Optimum Design Of On Grid Pv System Using Tracking System

Saeed Mansour, Dr. Wagdy R. Anis, Dr. Ismail M. Hafez

Abstract: The fossil fuel is a main issue in the world, due to the increase of fossil fuel cost and the depletion of the fossil fuel with continuous increasing demand on electricity. With continuous decrease of PV panels cost, it is interesting to consider generation of electricity from PV system. To provide electric energy to a load in a remote area where electric grid utility is not available or connection with grid utility is available, there are two approaches of photovoltaic system, PV without tracking system (Fixed System) and PV with tracking systems. The result shows that the energy production by using PV with tracking system generates more energy in comparison with fixed panels system. However the cost per produced KWH is less in case of using fixed panels. This is the backbone in choice between two approaches of photovoltaic system. In this work a system design and cost analysis for two approaches of photovoltaic system are considered.

Index Terms: Photovoltaic (PV) system, Tracking, ON Grid, Economics

1 INTRODUCTION

Energy is basis of progress in agriculture and industry, a center of development in all fields, due to the high fuel prices and the difficulty of getting in a time of crisis, which was repeated in recent times, and power outages, due to the force of conventional energy and ending a period of not more than a century ago We went towards an alternative source, we could not find better than solar energy, Where sunlight provides by far the largest of all carbon-neutral energy sources. Sunlight strikes the Earth in one hour \(4.3 \times 10^{20} \text{ J}\) is more than all the energy consumed on the planet in a year \((4.1 \times 10^{20} \text{ J})\), Sunlight is abundant sources of energy in the future. It is readily available, secure from geopolitical tension, and poses no threat to our environment through pollution or to our climate through greenhouse gases. In 2001 the solar electricity provided less than 0.1% of the world's electricity, and the solar fuel from modern (sustainable) biomass provided less than 1.5 % of the world's energy [9].

1.1 Solar Radiation applications

Solar energy has two main applications; thermal applications as well as photovoltaic applications. The main thermal applications are, [4], [7]:

a) Flat-plate air collector: A device having an insulated blackened flat surface with a transparent glass window above it that works with the micro greenhouse effect.

b) Solar dryer: A device that uses solar energy for drying applications.

c) Greenhouse: A microclimate, which can be created by using the transparent glass/plastic house similar to the global greenhouse concept. It can be Used for optimum growth of living plants (e.g. flowers, vegetables, etc.) for maximum crop production during season as well as off-season (post-harvest and pre-harvest period) and is generally known as greenhouse technology. The greenhouse can also be used for crop drying for storage purposes.

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

1.2 Sun–Earth Angles

The energy flux of beam radiation on a surface with arbitrary orientation can be obtained by the flux either on a surface perpendicular to the Sun rays or on a horizontal surface. The various Sun–Earth angles required to understand the solar energy received are as follows [1], [3].

1.2.1 Solar Declination (\(\delta\))

The angle that the Sun's rays make with the equatorial plane is known as the declination angle (Figure 1). This angle is the solar declination. On any day, \(\delta\) is taken as a constant which changes on the next day. Cooper’s empirical relation for calculating the solar declination angle (in degrees) is [1], [5], and [8]

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

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

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 \(23.45^\circ\) on 21 December and the minimum is – \(23.45^\circ\) on 21 June.

1.2.2 Latitude (\(\phi\)) and Longitude (\(L_\phi\))

Latitude \(\phi\) 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.

**Fig2. Latitude (φ) and Longitude (Lt).**

On the Earth, a meridian (Lt) 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 [1], [9], [11].

### 1.2.3 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°) [1],[6],[9].

**Fig3. Hour angle.**

### 1.2.4 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 γYγ 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 γYγ=0, then the angle of incidence θh becomes equal to the zenith angle [1], [2].

**Fig1. Latitude (φ) and Longitude (Lt).**

### 1.3 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 [1]. Beam radiation (H_D): 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 (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 (KWh/m²) on surface normal to solar beams is constant and equal to solar constant $G_{SC}(=1.35 \text{ KWh/m}^2)$ is given by [10]

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

Clearness index

$$K_T = \frac{H_B}{H_{ext}} \quad (3)$$

### 1.3.1 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 [1], [7]

$$H_B = H_D \cos \theta_z + H_d \quad (4)$$

Where H_B is the global irradiance on a horizontal surface, H_d the diffuse irradiance, H_D the direct beam irradiance on a surface perpendicular to the direct beam and θ_z the Sun’s zenith angle.
is given by \[10\] 

\[
\sin \omega_1 \cdot \sin \omega_2 \cdot \sin \varphi \cot \beta
\]

Ratio between direct radiations on tilted surface to on horizontal surface Ref. [10], [14]

\[
R_b = \frac{H_{D,\beta}}{H_{D,\theta}}
\]

The total radiation for any inclined (inclination = \(\beta\)) with any orientation of solar thermal device (for east, south, west and north) \(\gamma = -90^\circ, 0^\circ, +90^\circ\) and \(\pm 180^\circ\) for a given latitude \(\varphi\) can be evaluated using the formula Ref. [10]

\[
H_T = H_\beta[1.13K_T R_b + 0.5(1 + \cos \beta)(1 - 1.13K_T) + 0.5\rho(1 - \cos \beta)]
\]

When Reflectivity of ground (\(\rho = 0.2\) for normal ground and \(\rho = 0.7\) for snow)

\[
G_T = \frac{\pi}{24} H_T \frac{\cos \omega_1 \cdot \cos \omega_2}{\sin \omega_1 - \omega_2 \cdot \cos \omega_2}
\]

**1.4 Parameters of Solar Cells**

**1.4.1 I V Characteristics**

The standard solar cell I-V characteristics is given by Eq.(10), \(R_s\), should be small and the shunt (parallel) resistance, \(R_p\), should be large [1], [12], and [15].

\[
I = [I_L - I_s(e^{V/R_s/Vt} - 1)] - \frac{V + 1}{R_{sh}}
\]

**Fig 8. I-V Characteristic for solar cell.**

The short circuit current \(I_{SC}\) defined as [1], [11], and [12]. The array current I when \(V = 0\)

Then \(I_{SC} = I_L \ldots (I_L \equiv \text{current generated from light})\)

\[
I = I_L - V/e^{V/R_s/Vt} - 1
\]

At \(I \equiv I_{\text{max}}\)

\[
I_{\text{max}} = I_L - V/e^{V_{\text{max}}/Vt} - 1
\]

The open circuit voltage \(V_{oc}\) when \(I = 0\) and defined as [1], [12], [15].

\[
V_{oc} = V_t \ln (\frac{I}{V_t}) + 1
\]

The power delivered by the solar cell output is defined as [1]

\[
P = I_L - V/e^{V/R_s/Vt} - 1
\]

**1.4.2 Maximum Power \(P_{\text{max}}\)**

No power is generated under short or open circuit. The power output is defined as [1], [12], and [13].

\[
P_{\text{out}} = V_{out} \times I_{out}
\]

The maximum power \(P_{\text{max}}\) provided by the device is achieved at a point on the characteristics, where the
product IV is maximum. Thus $P_{\text{max}}$ is defined as [1], [12], and [17].

$$ P_{\text{max}} = V_{P_{\text{max}}} \times I_{P_{\text{max}}} $$  \hspace{1cm} (17)

**PV Standard Modules**

Our design is based on 200 W, 24 V PV module and its parameters at AM1 and $T_C = 25$ are $V_{OC} = 33$ V, $V_{P_{\text{max}}} = 25$ V and $I_{SC} = 8.27$ A.

1.5 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 each part of the system is calculated at each step of the simulation using either time-based or time-integration methods. A detailed simulation program is developed considering climatic conditions of Egypt.

The instantaneous global radiation on tilted surface [10].

$$ G_T = \frac{n}{24} H_T \cos \omega_s - \cos \omega_s \cos \omega_\phi \sin \omega_s $$

Tracking instantaneous radiation on tilted surface [10].

$$ G_{\text{Tracking one axis}} = G_T \times K_T \left( \frac{\cos \delta}{\cos \theta_T} \right) + (1 - K_T) \times G_T $$

Tracking instantaneous radiation on tilted surface [10].

$$ G_{\text{Tracking two axis}} = G_T \times K_T \left( \frac{1}{\cos \theta_T} \right) + (1 - K_T) \times G_T $$

Current output from PV array [11].

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

2.1 Design without Tracking (fixed panels system)

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

**Fig10. Block diagram of fixed panels system at $\beta=30$ 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.

**Fig11. Block diagram of Manual Tracking System without storage batteries and on grid when Tilt angle changing every day $\beta=(\phi - \delta)$.**
2.3 Design with Automatic Tracking System

2.3.1 Design with Automatic Tracking One Axis System
Obtain the array size for each solution at tracking in one axis (when Latitude Angle constant and Zero Azimuth Angle Constantly ($\gamma = 0$)). Calculate energy production per array size using Matlab simulation program. Compare energy production cost from each solution.

2.3.2 Design with Automatic Tracking Two Axis System
Obtain the array size for each solution at tracking in two axis (when subtract between Latitude Angle and declination angle changing every day and Zero Azimuth Angle Constantly ($\gamma = 0$)). Calculate energy production per array size using Matlab simulation program. Compare energy production cost from each solution.

| Figure (12) Block diagram of Automatic Tracking System for One Axis without storage batteries and on grid when Zero Azimuth Angle and $\beta = \varphi$. |

| Figure (13) Block diagram of Automatic Tracking System for Two Axis without storage batteries and on grid when Azimuth Angle=0 and $\beta = (\varphi - \delta)$. |

3 Results

3.1 Design without Tracking (Fixed panels System)
For $\varphi=30^\circ$ (Cairo, Egypt), Tilt angle $\beta=30^\circ$. Monthly daily average energy produced by 1 Kwp array installed in Cairo (30°N) in KWh per day is shown below:

| Table 1.1 Monthly daily average energy produced by 1 Kwp 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 |

The total energy annually for system (1 KWh/ day) = 1816.2 KWh/ year = 1.8162 MW/ year. For the 110 Kwp system is considered since it is standard with conventional two axis tracking. The total energy annually for system (110 KWh/day) = 199.784 MW/year.

3.2. Design with Manual Tracking System
For $\varphi=30^\circ$ (Cairo, Egypt), the optimum tilt angle $\beta$ is ($\varphi - \delta$). This value makes solar beam perpendicular on PV modules at noon. Monthly daily average energy produced by 1 Kwp array installed in Cairo (30°N) in KWh per day is shown below:

| Table 1.2 Monthly daily average energy produced by (1 Kwp) for manual tracking system. |
|---|---|---|---|---|---|---|
| Month | Jan | Feb | Mar | Apr | May | Jun |
| Energy KWh/day | 4.22 | 5.40 | 5.63 | 5.41 | 6.10 | 6.28 |

The total energy annually for system (1 KWh/ day) = 1816.2 KWh/ year = 1.8162 MW/ year. For the 110 Kwp system is considered since it is standard with conventional two axis tracking. The total energy annually for system (110 KWh/day) = 199.784 MW/year.
Monthly daily average energy produced by 1 KWp installed in Cairo (30°N) in KWh per day is shown below:

Table 1.3 Monthly daily average energy produced by (1 KWp) for automatic One axis tracking system.

<table>
<thead>
<tr>
<th>Month</th>
<th>Jan</th>
<th>Feb</th>
<th>Mar</th>
<th>Apr</th>
<th>May</th>
<th>Jun</th>
</tr>
</thead>
<tbody>
<tr>
<td>Energy KWh/day</td>
<td>5.2</td>
<td>7.31</td>
<td>8.09</td>
<td>7.77</td>
<td>7.98</td>
<td>7.89</td>
</tr>
</tbody>
</table>

The total energy annually for system (1 KWh/ day) =1945.5 KWh/ year =1.9455 MWh/year. The total energy annually for system (110 KWh/day) =214 MWh/year.

3.3 Design with Automatic Tracking System

3.3.1 Design with Automatic Tracking One Axis System

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

Table 1.4 Monthly daily average energy produced by 1 KWp for automatic two axis tracking system.

<table>
<thead>
<tr>
<th>Month</th>
<th>Jan</th>
<th>Feb</th>
<th>Mar</th>
<th>Apr</th>
<th>May</th>
<th>Jun</th>
</tr>
</thead>
<tbody>
<tr>
<td>Energy KWh/day</td>
<td>5.93</td>
<td>7.75</td>
<td>8.15</td>
<td>8.01</td>
<td>8.85</td>
<td>9.20</td>
</tr>
</tbody>
</table>

The total energy annually for system (1 KWh/ day) =2621.8 KWh/ year =2.6218 MWh/year. The total energy annually for system (110 KWh/day) =288.395 MWh/year.

3.3.2 Design with Automatic Tracking Two Axis System

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

The total energy annually for system (1 KWh/ day) =2832.1 KWh/ year =2.8321 MWh/year. The total energy annually for system (110 KWh/day) =311.530 MWh/year.

Comparing average daily energy produced from station (110 KWp) in Cairo, Egypt (Fixed System, Manual Tracking System, Automatic One Axis Tracking System and Automatic Two Axis Tracking System)
4 ECONOMIC ANALYSIS

Compare between initial cost, cost (EGP) per KWh and interest rate for all system When it is implemented in Egypt and sold to the Egyptian government [16], [17].

Table 1.5 Comparing between initial cost, cost (EGP) per KWh and interest rate for each solution with all systems.

<table>
<thead>
<tr>
<th>Compare</th>
<th>Fixed System</th>
<th>Manual Tracking System</th>
<th>Automatic Tracking One Axis System</th>
<th>Automatic Tracking Two Axis System</th>
</tr>
</thead>
<tbody>
<tr>
<td>Initial Cost (EGP)</td>
<td>1,272,000</td>
<td>1,453,326.2</td>
<td>2,017,975</td>
<td>2,255,300</td>
</tr>
<tr>
<td>Cost / KWh (EGP)</td>
<td>0.75</td>
<td>0.81</td>
<td>0.83</td>
<td>0.86</td>
</tr>
<tr>
<td>Interest rate (%)</td>
<td>11.50</td>
<td>10.60</td>
<td>10.10</td>
<td>9.70</td>
</tr>
<tr>
<td>Loan 4%</td>
<td>0.73</td>
<td>0.78</td>
<td>0.80</td>
<td>0.83</td>
</tr>
<tr>
<td>Interest rate (%)</td>
<td>19.80</td>
<td>18.30</td>
<td>17.60</td>
<td>14.20</td>
</tr>
<tr>
<td>Loan 14%</td>
<td>0.88</td>
<td>0.94</td>
<td>0.97</td>
<td>1</td>
</tr>
<tr>
<td>Interest rate (%)</td>
<td>9.89</td>
<td>7.56</td>
<td>- 1.79</td>
<td>1</td>
</tr>
</tbody>
</table>

Is the investment acceptable?
Acceptable when the Interest Rate is greater than the banking investment interest (11%) in Egypt Otherwise it is unacceptable [18], [19].

Table (6) compare between investment (acceptable or unacceptable) for each solution with all systems.

<table>
<thead>
<tr>
<th>Compare</th>
<th>Fixed System</th>
<th>Manual Tracking System</th>
<th>Automatic Tracking One Axis System</th>
<th>Automatic Tracking Two Axis System</th>
</tr>
</thead>
<tbody>
<tr>
<td>Without Loan</td>
<td>Interest rate (%)</td>
<td>11.50</td>
<td>10.60</td>
<td>10.10</td>
</tr>
<tr>
<td>State investment (Acceptable or Unacceptable)</td>
<td>A</td>
<td>U</td>
<td>U</td>
<td>U</td>
</tr>
<tr>
<td>Loan 4%</td>
<td>Interest rate (%)</td>
<td>19.80</td>
<td>18.30</td>
<td>17.60</td>
</tr>
<tr>
<td>State investment (Acceptable or Unacceptable)</td>
<td>A</td>
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</tr>
<tr>
<td>State investment (Acceptable or Unacceptable)</td>
<td>U</td>
<td>U</td>
<td>U</td>
<td>U</td>
</tr>
</tbody>
</table>
5 CONCLUSION
The research showed that PV system is a promising project since PV panel cost is continuing decrease in cost. This research considered comparison among PV systems (Fixed – Manual – One axis – Two axis) using on grid tracking 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. However, it is shown that two axis automatic tracking system produces maximum energy. But PV fixed panels system is Optimum economically among PV systems, 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 % and also in this system total cost to produce 1 KWh is about 0.73 EGP/ KWh. It is less the cost price of production 1 KWh by conventional methods.

6 REFERENCES