Università degli Studi di Pavia
Facoltà di Ingegneria

Corso di

Principi e Applicazioni di

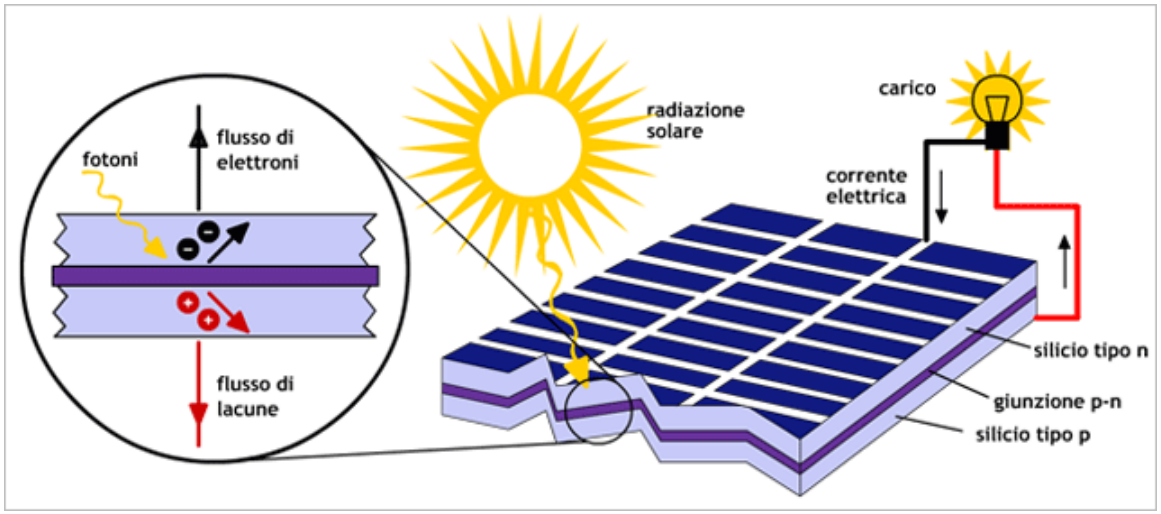
Elettrotecnica

Generatore fotovoltaico

Dipartimento di Ingegneria Elettrica

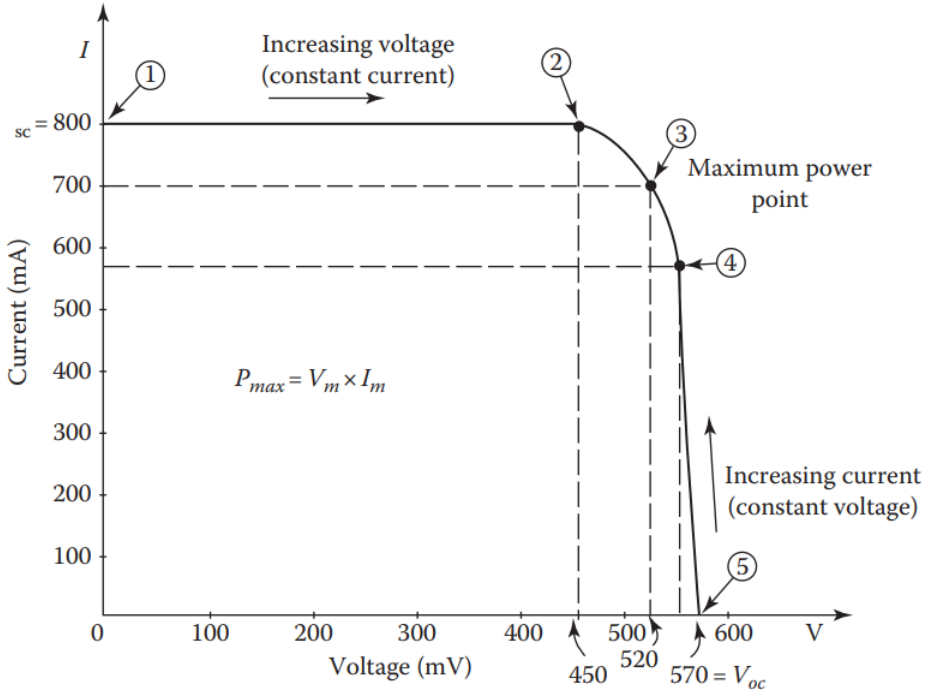
www.unipv.it/electric/cad

Generatori solari: cella fotovoltaica



Silicio drogato p (e.g. atomi boro): eccesso di lacune
Silicio drogato n (e.g. atomi fosforo): eccesso di elettroni
Giunzione p-n : separazione di carica
Fotone incidente: generazione di nuove coppie elettrone-lacuna
Effetto: forza elettromotrice ai morsetti

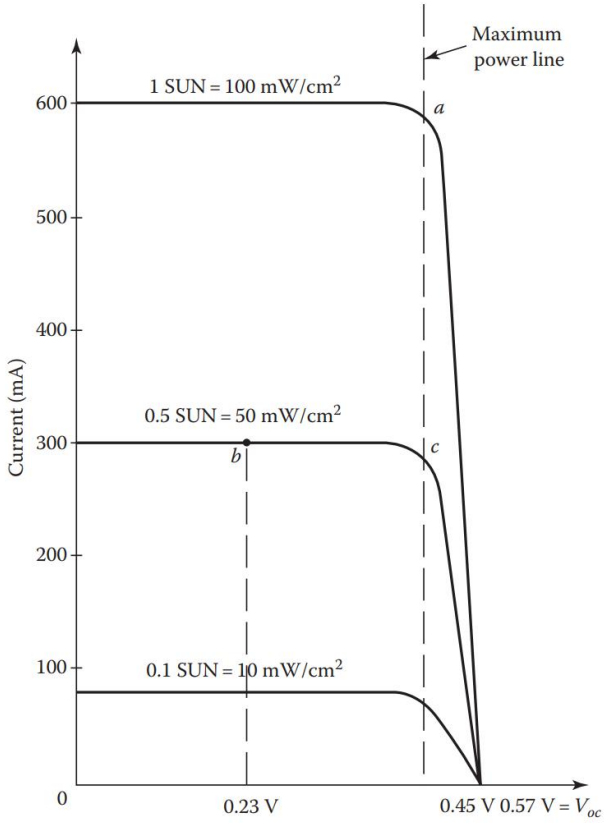
Solar cell - 1



Cella fotovoltaica: generatore di forza elettromotrice in regime DC

Caratteristica elettrica non lineare

Solar cell - 2


Maximum
power line
1 SUN = 100 mW/cm²
0.5 SUN = 50 mW/cm²
0.1 SUN = 10 mW/cm²
a
b
c
600
500
400
300
200
100
0
Current (mA)
0.23 V
0.45 V
0.57 V = V_{oc}

Temperature effect

$$E_0 = E_R - 0.0021(T - 25) \tag{13.3}$$

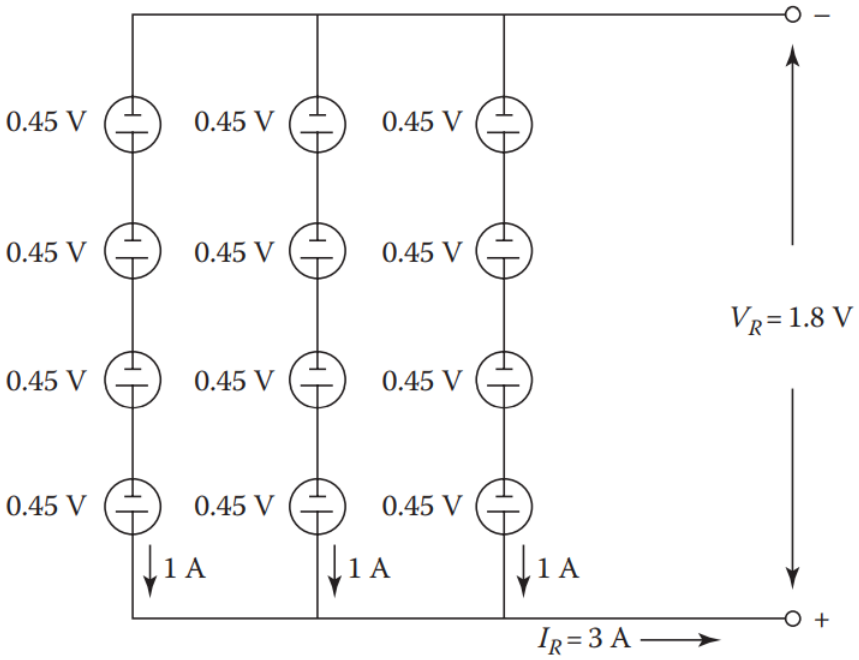
and

$$I_0 = I_R + 0.025A(T - 25) \tag{13.4}$$

where E_R and I_R are the cell ratings in volts and mA at 25°C. E_0 and I_0 will be the cell voltage and current at the new temperature T in degrees Celsius. A is the cell area in square centimeter.

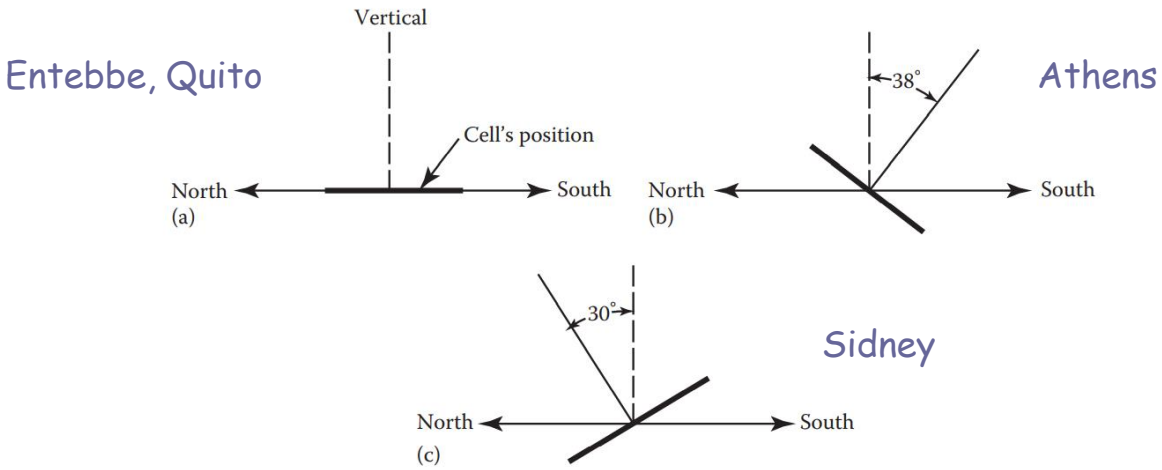
Cells operate more efficiently when they are cooler

From solar cell to solar panel

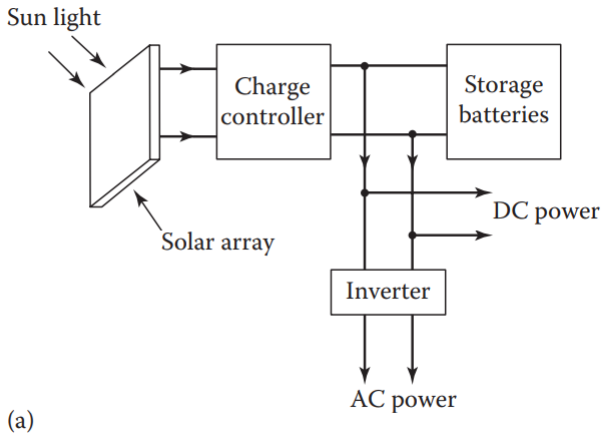


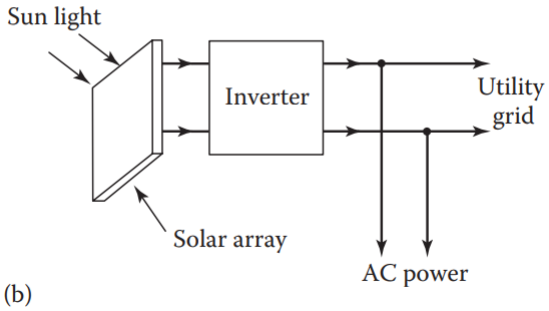
The Latitudes of Selected Cities around the World

Location	Latitude	Location	Latitude
Athens, Greece	38° N	Madrid, Spain	40° N
Berlin, Germany	53° N	Miami, Florida	26° N
Bogota, Columbia	2° N	Montreal, Quebec	46° N
Bombay, India	20° N	Moscow, Russia	55° N
Buenos Aries, Argentina	20° N	Munich, Germany	48° N
Cairo, Egypt	30° N	Oslo, Norway	60° N
Edinburgh, Scotland	56° N	Paris, France	49° N
Entebbe, Uganda	0°	Quito, Ecuador	0°
Honolulu, Hawaii	20° N	Rio de Janeiro, Brazil	23° S
Houston, Texas	30° N	Rome, Italy	42° N
Kansas City, Missouri	39° N	Seattle, Washington	47° N
Las Vegas, Nevada	36° N	Sidney, Australia	35° S
Lima, Peru	12° S	Thule, Greenland	77° N
London, England	52° N	Tokyo, Japan	36° N
Los Angeles, California	34° N	Valparaiso, Chile	36° N



Solar generator configurations

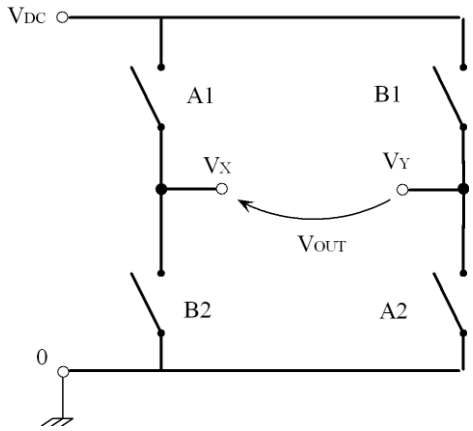


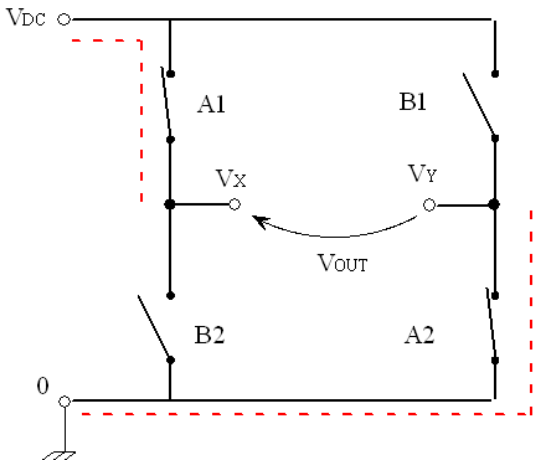


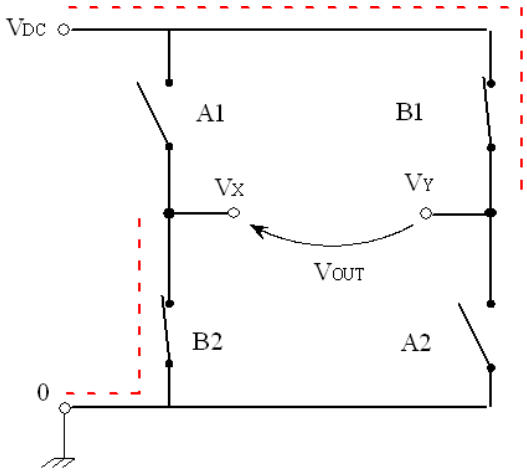
Stand-alone system

Co-generation system

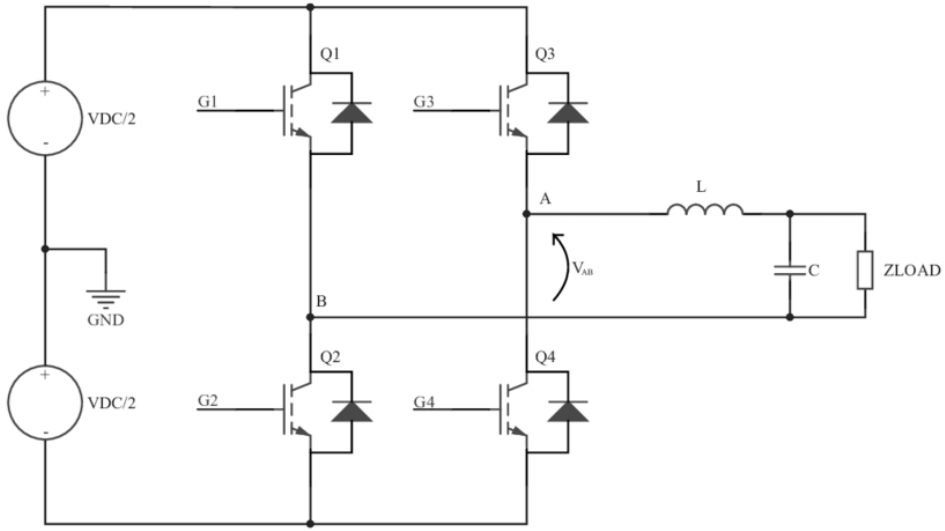
Inverter operation principle







Inverter circuit



Roma

PV array

5,185 × 10,98 m roof size

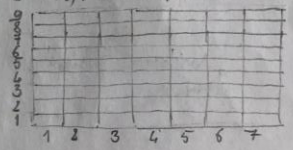
Solar panel : at 50 °C 14,7 V, 2,27 A → 33 W/panel

size 30,5 × 122 cm² = 0,3721 m²

Clearance : 122 cm at the roof edges → $\frac{(5{,}185 + 2{,}44)(10{,}98 + 2{,}44)}{0{,}3721} \sim 63$

→ 63 panels → 7 in a row → 7 × 122 cm = 8,56 m

9 rows → 9 × 30,5 cm = 2,75 m



P_{max} = 63 panels · 33 $\frac{W}{panel}$ = 2102 W

Single-phase inverter P_{max} = 2,5 kW, I_{max} = 25 A

DC → AC

MPPT (R_L adaption) 60 $V_{DC} \leq V_{input} \leq$ 120 V_{DC}, $V_{max,out}$ = 120 V_{AC}

efficiency 95%

CONFIGURATION

7 panels series connected : 7 × 14,7 = 102,9 V peak voltage

9 rows in parallel : 9 × 2,27 = 20,43 A peak current

within the inverter limits

Tilt angle: 42° towards South
3,29 SUN hours per day

at 50 °C : $P_{max} = 102{,}9\ V \cdot 20{,}43\ A \cong 2102\ W$ peak power output

average daily energy = $2102\ W \times 3{,}29\ h \cong 6{,}92\ kWh$ per day
(full sun hours per day (yearly average))

average energy produced per day

$6{,}92\ kWh/day \cdot 0{,}95 \cong 6{,}6\ kWh/day$
(inverter efficiency)

$6{,}6\ kWh/day \times 365\ days/year = 2409\ kWh/year$

10 cents/kWh ⟶ savings 240,9 €/year

solar array cost $P_{max} \times \frac{0{,}50\ €}{W} = 2102 \times 0{,}50 = 1051{,}00\ €$

break-even point (payback time) $n = \frac{€\ 1051}{€\ 240{,}9} \cong 4{,}4$ years