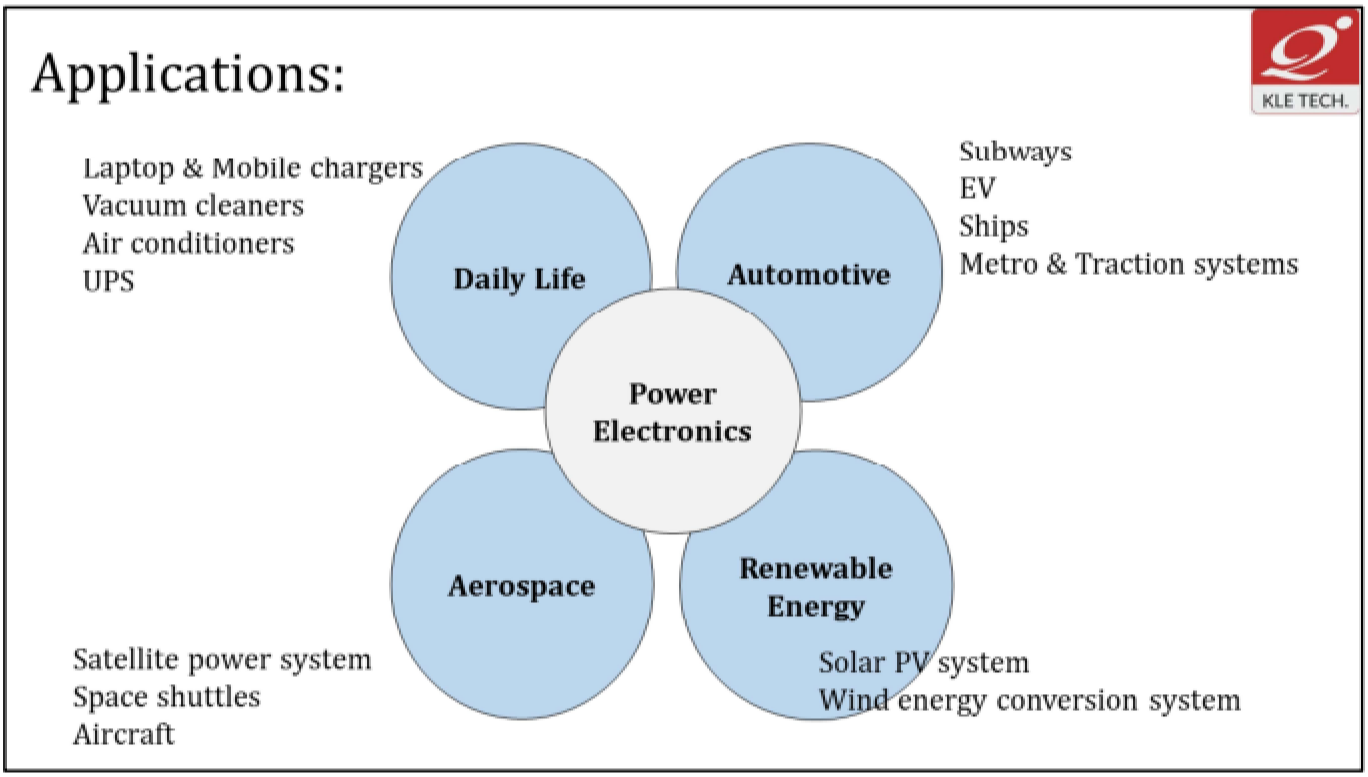


What is Power Electronics?

Power Electronics is application of solid-state electronics to the control and conversion of electric power to bring about compatibility between source and load.

Introduction to Power Electronics:

- Power can be of two types AC/DC power
- Power Electronics came into existence to bring about compatibility between different types of sources and loads.
- Whenever there is mismatch between the type of the source and load (in variety of applications which we will discuss later), A power Electronics converter is employed to bring about the compatibility between source and load.



Applications

- Power Electronics has variety of applications ranging from **Watts to Megawatts.**
- Few of the major application areas are discussed here.
- **Daily life**: these are applications we see in day to day life, namely
    1. Laptop & Mobile chargers: Input is AC from grid , but mobile and laptop batteries require DC charging (AC-DC)
    2. Vaccum cleaner: Required to change the speed for controlled cleaning (variable speed drive application)
    3. Air conditioners: Are now inverter based (fixed AC- variable AC) to facilitate automated temperature cooling
    4. UPS: Takes input from battery (DC) and powers domestic appliances (AC) - (DC-AC)
- **Automotive:** Subways, EV, Ships and Metro & Traction systems (variable speed applications)
- **Renewable Energy:** This is going to be future of the energy sector.
    1. Solar PV system: Solar panels generate DC power, But grid requires AC power, to match the voltage levels and bring compatibility, DC-DC converter and Inverter is employed . (If you remember the block the block diagram in Chapter 1 of Solar PV system).

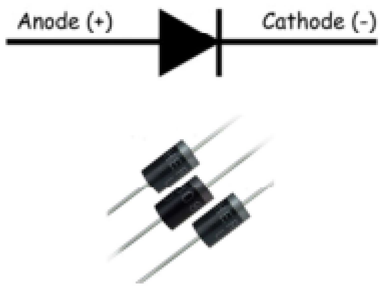
2. Wind Energy Conversion System: Power in Wind is harnessed using Generator, then the raw power is processed using Power Electronics to feed it to the load or the grid.

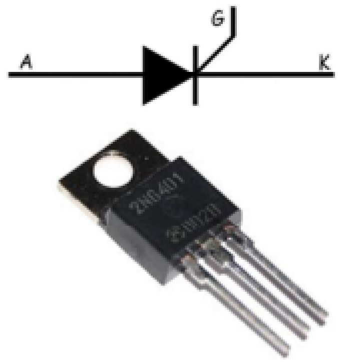
- **Aerospace:**
    1. Satellite power system is again solar PV system but more sophisticated.
    2. DC-DC converters find wide range of applications in space shuttles.

Power Semiconductor Switches: Types

Power Electronic switches are classified into three types namely:

1. Uncontrolled devices : Power diode
2. Semi controlled devices: SCR or thyristor
3. Fully controlled devices: IGBT and MOSFETs





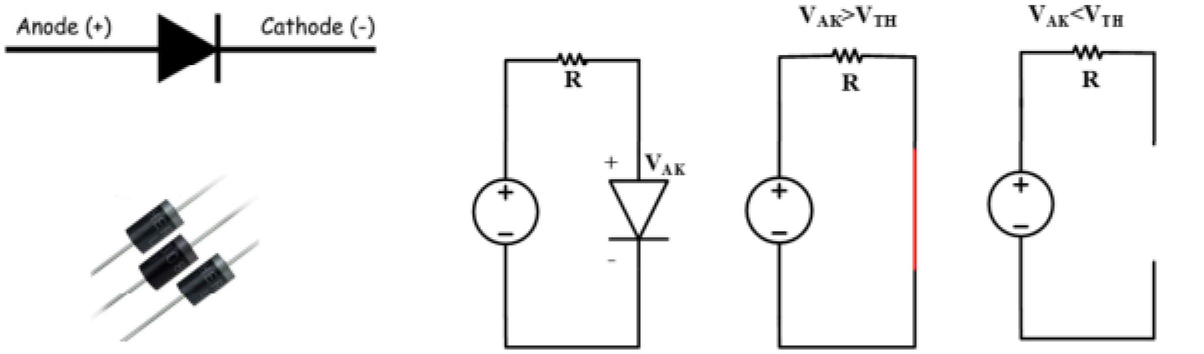
<u>Power Semiconductor Switches: Types</u>

Uncontrolled devices: Are the switches whose turning ON and turning OFF cannot be controlled.
Semicontrolled devices: Are the devices whose turning On can be controlled, turning off cannot be controlled.
Fully controlled devices: Are the devices whose both turning ON and turning OFF can be controlled.

Acronyms:
MOSFET – Metal-oxide Semiconductor Field Effect transistor
IGBT- Insulated Gate Bipolar junction transistor.

First diodes were invented, then SCR's and then came Fully controlled devices like MOSFET and IGBT, This is how power electronics and power electronics converters are evolved.

Power Semiconductor Switches: Diode



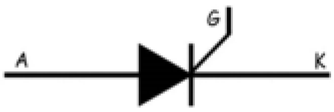
- Diodes conduct when forward voltage is applied across the Anode & cathode (V_{AK}).
- For diode to conduct $V_{AK}>V_{TH}$ as defined by the manufacturer.
- Diode blocks the reverse voltage, when off.

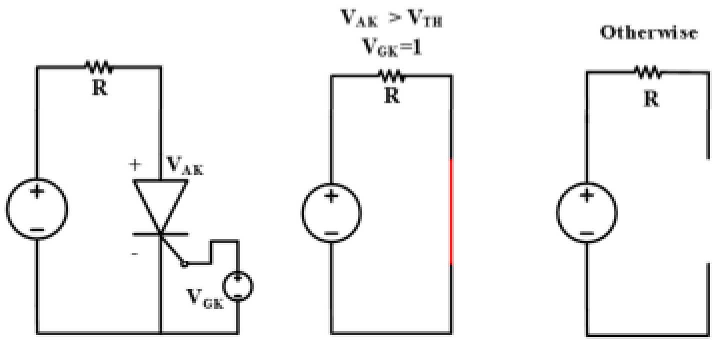
<u>Power Semiconductor Switches: Diode</u>

- Diode is uncontrolled device whose turn on and off is not under our control.
- Diode conducts when it is forward biased ($V_{AK} > V_{TH}$) where , V_{AK} is Anode to cathode voltage, V_{TH} is Threshold voltage (For ideal components it is zero)
- Diode is off when it is reverse biased ($V_{AK} < V_{TH}$) .

- Use animations as per your convenience.

Power Semiconductor Switches: SCR/Thyristor





- SCR is semi controlled device because only its turning on can be controlled
- SCR turns on when, ($V_{AK} > V_{TH}$ & $V_{GK} = 1$.)
- If any of one condition is not fulfilled, SCR is off.

Power Semiconductor Switches: SCR/Thyristor

SCR is semicontrolled device as discussed earlier, Only its turning ON can be controlled , not turning OFF.

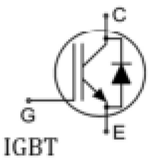
Two conditions are necessary for SCR to conduct:

1. The SCR should be forward biased ($V_{AK} > V_{TH}$) where , V_{AK} is Anode to cathode voltage, V_{TH} is Threshold voltage (For ideal components it is zero)
2. A gate pulse is required to turn on the SCR.

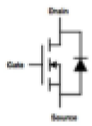
   Only when both conditions are fulfilled, the SCR will conduct, not otherwise.

Use animations as per your convenience.

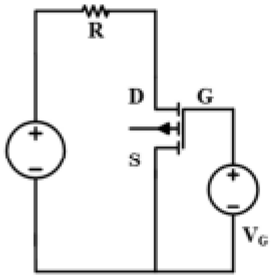
Power Semiconductor Switches: MOSFET/IGBT

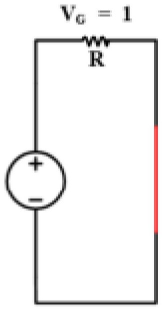


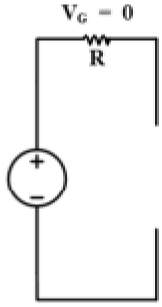
IGBT



MOSFET







Fully controlled devices are the ones, whose switching on and off instants can be controlled.

Gate terminal is used to exercise control to turn on/off the device.

If $V_G = 1$, switch is on

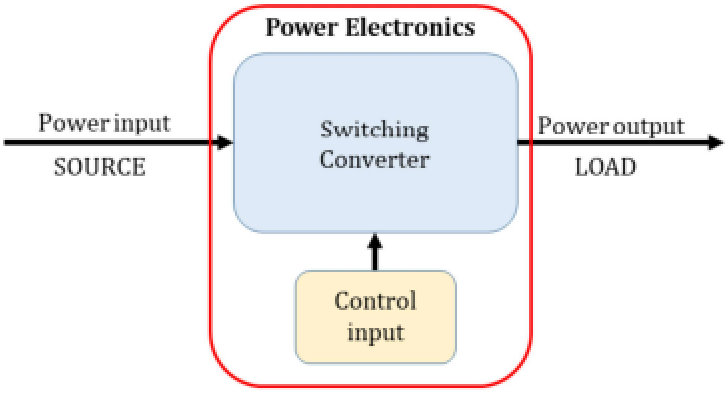
If $V_G = 0$, switch is off

Power Semiconductor Switches: MOSFET/IGBT

MOSFETS are fully-controlled devices, Both turning on and off times can be controlled

MOSFET/IGBT is ON when, $V_G = 1$, where, V_G is the gate voltage applied.
MOSFET/IGBT is OFF when, $V_G = 0$,

Power Converter: Types



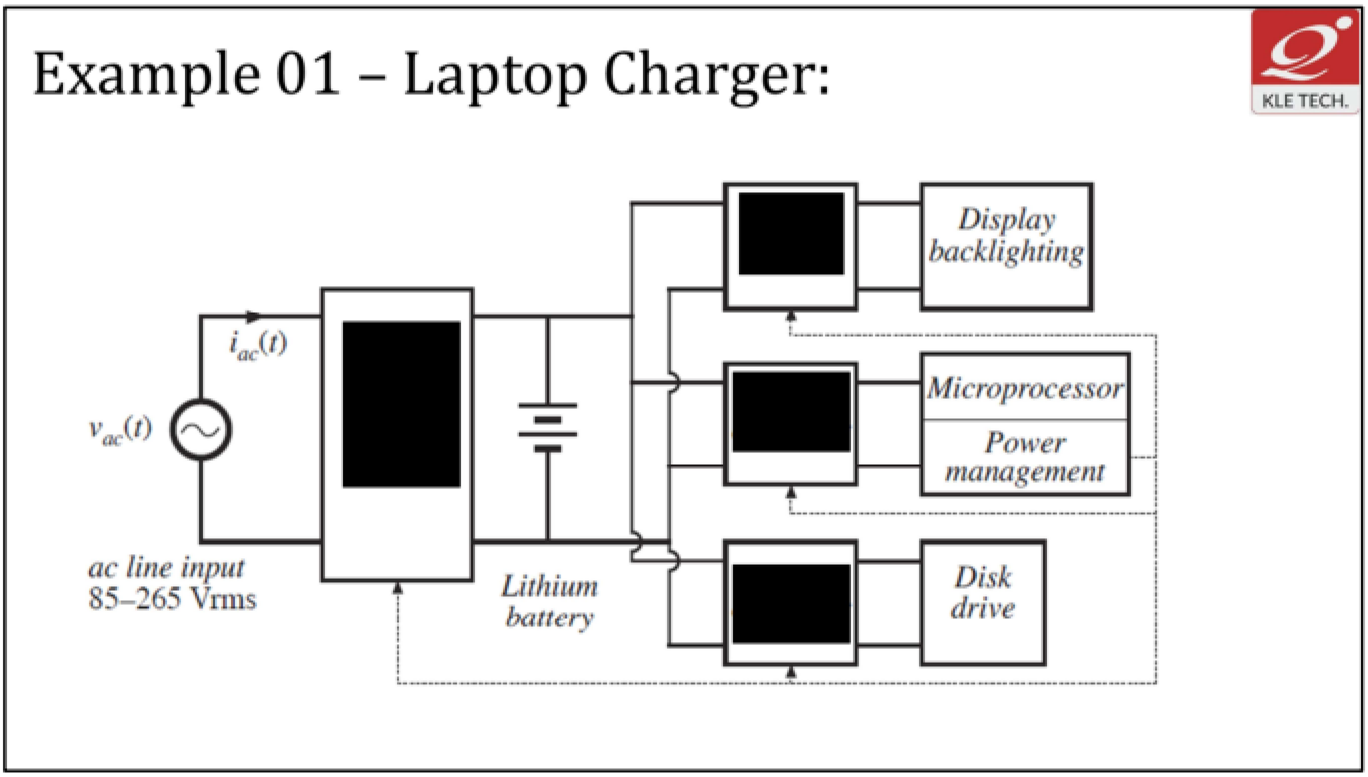
Classification of Power converters:

1. AC-DC conversion: Rectifiers
2. DC-DC conversion: Choppers
3. DC-AC conversion: Inverters
4. AC-AC conversion: Cycloconverters

<u>Power Converter: Types</u>

Converters are classified based on the type of the input and the output.

Power Electronic converters are basically classified into four types based on source input and load output namely:
DC-DC conversion: input is fixed DC, output is variable DC (Change and control voltage and current magnitude)
AC-DC rectification: input is AC , output is controlled DC (Possibly control dc voltage, ac current)
DC-AC inversion: input is DC, output is AC (Produce sinusoid of controllable magnitude and frequency)
AC-AC cycloconversion: Input is fixed AC, output is variable AC (Change and control voltage magnitude and frequenc)



<u>**Example 01 – Laptop Charger:**</u>

Let us consider Example of Laptop charger and its power system:

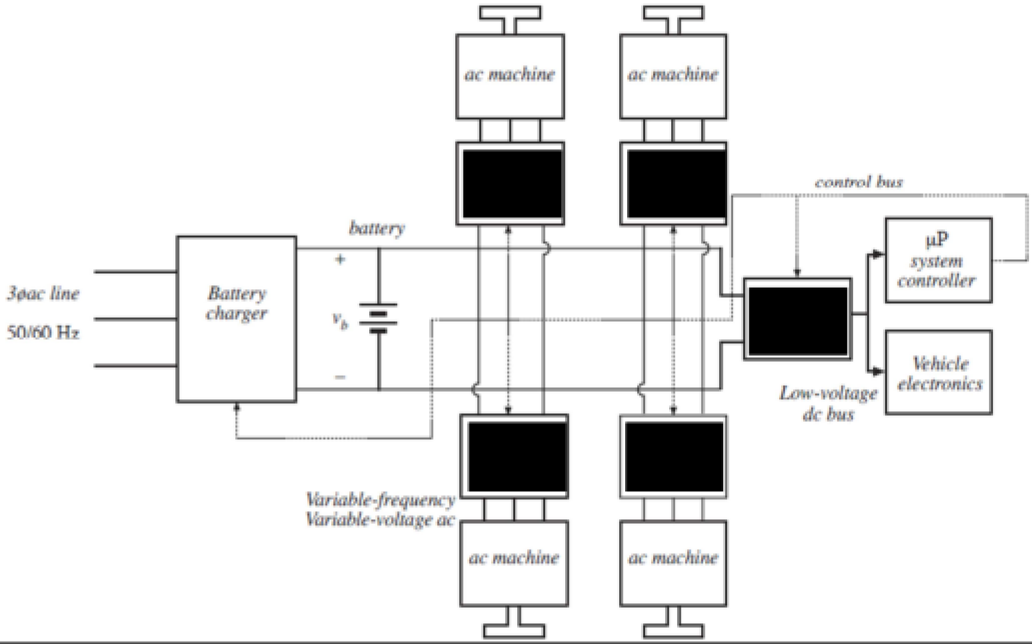
First explain the diagram or the system with curtains.
W.K.T, The input to the laptop charger is AC. And the laptop has DC batteries to charge. Also Laptop has different peripherals like IPS display, Processor and disk drive

Ask them to take a guess of which converters will be employed in these blocks.

Then raise the curtains:

1. Rectifier is used to convert the AC power to DC power.
2. A mini inverter is used to convert the DC power again to AC power, because Display is similar to TV.
3. Processor need low voltage DC power (Hence Buck converter)
4. Disk-drive needs high voltage DC power (hence Boost converter)

Example 02 – Electric Vehicle



Example 02 – Electric Vehicle

Explanation of the system (EV)

- Source of power in EV is batteries, it is charged from AC, So the charger must have a rectifier circuit.
- From the battery, the power is fed to the four AC machines, so there is need of 4 power electronic converters…
- Also, the EV has a controller controlled by the micro-processor working on low voltage DC power.

Ask students to take guesses….

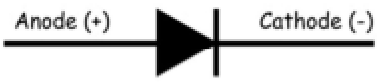
Once the curtains are raised…

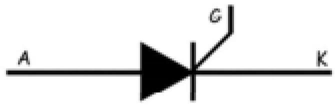
- To feed ac machines using battery, Inverters are needed.
- And to supply microcontroller using batteries, A buck converter is needed (to buck/reduce the voltage)

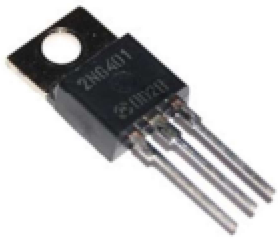
AC-DC Converters: Rectifiers

Rectifiers convert AC power to DC power and are of two types, namely:

1. Uncontrolled rectifiers: using power diodes
2. Controlled rectifiers: using thyristors/SCR’s

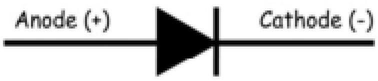


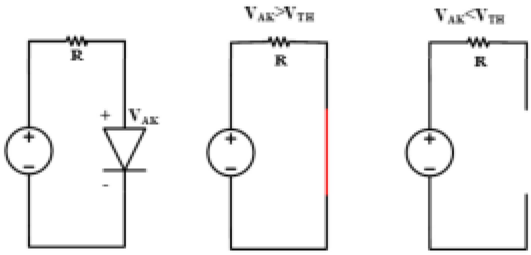




This slide is self explanatory

Power Semiconductor Switches: Diode

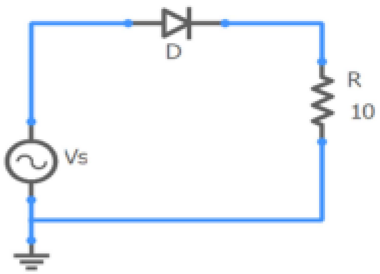


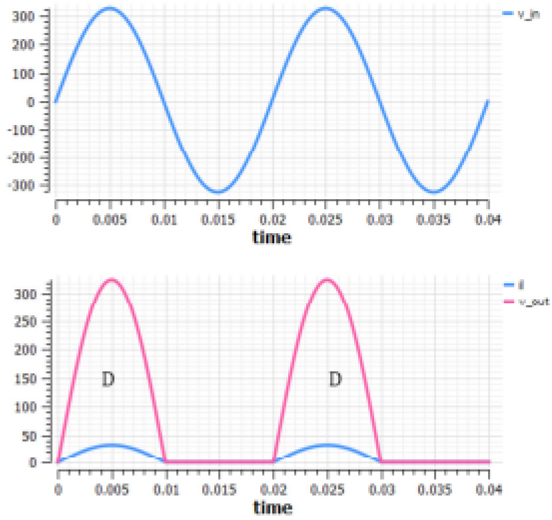


- Diodes conduct when forward voltage is applied across the Anode & cathode (V_{AK}).
- For diode to conduct $V_{AK}>V_{TH}$ as defined by the manufacturer.
- Diode blocks the reverse voltage, when off.

It's a repetition, just for students to revisit the working before explaining diode rectifiers…

Rectifiers :Half-wave diode rectifier





Rectifiers :Half-wave diode rectifier

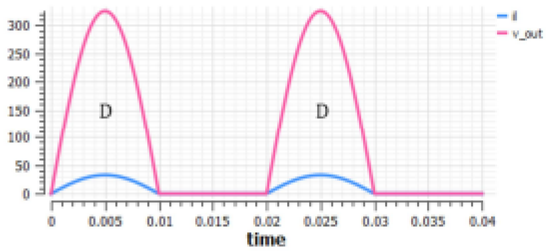
$$V_o = \frac{1}{2\pi}\int_0^{\pi} V_m \, Sin(\omega t)\, d(\omega t)$$

$$= \frac{V_m}{2\pi} - Cos\omega t \Big|_0^{\pi}$$

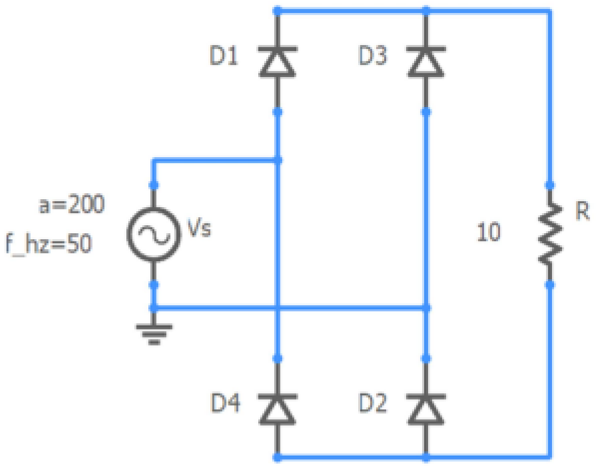
$$= \frac{V_m}{\pi}$$

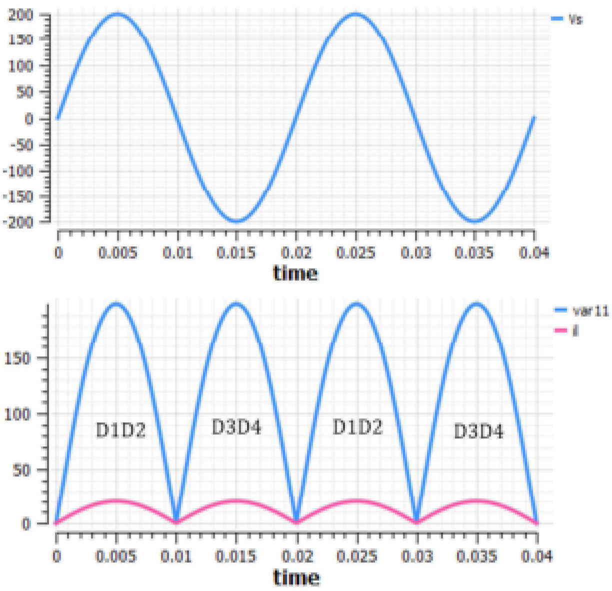
$$I_o = \frac{V_o}{R} = \frac{V_m}{R} \cdot \frac{1}{\pi}$$

- Average value of output voltage: 0.3185 Vm
- Rectification ratio : 0.405 or 40.5%
- Output DC voltage is not controllable



Rectifiers :Bridge rectifier





Rectifiers :Bridge rectifier

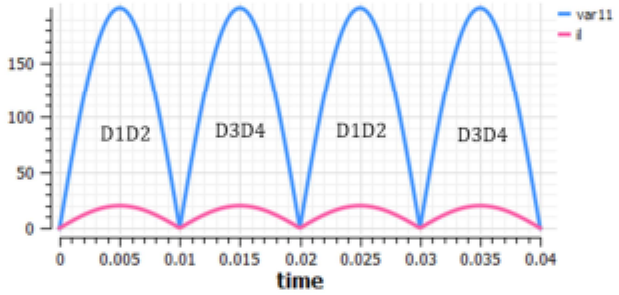
$$V_o = \frac{2}{2\pi}\int_0^{\pi} V_m\, Sin(\omega t)\, d(\omega t)$$

$$= \frac{V_m}{\pi} - Cos\,\omega t \Big|_0^{\pi}$$

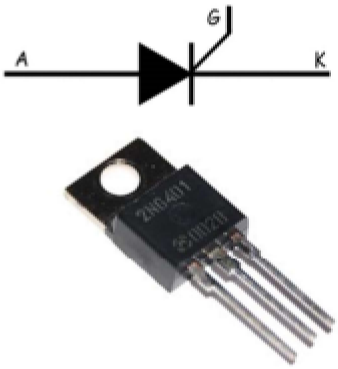
$$= \frac{2V_m}{\pi}$$

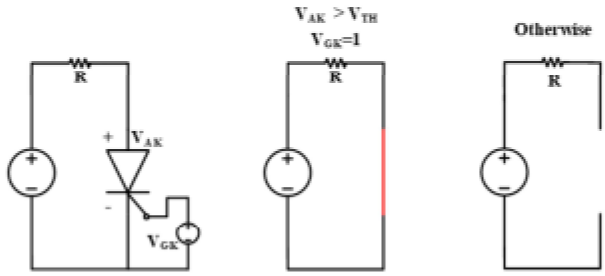
$$I_o = \frac{V_o}{R} = \frac{2V_m}{R}\cdot\frac{1}{\pi} = \frac{V_m}{R}\left(\frac{2}{\pi}\right)$$

- Average value of output voltage: 0.637 Vm
- Rectification ratio : 0.81 or 81%
- Output DC voltage is not controllable



Power Semiconductor Switches: SCR/Thyristor

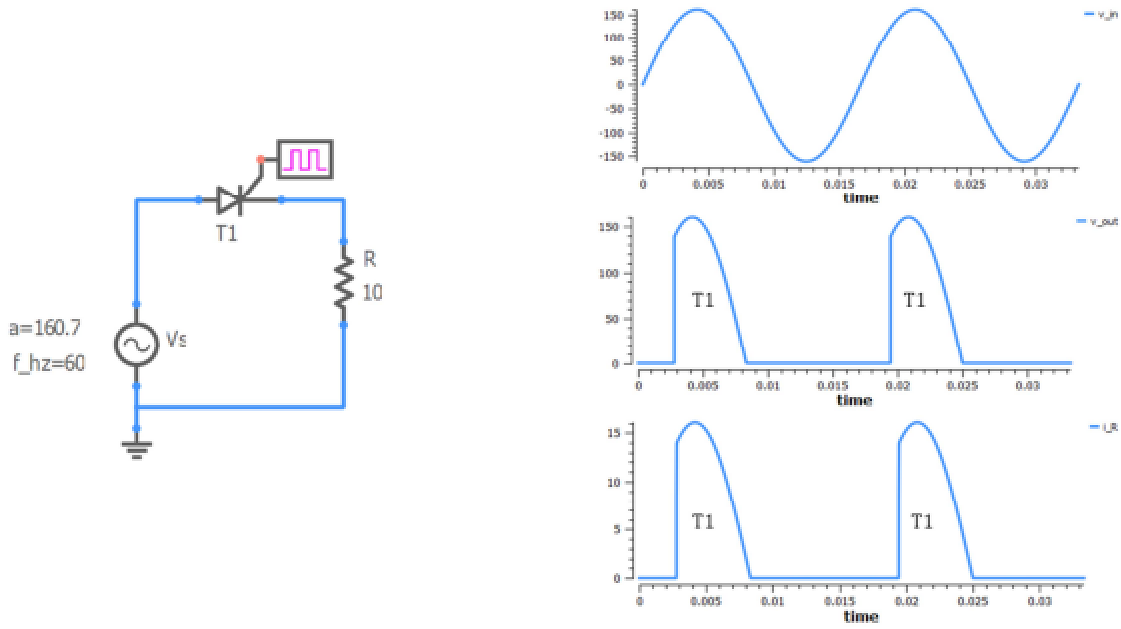




- SCR is semi controlled device because only its turning on can be controlled
- SCR turns on when, ($V_{AK} > V_{TH}$ **&** $V_{GK} = 1$.)
- If any of one condition is not fulfilled, SCR is off.

It's a repetation, just for students to revisit the working before explaining controlled rectifiers…

Rectifiers :Half-wave controlled rectifier



Rectifiers :Half-wave controlled rectifier

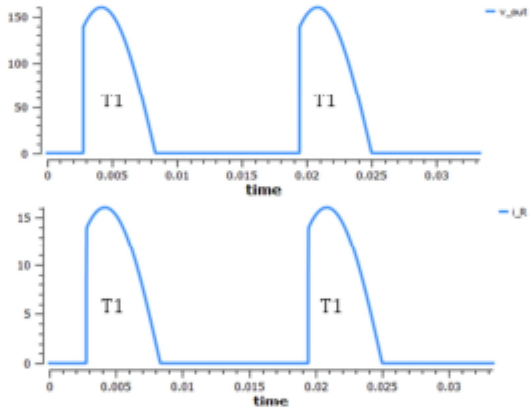
$$V_o = \frac{1}{2\pi}\int_{\alpha}^{\pi} V_m \, Sin(\omega t)\, d(\omega t)$$

$$= \frac{V_m}{2\pi} - Cos\,\omega t \, \Big|_{\alpha}^{\pi}$$

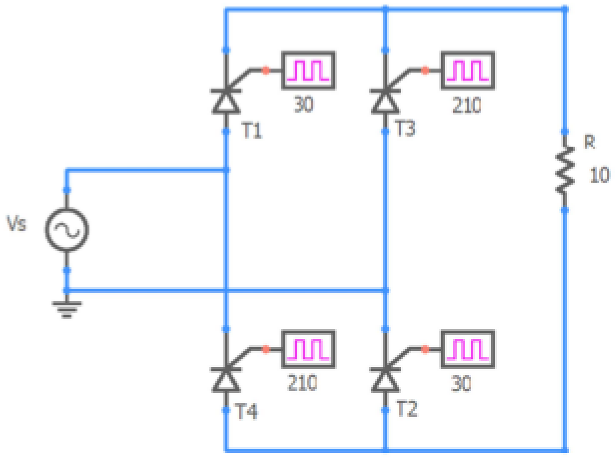
$$= \frac{V_m}{2\pi}(1 + Cos\,\alpha)$$

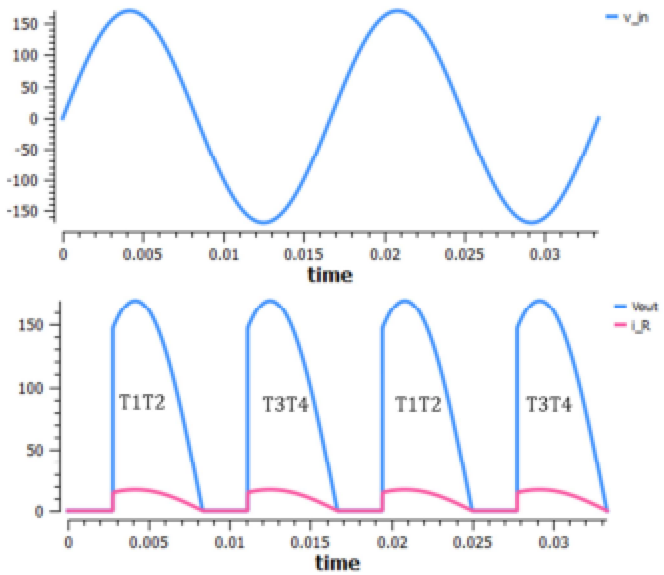
$$I_o = \frac{V_o}{R} = \frac{V_m}{R} \cdot \frac{1}{2\pi}(1 + Cos\,\alpha)$$

- Average value of output voltage: 0 to 0.3185 Vm
- Rectification ratio : 0.405 or 40.5%
- Output DC voltage is not controllable



Rectifiers :Controlled bridge rectifier





Rectifiers :Controlled bridge rectifier

$$V_o = \frac{2}{2\pi}\int_{\alpha}^{\pi} V_m \, Sin\,(\omega t)\, d(\omega t)$$

$$= \frac{V_m}{\pi} - Cos\,\omega t \Big|_{\alpha}^{\pi}$$

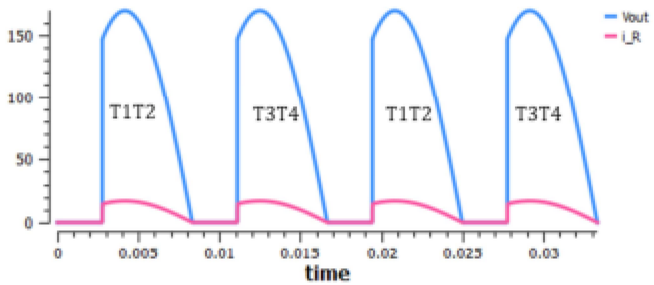
$$= \frac{V_m}{\pi}(1 + Cos\,\alpha)$$

$$I_o = \frac{V_o}{R} = \frac{V_m}{R} \cdot \frac{1}{\pi}(1 + Cos\,\alpha)$$

Average value of output voltage: 0.637 Vm

Rectification ratio : 0.81 or 81%

Output DC voltage is not controllable



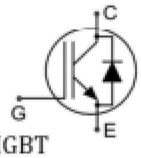
DC-DC Converters

- Dc-dc converters are power electronic circuits that convert a dc voltage/current to a different dc voltage/current level, often providing a regulated output.
- Fully controlled switches like MOSFETS & IGBT's are employed for operation of these converters.
- Only lossless components like inductors and capacitors are used to increase the efficiency of the converters
- Three basic DC-DC converters are:
  1. Buck converter (Output voltage < Input Voltage)
  2. Boost converter (Output voltage > Input Voltage)

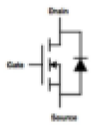
DC-DC Converters

- Power Semiconductor device is used as a switch which is turned ON and OFF by a controller and changes the duty cycle of the switching waveforms.
- Inductor plays a vital role in transferring energy from source to load during each switching cycle.
- When device is turned ON inductor gains the energy
- When the device is turned OFF voltage across the inductor reverses the polarity
- Hence inductor act as a supply source and discharge to the load
- To filter out ripples in the output voltage capacitor has to be connected across the load.

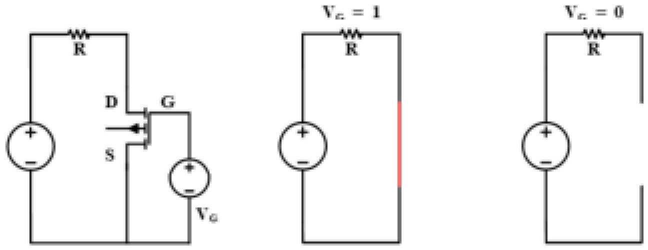
Power Semiconductor Switches: MOSFET/IGBT



IGBT



MOSFET



Fully controlled devices are the ones, whose switching on and off instants can be controlled.

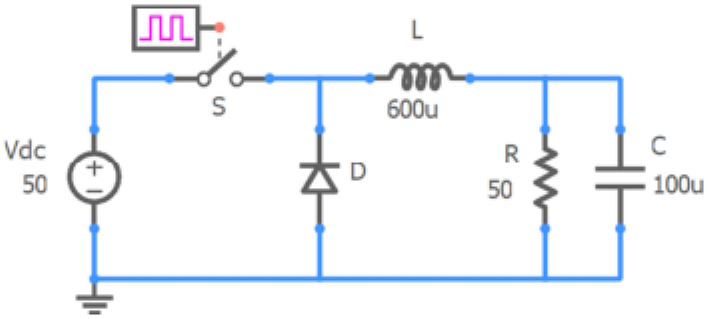
Gate terminal is used to exercise control to turn on/off the device.

If $V_G = 1$, switch is on

If $V_G = 0$, switch is off

It’s a repetition, just for students to revisit the working before explaining DC-DC converters

DC-DC Converters: Buck Converter



- Output Voltage: $V_0 = D*V_{dc}$
- Output Current: $I_0 = I_{in} / D$
- Pin = Pout
- D = 0 to 1

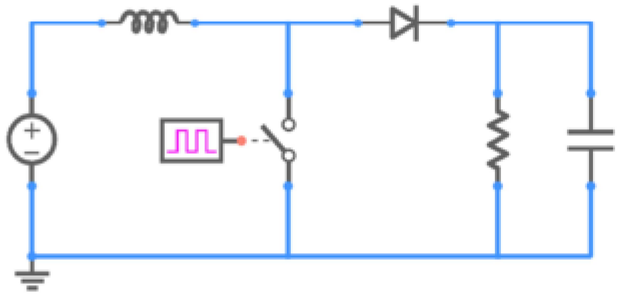
- Output voltage is less than input voltage
- Output current is more than input current
- If all the components are assumed lossless, then input power will be equal to output power

<u>DC-DC Converters: Buck Converter</u>

Working:

- During the on-time of the switch, the energy is stored in the inductor and is transferred to the load during the off-time of the switch.
- It is called buck converter, because the output voltage is (bucked) less than input voltage always.
- Basically it converts high voltage, low current DC power to low voltage, high current Dc power.
- The input power is equal to output power for ideal buck converter.

DC-DC Converters: Boost Converter



- Output Voltage: $V_0 = V_{dc}/(1\text{-}D)$
- Output Current: $I_0 = I_{in} * (1\text{-}D)$
- Pin = Pout
- D = 0 to 1

- Output voltage is more than input voltage
- Output current is less than input current
- If all the components are assumed lossless, then input power will be equal to output power

<u>DC-DC Converters: Boost Converter</u>

Working:

- During the on-time of the switch, the energy is stored in the inductor and is transferred to the load during the off-time of the switch.
- It is called Boost converter, because the output voltage is (boosted) more than input voltage always.
- Basically it converts low voltage, high current DC power to high voltage, low current Dc power.
- The input power is equal to output power for ideal buck converter.

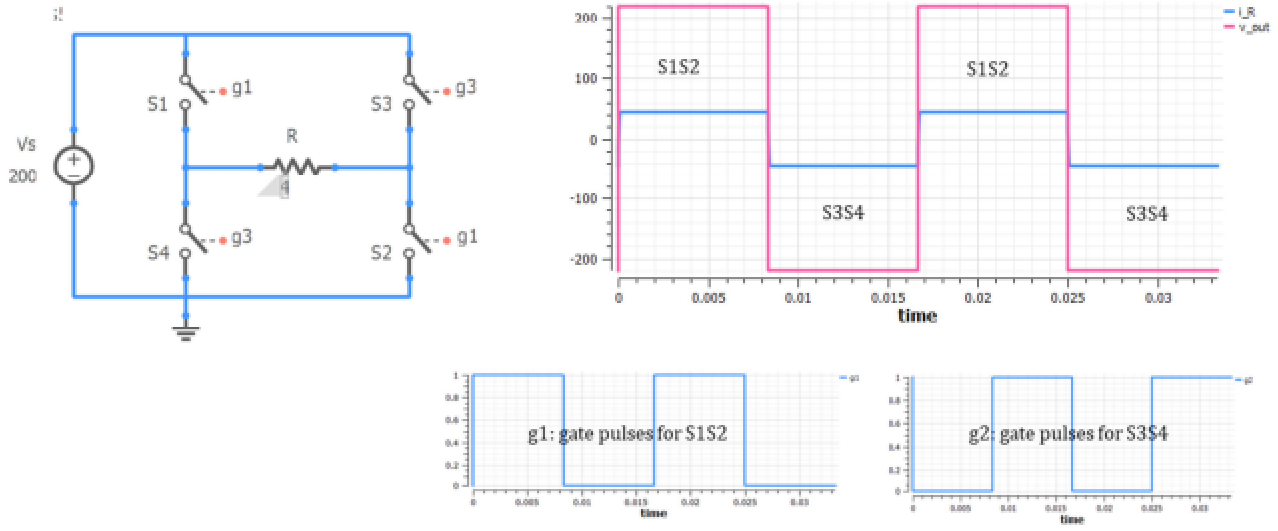
DC-AC Converters: Inverters

- Inverters are power electronic circuits which convert DC input power to AC output power.
- Inverter circuits are realised using fully controlled switches like MOSFETS and IGBT's
- Based on application, type of load and the power rating, the inverters can be categorized as:
  1. Single phase inverters
  2. Three phase inverters

DC-AC Converters: Inverters

The content is self explanatory

DC-AC Converters: Single Phase Inverters

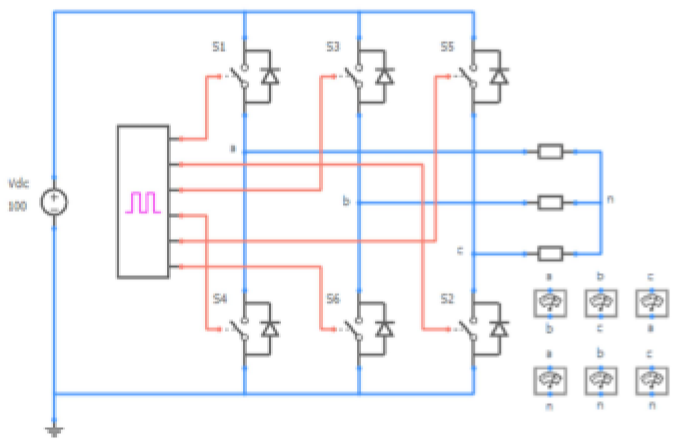


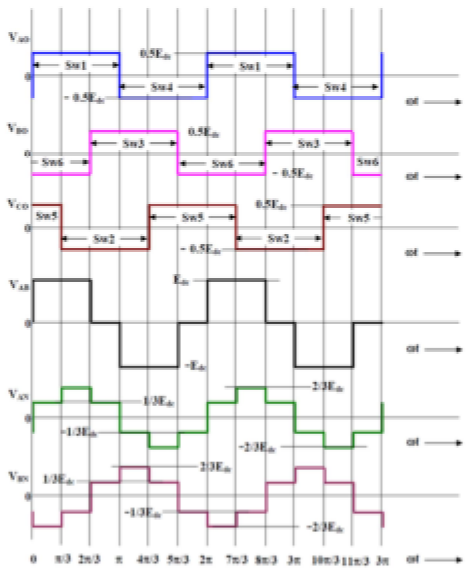
DC-AC Converters: Single Phase Inverters

Explanation of the circuit:
- Single phase inverters consists of 4 fully controlled switches like MOSFETS /IGBT's (S1, S2, S3, and S4)
- S1 and S2 conduct at the same time and S3,S4 conduct during other time.
- Control pulses given for S1 and S2 is g1
- Control Pulses given for S3,S4 is g2
- It is evident from the figure that the pulses g1 and g2 are out of phase.

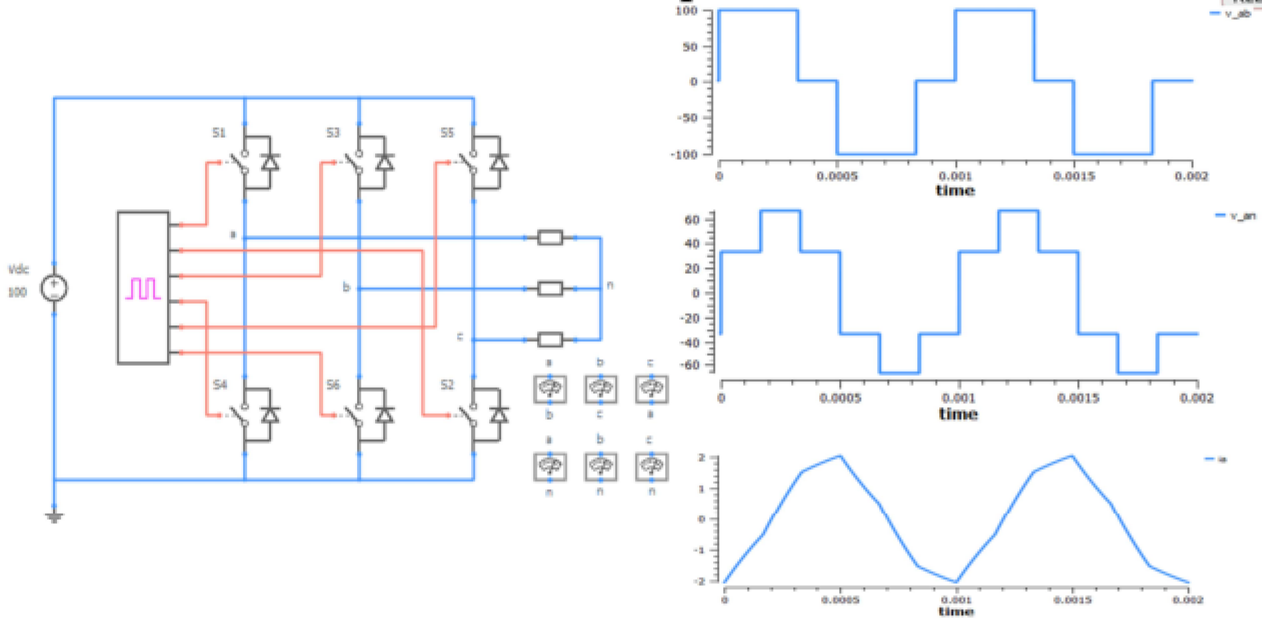
Working:
- When S1 and S2 conduct, positive voltage is applied across the load
- When S3 and S4 conduct, negative voltage is applied across the load.
- And the cycle repeats applying alternating voltage across load and hence converting the DC power to the AC power.

DC-AC Converters: Three phase inverters

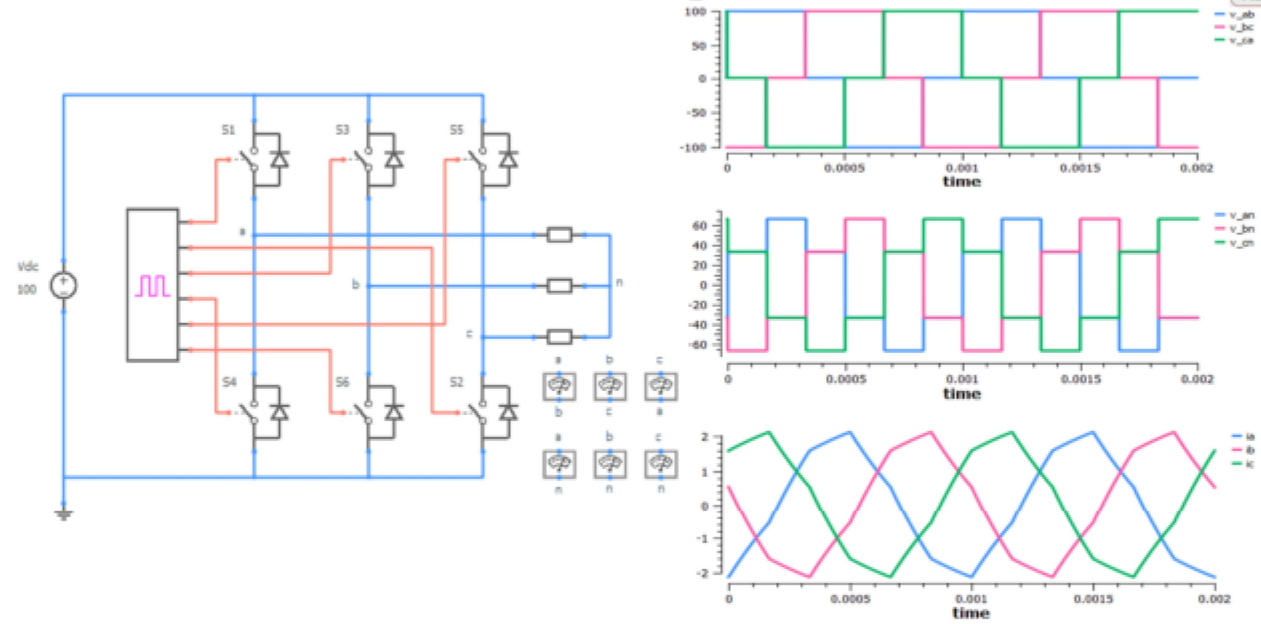




DC-AC Converters: Three phase inverters



DC-AC Converters: Three phase inverters



Summary:

Input \ Output	DC	AC
DC	DC-DC Converter	Inverters
AC	Rectifiers	Cyclo-converters

Summary:

- As discussed earlier, it all boils down to Source (input) and load (output)
- Explain the table, table is self explanatory.

Thank You