The Effect Of Temperature On The Performance Of PV Array Operating Under Concentration

Eng. Sameh. M.El –Sayed, Dr. Wagdy R. Anis, Dr. Ismail M.Hafez

Abstract: The sun is the world's sole source of energy. In fact, all of the energy being used on the earth today is driven from solar energy. Because of the increase in world energy demand and the threat of global warming; there is a pressing need for the development of reliable, cost-effective sources of renewable energy. Renewable energy sources include indirect solar energy such as hydro, wind and direct solar energy conversion through thermal receivers or photovoltaic. This paper discusses the parameters that affects on the cell temperature under concentration. Comparison between fixed modules and solar cells operating under concentration to get the optimum solution. By increasing the concentration factor one minimizes the area of the cell .System uses special cell (Fresnel lens and multilayer cells).This cell has large efficiency and bear high temperature. The economic studies are necessary to calculate the cost of 1kwh for each case.

Index Terms: Photovoltaic (PV) system, Concentration photovoltaic (CPV) system, Special cell(soitec module), Economics

1 INTRODUCTION

However, most of the energy that is used today is in the form of fossil fuels, which also originated from the Sun but has been stored in the earth for millions of years. If the current trends of global energy use and demand continue, the supply of fossil fuels are predicted to be exhausted within 50-100 years from now[1]. Burning fossil fuels releases stored carbon into the environment. This disturbs the global carbon cycle and leads to an increase in atmospheric CO2 levels [2]. Photovoltaic (PV) cells are semiconductor devices that can convert sunlight into electricity. Photons below a threshold wavelength have enough energy to break an Electron-hole bond in the semiconductor crystal, which in turn can drive a current in a circuit. The solar radiation consists of photons at a range of wavelengths and corresponding energies. Photons with wavelengths above the threshold are converted into heat in the PV cells. This waste heat must be dissipated efficiently in order to avoid excessively high cell temperatures, which have an adverse effect on the electrical performance of the cells. The cells are the most expensive part of a photovoltaic system. A simple way of reducing system costs is therefore to replace some of the photovoltaic area with less expensive optics such as mirrors or lenses. The optical devices focus the sunlight onto a small area of cells. Because fewer cells are needed, one can afford to use higher efficiency cells. Under high concentration there is also a considerably higher heat load that needs to be dissipated [3]. When photovoltaic cells are used under concentrated illumination, they experience a high heat load because the photons not converted to electricity are dissipated in the cells as heat. Thus, an essential requirement for a successful photovoltaic concentrator is a cooling system which can efficiently remove the dissipated heat while keeping the cells at the desired temperature. Concentrating sunlight onto photovoltaic cells, thus replacing expensive photovoltaic area with less expensive concentrating mirrors or lenses, is seen as one method to lower the cost of solar electricity. Because of the smaller area, more costly, but higher efficiency PV cells (special cells) may be used. However, only a small portion of the incoming sunlight onto the cell is converted into electrical energy (a typical efficiency value for concentrator cells is 25% [4]). The remainder of the incoming energy will be converted into thermal energy in the cell and cause the junction temperature to rise unless the heat is efficiently dissipated to the environment. The photovoltaic cell efficiency decreases with increasing temperature [5-6]. Cells will also exhibit long-term degradation if the temperature exceeds certain limit [7, 8]. The cell manufacturer will generally specify a given temperature degradation coefficient and a maximum operating temperature for the cell. The cell efficiency is known to decrease due to non-uniform temperatures across the cell [9, 10]. In a photovoltaic module, a number of cells are electrically connected in series, and several of these series connections can be connected in parallel. Series connections increase the output voltage, while the parallel connection increases the current. The aim of this paper is to study the effect of temperature on performance of PV system operating under concentration to get solutions to minimize the cost of 1kwh.

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1.1 Concentrator geometries

It is sensible to distinguish between concentrators according to their method for concentrating (mirrors or lenses), because the requirements for cell, we can use parabolic mirrors or Fresnel lenses to achieve the concentration. Cooling techniques differ considerably among the various types of concentrator geometries. If lenses are used, the cells are normally placed under the light source; the sunlight is usually focused onto each cell individually [11].

1.2 Why we use concentration?

In the past (20 years ago) the cost of solar cells was very high (1wp ~ 5$) which forced us to get a solution to reduce the system cost.

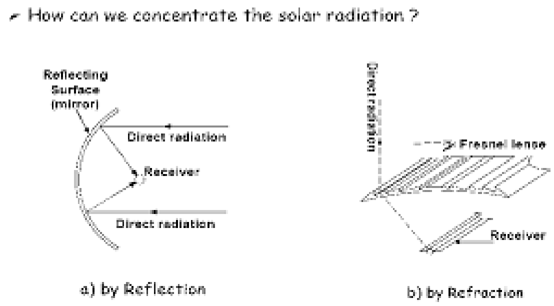

Fig1. *Comparison between mirrors and Fresnel lens under concentration. [12]*

One of the proposed solutions is to use concentrators. The system is composed of low cost mirrors (or lenses) plus a small number of high cost PV cells. Thus the overall system is redused significantly by decreasing the number of expensive cells that will give me the same output power of concentration, for example we can use concentrators with concentration factor (Cth=10) and concentrate the irradiation on a single cell which was cheaper than usage ten cells so it was effective to increase the concentration factor instead of increase number of cells but the disadvantages of concentration techniques is the two axis tracking. Now due to decreasing the cost of solar cells (1wp ~ 0.5$) , the economical usage of concentration systems with tracking system need to be restudied which we spot in this paper added to that the disadvantages of this technique is using tracking systems that increases the cost of the PV systems and is more complex which need periodic maintenance .

2 Electrical output power under concentration

For concentration CPV with tracking the relation between electrical output power (P_{el}) under concentration and the instantaneous irradiation (G_{eff}) track:

$C_{th}=A_1/A_2$ concentration factor (1)

A_1: Area of mirrors or lenses (large area)

A_2: Area of cell

70% directed radiation (can be concentrated)

30% diffused radiation (scattered can't be concentrated)

(G_{eff}) track= $((0.7*C_{th})+0.3)*(G_T)$ tracking (KW/m2) (2)

$\eta_{ctrackeff}=(\eta_{co}*(1-B_c*(T_a+((\alpha_c*(G_{eff})track*1000)/U_l')-T_{co}))/(1-(B_c*\eta_{co}*(G_{eff})track)*1000/U_l')))$ (dimentionless) (3)

$A_{hs}=C_{th}.*A_c.*F_f$ (m^2) (4)

$P_{el}=1000*A_{hs}*\eta_{ctrackeff}*(G_{eff})$ track) (watt) (5)

$U_l'=U_l/F_p$ (watt/m2) (6)

U_l: heat loss coefficient of solar cell to the ambient

$U_l=2*(2.8+(3*w))$ w: wind speed (m/sec) (7)

P_{el} : electrical output power under concentration with tracking $(G_{eff})_{track}$: The instantaneous irradiation under concentration with tracking.

A_{hs}: area of heat sink. F_f: fins factor. (Dimensionless)

F_p: packing factor (ratio between areas of cell to the area of module) T_a: ambient temperature (C)

T_{co}: temperature of the cell at room temperature (C)

Bc: coefficient of efficiency drop per degree centigrade =0.005 for silicon. (C-1) α_c: solar cell absorption coefficient for incident radiation (dimensionless)

$\eta_{ctrackeff}$: efficiency of the solar cell that work under concentration with tracking (dimensionless)

η_{co}: efficiency of the solar cell at room temperature (25°c). (Dimensionless)

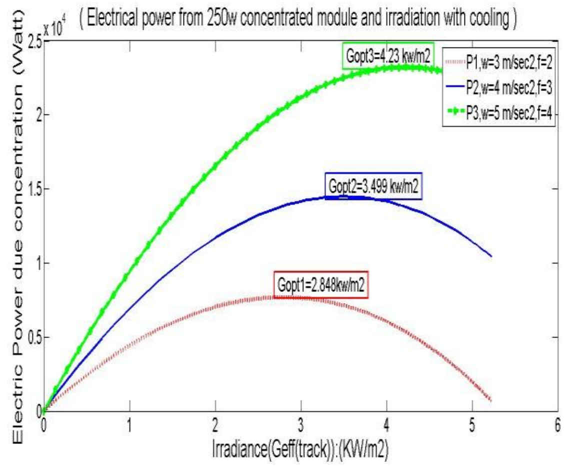

Fig2*. Power- concentration relationship with cooling*

AS (G_{eff}) track increases Isc increase then Pel increases and Tc increases that decrease cell efficiency (ηc), so concentration increases G_{eff} but simultaneously, Tc increases and cell efficiency's reduced. As result Pel increases till certain Tc is reached and ηc drops. Thus there is an optimum G at which Pel is reached its maximum. [13]

3 Effect of temperature on the performance of PV systems using concentration:

3.1 Effect of fins factor of heat sink on cell temperature by vary wind speed

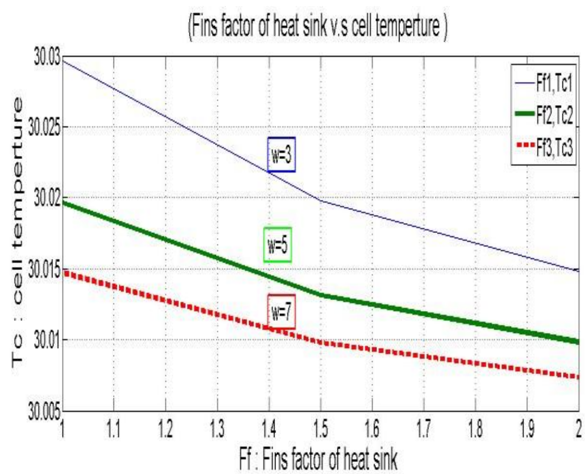

Fig. 3 *show the relation between Ff (fins factor) and Tc(cell temp.) for different values of w(wind speed).As seen, one can observe that as fins factor and wind speed increase then cell temperature decreases.*

Equations:

$\eta_c=30\%$, $U_l=2*(2.8+(3*w))$ empirical formula

$T_c=(Ta+(G_T*(1-\eta_c)/(U_l*F_f)))$ (8)

3.2 Effect of wind speed and cell temperature by vary concentration power

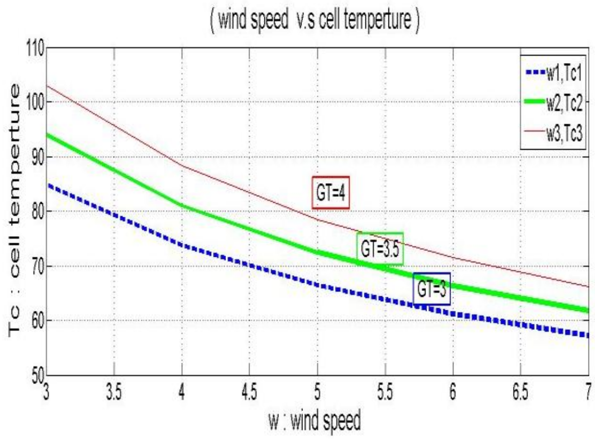

Fig.4 *show the relation between w (wind speed) and Tc (cell temp.) for different values of GT (concentration power). As seen, one can observe that as wind speed and concentration power decrease then cell temperature decreases.*

Equations:

F_p=0.7 , $U_l' = (U_l/F_p)$ (8)

U_l=2*(2.8+ (3*w)) empirical formula

$T_c = (T_a + (((\alpha_c * F_p)/ U_l')*G_T*1000))$ (9)

3.3 Effect of packing factor on cell temperature by vary wind speed

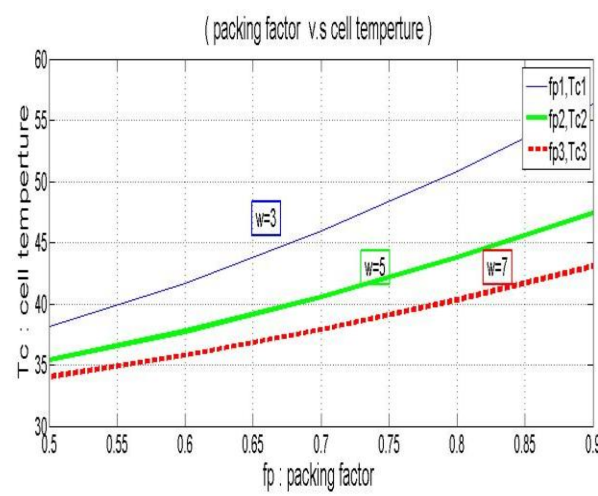

Fig.5 *show the relation between Fp (packing factor) and Tc(cell temperature) for different values of w(wind speed). As seen, one can observe that as packing factor decrease and wind speed increase then cell temperature decreases.*

Equations:

Ul'=(Ul/Fp) , Ul=2*(2.8+(3*w)), Tc=(Ta+(((αc* Fp)/ Ul')*GT*1000))

3.4 Effect of concentration power on cell temperature by vary packing factor

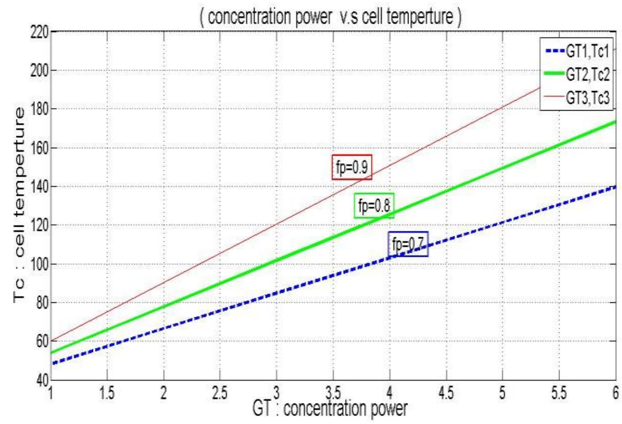

Fig.6 *show the relation between GT (concentration power) and Tc(cell temperature) for different values of Fp (packing factor). As seen, one can observe that as packing factor decrease and wind speed increase then cell temperature decreases.*

Equations:

$U_l' = (U_l/F_p)$ (9)

U_l=2*(2.8+ (3*w)) empirical formula

$T_c = (T_a + (((\alpha_c * F_p)/ U_l')*G_T*1000))$

4 To compare the system using concentration with standard fixed system, a detailed simulation program for both fixed system and system) under concentration(special cell (soitec module)) is developed.

4.1 Design without Tracking (fixed panels system)

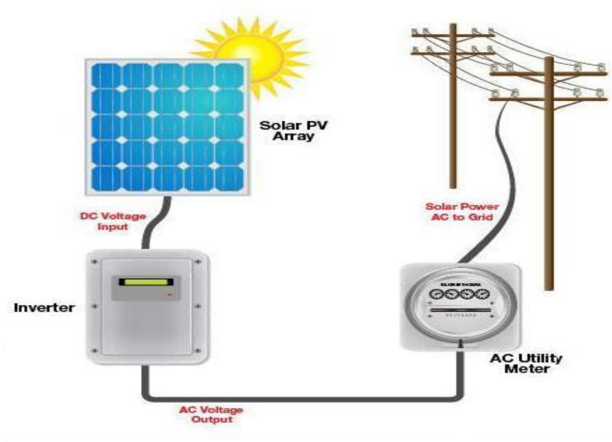

Fig.7 *Block diagram of on grid fixed panels system at β=30*

Fig.(8) shows the monthly average daily energy produced by 1kw peak array throughout a complete year. Those values are put in table (1) and they are plotted in fig. (8).The tilt angle β of the array is taken equal to latitude angle φ=30°.

Table 1 *Monthly daily average energy produced by 1 KWp for fixed system.*

Month	**Jan**	**Feb**	**Mar**	**Apr**	**May**	**Jun**
Energy KWh/day	2.867	4.473	5.085	5.2948	5.5548	5.8591
Month	**Jul**	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**
Energy KWh/day	5.9535	6.0352	5.6600	5.2019	3.4032	2.6865

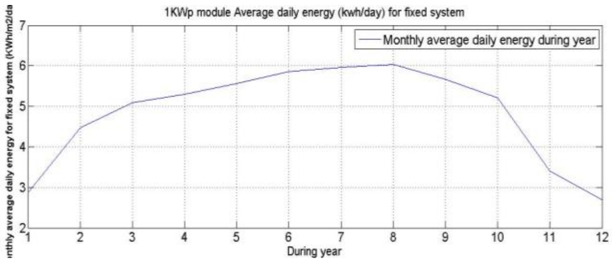

Fig.8 *Monthly daily average energy during a year produced by 1 KWp in Cairo (30°N) with fixed system at β=30.*

4.1.1 Comparison between calculated and measured results for monthly daily average energy during a year produced by 40KWp in Cairo (30°N) with fixed system at β=30°.

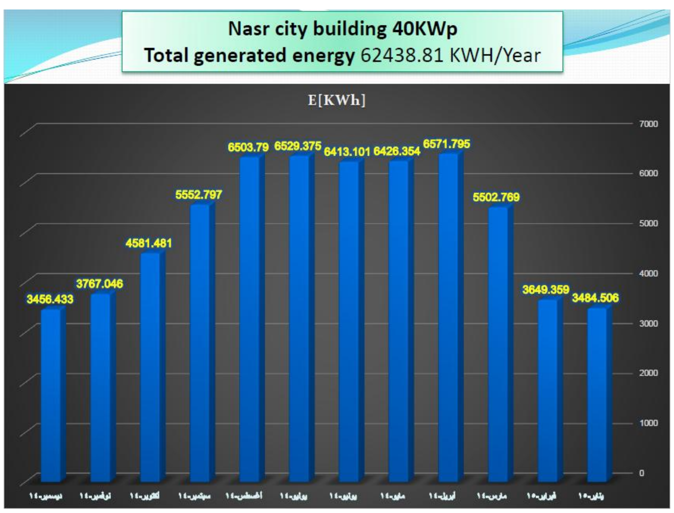

Fig.9 *Show total generated energy during a year from Nasr city building.*

Table.2 *Comparison between calculated and measured results for monthly daily average energy during a year produced by 40KWp in Cairo (30°N) with fixed system at β=30°.*

Months	1	2	3	4	5	6
Calculated results(kwh /month)	103.212	161.028	182.916	190.6128	199.9728	210.9276
Measured results(kwh /month)	112.40	130.33	177.50	219.06	207.30	213.77
months	7	8	9	10	11	12
Calculated results(kwh /month)	214.326	217.2672	203.76	187.2684	122.5152	96.714
Measured results(kwh /month)	210.625	209.79	185.09	147.78	125.56	111.5

Total calculated generated energy results = 63.576 MWh/year
Total measured generated energy values=62.438 MWh/year
Error=1.8%

4.2 Special cell (Soitec module)

Multi-junction solar cells

Soitec CPV technology uses optimized III-V-based multi-junction solar cells in which different sub-cells are stacked on top of one another. Each sub-cell is designed to convert a certain range of the solar spectrum: short wave radiation, medium wave radiation and infrared. Soitec's concentrator photovoltaic (CPV) modules use Fresnel lenses to concentrate sunlight 500 times and focus it onto small, highly efficient multi-junction solar cells. With this technology, Soitec achieves a module efficiency of 31,8%. This is almost twice as high as the efficiency of conventional silicon photovoltaic modules. The materials used in the cell include GaInP, GaAs and Ge. Such cell construction maximizes the utilization of solar spectrum energy so that cell efficiency is maximized .The increase of cell efficiency will decrease the area required to generate same energy. In comparison to conventional solar cells, multi-junction solar cells are more efficient but also more expensive to manufacture. By using concentrating optics to focus the sunlight on these multi-junction solar cells, it is possible to minimize the amount of semiconductor material needed down to a small fraction, using cells of only a few square millimeters. This principle enables the manufacturing of CPV modules efficient and inexpensive.[14]. Soitec's technology is a concentrator photovoltaic (CPV) technology, whereby sunlight is focused onto highly efficient solar cells using Fresnel lenses. CPV offers efficiencies twice those of standard silicon photovoltaic technologies. [15].

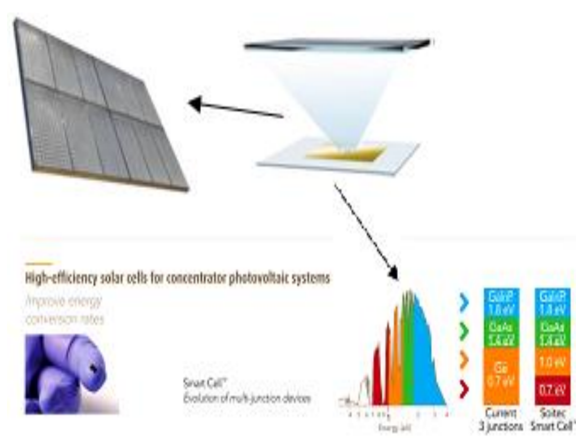

Fig.10 *special cell (soitec module)*

Materials in multilayer cell are arranged so that materials with larges energy gab is put in the top of multilayer cell and that with minimum energy gab is put in the bottom.

4.2.1 Design of PV system under concentration using soitec module

To evaluate the CPV system under concentration with tracking by using special cell (multilayer cell).

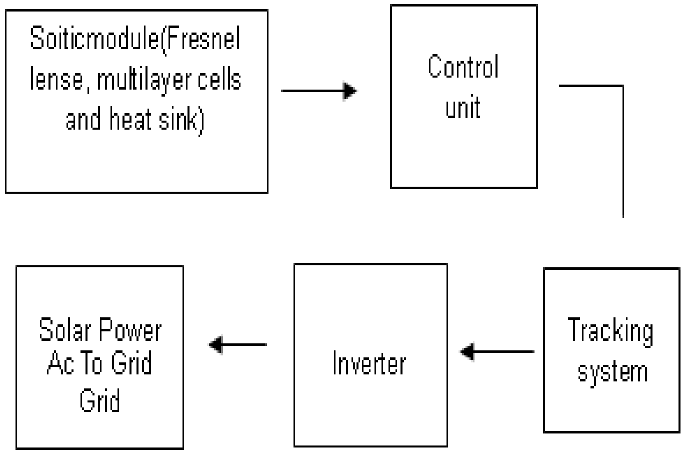

Fig. (10) *Block diagram of PV system under concentration using soitec module.*

Control unit: for protection the tracking system as breking it in the case of very high wind speed.
Inverter: convert dc signal to ac signal.

4.2.2 Soitic module discreption:

Concentration ratio (C_{th}) =500
Array size=P_p=2450w_p
Max. power voltage(vm_p)=645v
Max. power current(Im_p)=3.8A
I_{sc}=4.2A
V_{oc}=740v
The efficiency of this special cell (η_c) =31.8%. [16]

Fig.(11) *shows the monthly average daily energy produced by 2451w peak array throughout a complete year. Those values are put in table (3) and they are plotted in fig.(9).The concentration factor=500 and the efficiency of this special cell=31.8%.*

Table.3 Monthly daily average energy using soitec cpv module.

Month	Jan	Feb	Mar	Apr	May	Jun
Energy KWh/day	14.4	18.14	19.01	19.9	21.85	23.55
Month	**Jul**	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**
Energy KWh/day	23.2	22	20.02	19.2	15.58	14.03

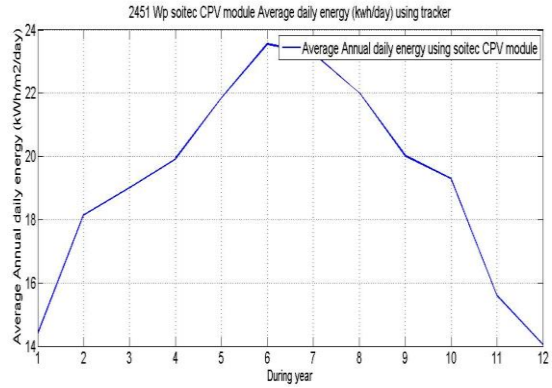

Fig.11 *A verage annual daily energy during a year by 2451wp soitec cpv module*

5 Cost estimation

Compare between initial cost, cost (EGP) per KWh and interest rate for fixed module and CPV using soitec module When it is implemented in Egypt and sold to the Egyptian government.

5.1 Economical study

5.1.1 for fixed module:

Using data of 200wp module
For silicon:
Cell area=15*15cm2
Isc(1cm2)=37mA
Isc(15*15cm2)= 37mA *15*15=8.3 A
Operating voltage (one cell) =0.5 v
Pel(one cell)=8.3*0.5=4 (w/cm2)
For module of 48 series cells:
Pel=4*48=200w
200wp cost =120$
One cell cost=120/48=2.5$
Cost/1cm2=2.5$/225=0.011$ (for silicon)
PV modules=0.65$/wp as 120$/200 wp =0.6$ wp

5.1.2 For soitec module:

Module area=8.77m2
Cells area=Module area/concentration ratio=8.77m2/500=8.77*10000/500=175.4cm2
Operating voltage of one cell=0.4v
The no. of cells=vmp/operating voltage=645/0.4=1612cells
Area per one cell=175.4/1612=0.11cm2
Special cell cost=15 times silicon cell=15*0.011=0.165$/cm2
Module cells cost=175.4*0.165=28.941$
Area of each fresnel lense =area per cell*concentration factor=0.11*500=55cm2
Cost of one lens=0.5$
Pel(one module)= Imp* vmp=3.8*6451wp=2.5kwp (10)

5.2 Economical analysis for 1MWp

Table.4 *Economical analysis for 1MWp*

Economical analysis	Fixed si module	Soitic multilayer module under concentration

PV modules	0.65$/$w_p$	3$/$w_p$
Inverter	250000$ for system	250000$ for system
Mounting	0.18$/$w_p$	1.1$/$w_p$
Dc cables	0.03$/$w_p$ so 30000$ for system	30000$ for system
Ac cables	30000$ for system	30000$ for system
Earthling and lightning	5000$ for system	5000$ for system
Step up transformer s	30000$ for system	30000$ for system
weather station	5000 $ for system	5000 $ for system
land preparation	0.3$/$w_p$ so 300000$ for system	150000$ for system as land preparation is halved
accessories and installation cost	25000$ for system	25000$ for system
Tracking system	----------------------- -	=1.2$/$w_p$
Total initial fixed cost	1505000$*8=12.04*$10^{6}$ I.E	5825000$*8=46.6*$10^{6}$ I.E

For fixed module 1MWp:
Average daily energy=4.8395*10^3kwh/day
Annual average daily energy=4.8395*10^3*365day*0.9(dc to ac) =1.589*10^6 kwh/year
For soitec module 1MWp:
Average daily energy=7.5*10^3kwh/day
Annual average daily energy=7.5*10^3*365day*0.9(dc to ac)=2.52*10^6 kwh/year

5.3 Compare between cost (EGP) per KWh and interest rate for fixed module and cpv using soitec module when it is implemented in Egypt and sold to the Egyptian government

Geometric series equation:

$$P=E_o*C_o*(1((1+g)/ (1+i)) ^N)/ (i-g)) \quad (11)$$

P: initial cost
i: interest rate
C_o : selling price=0.136$/kwh
g:degredation factor= -2%
E_o: energy generated first year
N:payback period=25years

Table.5 *Compare between cost (EGP) per KWh and interest rate for fixed module and CPV using soitec module when it is implemented in Egypt and sold to the Egyptian government*

Economical analysis for 1MW$_p$	Fixed si module	Soitic multilayer module under concentration
interest rate(i) given that C_o= 0.136$/kwh	11.86%	1.35%
selling price(C_o)	1.02L.E	2.51L.E

For Egyptian market the available bank interest rate is about 11% , thus if IRR is less than 11% ,the investment is rejected, On the other hand if IRR exceed 11% ,the investment is accepted. Accordingly, the investment in case of fixed array is accepted while that of PV system under concentration and using tracking is rejected due to low IRR. The results show that the cost per KWh for fixed system is 1.02 LE while it is 2.5 LE for system using concentrators. Thus the fixed system's KWh cost is about 40% that of system using concentrator. Hence fixed system is recommended.

6 CONCLUSIONS

Detailed study of both fixed PV system and system operating under concentration showed that economically wise, the fixed system is superior. This means that the cost per kwh delivered to grid utility is less in case of fixed system. Although the PV system with concentration reduces the cell area required, the necessity of two axes tracking beside the concentrator raised the cost per kwh produced.

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