



Cairo University

# **OPTIMUM DESIGN OF PHOTOVOLTAIC PANEL ORIENTATION ANGLES**

By

**Ahmed Yahia Salah Abd El-Maksoud**

A Thesis Submitted to the  
Faculty of Engineering at Cairo University  
in Partial Fulfillment of the  
Requirements for the Degree of  
**MASTER OF SCIENCE**  
in  
Mechanical Design and Production Engineering

**FACULTY OF ENGINEERING, CAIRO UNIVERSITY  
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**Title of Thesis:**

Optimum Design of Photovoltaic Panel Orientation angles

**Keywords:**

Solar energy; Tilt, Incidence and Azimuth angles; Surface fitting;  
Photovoltaic; Cost.

**Summary:**

Optimization of the PV panel orientation angles to get the maximum energy output are presented. For fixed panel, there are annually, half annually, seasonally and monthly optimum tilt angle which produce maximum energy at south facing azimuth angle. on the other hand, for full tracking, there are two branches in the presented work. First one, the focusing on the incidence angle to compare between the always perpendicularity of the solar panel all the year and the optimum incidence angle. Second one, how to get an equation for each optimum tilt and optimum azimuth angle as function of hours and days. Finally, comparison has also been made between the cost of the fixed and full tracking photovoltaic system.

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## Nomenclature

|              |   |
|--------------|---|
| $h$          | hour angle  |
| $\varphi$    | latitude angle  |
| $\delta$     | declination angle   |
| DN           | day number  |
| $\alpha$     | solar altitude angle  |
| $\gamma$     | solar azimuth angle   |
| $\gamma_s$   | surface azimuth angle   |
| $\beta$      | tilt angle  |
| $\emptyset$  | solar zenith angle  |
| $Z_s$        | surface azimuth angle   |
| $Z$          | solar azimuth angle   |
| $G_G$        | irradiance incident on a horizontal surface [ $\text{W}/\text{m}^2$ ] |
| $G_B$        | beam irradiance [ $\text{W}/\text{m}^2$ ]                             |
| $G_D$        | diffuse irradiance [ $\text{W}/\text{m}^2$ ]                          |
| $R_D$        | tilt factor for diffuse radiation,                                    |
| $R_R$        | tilt factor for reflected radiation and                               |
| $R_B$        | tilt factor for beam radiation  |
| $\rho_g$     | ground reflection factor (albedo)                                     |
| $T_c$        | cell temperature [ $^{\circ}\text{C}$ ]                               |
| $T_a$        | ambient temperature [ $^{\circ}\text{C}$ ]                            |
| $G_T$        | total solar radiation striking the PV array [ $\text{W}/\text{m}^2$ ] |
| $\tau$       | solar transmittance of any cover over the PV array [%]                |
| $\alpha$     | solar absorptance of the PV array [%]                                 |
| $\tau\alpha$ | effective transmittance-absorptance product                           |
| $\eta_{mp}$  | maximum power point efficiency [%]                                    |
| $\alpha_p$   | temperature coefficient of power [%/ $^{\circ}\text{C}$ ]             |
| $Y_{PV}$     | rated capacity of the PV array [W]                                    |
| $f_{PV}$     | PV derating factor [%]  |
| $\alpha_p$   | temperature coefficient of power [%/ $^{\circ}\text{C}$ ]             |

## Subscripts

|      |                                    |
|------|------------------------------------|
| NOCT | nominal operating cell temperature |
| STC  | standard test conditions           |

## Abstract

Nowadays, with rising fuel cost and its bad effect on the atmosphere, there are many other possible alternatives such as solar energy. With the recent wide spread use of solar energy and photovoltaic solar cells, the researchers work hard to improve their performance to be attractive alternative to fossil fuel. This work presents the optimization of the output power of the photovoltaic solar cell. This power is optimized based on studying the effect of the tilt, the azimuth and the incidence angles on its performance. Meta-model is utilized as an optimization technique. A case study develops 2<sup>nd</sup>, 3<sup>rd</sup>, and 4<sup>th</sup> order hyper-surface equations to get the optimum tilt angle and optimum azimuth angles for the city of Hurghada. The power produced from the 4<sup>th</sup> order hyper-surface model at full tracking system increases by 24.2% more than the optimum tilt at fixed azimuth angle (facing south). By comparing the meta-model and the performance optimization technique, the error has been around 1.1%. Comparison has also been made between the cost of the fixed and full tracking photovoltaic system.

# **Chapter 1 : Introduction and Literature Review**

## **1.1 Introduction**

Since the oil crises in 1970s, the words "energy crisis" and "energy security" continue to dominate the news. Added to these worries, the issues of climate changes due to drastically increase of fossil fuels utilization. However, the main problem facing humankind is that oil and gas reserves at current rates of consumption would meet the human demand of energy for about 40 and 60 years, respectively. If we try to see the consequences of these limited reserves, we will be faced with another problem which is the rapid increase of oil and natural gas prices. In order to avoid further impacts of these problems, two main alternatives were proposed: improving fossil fuels' quality and reducing their harmful emissions in to the atmosphere, or more significantly, replacing fossil fuels usage with other energy resources that have a lesser impact on the environment, i.e. renewable energy sources.

Many alternative energy sources can be used instead of fossil fuels and the decision of what type of renewable energy sources is the optimal to be used depends on some environmental, economic and safety considerations. Solar energy is one of the promising renewable energy sources, especially in case of small and medium applications, because of some inherent advantages such as zero emissions, reliability, and availability at no cost. But, on the other hand, it has some disadvantages that limit its usage on a wider range of applications such as uneven distribution around the world, low intensity, complicated sun tracking technology, high initial costs, and long payback periods. Solar energy has been used by humankind through history for thousands of purposes such as food growing, drying clothes. Nowadays, it is used in some new domestic and industrial applications such as water heating, air conditioning, refrigeration, operating engines and pumps, water desalination and power generation.

### **1.1.1 Global Energy Consumption**

According to the 2009 reference case of the U.S. Energy Information Administration (EIA)[1], the annual growth in world energy consumption will decrease from 2.0 % in the period 1980–2006 to 1.4 % in the period 2008–2030 as shown in Fig. 1-1.

Consumption of all energy sources is expected to increase over time supposing that world oil prices remain relatively high through most of the time period included in the study. Petroleum products are the world's energy sources that grow most slowly in this scenario with an average annual rate of 1.0 % from 2008 to 2030, (See Table 1-1). Renewable resources are anticipated to have the fastest growing energy sources, with consumption increasing 2.7% per year. Many factors such as planned in oil prices, rising concern about the environmental impacts of fossil fuel use, and strong support of governments are expected to improve the prospects for renewable energy worldwide. Although liquid fuels are expected to remain the largest source of energy, their contribution of marketed world energy consumption decreases in the reference case from 35.3 % in 2008 to 31.8 % in 2030. This scenario assumes that rising world oil prices encourages many energy users, especially in the industrial and power