ISSN 2320-5407 International Journal of Advanced Research (2016), Volume 4, Issue 3, 2001-2017

ISSN NO. 2320-5407

Journal homepage: http://www.journalijar.com

INTERNATIONAL JOURNAL OF ADVANCED RESEARCH

RESEARCH ARTICLE

Comparative Study Between Silicon & Gallium Arsenide ON Grid PV System

Mahmoud M Ismail, .Wagdy R Anis, Rasha Ghoneim

1. National Research Institute of Astronomy And Geophysics (NRIAG) , Helwan , Egypt.
2. Faculty Of Engineering Ain-Shams University, Cairo, Egypt.

Manuscript Info

Manuscript History:

Received: 14 January 2016
Final Accepted: 19 February 2016
Published Online: March 2016

Key words:
Photovoltaic (PV) system, Gallium Arsenide (GaAs), Silicon (Si), ON Grid, Economics.

****Corresponding Author***

Mahmoud M Ismail

Abstract

Due to the increasing demand of high performance solar cells with low cost. A comparative study between the materials gallium arsenide (GaAs) and silicon (Si) takes place in this work. We show that (GaAs) responds differently than (Si) at the same conditions, the GaAs module produced more power at increasing temperature. Two approaches are applied, photovoltaic system (PV) without tracking system (Fixed System) and PV with manual tracking systems to show the differences between using (Si) and (GaAs) solar cells. Results show that energy produced by GaAs PV system generates more energy than that produced by silicon PV system. Knowing that the cost per produced KWH is less in case of using fixed panels. A comparison is done between the cost of both systems shows that the system that use (Si) has low cost than the system that use (GaAs).
.

Introduction

Solar cells or photovoltaic energy converters has had a many years of successful development and application .It was born in the early days of solid-state electronics and reached maturity during 1960's when there was a demand for electric power in a space environment. With the recent increase in activity in the photovoltaic field like agriculture and industry, it seemed quite appropriate to have studies about everything related to solar energy and solar cells [1]. Sunlight strikes the Earth in one hour (4.3 × 10^20 J) is more than all the energy consumed on the planet in a year (4.1 × 10^20 J), Sunlight is abundant sources of energy in the future [2]. An estimated 8.2% of global energy consumption in 2010 was supplied by renewable energy (Biomass, hot water, heating, geothermal and solar). However in 2011 nearly half of the new electric power capacity installed was from renewables alone. The percentage of energy from renewables especially solar cells has increased every year for the past several years, and is predicted to continue with this trend in the future [3]. The economic comparison with conventional energy sources is certain to receive a further boost as the environmental and social costs of power generation are included fully in the picture [4], [5].

1.2 Important Definitions

a) Sun: is the star at the center of the Solar System. It is almost perfectly spherical and consists of hot plasma interwoven with magnetic fields, about half the incoming solar energy reaches the Earth's surface , Earth receives 174 petawatt (PW) (10^{15}.+`watts) of incoming solar radiation at the upper atmosphere. Approximately 30% is reflected back to space while the rest is absorbed by clouds, oceans and land masses.

b) Semiconductor: is a substance, usually a solid chemical element or compound, that can conduct electricity under some conditions but not others, making it a good medium for the control of electrical current.

c) Photovoltaic (PV device): A device used to convert short radiation into direct current (dc) electricity etc.

d) Air Mass: is a volume of air defined by its temperature and watervapour content, For a path length L through the atmosphere, for solar radiation incident at angle ϴ relative to the normal to the Earth's surface, the air mass coefficient is

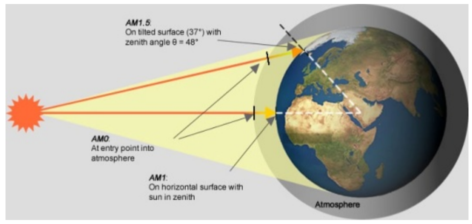


Fig 1. The Path length of the solar radiation through the Earth's atmosphere in units of Air Mass (AM).

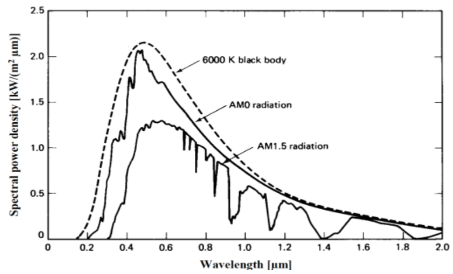


Fig 2. Radiation from a black body at 6000K, and typical power distribution emitted from the sun at AM0 and AM1.5.

e) **Band Gap**: is an energy range in a solid where no electron states can exist as shown in Fig 3. [6]

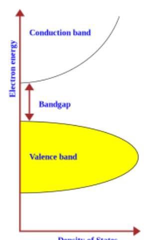


Fig 3.band gap.

and the types of band gaps for Si and GaAs :

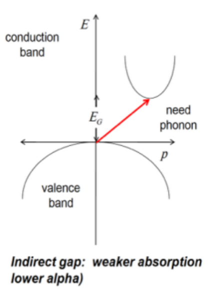


Fig 4.“ **Silicon band gap “** is an Indirect gap semiconductors where the minima of the conduction band (in general, more than one) lie at a another point of the first Brillouin zone, with a different value of the wave vector k.

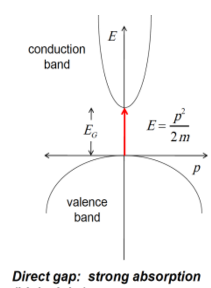
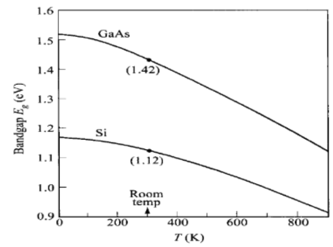


Fig 5.“ GaAs band gap“ is Direct gap semiconductor where the top of the valence band and the bottom of the conduction band lie at the F point of the first Brillouin zone (i.e., at zero wave vector k - 0).

with temperature is show that as temperature increase the band gap decrease as in the figure 6 [7].

Fig 6. Energy band gaps of Si and GaAs as a function of temperature.



f) The Room temperature properties of Si and GaAs shown in Figure 7. [8]

Room temperature properties of Si and GaAs

Quantity	*Symbol*	*Si*	*GaAs*	*(Unit)*
Crystal structure		D	Z	–
Gap: Direct (D) / Indirect (I)		I	D	–
Lattice constant	$a_0 =$	5.43095	5.6533	Å
Bandgap energy	$E_g =$	1.12	1.42	eV
Intrinsic carrier concentration	$n_i =$	1.0×10^{10}	2.0×10^{6}	cm^{-3}
Effective DOS at CB edge	$N_c =$	2.8×10^{19}	4.4×10^{17}	cm^{-3}
Effective DOS at VB edge	$N_v =$	1.0×10^{19}	$\times 7.7{*}10^{18}$	cm^{-3}
Electron mobility	$\mu_n =$	1500	8500	$cm^2/(Vs)$
Hole mobility	$\mu_p =$	450	400	$cm^2/(Vs)$
Electron diffusion constant	$D_n =$	39	220	cm^2/s
Hole diffusion constant	$D_p =$	12	10	cm^2/s
Electron affinity	$\chi =$	4.05	4.07	V
Minority carrier lifetime	$\tau =$	10^{-6}	10^{-8}	s
Electron effective mass	$m_e^* =$	0.98 m_e	0.067 m_e	–
Heavy hole effective mass	$m_{hh}^* =$	0.49 m_e	0.45 m_e	–
Relative dielectric constant	$\varepsilon_r =$	11.9	13.1	–
Refractive index near E_g	$\bar{n} =$	3.3	3.4	–
Absorption coefficient near E_g	$\alpha =$	10^3	10^4	cm^{-1}

- D = Diamond. Z = Zincblende. W = Wurtzite. DOS = Density of states. VB = Valence band. CB = Conduction band
- The Einstein relation relates the diffusion constant and mobility in a non-degenerately doped semiconductor: $D = \mu (kT/e)$
- Minority carrier diffusion lengths are given by $L_n = (D_n \tau_n)^{1/2}$ and $L_p = (D_p \tau_p)^{1/2}$
- The mobilities and diffusion constants apply to low doping concentrations ($\approx 10^{15}\ cm^{-3}$). As the doping concentration increases, mobilities and diffusion constants decrease.
- The minority carrier lifetime τ applies to doping concentrations of $10^{18}\ cm^{-3}$. For other doping concentrations, the lifetime is given by $\tau = B^{-1} (n + p)^{-1}$, where $B_{Si} \approx 5 \times 10^{-14}\ cm^3/s$, $B_{Ge} \approx 5 \times 10^{-13}\ cm^3/s$, and $B_{GaAs} = 10^{-10}\ cm^3/s$.

Fig 7.

j) Optical absorption for Si and GaAs : In indirect-gap semiconductors is considerably weaker than in direct gap semiconductors, as shown in Fig 8 . [9] .

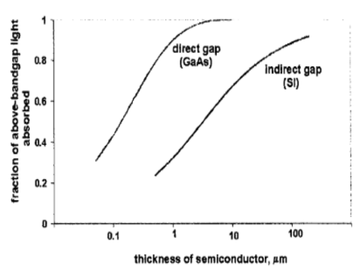


Fig 8.A comparison of the difference in strength of the optical absorption in direct and indirect semiconductors, illustrated on the examples of silicon and gallium arsenide.

1.3 Solar Declination (δ)

The angle that the Sun's rays make with the equatorial plane is known as the declination angle (Fig. 9). This angle is the solar declination. On any day, is taken as a constant which changes on the next day. Cooper's empirical relation for calculating the solar declination angle (in degrees) is [10], [11], and [12]

$$\delta = 23.45\, sin\left[(284 + n)\times\frac{360}{365}\right] \quad (1)$$

Where that: n = day of the year ($1 \le n \le 365$).

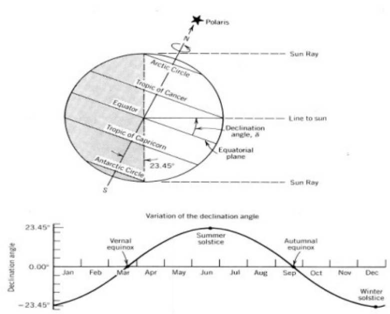


Fig 9.Solar declination angle.

Solar declination can also be defined as the angle between the line joining the centers of the Sun and the Earth and its projection on the equatorial plane. The solar declination changes mainly due to the rotation of Earth about an axis. Its maximum value is 23.45° on 21 December and the minimum is – 23.45° on 21 June.

1.3.1 Latitude (φ) and Longitude LongitudeL_t

Latitude φ gives the location of a place on Earth, i.e. north or south of the equator. Latitude is an angular measurement ranging from 0° at the equator to 90° at the poles (90°N or 90°S) for the north and south poles.

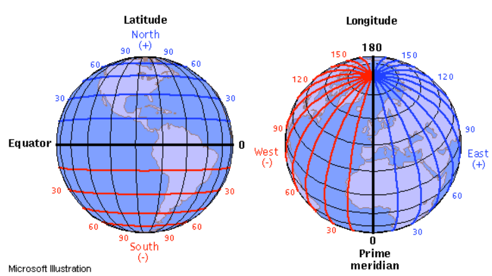


Fig 10.Latitude (φ) and Longitude Longitude (L_t)

On the Earth, a meridian (is an imaginary north–south line between the North Pole and the South Pole that connects all locations with a given longitude. The position on the meridian is given by the latitude, each being perpendicular to all circles of latitude at the intersection points. The meridian that passes through Greenwich (England) is considered as the prime meridian, all the places on that meridian have the same longitude. The Earth can be divided in two parts with reference to the prime meridian, viz. eastern and western hemispheres. The maximum distant meridian on both sides can be at 0° to 180° from the principal meridian [10], [2], [13].

1.3.2 Hour Angle (ω)

The hour angle is the measure of the angular displacement of the Sun through which the Earth has to rotate to bring the meridian of the place directly under the Sun, At sunrise, the value of ω will be maximum, then it will slowly and steadily reduce and keep reducing with time until solar noon. At this point ω becomes zero. It starts increasing the moment after solar noon and will be maximum at sunset. The values at sunrise and sunset are numerically the same but have opposite signs. Which gives the time elapsed since the celestial body's last transit at the observer's meridian for a positive hour angle or the time expected for the next transit for a negative hour angle (1 hour =15°) [10],[14].[2].

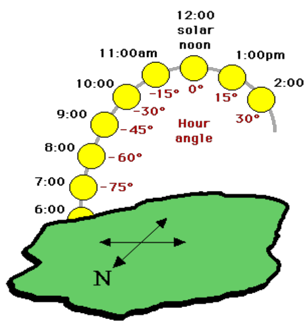


Fig 11.Hour angle.

1.3.3 Angle of Incidence

The angle of incidence is the angle between a beam incident on a surface and the line perpendicular to the surface. β is the inclination of the plane (a surface on which beam radiation is falling) with the horizontal surface and Ɣ is the wall azimuth angle (due south) that specifies the orientation of the surface. This angle decides the distance of a tilted plane from the south orientation. If its value is 0° then the surface is facing towards south.

If the plane under consideration is horizontal, i.e. β=0 and also Ɣ=0, then the angle of incidence =0, then the angle of incidence θh becomes equal to the zenith angle [10], [15]

1.4 Measurement of Solar Radiation on Earth's Surface

The solar radiation reaching the Earth's surface through the atmosphere can be classified into two components: beam (direct) and diffuse radiation [10].

Beam radiation Beam radiation (H_D): The solar radiation propagating: The solar radiation propagating along the line joining the receiving surface and the Sun. It is also referred to as direct radiation. Diffuse radiation (H_d): The solar radiation scattered by aerosols, dust and molecules. It does not have any unique direction. Total radiation Total radiation (H_B): The sum of the beam and diffuse radiation, sometimes known as global radiation on horizontal surface. Solar radiation is energy received per (m2/day) and it measured always on horizontal surface it donated by H_B (KWh/ m2 /day). The extraterrestrial solar irradiance (KW/m2) on surface normal to solar beams is constant and equal to solar constant G_{SC} (=1.35 KWh/ m2) is given by [16]

$$\mathrm{H_{ext}} = \frac{24}{\pi}\mathrm{G_{SC}}[\cos\delta\cos\varphi\sin\omega_s + \omega_s\sin\delta\sin\varphi] \quad (2)$$

$$\mathrm{K_T} = \frac{\mathrm{H_B}}{\mathrm{H_{ext}}} \text{Clearness index} \quad (3)$$

1.4.1 Solar Radiation on a Horizontal Surface

The combination of both forms of solar energy (beam and diffuse) incident on a horizontal plane at the Earth's surface is referred to as global solar energy and these three quantities (specifically their rate or irradiance) are linked mathematically as [10], [17]

$$H_B = H_D \cos\theta_Z + H_d (4)$$

Where HB is the global irradiance on a horizontal surface, surface, Hd the diffuse irradiance, HDthe direct beam irradiance on a surface perpendicular to the direct beam and θZthe Sun's zenith angle.

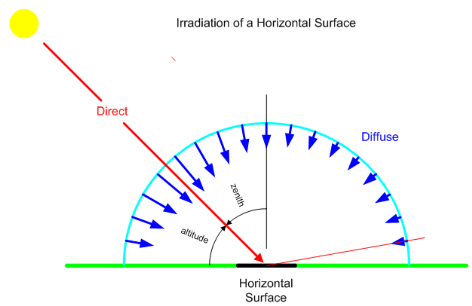


Fig 12.Solar radiation on a horizontal surface.

Direct radiation on horizontal surface H_D is given by [16]

$$H_D = \frac{24}{\pi} G_n[\cos\delta \cos\varphi \sin\omega_s + \omega_s \sin\varphi \sin\delta] (5)$$

1.4.2 Solar Radiation on an Inclined Surface

Direct radiation on tilted surface is given by [16]

$$H_{D,t} = \frac{24}{\pi} G_n[\cos\delta \cos(\varphi - \beta) \sin\omega_s` + \omega_s` \sin(\varphi - \beta) \sin\delta] (6)$$

Ratio between direct radiations on tilted surface to on horizontal surface Ref. [16], [18]

$$R_b = \frac{H_{D,t}}{H_D}$$

$$R_b = \frac{\cos\delta \cos(\varphi-\beta) \sin\omega_s` + \omega_s` \sin(\varphi-\beta) \sin\delta}{\cos\delta \cos\varphi \sin\omega_s + \omega_s \sin\varphi \sin\delta} (7)$$

The total radiation for any inclined (inclination = β) with any orientation of solar thermal device (for east, south, west and north) Ɣ = – 90°, 0°, +90° and ±180° for a given latitude φ can be evaluated using the formula Ref. [16]

$$\mathrm{H_T} = \mathrm{H_B}[1.13\mathrm{K_T}\,\mathrm{R_b} + 0.5(1 + cos\,\beta)(1 - 1.13K_T) + 0.5\rho(1 - cos\,\beta)](8)$$

When Reflectivity of ground (ρ = 0.2 for normal ground and ρ = 0.7 for snow) .

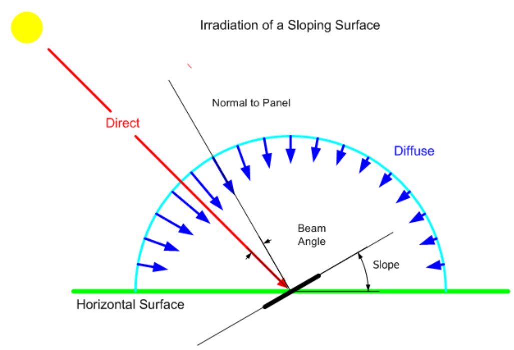


Fig 13.Solar Radiations on an Inclined Surface.

Instantaneous global radiation on tilted surface defined as [16]

$$G_T = \frac{\pi}{24} H_T \frac{cos\,\omega - cos\,\omega_s``}{sin\,\omega_s` - \omega_s`\,cos\,\omega_s``}(9)$$

1.5 Parameters of Solar Cells

1.5.1 I-V Characteristics

The standard solar cell I-V characteristics is given by Eq.(10), Rs, should be small and the shunt (parallel) resistance,Rp, should be large [10], [19], and [20].

$$I = [I_L - I_{\circ}\left(e^{(V+IR_s)/V_t} - 1\right) - \frac{V+IR_s}{R_{sh}}](10)$$

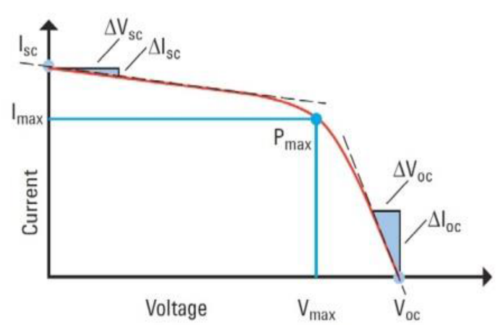


Fig 14. . I-V Characteristic for solar cell.

The short circuit current ISC defined as [10], [13], and [19]. The array current I when V = 0
Then ISC= IL… (IL ≡current generated from l

$$I = I_L - I_\circ(e^{V/V_t} - 1) \qquad (11)$$

At I ≡ I_{pmax}

$$I_{pmax} = I_L - I_\circ(e^{V_{pmax}/V_t} - 1) \qquad (12)$$

And at $I_\circ = I_L e^{-V_{oc}/V_t}$ (13)

The open circuit voltage when I = 0 and defined as [10], [19], [20]

$$V_{oc} = V_t \, ln(\frac{I_L}{I_\circ} + 1) \qquad (14)$$

Thepower delivered by the solar cell output is defined as [10]

$$P = I_L - I_\circ V(e^{V/V_t} - 1) \qquad (15)$$

1.5.2 Maximum Power (P_{max})

No power is generated under short or open circuit. The power output is defined as [10], [19], and [21].

$$P_{out} = V_{out} \times I_{out} (16)$$

The maximum power Pmax provided by the device is achieved at a point on the characteristics, where the product IV is maximum. ThusPmaxis defined as[10], [19], and [22].

$$P_{max} = V_{Pmax} \times I_{Pmax} (17)$$

1.6 PV Standard Modules

Our design is based on 200 W, 24 V PV module, TC= 25Depth of discharge (DOD) =0.7, Charge efficiency=0.8, Discharge efficiency=0.9, Battery Voltage (VB) = 25 and Parameters of Silicon and Gallium Arsenide shown in Table 1 [23].

Table 1.1 Parameters of Silicon and Gallium Arsenide

	Voc	**Isc**	**Jsc**	**Fill Fact or**	Imax	Vmax	Pmax
Ga As	0.89 V	3.7mA	21.4 mA/c m2	75.85 %	3.44m A	0.72V	2.5m W
Si	0.62 V	2.5 mA	35 mA/c m2	75 %	0.75 mA	0.42 V	0.32 mW

1.7 Simulation Program

MATLAB Simulation software is used to simulate the dynamic behavior of a system that is represented by a mathematical model. While the model is being simulated, the state of eachpart of the system is calculated at each step of the simulation using either time-based. A detailed simulation program is developed considering climatic conditions of Egypt.

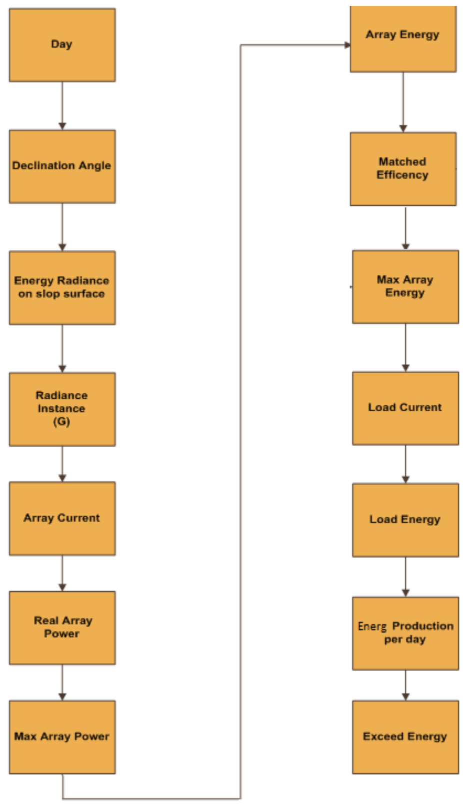


Fig 15.Flow chart for simulated program.

2 . Design

This design has been building the system and the work of the technical and economic analysis on the basis that the photovoltaic Array Production energy (110 KWh/day) in Cairo, Egypt. We will measure the output Energy for both materials (Silicon and Gallium Arsenide) at the same conditions. Declination angle:

$$\delta = 23.45 \sin\left[(284 + n)\times\frac{360}{365} \right]$$

The instantaneous global radiation on tilted surface [16].

$$G_T = \frac{\pi}{24} H_T \frac{\cos\omega - \cos\omega_s''}{\sin\omega_s' - \omega_s' \cos\omega_s''}$$

Current output from PV array [13].

$$I_A = I_{SC}\times G_T - (I_\circ \times e^{V/V_t})$$

Table 1.2 The monthly average values of Hb, Ta and KT for Cairo[24].

	Hb	**Ta**	**KT**
January	3.3	18	0.6
February	4.5	22	0.61
March	5.7	23	0.62
April	6.6	28	0.63
May	7.5	30	0.65
June	7.8	35	0.7
July	7.7	36	0.7
August	7.2	34	0.7
September	6.2	32	0.65
October	5	30	0.65
November	3.5	24	0.62
December	3	20	0.6

2.1 Design without Tracking (fixed panels system)

Obtain the array size for each solution at fixed Tilt angle β=30.Calculate energy production per array size using Matlab simulation program. Compare energy production cost from each solution.

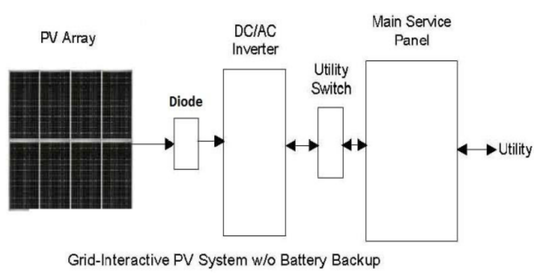


Fig 16. Block diagram of fixed panelssystem atβ=30 without storage batteries and on grid.

2.2 Design with Manual Tracking

Obtain the size for each solution at Tilt angle changing every day. Calculate energy production per array size using Matlab simulation program. Compare energy production cost from each solution.

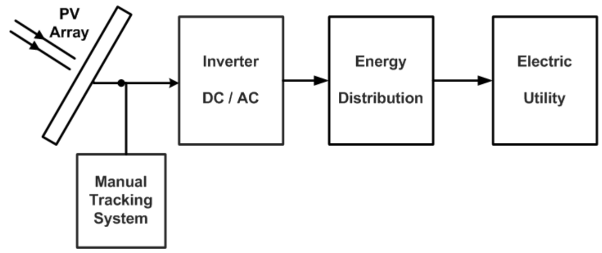


Fig 17. Block diagram of Manual Tracking System without storage batteries and on grid when Tilt angle changing every day β=(φ -δ).

3 RESULTS

3 .1 Design without Tracking (Fixed panels System)

For φ=30°(Cairo, Egypt), Tilt angle β=30°. Monthly daily average energy produced by 1KWp Silicon array installed in Cairo (30°N) in KWh per day is shown below: -

Table 1.3 Monthly daily average energy produced by 1 KWp Silicon array for fixed system.

Month	**Jan**	**Feb**	**Mar**	**Apr**	**May**	**Jun**
Energy KWh/ day	3.78	5.10	5.63	5.41	5.49	5.37
Month	**Jul**	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**
Energy KWh/ day	5.38	5.62	5.44	5.16	3.86	3.44

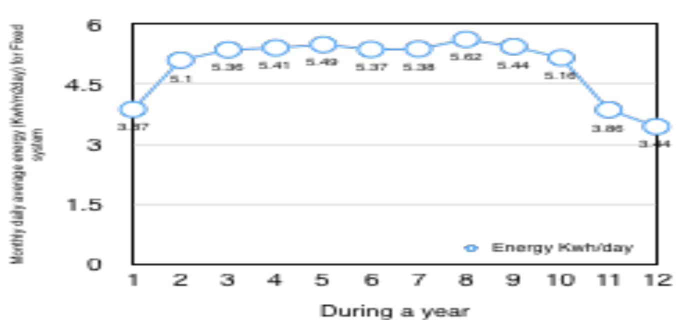


Fig 18. Monthly daily average produced by 1KWp in Cairo (30°N) with fixed system at β=30 (Silicon).

For GaAs array fixed system: -

Table 1.4 Monthly daily average energy produced by 1KWp GaAs array for fixed system

Month	Jan	Feb	Mar	Apr	May	Jun
Energy KWh/day	4.23	6.27	6.53	6.27	6.37	6.23
Month	**Jul**	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**
Energy KWh/day	6.236	6.52	6.31	5.98	4.48	3.99

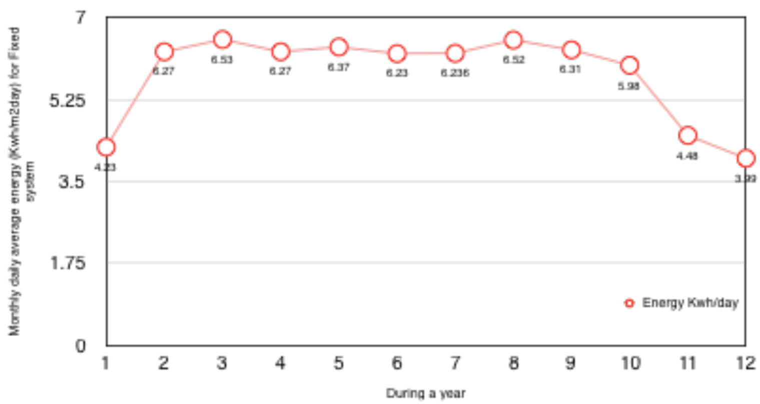


Fig 19. Monthly daily average produced by 1KWp in Cairo (30°N) with fixed system at β=30 (GaAs).

The difference between Monthly daily average energy for Silicon and GaAs fixed panels System: -

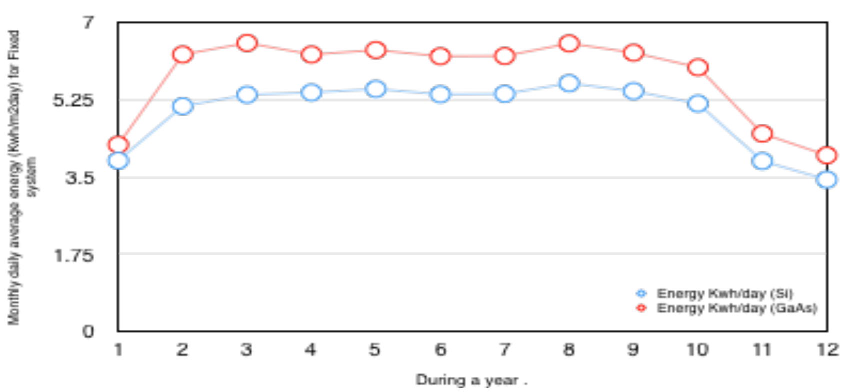


Fig 20. Monthly daily average produced by 1KWp in Cairo (30°N) with fixed system at β=30 For Silicon and GaAs.

3.2. Design with Manual Tracking System

For φ =30°(Cairo, Egypt), the optimum tilt angle β is (φ –δ). This value makes solar beam perpendicular on PV modules at noon. Monthly daily average energy produced by 1KWp Silicon array installed in Cairo (30°N) in KWh per day is shown below:-

Table 1.5 Monthly daily average energy produced by 1KWp Silicon array for fixed system.

Month	**Jan**	**Feb**	**Mar**	**Apr**	**May**	**Jun**
Energy KWh/day	4.22	5.40	5.63	5.41	6.10	6.28
Month	**Jul**	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**
Energy KWh/day	6.14	5.82	5.44	5.30	4.26	3.92

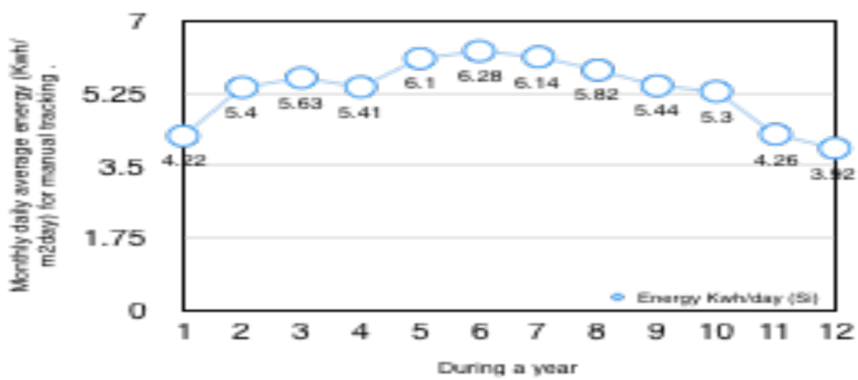


Fig 21. Monthly daily average produced by 1KWp in Cairo (30°N) with manual tracking at change Tilt angle every month (Silicon).

For GaAs array manual tracking system: -

Table 1.6 Monthly daily average energy produced by 1KWp GaAs array for manual tracking system.

Month	**Jan**	**Feb**	**Mar**	**Apr**	**May**	**Jun**
Energy KWh/day	4.89	6.26	6.53	6.28	7.07	7.28
Month	**Jul**	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**
Energy KWh/day	7.12	6.75	6.31	6.30	4.95	4.55

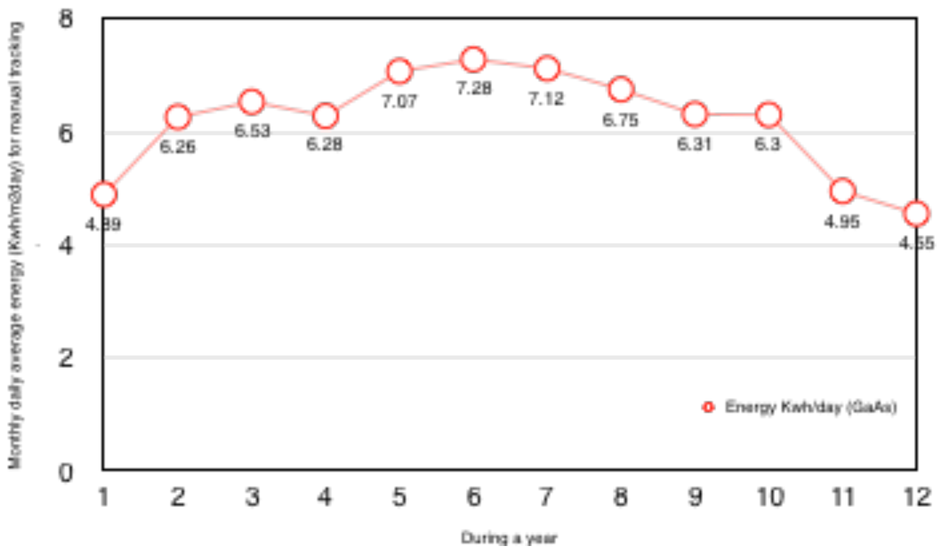


Fig 22. Monthly daily average produced by 1KWp in Cairo (30°N) with manual tracking at change Tilt angle every month.

The difference between Monthly daily average energy for Silicon and GaAs with Manual Tracking System:

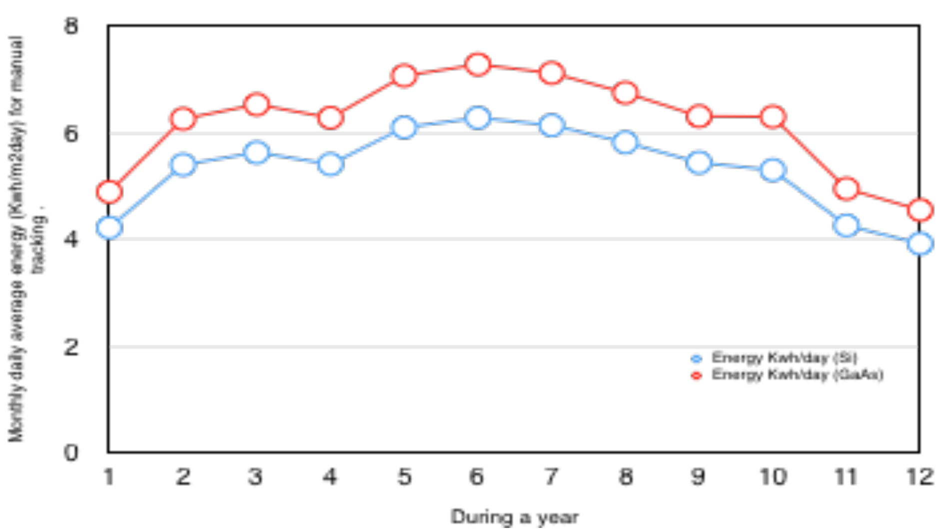


Fig 23. Monthly daily average produced by 1KWp in Cairo (30°N) with manual tracking at change Tilt angle every month for Si and GaAs.

4 ECONOMIC ANALYSIS

Compare between initial cost (EGP) per KWh and interest rate for all system when it is implemented in Egypt and sold to the Egyptian government [25], [22].

Table 1.7 Comparing between initial cost, cost (EGP) per KWh and interest rate for each solution with all systems.

Compare		Fixed System (Silicon)	Fixed System (GaAs)	Manual Tracking System (Silicon)	Manual Tracking System (GaAs)
Initial Cost (EGP)		1,272,000	1,526,400	1,453,326.2	1,707,326
Without Loan	Cost / KWh (EGP)	0.75	1.05	0.81	1.13
	Interest rate (%)	11.50	12.75	10.60	11.20
Loan 4 %	Cost / KWh (EGP)	0.73	1.022	0.78	1.092
	Interest rate (%)	19.80	25.30	18.30	23.08
Loan 14%	Cost / KWh (EGP)	0.88	1.23	0.94	1.316
	Interest rate (%)	9.89	11.84	7.56	8.56

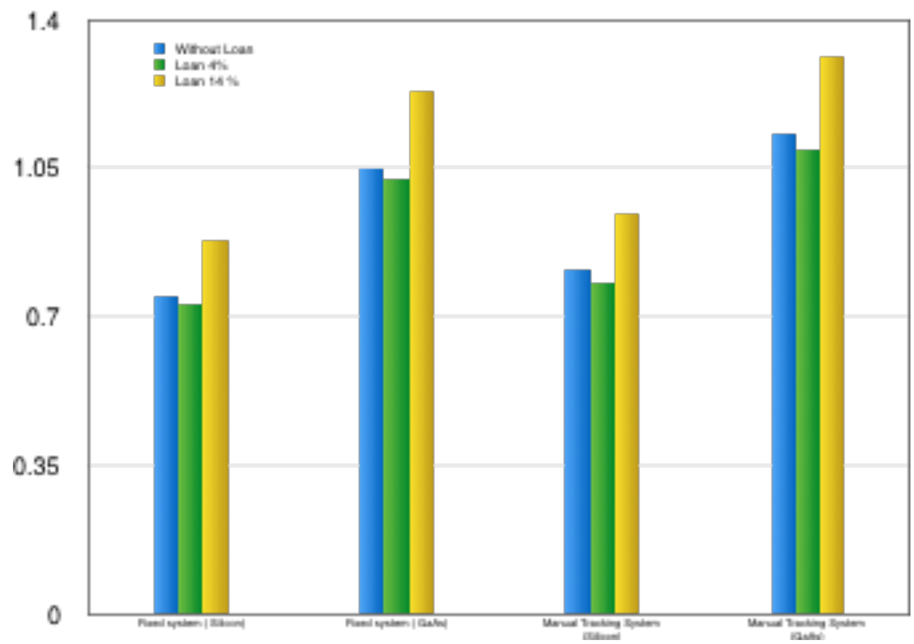


Fig 24. Compare between Cost [(EGP) / KWh] when used payment method [without loan and loan 4% and loan 14%] for all systems.

5 CONCLUSION

This research considered comparison among PV systems (Fixed –Manual) using on grid system for producing 110 KWp. The criterion used in this research to determine the optimum solution is the cost of produced one-kilo watt-hour. PV fixed panels system is Optimum economically among PV systems for both silicon and GaAs, where it is less expensive to produce energy and more profitable. If exceeded energy is sold to Egyptian government (according to new laws approved by Egyptian government), according to governmental facilities approved, it is allowed borrow up to 70% of the initial cost of the project. Economic analysis showed that borrowing at 4% interest gives minimum system cost. The profit in this case return on this project is expected to be 19.8 % for silicon and 25.30 for GaAs, also in this system total cost to produce 1KWh is about 0.73 EGP/KWh for silicon and 1.022 EGP/KWh For GaAs , It is less the cost price of production 1KWh by conventional methods. We approved that GaAs have more efficiency than Silicon but cost of silicon is less than GaAs.

6 REFERENCES

[1]Klein, S. A. “Calculation of monthly average insolation on tilted surfaces”.Solar energy,19(4), 325-329,1977.

[2]Zimmerman, J. C.”Sun-pointing programs and their accuracy”.NASA STI/Recon Technical Report N,81, 30643, 1981.

[3]M. L. Cohen and J. R. Chelikowsky, Electronic Structure and Optical Properties of Semi-conductors, 2nd Ed., Springer-Verlag, Berlin, 1988.).

[4]Prepared for educational purposes by E. F. Schubert ,https://www.ecse.rpi.edu/~schubert/Educational-resources/Materials-Semiconductors-Silicon-Germanium-&-GaAs.pdf .

[5]Watmuff, J.H., Charters, W. W. S., & Proctor, D. “Solar and wind induced external coefficients-solar collectors”.CooperationMediterraneenne pour l'Energie Solaire,1, 56,(1977).

[6]Linn, J. K., & Zimmerman, J. C.“Method for calculating shadows cast bytwo-axis tracking solar collectors“(No. SAND-79-0190). Sandia Labs., Albuquerque, NM (USA)., 1979.

[7]Blank, L., & Tarquin, A.”McGraw-Hill series in industrial engineering and management science.Engineering Economy”, 2005.

[8]Green, M. A. “Solar cells: operating principles, technology, and system applications”, 1982.

[9]Tiwari, GopalNath.“Solar energy: fundamentals, design, modelling and applications”. Alpha Science Int'l Ltd., 2002.

[10]Sullivan, W. G., Bontadelli, J. A., & Wicks, E. M. Engineering Economy.Printice Hall, 68, 2000.
[11]Kumar, A., & Kandpal, T. C.“ Solar drying and CO 2 emissions mitigation: potential for selected cash crops in India”.Solar Energy,78(2), 321-329, 2005.
[12]Hossain, M. A., Woods, J. L., &Bala, B. K.”Optimisation of solar tunnel drier for drying of chilli without color loss.Renewable Energy”,30(5), 729-742, 2005.
[13]Tomas, 2000
[14]Samuelson,P. A., &Nordhaus, W. D. “Economics. InternationalEdition”.New York. McGraw-Hill Inc, 1995.
[15]Thomas et al. 1999.
[16] Renewables 2012: Global Status Report," REN21, 2012.
[17]Witt et al, 2001 .
[18]V. Alex, S. Finkbeiner, and J. Weber, “Temperature Dependence of the Indirect Energy Gap in Crystalline Silicon,”J. Appl. Phys., 79, 6943 (1996).
[19]High -efficiency tandem solar cells on single- and poly- crystalline substrates , J.A. Hutchby , M.L. Timmons, R. Venkatasubramaniam, P.R. Sharps, R.A. Whisnant , 1994).
[20]Tiwari, GopalNath, and SwapnilDubey.”Fundamentals of photovoltaic modules and their applications”.No. 2.Royal Society of Chemistry, 2010.
[21]Lewis, Nathan S., and George Crabtree. "Basic research needs for solar energy utilization: report of the basic energy sciences workshop on solar energy utilization, April 18-21, 2005.", 2005.
[22]Fröhlich, C., and R. W. Brusa."Solar radiation and its variation in time."Physics of Solar Variations.Springer Netherlands, 1981.209-215.
[23]D.rapp.”Solar Energy”.New Jersey, 1981.
[24]Pluta, W. “Solar elctricity.An economic approach to solar energy”, 1978.
[25]Anis, Wagdy R., Robert P. Mertens, and R. Van Overstraeten."Analysis of a photovoltaic powered reverse osmosis water desalination system."Solar cells15, no. 1 ,1985
[26]Cooper, P. I..“The absorption of radiation in solar stills.Solar energy”,12(3), 333-346, 1969.
[27]Duffie, J. A., & Beckman, W. A. “Solar engineering of thermal processes”,(Vol. 3). New York etc.: Wiley, 1980.
[28]Solar cells : Materials, Manufacture and operation Tom Markvart ,2005.