# SUN TRACKERS AND CHARGE CONTROLLERS FOR SOLAR PANELS

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- Solar panel types (Photovoltaic, Concentrated Photovoltaic, Concentrated Solar Power )

- Solar trackers for Solar Panels
  - Introduction to position control of PV.
  - Types of position control of PV:
  - Fixed – panels
  - Manually adjusting the tilt.
  - Sun Trackers (Single axis tracking, Dual-axis tracking)

- Automatic Sun tracking controllers.
  - Types of controllers for sun trackers:
    - Closed loop controllers with light sensors.
    - Programed controller based on location (latitude), date and time.
    - Automated controller based on GPS system
  - Closed loop systems (analogue and numerical regulators)
  - Types of electronic regulators: On/OFF, proportional (P, PI, PD, PID), numerical PID.
  - Actuators for PV position control (Servomotors, steppers motors, Electric linear actuators).
  - Sensors for sun light position detection (single axis or dual-axis control)
  - Block diagram of Sun Tracker controller.

- Solar Charge Controller Types
  - PWM Charge Controllers
  - MPPT (Maximum Power Point Tracking) solar controller
  - Other function for Solar Charge Controller: low voltage disconnect (LVD), Battery temperature sensing

## ❖ Conversion of sun energy into electricity

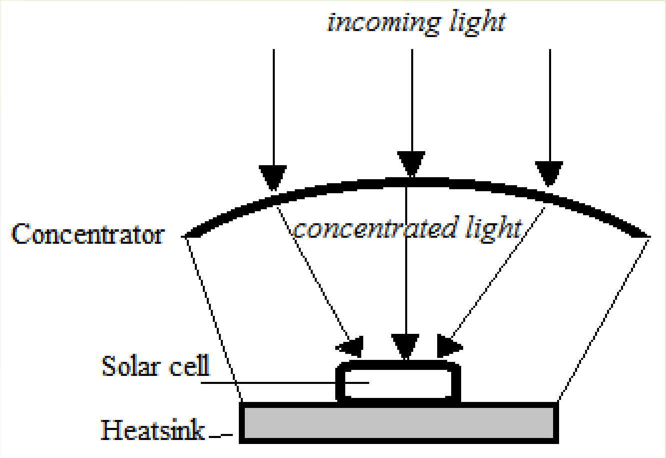
Sun energy can be converted into electrical energy using two main methods:

- light is converted in current/voltage in photovoltaic panels.
- light is concentrated onto a small surface using mirrors to reflect the light from sun, for heating a liquid to generate the electrical energy.

**Solar panel types:**

***Photovoltaic (PV) Panels***
Photovoltaic panels convert solar radiation into electrical current/voltage. They are composed by a number of cells containing photovoltaic material (often silicon).

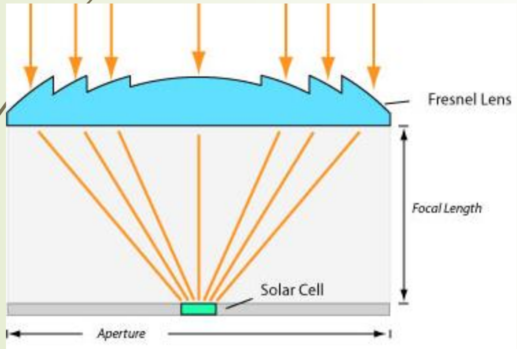
- ***Concentrated Photovoltaic (CPV)***



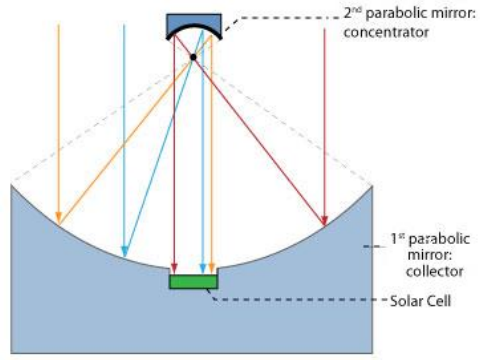

Uses the same photovoltaic material as PV. The radiation from the sun is concentrated onto the solar cell surface using lens (concentrators), producing more electrical energy but with the same size of cell.

The panel need to be oriented to sun direction (follow the sun) to work properly.

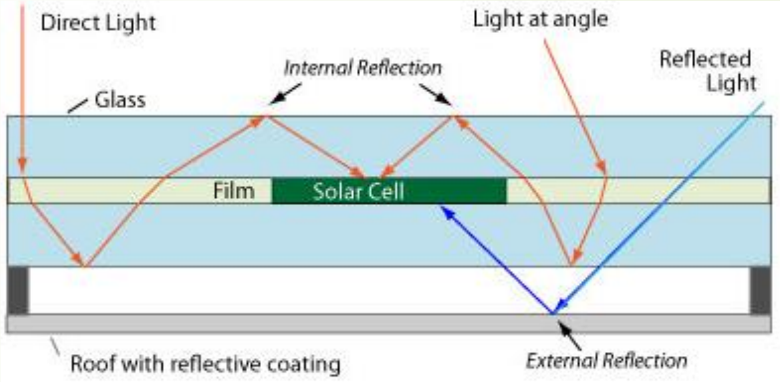
They can be constructed in different forms:



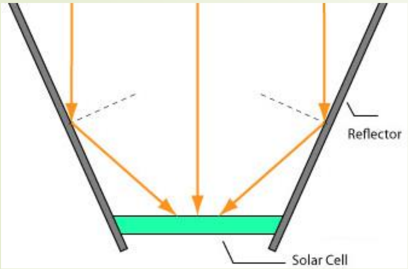
Fresnel Lens



Parabolic Mirrors



Luminescent Concentrators



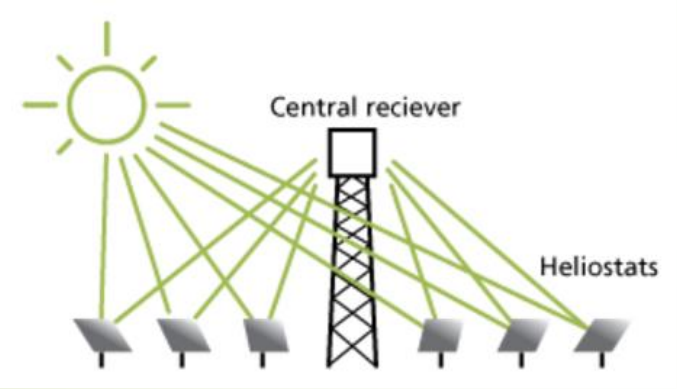
Reflectors

http://www.greenrhinoenergy.com/solar/technologies/pv_concentration.php

- ***Concentrated Solar Power (CSP)***

Concentrated Solar Power are composed by multiple mirrors that concentrate solar radiation onto a small surface which contains a liquid that is heated.

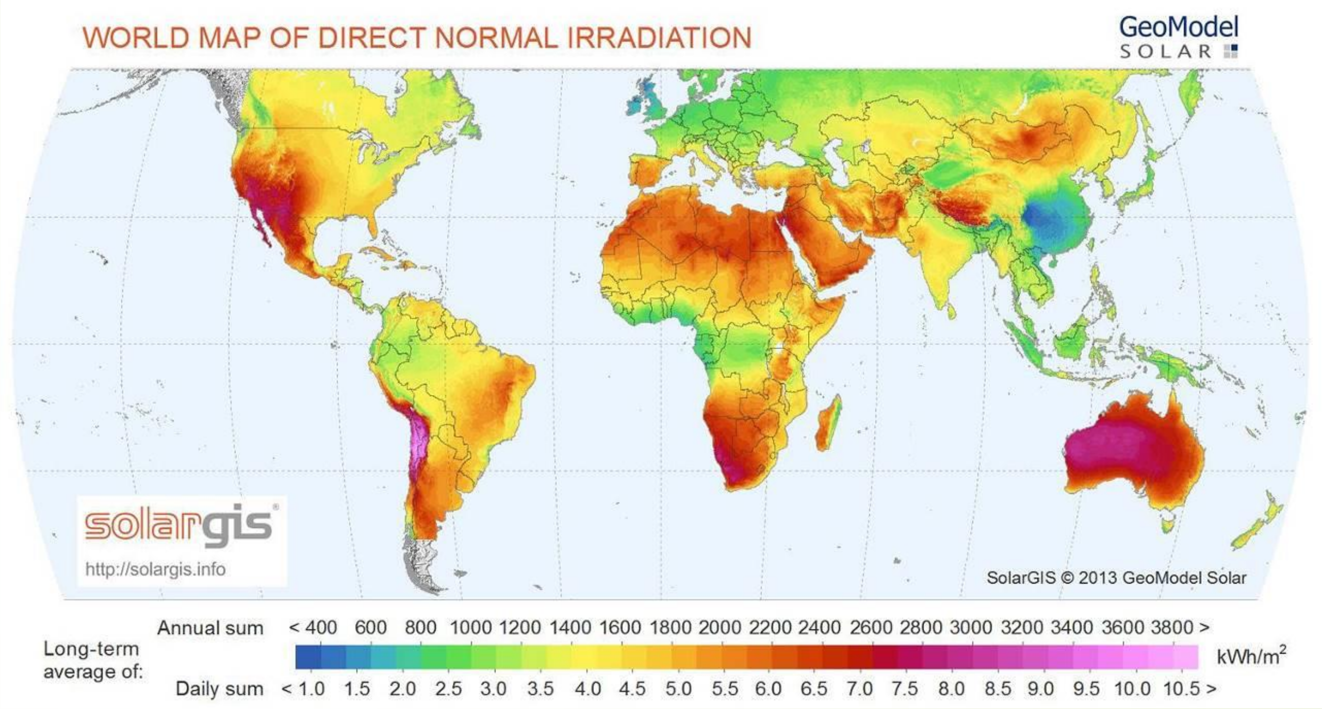
All panels need to be oriented to proper direction and follow the sun precisely, in order to work properly.




PS10 solar power tower - 11 megawatt, 624 large movable mirrors – Andalusia, Spain

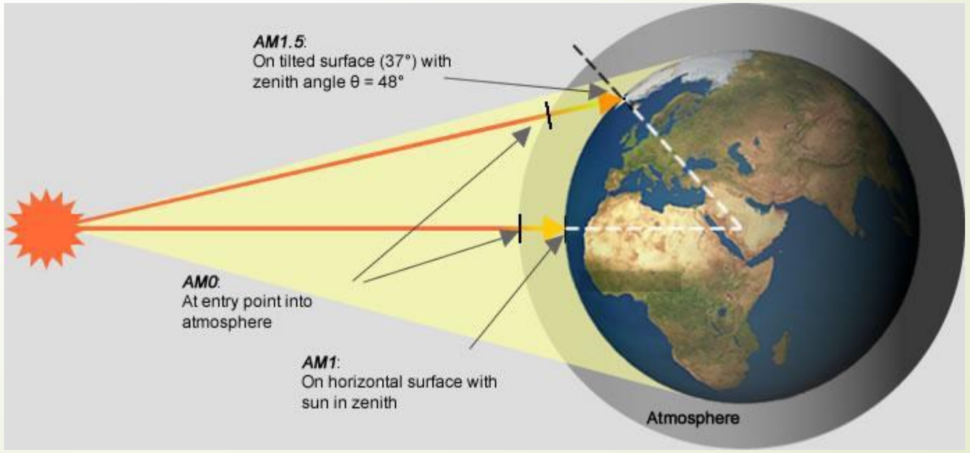
# ❖Solar trackers for Solar Panels

Sun radiation on Earth




*Source: http://sollargis.info*

Sun radiation distribution on Earth



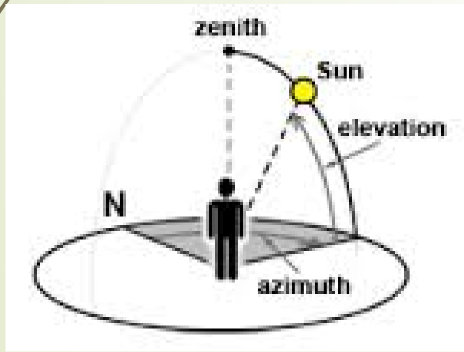

*Source: http://greenrhinoenergy.com*

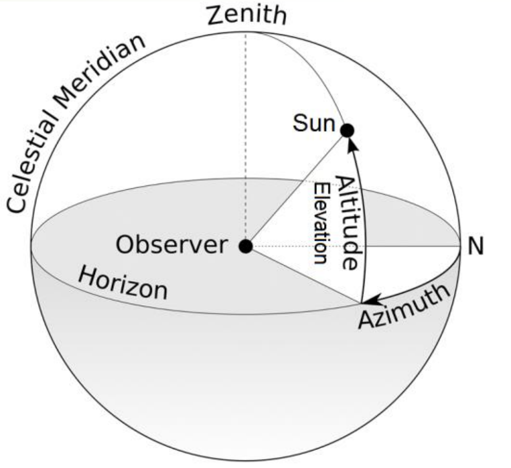
Sun localization on the sky relative to a specific observation point is defined using two angles:

- azimuth is the angle between a celestial body (sun, moon) and the North, measured clockwise around the observer's horizon.
- Elevation (tilt) is the angle between horizontal line and the height on a circle surface.

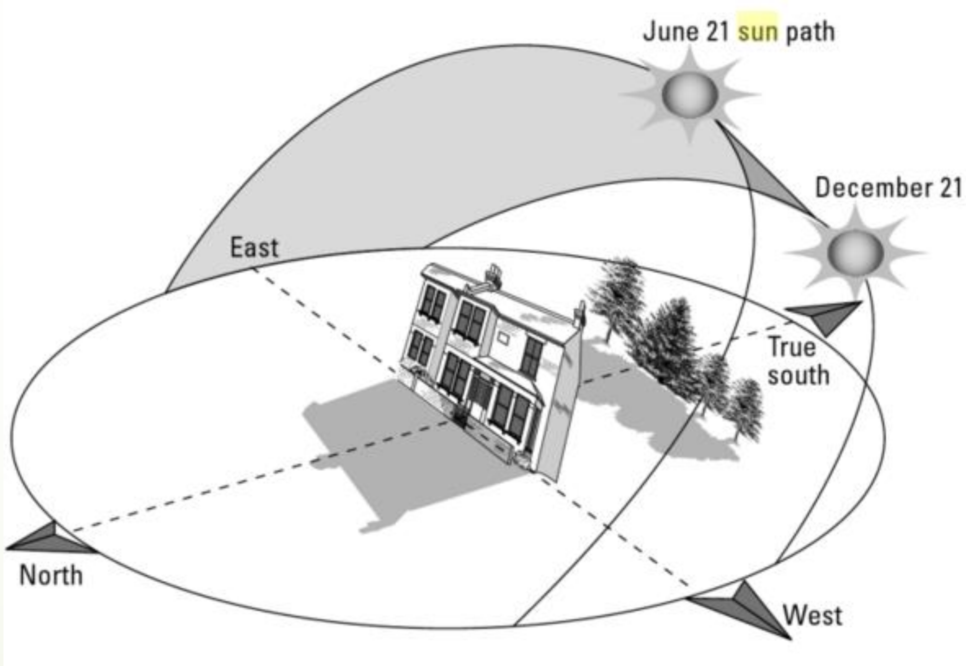
These values changes with seasons, latitude and longitude, and time of the day.

For localization, the best coordinating system to use is spherical coordinating system (two angles and radial distance)




https://en.wikipedia.org/wiki/Azimuth




Solar window from summer to winter for North hemisphere

## Solar constant

The solar constant, a measure of flux, is the amount of incoming solar electromagnetic radiation per unit area that would be incident on a plane perpendicular to the rays, at a distance of one astronomical unit (AU ≈ 150 million km) (mean distance from the Sun to the Earth)
Outer in space, S = 1367 $W/m^2$

$$\text{Intensity} \approx \frac{1}{r^2}$$

The intensity decreases in terrestrial atmosphere with about 20% because of absorption, so at the Earth surface at sea level, in a sunny day, the values become S = 1000 $W/m^2$

SunRise angle (azimuth) refers to height on the sky, measured from a horizontal point. We need to know altitude and elevation from a point. Maximum angle is at noon time and depends by latitude and SunSet angle.

$$\text{SunRise angle} = 12 - \frac{1}{15}\cos^{-1}\left(-\frac{\sin\varphi\sin\delta}{\cos\varphi\cos\delta}\right) - \frac{TC}{60}$$

$$B = \frac{360}{365}(d - 81)$$

$$\text{Azimuth angle} = \cos^{-1}\frac{(\sin(\delta)\ \cos(\theta) - \cos(\delta)\ \sin(\theta)\ \cos(HRA))}{\cos(\alpha)}$$

$$15 = \frac{360}{24}\ \text{hours}$$

$$TC = 4(Longitude - LSTM) + EoT$$

$$EoT = 9.87\sin(2B) - 7.53\cos(B) - 1.5\sin(B)$$

$$LSTM = 15 * \Delta T_{GMT}$$

EoT - Equation of Time
LST - Local Solar Time
LSTM - Local Standard Time Meridian
d - the number of days since the start of the year

TC - Time Correction Factor
LT - Local Time
HRA - Hour Angle

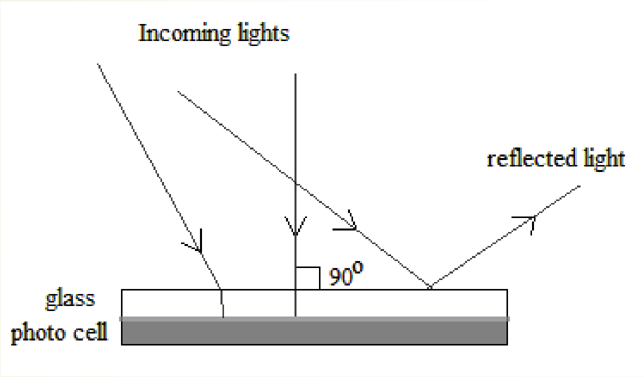
## Mounting of solar panels (PV)

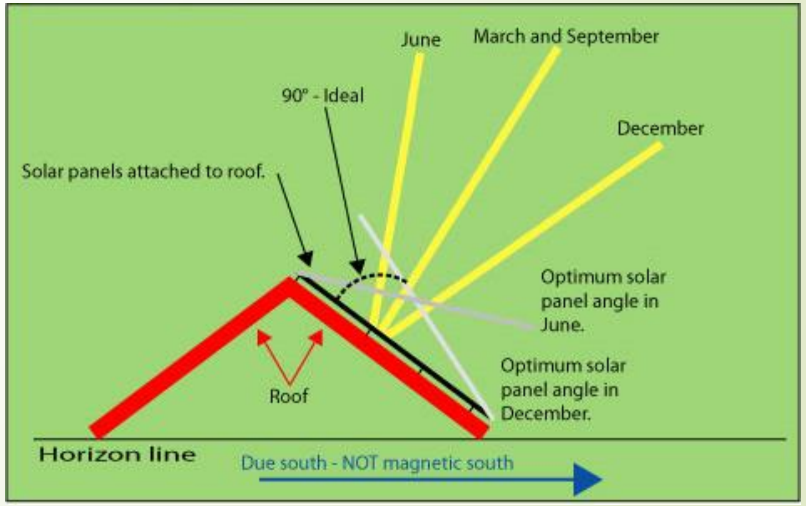
Photovoltaic panels can be installed with *fixed position* or with *position control*:

- ***Fixed position panels***

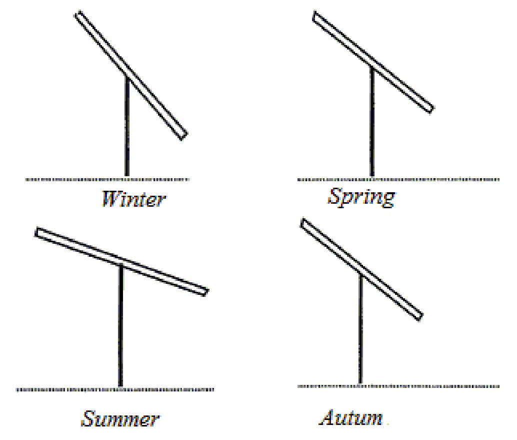
The optimal angle for the panel differs with:

- location on the Earth
- season (from winter to summer)



- ***Manually adjusting the tilt.***




This adjusting is made depending on season – can increase the total power generated within a year by the photovoltaic panel.

This manual adjustment can be made:

- Adjusting the tilt *one time a year*, for better efficiency in winter and summer year periods.
- Adjustin the tilt *two times* year

According to http://www.solarpaneltilt.com, the effect of adjusting the angle, in case of a 40° latitude:

| | Fixed | Adj. 2 seasons | Adj. 4 seasons | 2-axis tracker |
|---|---|---|---|---|
| % of optimum | 71.1% | 75.2% | 75.7% | 100% |

Adjusting the tilt two times a year

The following tble gives the best dates on which to adjust:

| | Northern hemisphere | Southern hemisphere |
|---|---|---|
| Adjust to summer angle on | March 30 | September 29 |
| Adjust to winter angle on | September 12 | March 14 |

Adjustin the tilt four times in a year

following table gives the best dates on which to adjust:

| | Northern hemisphere | Southern hemisphere |
|---|---|---|
| Adjust to summer angle on | April 18 | October 18 |
| Adjust to autumn angle on | August 24 | February 23 |
| Adjust to winter angle on | October 7 | April 8 |
| Adjust to spring angle on | March 5 | September 4 |

# Solar Panel Tilt Calculator

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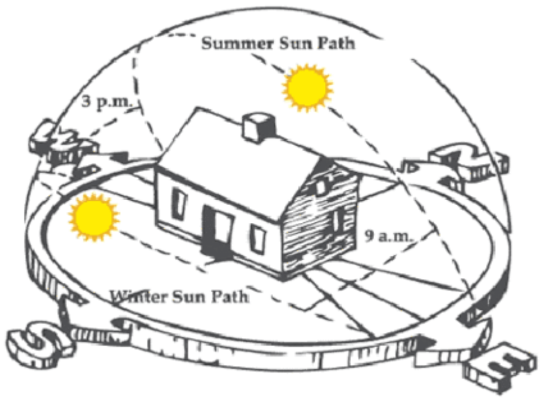
## What's the optimal angle for my solar panels?

Enter in your country, state, and city to calculate the optimum tilt of your solar panels every month.




### Solar Angle Calculator

Select Country: Romania

Select Town/City: Pitesti

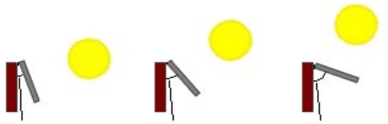
**Pitesti**
**Optimum Tilt of Solar Panels by Month**

Figures shown in degrees from vertical

| Jan | Feb | Mar | Apr | May | Jun |
|---|---|---|---|---|---|
| 29° | 37° | 45° | 53° | 61° | 68° |

| Jul | Aug | Sep | Oct | Nov | Dec |
|---|---|---|---|---|---|
| 61° | 53° | 45° | 37° | 29° | 22° |

**Winter** **Spring/Autumn** **Summer**



22° angle 45° angle 68° angle

**Notes:**
On the 21st December, the sun will rise 66° east of due south and set 66° west of due south.

On the 21st March/21st September, the sun will rise 91° east of due south and set 91° west of due south.

On the 21st June, the sun will rise 117° east of due south and set 117° west of due south.

*The optimal angle for your solar panels varies throughout the year, depending on the seasons and your location and this calculator shows the difference in sun height on a month-by-month basis. For even more precise angling, you would need to track the sun as it moves throughout the day on a minute-by-minute basis. This can be accomplished with an automated mechanical solar tracker, but unfortunately this is not very economical.*

*The sun reaches its peak at solar noon each day (exactly half way between sunrise and sunset) and this calculator shows the angle at that time of day. At solar noon, the irradiance from the sun is at its zenith and you can generate the most energy.*

*As an example, the sun is due south at solar noon in the northern hemisphere. To get the best performance out of your photovoltaic panels, you would face them due south at the optimum angle so that the panel is receiving as much sunlight as possible at this time.*

*The best angle for your solar project also depends on when you want to get the best out of your photovoltaic system. If you want the best performance during the summer months (when there is the most sunlight), you would angle your photovoltaic panels according to the height of the sun in the sky during these months.*

Source: http://www.gogreensolar.com/pages/solar-panel-tilt-calculator

- **Sun Trackers for PV**

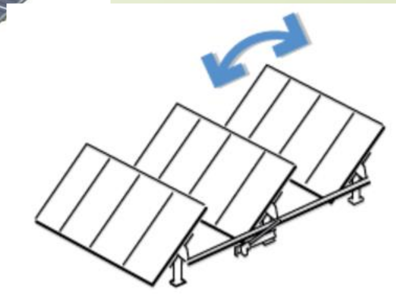
Sun trackers are devices that automatically orientates the photovoltaic panel towards the sun position on the sky. They can Increase the produced energy with 25-40%.

Types of sun tracking:

- ***Single-axis tracking***

- Azimuth tracking

The whole day – E-W one axes tracker (azimuth).
This tracking methods offers energy gain of more than 33% over fixed tilt systems and this single-axis azimuth tracker follows the sun from East to West throughout the day while holding a constant southern facing tilt for increased annual power production.



There are several implementation for single axis trackers:

**- HSAT (Horizontal single axis tracker)**

Rotation axis is oriented horizontally.
The advantage of this tracker is possibility to control multiple panels at a time, because they have parallel rotation axes.

**- HTSAT (Horizontal single axis tracker with tilted modules)**

The PV modules are installed at an angle from horizontal

## - VSAT (Vertical Single Axis Tracker)

E-W rotation. They are more efficient at high latitudes than horizontal trackers.
PV is oriented at a specific angle.

## - TSAT (Tilted Single Axis Tracker)

The rotation axes is oriented between horizontal and vertical.
The module is oriented parallel with rotation axis.
They are limited from atmospherical conditions or by terrain.

## - PASAT (Polar Aligned Single Axis Tracker)

Modules are tilted and they have axes oriented to polar star, like telescopes.

### ○ *Dual-axis tracking*

Has two degree of freedom (DOF). They can continuously follow the sun, whole day and whole year. The efficiency of panel is increasing. They permit orientation on vertical an horizontal simultaneously (azimuth and tilt).

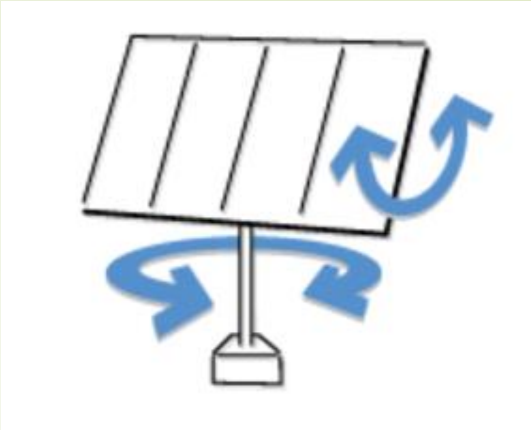
Variant of implementation of these trackers:

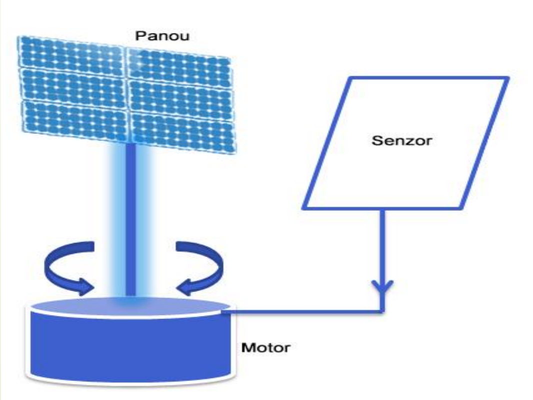
**- TTDAT (Tip-tilt dual axis tracker)**

Photovoltaic panel is mounted on the top of the support, using a H or T shape structure.

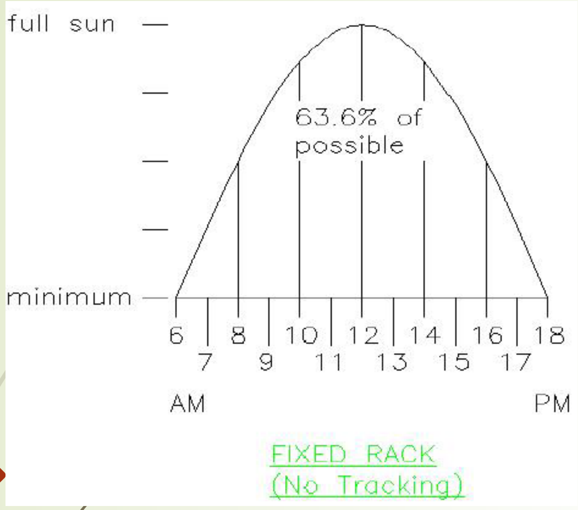
**AADAT (Azimuth-altitude dual axis tracker)**

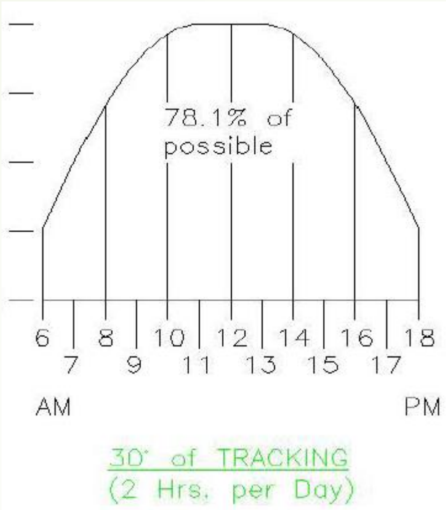
The advantage is that actuators (motors) are situated at base ring level, so they have the mass distributed on the entire base ring.

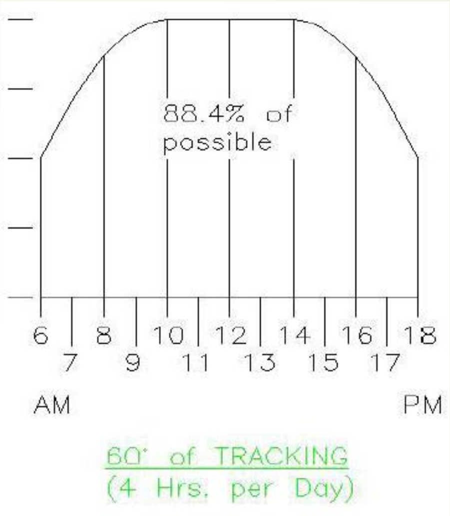


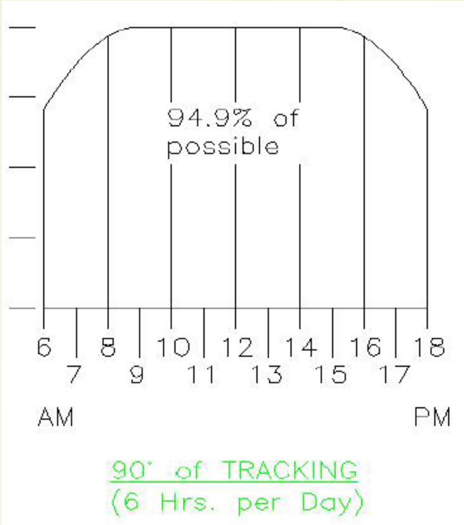


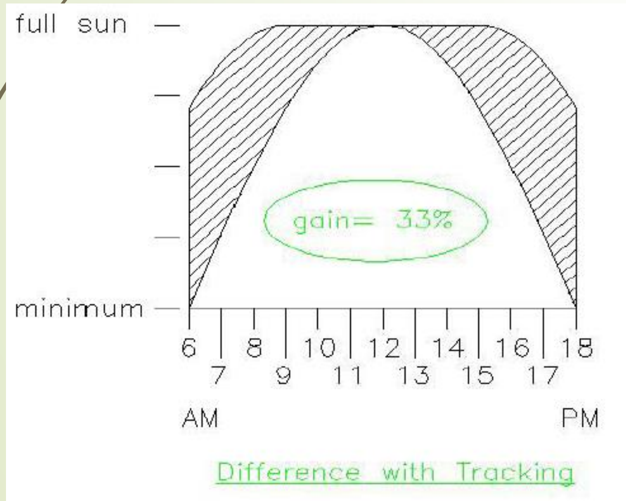
Comparison between fixed panel and sun trackers PV regarding the amount of energy produced.




Solar gain was estimated at Equinox, for clear sun.

*Source: Zomeworks Corporation*

- **Sun tracking controllers.**

Commonly types of drivers for PV system movement to track the sun position are:

- Manual trackers – user change the PV position, usually for several times per year or several times a day.

***Automatic sun tracking controllers.***

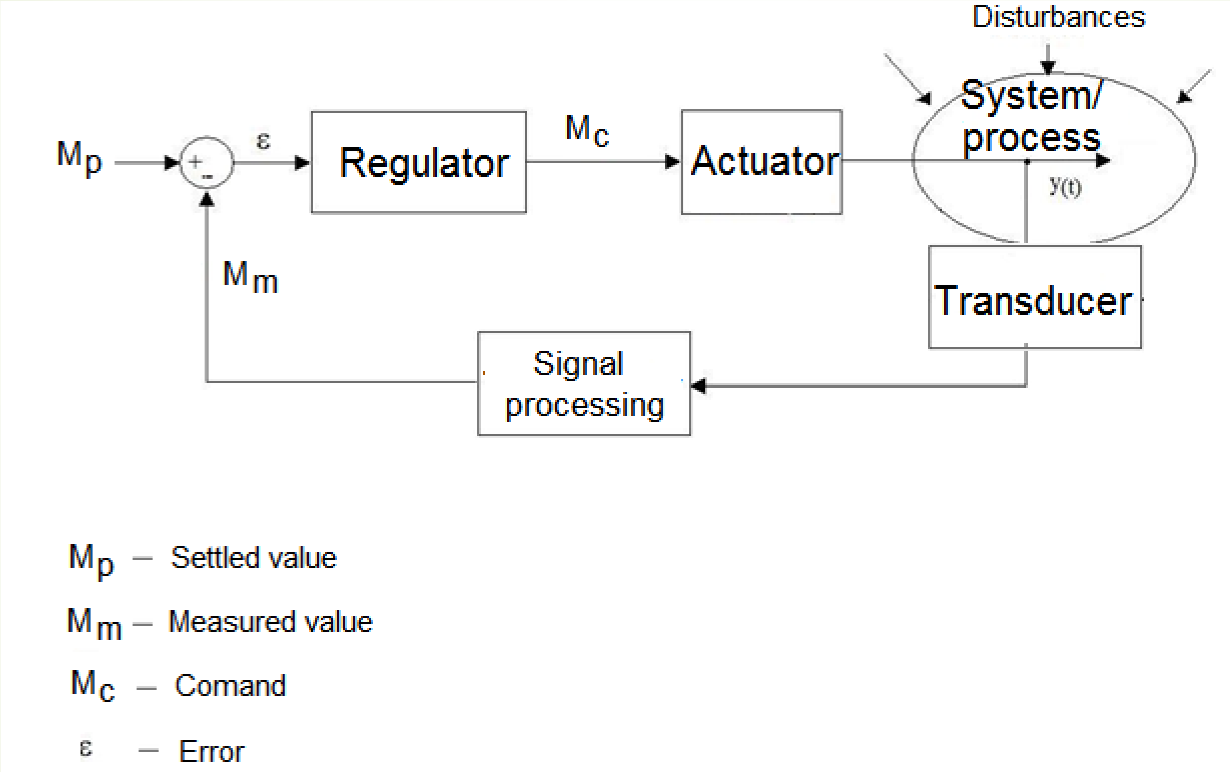
- Active drivers – they uses motors for position control one or more light sensors for determining the position of sun on sky (closed loop control).

- Programmed drivers (crono-drivers, based on real time clock) – rotates the PV as a speed equals with Earth rotation (but in opposite direction). For lower consumption of motors, there is not used a continuously movement, but gradual, in timed steps.

- Programmed drivers based on location (latitude), date and time, or GPS based controlled.

## ❖ Closed loop control with light sensors for active drivers.

Commonly closed loop control systems have the following block diagram:

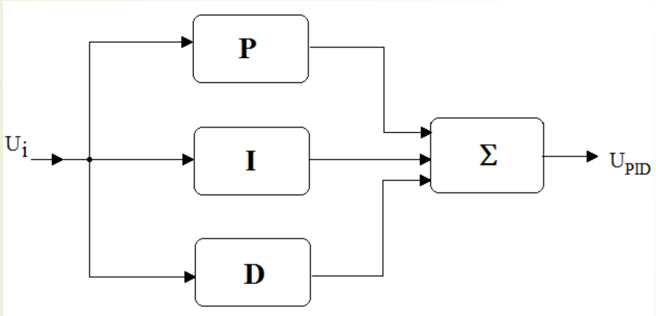


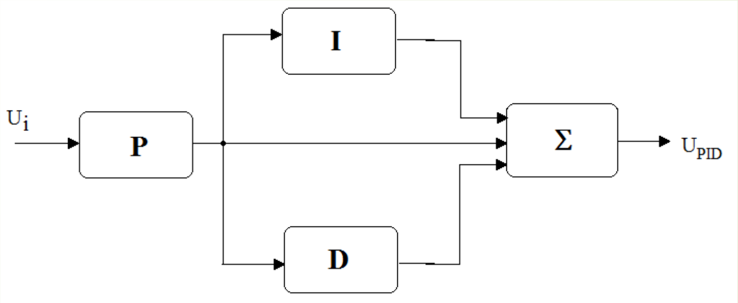
Regulators Types:

- On/Off – regulators (nonlinear regulators)

- Proportional controller P (Command is proportional with *error* between *Settled value* and *Measured value*)
  - PI (proportional–integral) controller
  - PD (proportional–derivative) controller
  - PID (proportional–integral–derivative) controller

PID controller

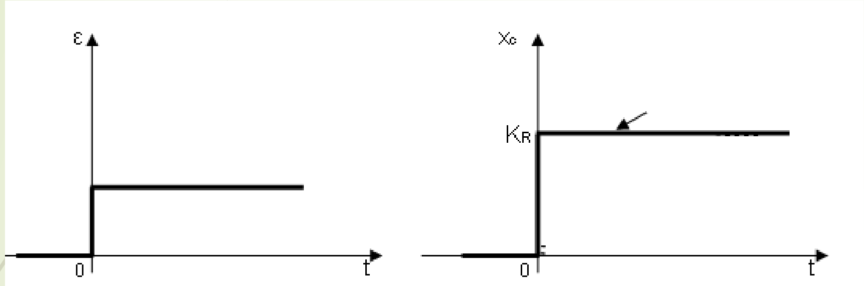


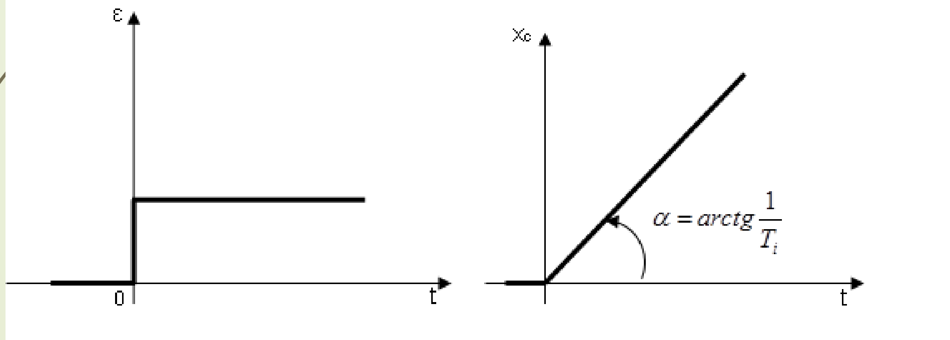

$$M_c(t) = K_p\varepsilon(t) + K_i\int_0^t \varepsilon(\tau)\,d\tau + K_d\frac{d}{dt}\varepsilon(t)$$

$$M_c(t) = K_p\left(\varepsilon(t) + \frac{1}{T_i}\int_0^t \varepsilon(\tau)\,d\tau + T_d\frac{d}{dt}\varepsilon(t)\right)$$

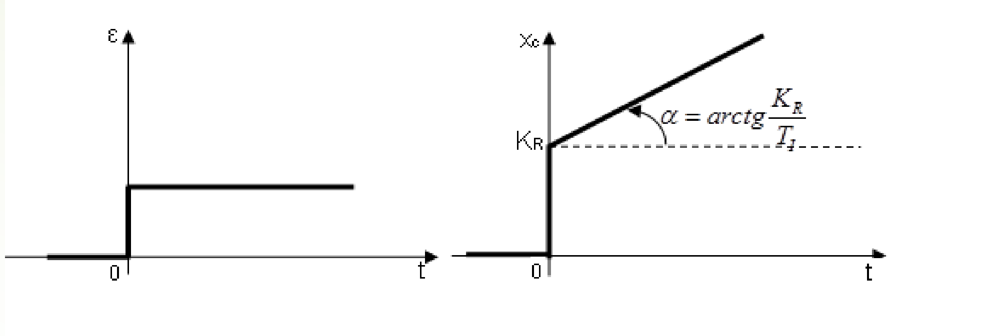
# Proportional controller time response



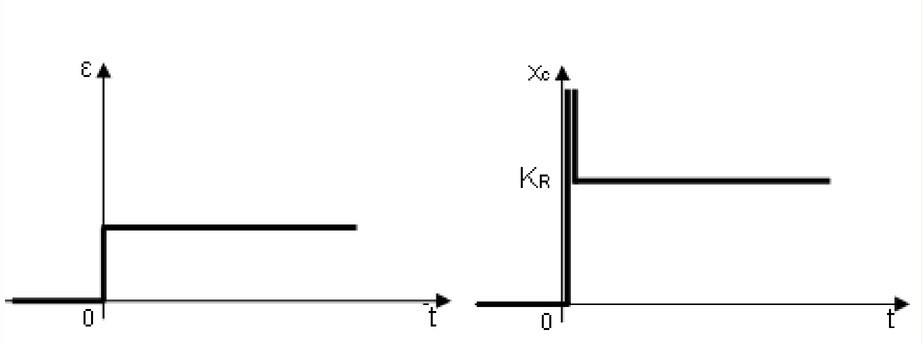

Proportional controller (P)



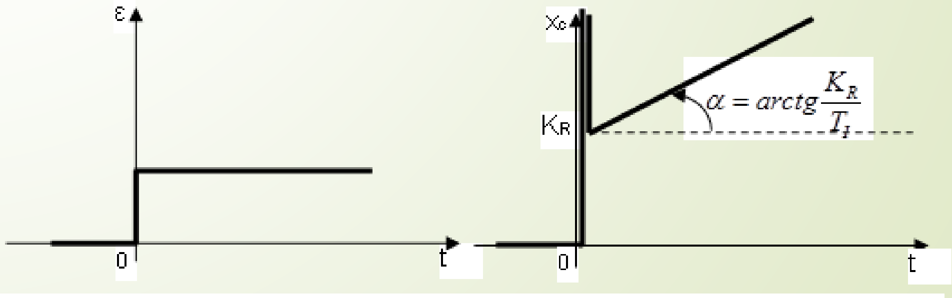

Integral controller (I)




Proportional-Integral controller (PI)

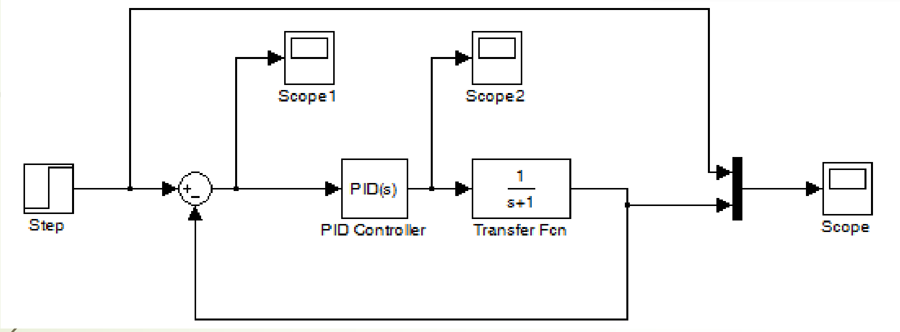


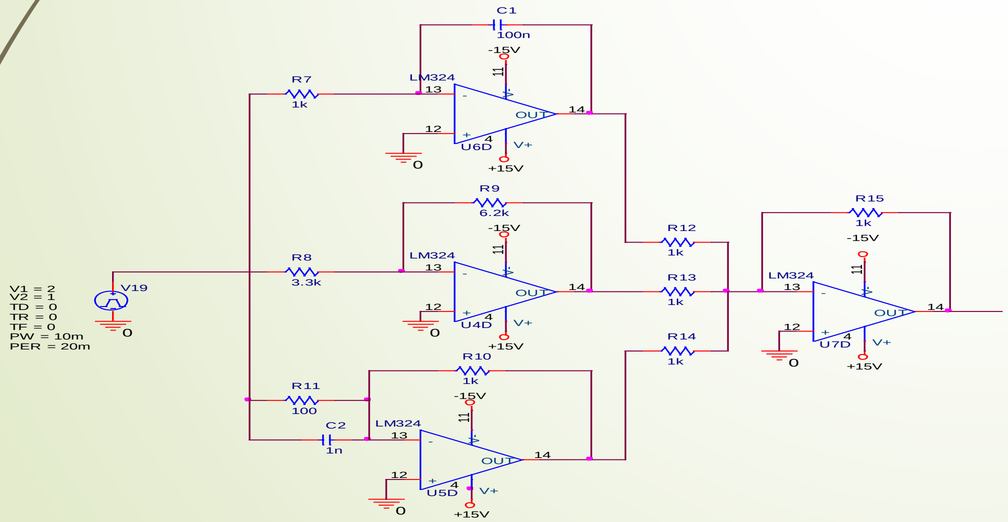

Proportional-Derivative controller (PD)

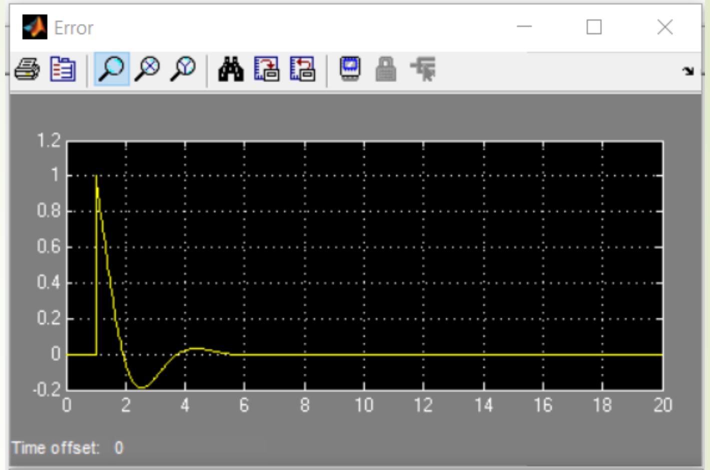


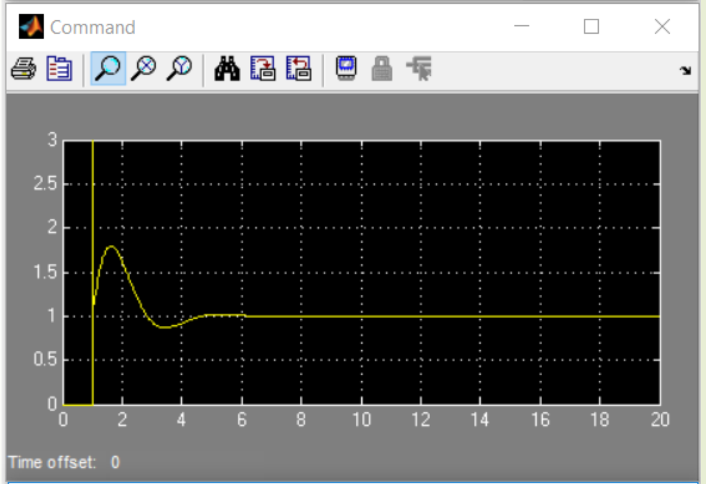

Proportional-Integral-derivative controller (PID)

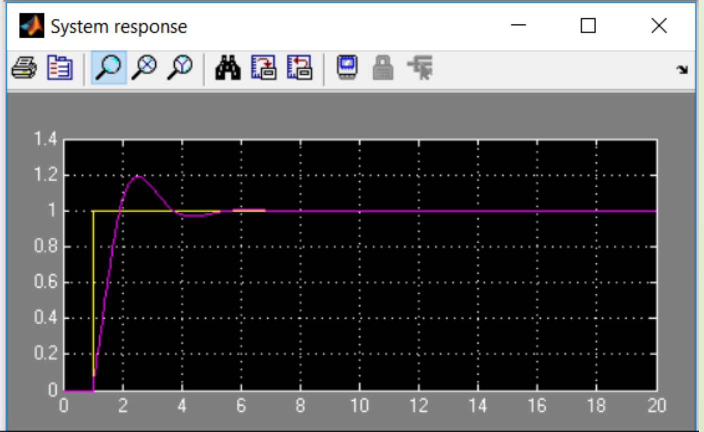
# PID controller response

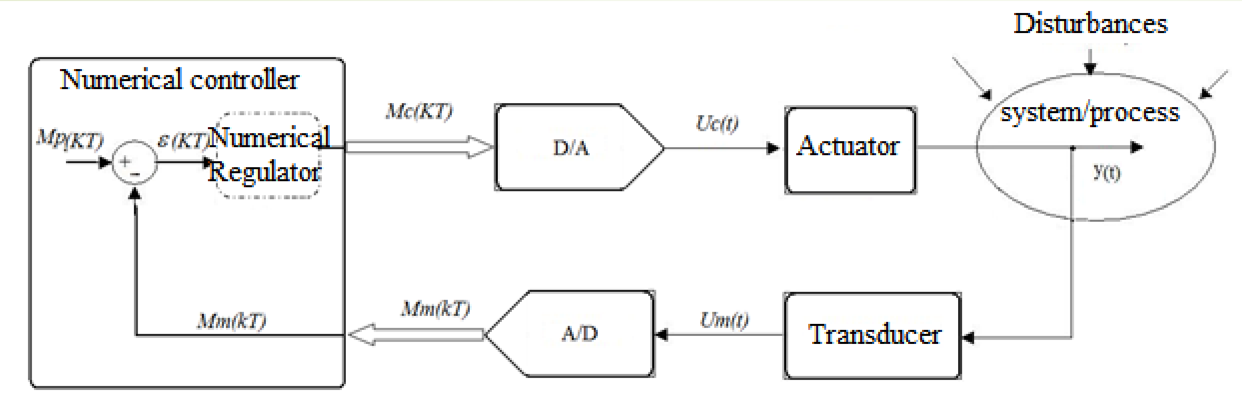


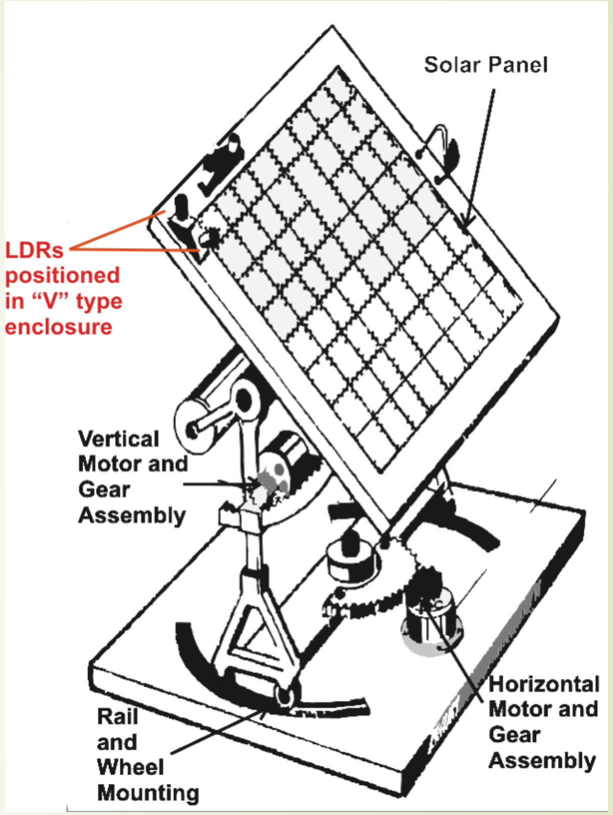





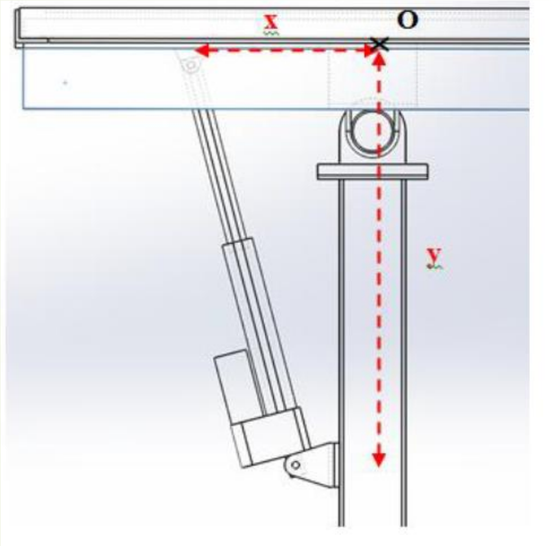

A typical two-axis photovoltaic panel tracker system:

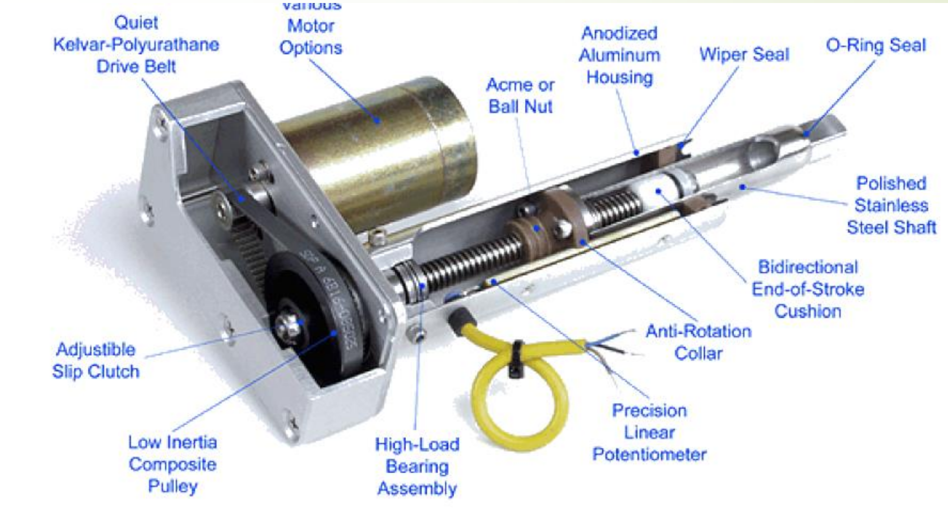
- Actuators (motors)
- Gears (to reduce speed and increase torgue)
- Light Sensors (photoresistors or photodiode/phototransistors)
- Controller (analogical or numerical)

Actuators used for changing position of PV to track the sun:

- DC servo motors (DC motors with encoder for position sensing) and gears
- DC motors with gears and accelerometer for movement sensing
- Stepper motors (with gears)
- Linear actuators

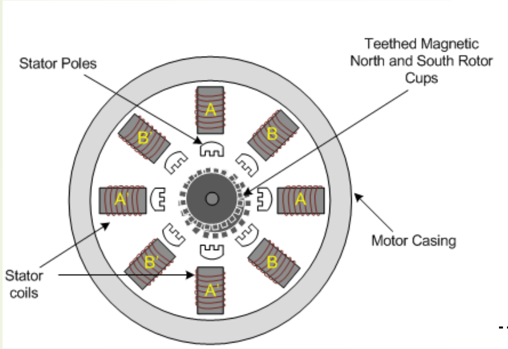
*Linear actuators.*

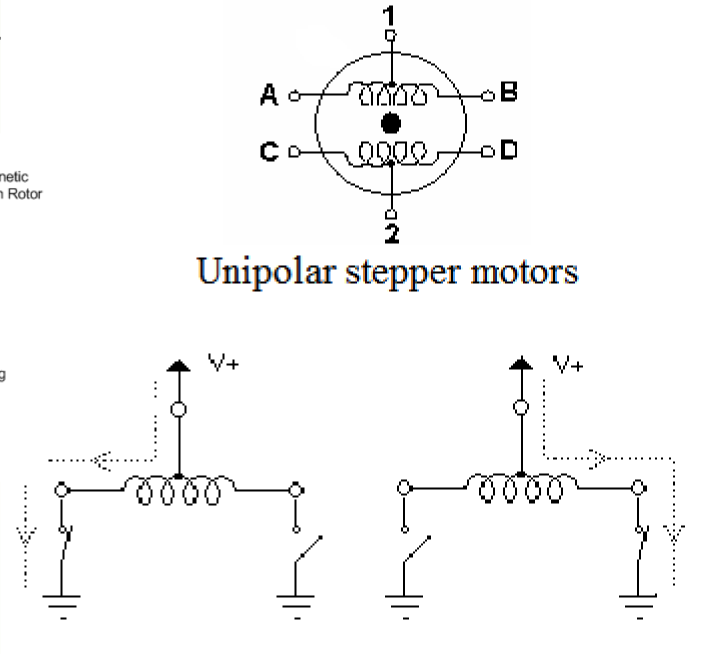


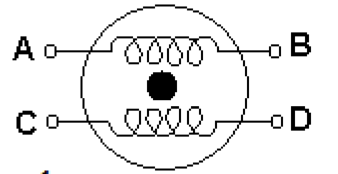
## *Stepper motors*

- They can be controlled in an sequential mode, user controls the number of steps and the speed of rotation. For positioning systems with stepper motors, there is no necessary to use encoders or other displa




Unipolar stepper motors




Bipolar stepper motors

Command mode:
- Full step
- Half step
- microstep

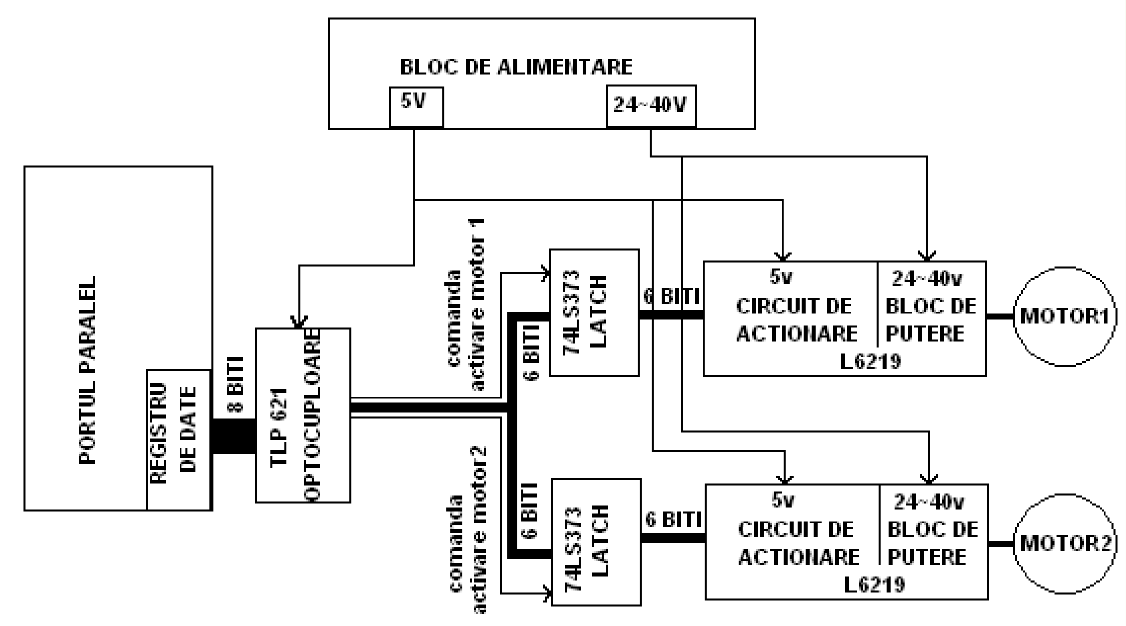
Full step

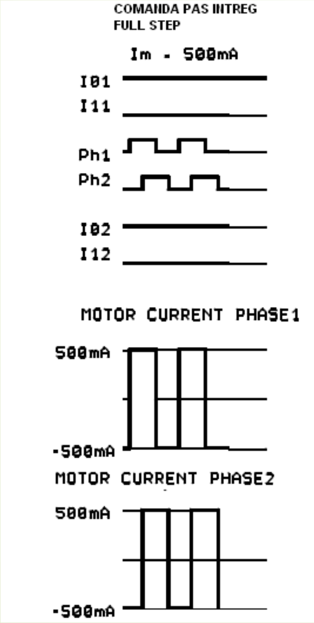
| Pas | A | B | C | D |
|---|---|---|---|---|
| start | 1 | 0 | 0 | 0 |
| 2 | 0 | 1 | 0 | 0 |
| 3 | 0 | 0 | 1 | 0 |
| 4 | 0 | 0 | 0 | 1 |

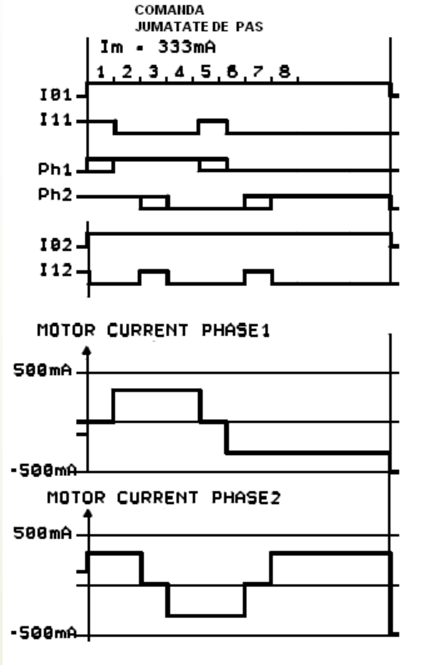
Half step

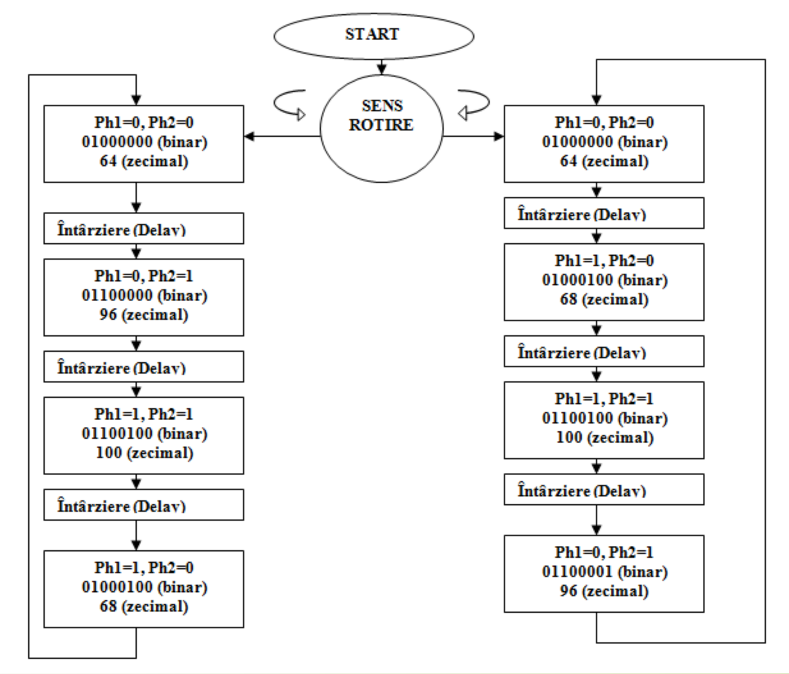
| Pas | A | B | C | D |
|---|---|---|---|---|
| start | 1 | 0 | 0 | 0 |
| 1/2 | 1 | 1 | 0 | 0 |
| 1 | 0 | 1 | 0 | 0 |
| 1 1/2 | 0 | 1 | 1 | 0 |
| 2 | 0 | 0 | 1 | 0 |
| 2 1/2 | 0 | 0 | 1 | 1 |
| 3 | 0 | 0 | 0 | 1 |
| 3 1/2 | 1 | 0 | 0 | 1 |
| 4 | 1 | 0 | 0 | 0 |

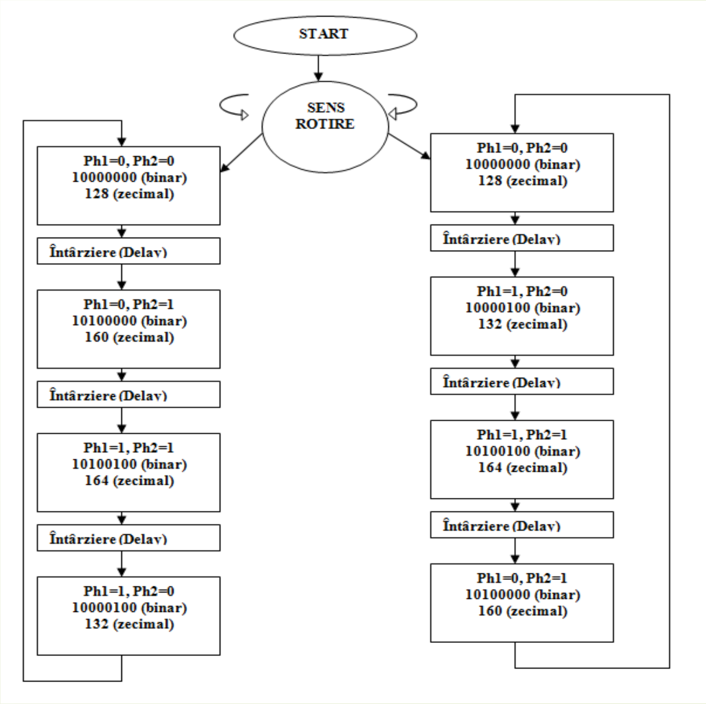
# Sun tracker implementation with two stepper motors and PC control



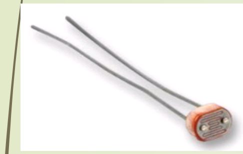



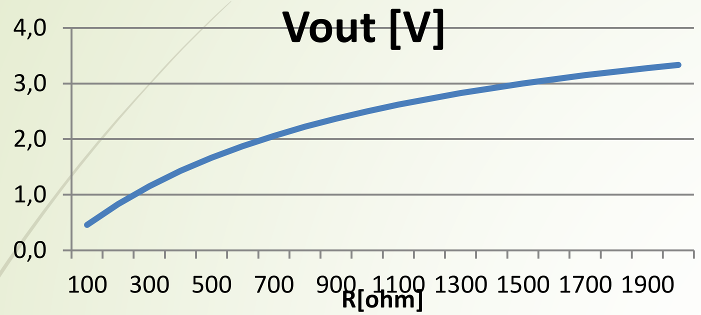



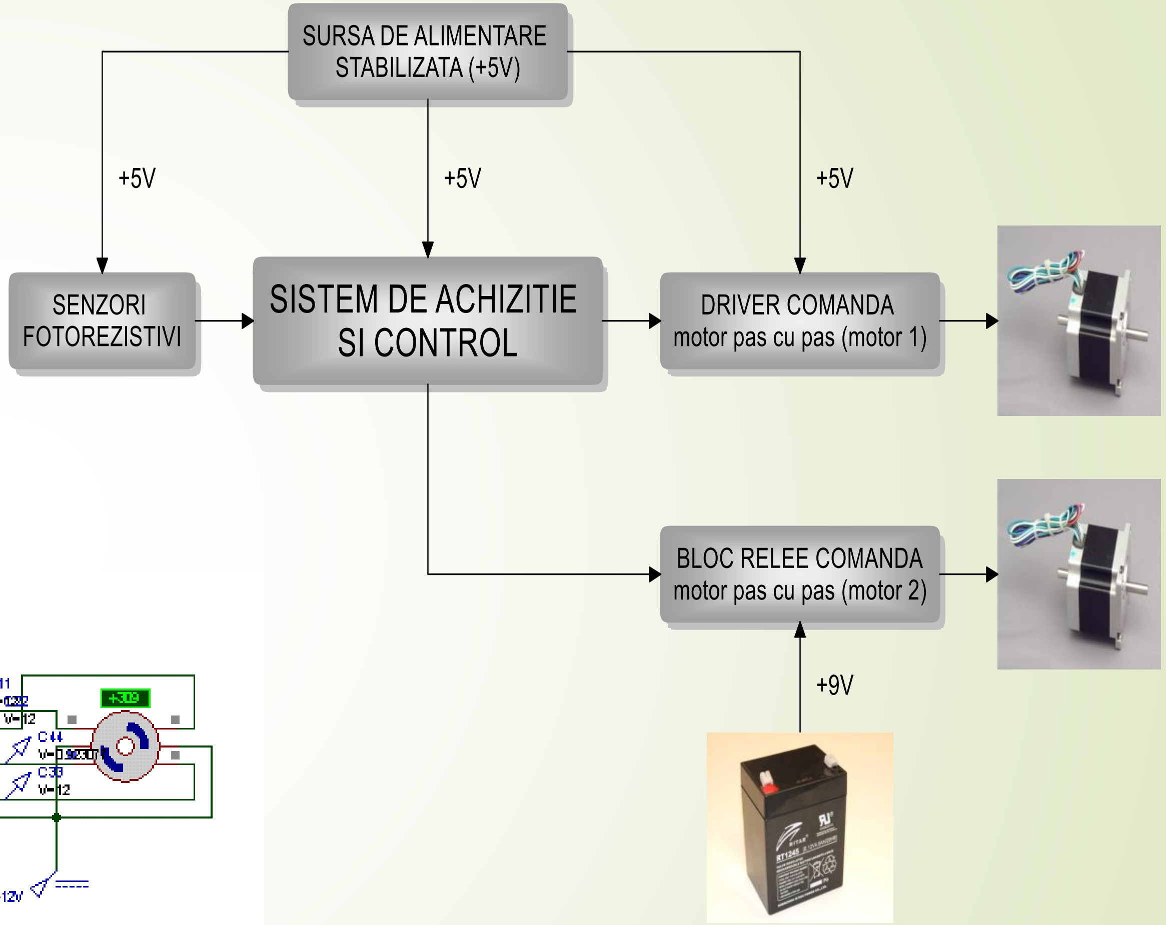



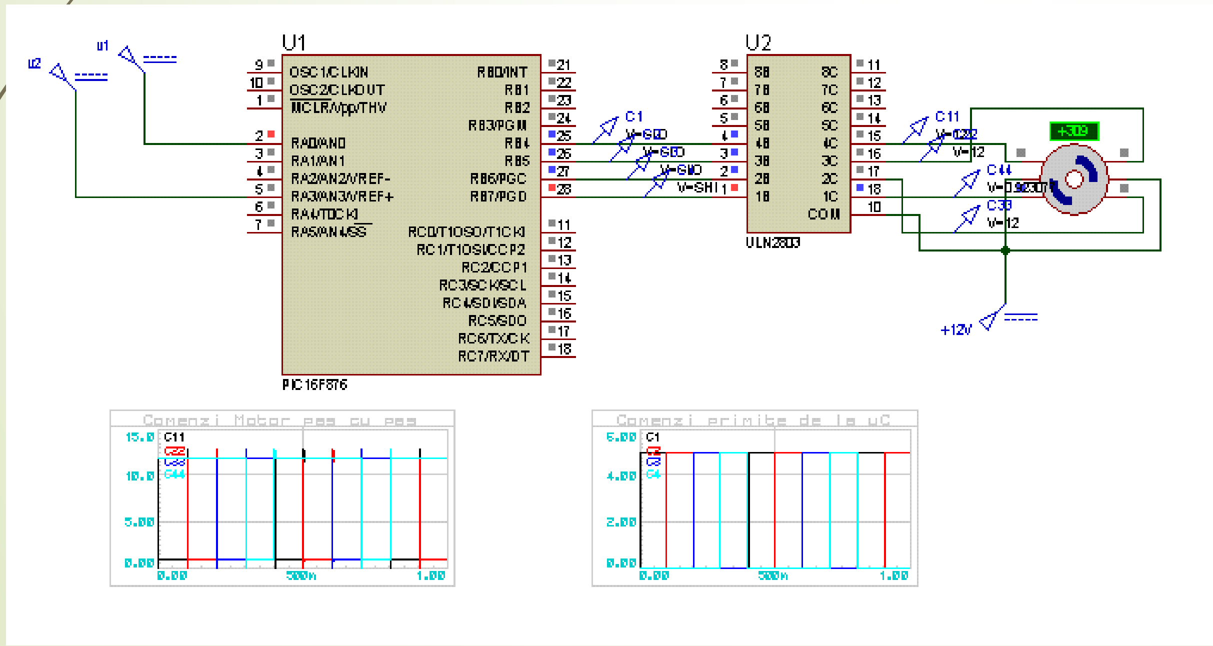



# Sun tracker implementation with two photoresistors sensors and two stepper motors



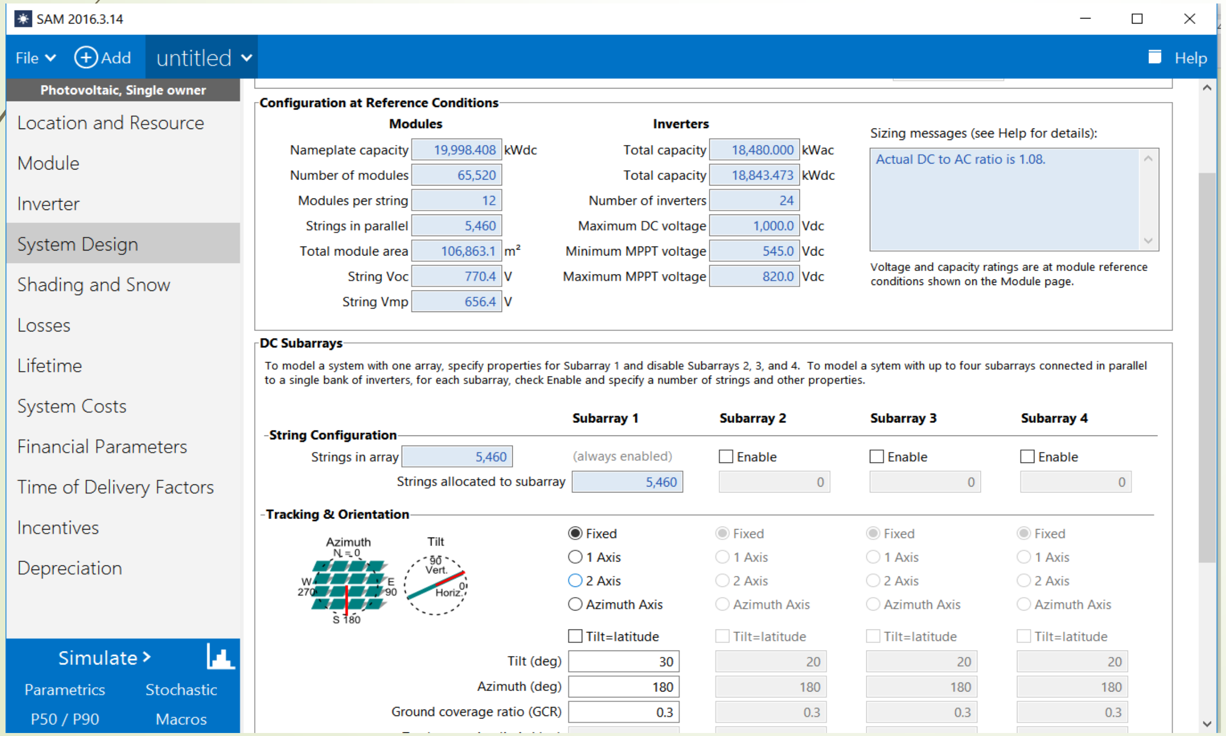


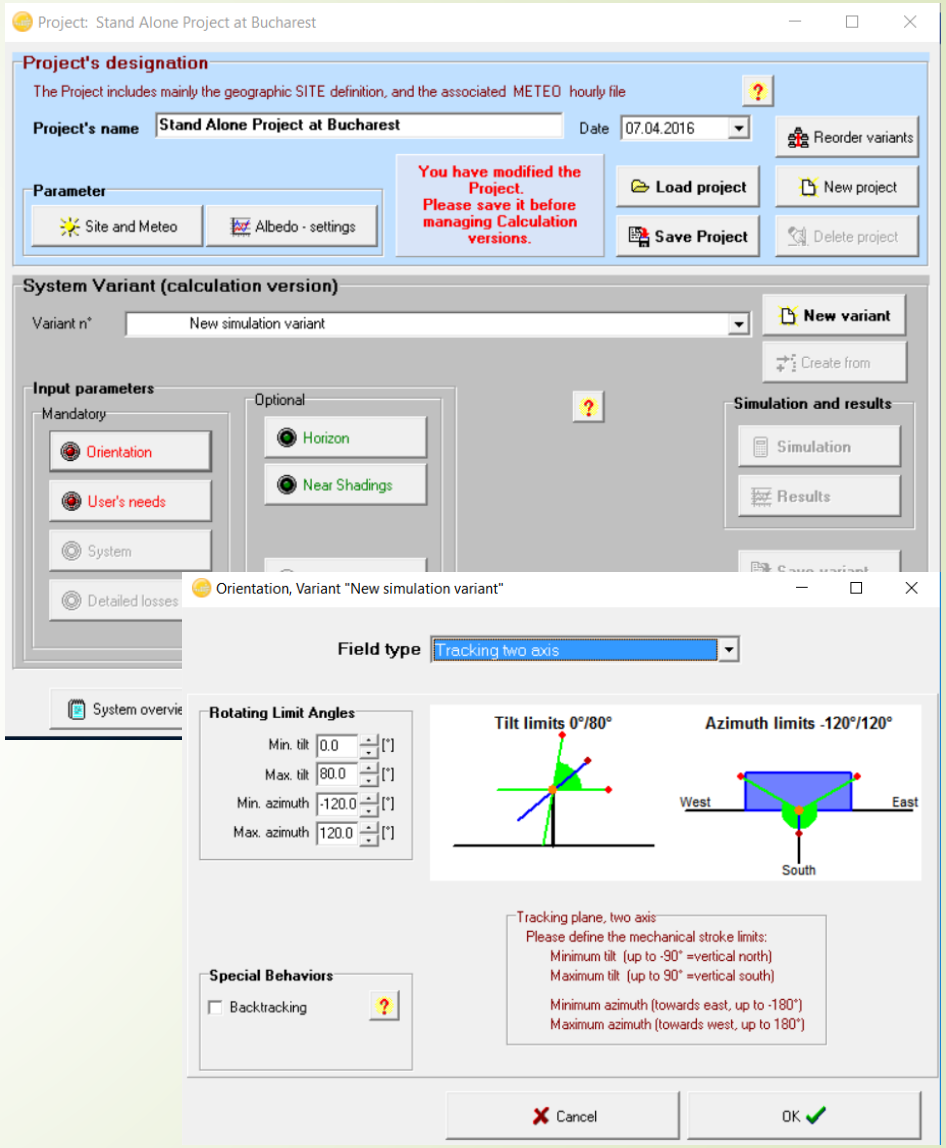



# Assisted system design

- Angle calculation using online web calculators
  - http://pvwatts.nrel.gov/
  - http://www.ecowho.com/tools/solar_power_calculator.php
  - etc.
- Standalone software like:
  - Homer Renewable Energy Microgrid Software
  - PVsyst (Photovoltaic Software)
  - System Advisor Model (SAM)
  - etc.



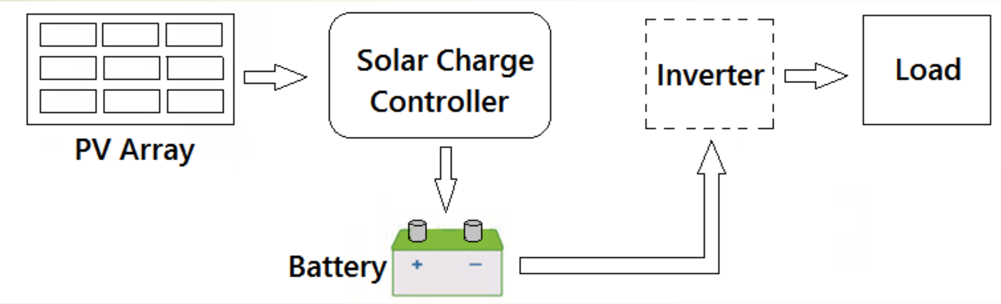



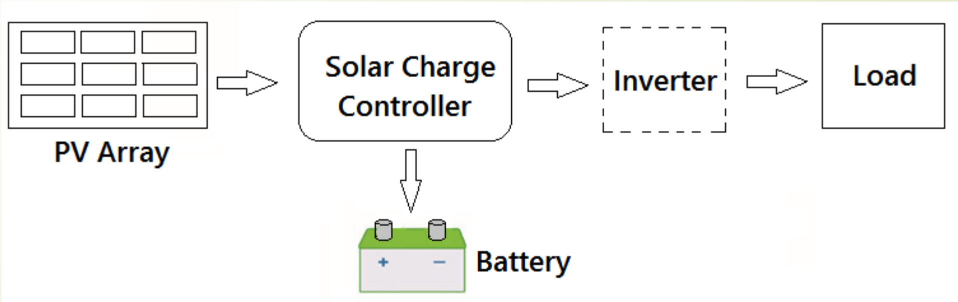
## ❖ Solar Charge Controller Types

Solar charge controllers (solar regulators) are electronic devices connected between photovoltaic panels and battery or load to provide the right voltage and current to them.

They are necessary to use from two reasons:

- the output voltage and power (P=V*I) generated by a PV depends the amount of radiation captured from the sun, and the sun light changes within a day or a year;
- some photovoltaic panels generates more voltage than battery nominal voltage;
- in case of generating of high power with panels placed at distance from the battery, using high voltage panels will result in lower current passing through wires, so wires can be thinner, which results in lowering the overall price.



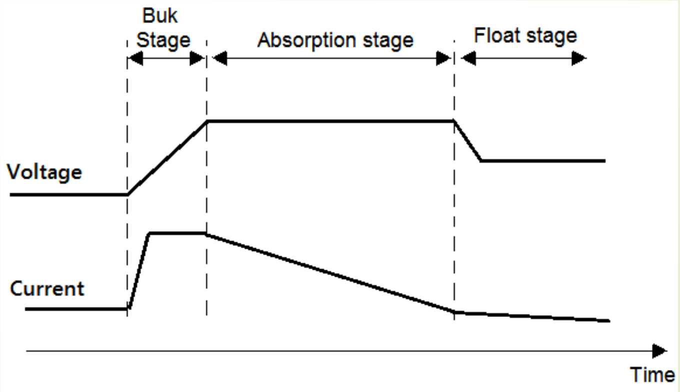
- ***The main function of the solar charge controllers are:***

- *Block reverse current* - when panel output voltage is lower than battery voltage (low light and full charged battery), because of reverse current of the panel;
- *prevent battery overcharge*
- *prevent battery overdischarge*
- *Control Set Points vs Temperature* (temperature compensation) - the ideal set points for charge control vary with battery temperature, so in case of low battery temperature, the charging current will be increased
- *Overload Protection* - overload can be caused by a fault (short circuit) in the wiring, or by a faulty appliance (a frozen water pump) and the current will be much higher than normal.
- *Control method and set point adapted to the battery type*
- Optionally, *display operating parameters* (battery status and the flow of power)

- ***Charger Performance***

- *Output Voltage Purity* - clean regulated voltage output with small spikes, ripple, noise and radio frequency interference
- *Efficiency* – (output power/input power) more than 90% (low energy loss in the charger
- *Maximum charging current*
- *Inrush Current* – the current that occur when the charger is initially switched on to an empty battery (higher than maximum charging current).

Current and voltage variation in case of a three stage charge cycle controller



- **Charge Controller Designs**

There are two main controller design, regarding to the regulating the charging of a battery from a PV:

- *Shunt regulation design*
- *Series regulation design*

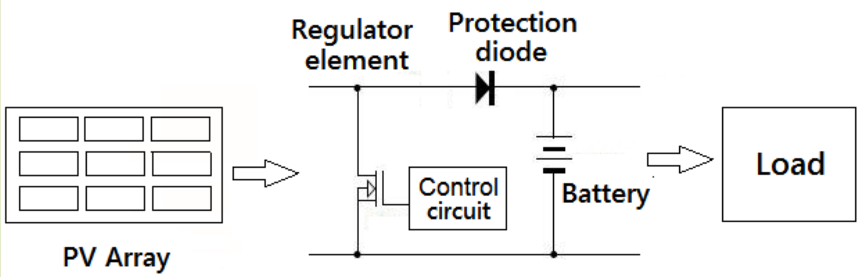
The shunt controller regulates the charging of a battery from the PV array by short-circuiting the array before battery (The PVs support to be short-circuited by design). They are simple and can operates with panels with low power (current under 20-30 amps).

Series regulators uses a control or regulation element in series between the array and the battery.

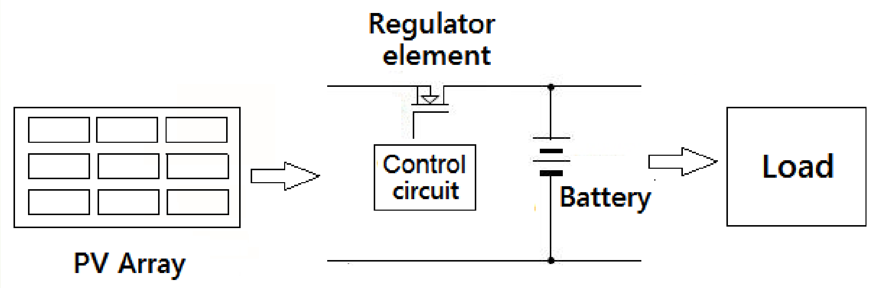
Another classification of charge controller designs can be made in function of the operating mode:

- *Linear design*
- *Pulsed or interrupting operation design*

For linear design, the regulation element (semiconductor device) acts as a variable resistor, changing the current/voltage drop continuously to maintain the battery voltage at the voltage regulation set point.



*Shunt Regulation Design*



*Series Regulation Design*

- **Pulse Width Modulation Controller (PWM)**

This method can be used with both series and shunt regulator design.

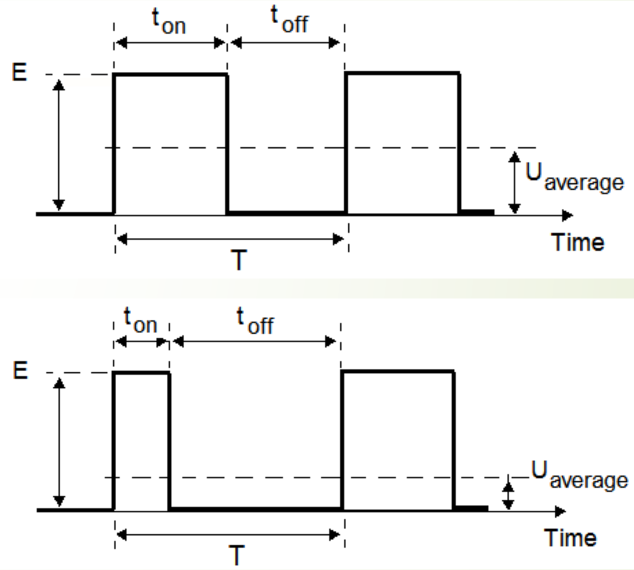
The control consist in switching an semiconductor element on and off at fixed frequency, with a variable duty cycle. This will conduct to a variable average current or voltage for charging the battery.

Principle of PWM

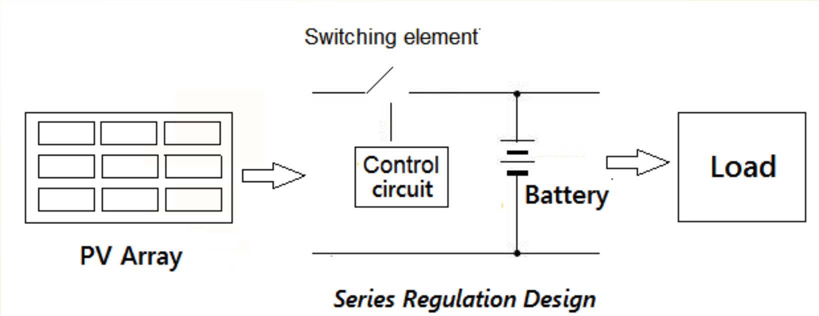
$$\tau = \frac{t_{on}}{T}$$ width factor

$$\tau = \frac{t_{on}}{T}$$

T = Period



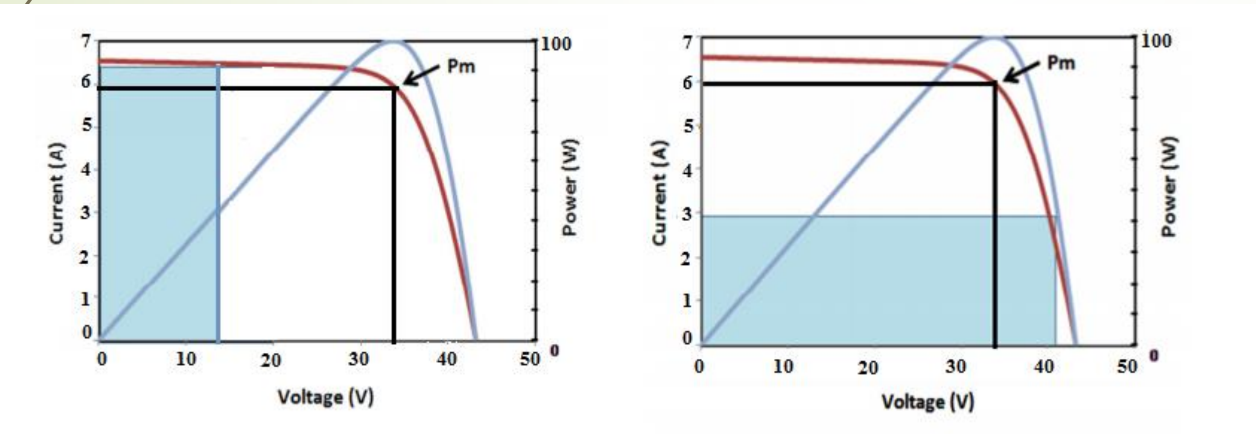

Series PWM Controller (series design):

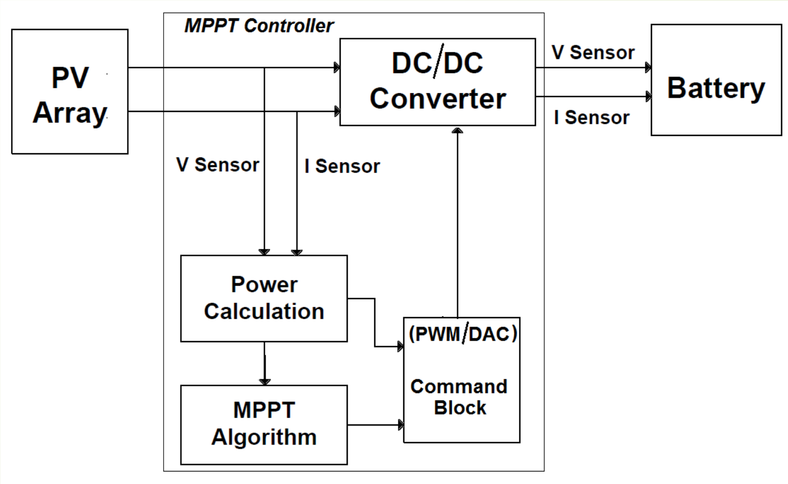


- **Maximum Power Point Tracking (MPPT) Controller**

MPPT controllers include a DC voltage converter that converts the voltage generated by photovoltaic panels to the voltage level required by the batteries, with less loss of power than other controllers.

It is more efficient in case of panels with much higher voltage than batteries, because it do not uses a voltage drop element like simple linear series controllers.

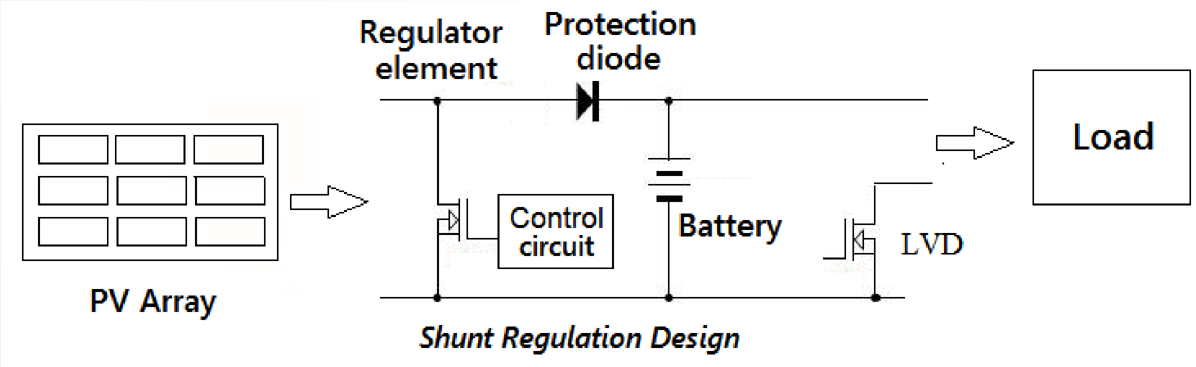


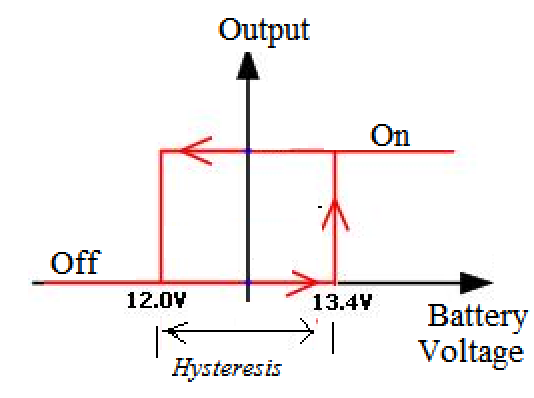



- **Low Voltage Disconnect (LVD)**

A low voltage disconnect (LVD) circuit will disconnect loads at a specific set point to protect battery from overdischarge. A typical LVD reset point is 13 volts for a 12V system (26 V on a 24 V system).

These LVD's automatically disconnect and reconnect loads based on battery condition; no operator action is required to protect the batteries. Wen tve battery is recharged and the voltage increases, then it automatically reconnect the load.



- **Battery Temperature Sensor (BTS)**

The BTS in mounted on a terminal of a battery, usually minus connector, to sense the intern temperature of battery.

It sends temperature information to charge controller, which automatically adjusts the set point of voltage to ensure full and right battery charge depending on the ambient temperature.

Source: http://www.xantrex.com/power-products/default/battery-temperature-sensor.aspx

Types of temperature sensors:

- Thermocouplers
- Thermoresistors (RTD – Resistance Dependent Resistor)
- PN semiconductor junction sensor
- IC temperature sensors with analogue Voltage output
- IC temperature sensors with digital output