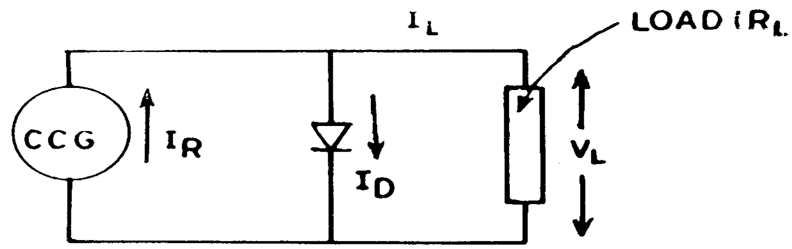
Ideal and real characteristics of solar cell.

The photovoltaic cell may be termed as a constant current generator (CCG). The equivalent circuit of an ideal solar cell is shown in figure below.



EQUIVALENT CIRCUIT OF AN IDEAL SOLAR CELL

(CCG IS CONSTANT CURRENT GENERATOR)

Figure.(3.3)

A) Ideal characteristics

If I_L, I_{ph} and I_0 are load current, photocurrent and reverse saturation current respectively for a cell of known area A,

$$I_L = I_{ph} - I_0 \left[\exp\left(\frac{qV_L}{kT} \right) - 1 \right]$$

This equation is the equation of an ideal cell considering ideality factor
$\eta = 1$.

1. Under the condition of open circuit i.e. $J_L = 0$ the open circuit voltage V_{oc} is given by:

$$V_{o.c.} = \frac{kT}{q} \ln \left[\frac{I_R}{I_0} + 1 \right]$$

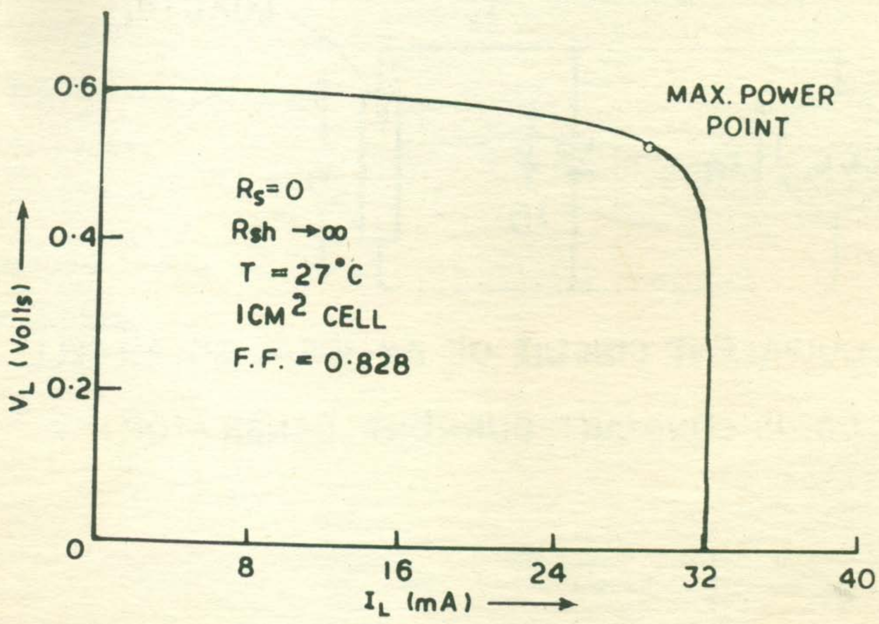
The open circuit voltage of a solar cell increases with:

- Decrease in resistively of the base material
- Increase in band gap of the semi conducting material
- Decrease in temperature of thee junction
- Increase in minority carrier lifetime of the base material

2. And under short circuit conditions $V_L = 0$ and hence

$$J_L = J_{SC} = J_{ph}$$

Relationship between V_L and I_L of an ideal load characteristic is given in the following figure.



Ideal $V_L - I_L$ curve of a solar cell.

Figure.(3.4)

The power obtained from the ideal cell

$$P_L = I_L^2 . R_L = [I_{ph} - I_O (\exp \frac{qV_L}{kT} - 1)]^2 R_L$$

and the maximum power is obtained if R_L is properly adjusted and $dP_L / dR_L = 0$. it is convenient to define maximum load power

Where $P_{Lmax.} = V_{Lm.p} \times I_{Lm.p} = V_{o.c} \times I_{s.c} \times F.F.$

$V_{Lm.p}$ is the voltage at maximum power

$I_{Lm.p}$ is the current at maximum power

F.F. is the fill factor

The efficiency η of a solar cell is defined as:

η = out put/in put = $P_{Lmax.} / P_{Linput}$.

P_{input}= 1 KW / M^2 x (Area of the cell in M^2) for AM I insulation.

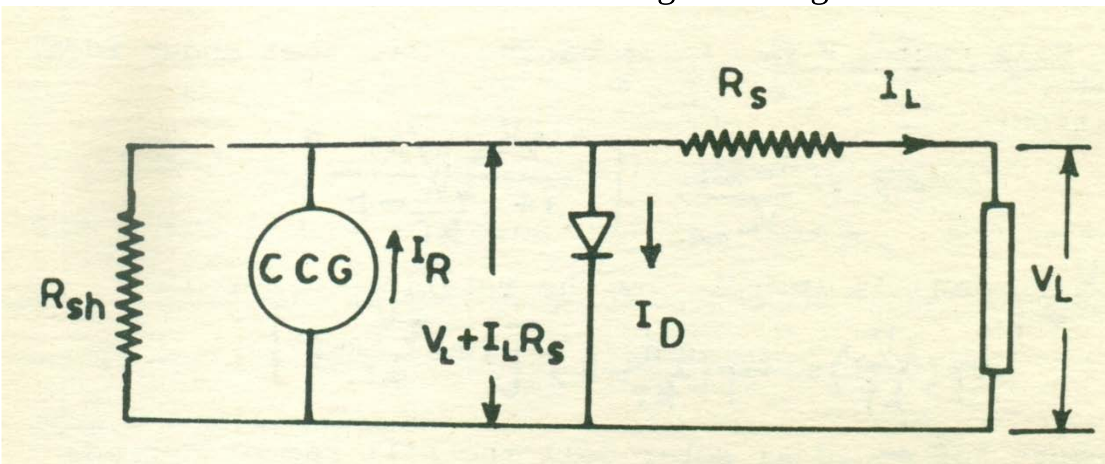
The maximum power obtained from a solar cell depends upon the open circuit voltage, short circuit current density and the fill factor.

B) **Non ideal (Real)characteristics**

Real cells have series and shunt resistance. The series resistance consists of:

- Resistance of the base layer
- Resistance of the top or diffused layer
- Resistance of the top and bottom contacts

The total series resistance is called R_s. Besides, the series resistance, the cell may have a shunt resistance R_{sh} due to various leakage paths. The equivalent circuit diagram of a solar cell with series and shunt resistance is given in fig.1 below



Under conditions of finite series and shunt resistances R_s and R_{sh} respectively, the load current I_L is given by

$$I_L = I_{ph} - I_o. [\exp \frac{q}{kT}(V_L + I_L R_S) - 1] - \frac{V_L + I_L R_s}{R_{sh}}$$

or $$\frac{q(V_L + I_L R_s)}{kT} = \ln. [\frac{I_{ph} - I_L}{I_0} + 1 - \frac{V_L + I_L R_s}{I_0 R_{sh}}]$$

gives $I_L - V_L$ characteristic of a P-N junction solar cell with series and shunt resistance. It can be shown that:

- For a finite series resistance I_{sc} decreases with decrease in shunt resistance and is different than the radiation current density

$$I_{s.c} = I_{ph} - I_o [\exp(\frac{q}{kT}.I_{sc}.R_s) - 1] - \frac{I_{sc}}{R_{sh}}$$

Computation show that I_{sc} is within 99% of Iph if $R_{sh} \geq 100\Omega$ for1 cm^2 cell. If R_{sh} is 10 ohm for 1 cm^2 cell, Voc first decrease slowly and then rapidly.

- As R_{sh} decreases Voc first slowly and than rapidly.
- V_{oc} is not affected by R_s since $V_{oc} = \frac{kT}{q}\ln[\frac{I_{ph}}{I_0} + 1 - \frac{V_{oc}}{R_{sh}}]$
- An increase in R_s reduces I_{sc}

Thee effect of series and shunt resistance on I-V characteristics is shown in Fig.2 and fig.3 respectively.

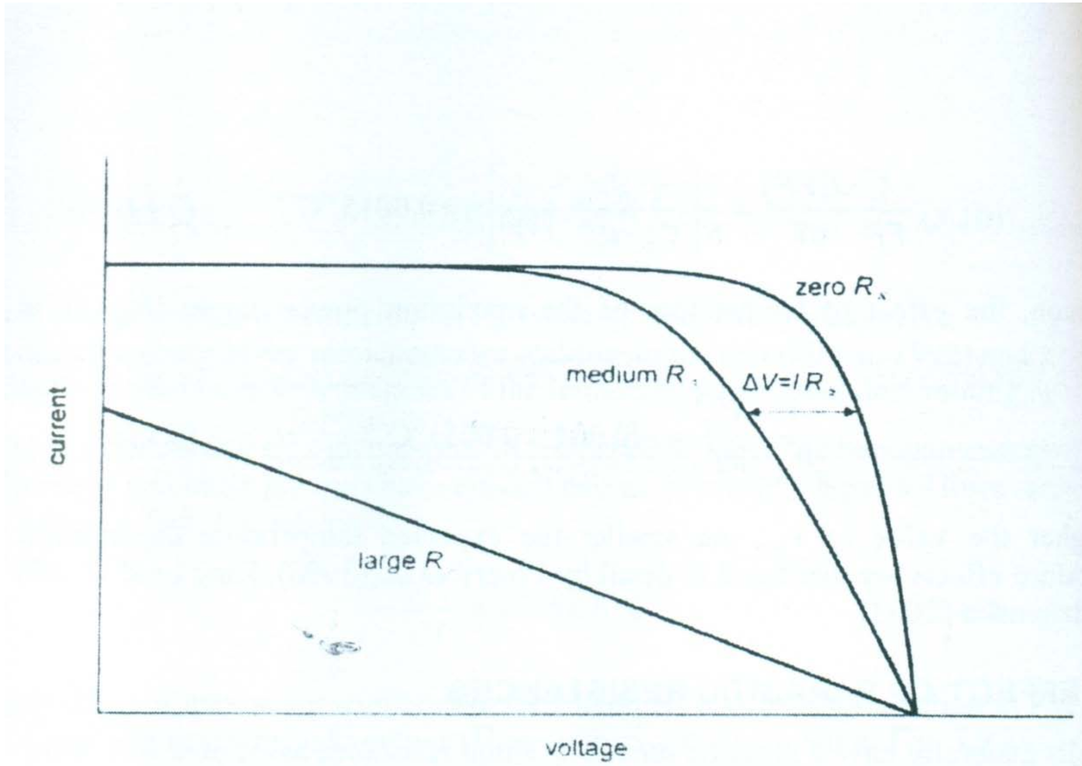


Fig.2 Effect of series resistance

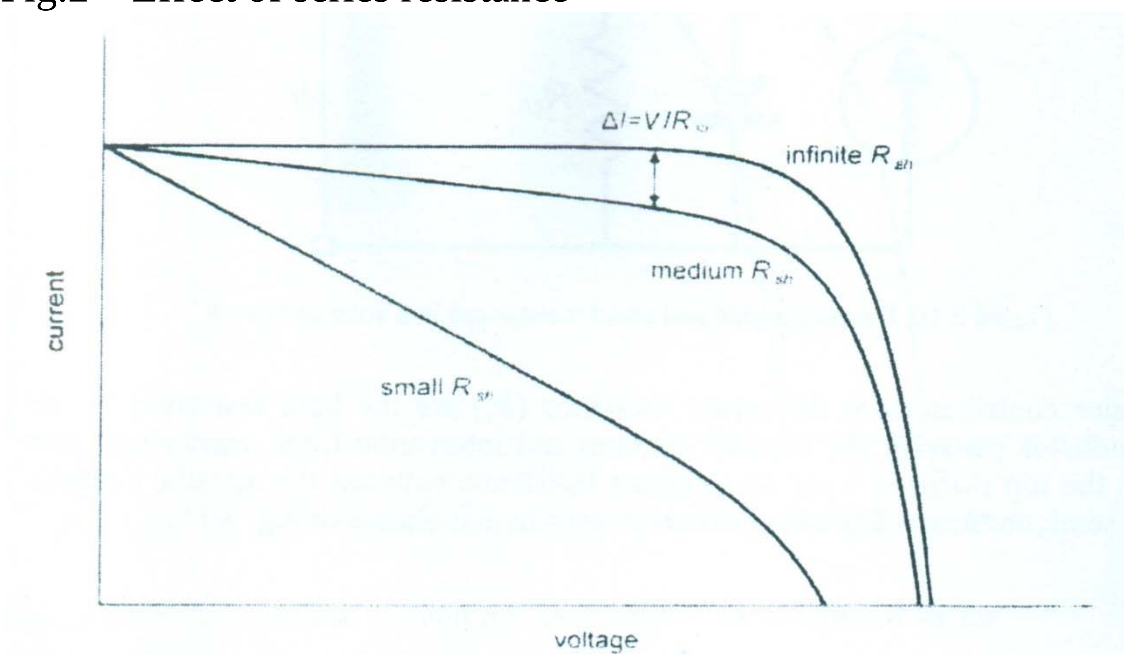


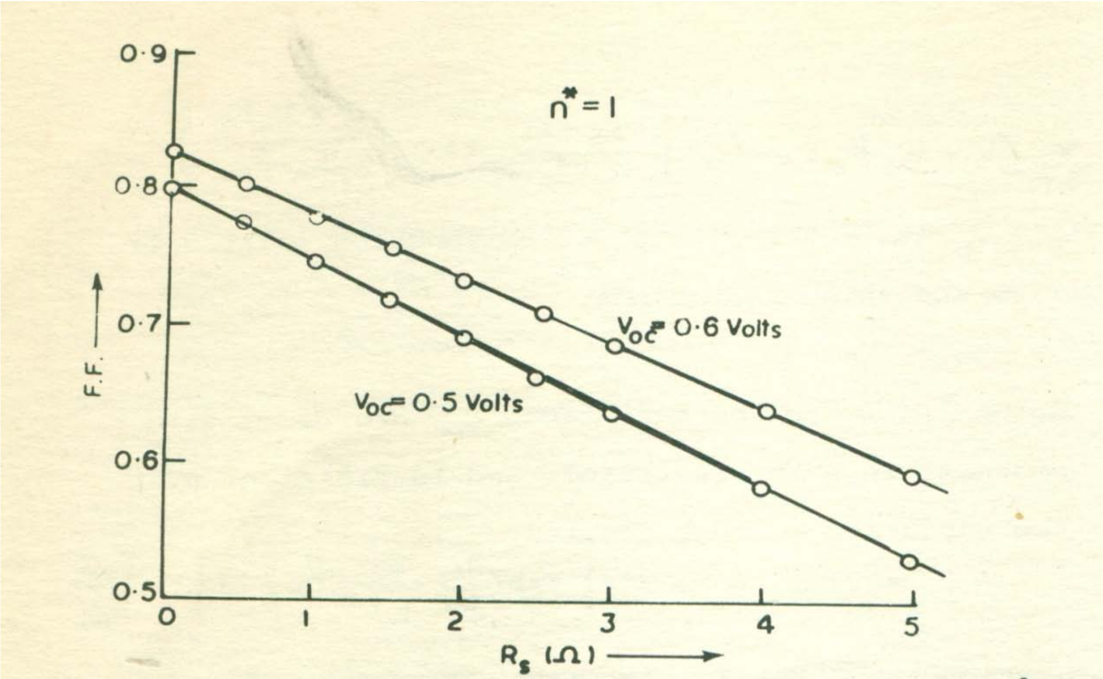
Fig. 3 Effect of shunt resistance

E) <u>Junction Ideality Factor</u>

Practically fabricated junctions are far from ideality. The $I_L - V_L$ characteristic can be better defined by the following equation

$$I_L = I_R - I_O\left[\exp\frac{q}{n^*\ kT}(V_L + I_L R_S) - 1\right] - \frac{V_L + I_L R_S}{R_{sh}}$$

Where are n^* is an empirical factor, known as the diode ideality factor. In this case, I_O in eq. (1)has only the meaning of a fitting constant and should not be interpreted as a true reverse saturation current. In the case of solar cells n^* affects the shape of the $I_L - V_L$ curve near the maximum power point.



Variation of F.F. with series resistance. (Cell area = 1CM²)

Figure shows the effect of n^* on the F.F. for two values of open circuit voltages.

EFFECT OF TEMPERATURE ON SOLAR CELL

The operating temperature of a solar cell is determined by the ambient air temperature, characteristics of the module in which it is encapsulated, the intensity of sunlight falling on the module, and also other variables such as wind velocity. Depending upon the efficiency of the cell a fraction of the solar energy is converted into electricity, the rest goes to heat the cell and the panel on which the cell is mounted. Unless the heat is extracted from the panel, the temperature of the cell would be higher than the ambient temperature.

The dark saturation current I_0 increases with temperature according to the equation

$$I_0 = BT\gamma \exp(-E_{go}/KT) \tag{1}$$

where B is independent of temperature. E_{go} is the linearly extrapolated zero temperature band gap of the semiconductor making up the cell and γ includes the temperature dependencies of the remaining parameters determining I_0.

The short circuit current (I_{sc}) increases very slightly with temperature, since the band gap energy (E_g) decreases and more photons have enough energy to cerate EH pairs. However, this is a small effect. For silicon

$$\frac{1}{I_{sc}}\frac{dI_{sc}}{dT} \approx 0.0006\ {}^{o}C^{-1} \tag{2}$$

The main effect of increasing temperature is a reduction in V_{oc}. The temperature dependency of V_{oc} and fill factor are given approximated by the following equations:

$$\frac{dV_{oc}}{dT} = \frac{-[V_{go} - V_{oc} + \gamma(kT/q)]}{T} \approx -\ 2mV/{}^{o}C \quad \text{(For silicon)} \tag{3}$$

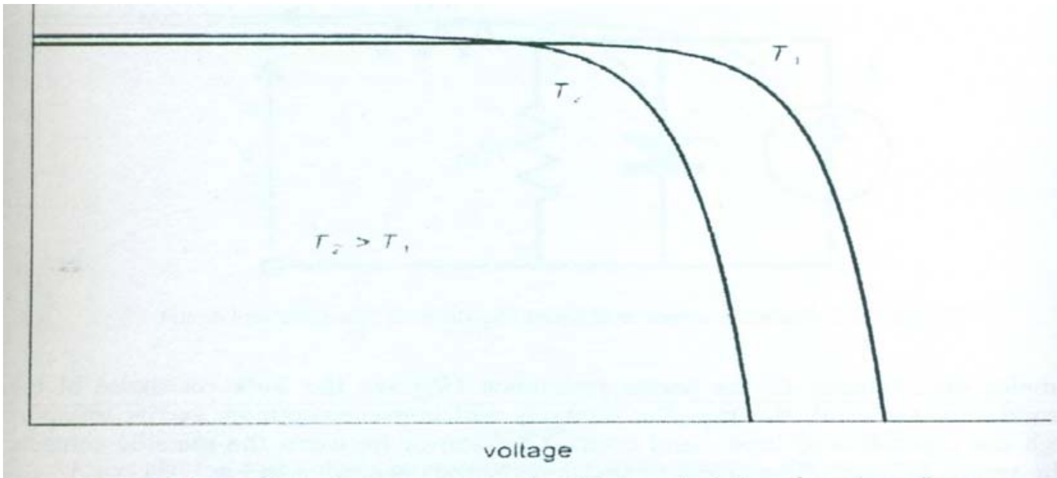
$$\frac{1}{V_{co}}\frac{dV_{oc}}{dT} \approx -0.0003{}^{o}C^{-1} \tag{4}$$

$$\frac{1}{FF}\frac{d(FF}{dT} \approx 1/6\ [\frac{1}{V_{oc}}\frac{dV_{oc}}{dT} - \frac{1}{T}] \approx -0.0015\ {}^{o}C^{-1} \quad \text{(For silicon)} \tag{5}$$

The effect of temperature on the maximum power output (P_{mp}) is as follows:

$$\frac{1}{P_{mp}}\frac{dP_{mp}}{dT} \approx -(0.004 \sim 0.005)\ {}^{o}C^{-1} \text{ (For Silicon)} \tag{6}$$

The higher the value of V_{oc}, the smaller the expected temperature dependence.
The effect of temperature on Isc and Voc is shown in the following I – V characteristics.



Effect of temperature on solar cell.

As a result of change in Isc and Voc and other parameters with temperature the efficiency decreases with increase in temperature. The change in efficiency with temperature is given by the relation,

$$\eta_c = \eta_{cr} . [1- \beta_r . (T_c - T_r)]$$

where η_{cr} is the efficiency of the cell at reference temperature.

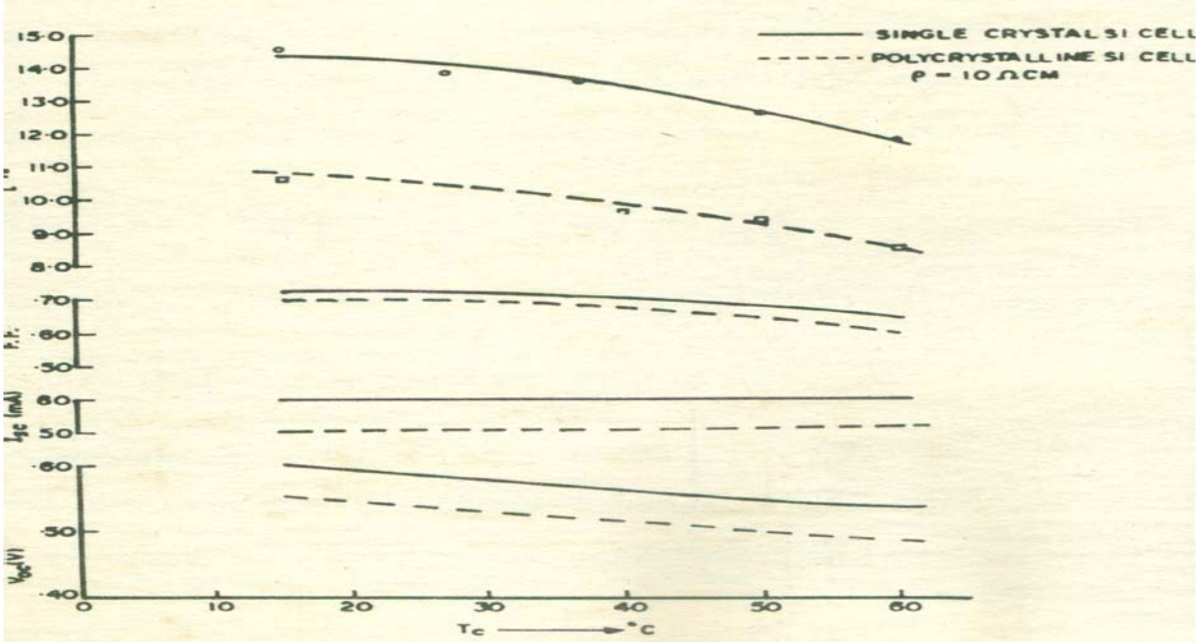
T_r is the reference temperature.

T_c cell temperature

β_r is the fractional decrease of the cell efficiency per unit temperature increase.

For silicon solar cells, the efficiency approaches to zero as the temperature approaches to 270^0C and hence β_r $=0.0041/^0$C.

Following figure shows the variations of voc , Isc, FF and η as a function temperature



Effect of temperature on cell parameters.

Advantages & disadvantages of Photovoltaic solar Energy Conversion:

Advantages:

1. Direct room temperature conversion of light to electricity through a simple solar device.
2. Absence of moving parts
3. Ability to function unattended for long periods as evidence in space programmed.
4. Modular nature in which desired current, voltages and powerlevels can be achieved by more integration.
5. Maintenance cost is low as they are easy to operate.
6. They do not create pollution
7. They have a long effective life.
8. They are lightly reliable.
9. They consume no fuel to operate as the sun's energy is free.
10. They have rapid response in output to input radiation changes; no long time constant is involved, as on thermal system; before steady state is reached
11. They have wide power handing capabilities from micro- watts to kilowatts or even megawatts when modules are combined into large area arrays. Solar cells can be used in combination with power conditioning circuitry to feed power into utility grid.
12. They are easy to fabricate, bring one of the simplest of semiconductor devices.
13. They have high power to weight ratio, this characteristic is more important foe space application than terrestrial, may be favorable for more some terrestrial application. The roof loading on a house top covered with solar cells, for

example,would be significantly lower than the comparable loading for conventional liquid solar water heaters.

14. Amenable to onsite installation, i e. decentralized or dispersed power; thus the problem of power distribution by wires could be eliminated by the use of solar cells at the site where the power is required
15. They can be used with or without sun tracking, making possible a wide range of application possibilities.

Disadvantages:

Their principle disadvantages are their high cost, and the fact that, in much application, energy storages is required because of no insolation at night. Effect is being made world-wide to reduce costs through various technological innovations.