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
GIZA, EGYPT
2017

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

Under the Supervision of

Prof. Dr. Sayed M. Metwalli

Professor Emeritus
Mechanical Design and Production
Engineering
Faculty of Engineering, Cairo University

Dr. Hesham A. Hegazi

Associate Professor
Mechanical Design and Production
Engineering
Faculty of Engineering, Cairo University

Dr. Mohamed S. El Morsi

Associate Professor
Mechanical Engineering
Faculty of Engineering,
American University in Cairo

FACULTY OF ENGINEERING, CAIRO UNIVERSITY
GIZA, EGYPT
2017

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

Approved by the
Examining Committee

____

Prof. Dr. Sayed Mohamed Metwalli, Thesis Main Advisor

____

Prof. Dr. Hesham Ahmed Hegazi, Member

____

Prof. Dr. Ahmed Ali El-Zoghby, Internal Examiner

____

Prof. Dr. Ashraf Osama Nassef, External Examiner

Dept. of Mechanical Engineering
American University in Cairo

FACULTY OF ENGINEERING, CAIRO UNIVERSITY
GIZA, EGYPT
2017

Engineer's Name: Ahmed Yahia Salah Abd El-Maksoud
Date of Birth: 15 / 4 / 1990
Nationality: Egyptian
E-mail: a.yehia.elsabawy@gmail.com
Phone: 0100-4742-034
Address: El-Souk St., Kerdasa, Giza
Registration Date: 1 / 10 / 2012
Awarding Date: / / 2017
Degree: Master of Science
Department: Mechanical Design and Production Engineering

Supervisors:

Prof. Dr. Sayed M. Metwalli
Dr. Hesham A. Hegazi
Dr. Mohamed S. El Morsi
Dept. of Mechanical Engineering,
American University in Cairo

Examiners:

Porf. Dr. Sayed M. Metwalli	(Thesis main advisor)
Porf. Dr. Hesham A. Hegazi	(Member)
Prof. Dr. Ahmed El-Zoghby	(Internal examiner)
Prof. Dr. Ashraf O. Nasef	(External examiner)

Dept. of Mechanical Engineering,
American University in Cairo

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.

Acknowledgments

I would like to thank my supervisor Prof. Sayed M. Metwalli for providing the opportunity to join the solar water desalination project, this opportunity was pivotal to the completion of this work, in fact, it was the initiation point of all the effort that was performed thereafter. It is because he introduced me to the project team members that I was able to communicate with them and achieve satisfactory results. I would like also to thank him again for all his valuable and helpful advice, his vast effort and patience to teach my much smaller mind.

I would like to also thank my supervisor Dr. Hesham A. Hegazi (Associate Professor, AUC Egypt and Cairo University) for the effort he made in helping me in this work.

I would like to also thank my supervisor Dr. Mohamed S. El Morsi (Associate Professor, AUC Egypt and Ain Shams University) for all the valuable knowledge and resources he made available to me, and the effort he made in explaining and helping me continue this work, and the attention he paid to my various inquiries throughout the performance of this work.

I wish to thank my colleagues at the Mechanical Power Engineering Department for their friendship, support. Special thanks go to Eng. Mohammed Zidan, Eng. Mohammed Hossam, and Eng. Mohammed Hany.

I would like to thank my parents for their special interest in my learning and their hard work to provide for it along the different levels of my study. I hope my progression will bring them pride and happiness that their effort to bring me up was not a waste in its entirety.

To any who taught me: I owe you and I can’t repay in full.

This work is partly supported by the U.S. Department of Agriculture and Egypt Science and Technology Development Fund, STDF Project #3832.

Table of content

List of Tables

List of Figures

Nomenclature

h	hour angle
φ	latitude angle
δ	declination angle
DN	day number
∝	solar altitude angle
γ	solar azimuth angle
γ_s	surface azimuth angle
β	tilt angle
∅	solar zenith angle
Z_s	surface azimuth angle
Z	solar azimuth angle
G_G	irradiance incident on a horizontal surface [W/m^2]
G_B	beam irradiance [W/m^2]
G_D	diffuse irradiance [W/m^2]
R_D	tilt factor for diffuse radiation,
R_R	tilt factor for reflected radiation and
R_B	tilt factor for beam radiation
ρg	ground reflection factor (albedo)
Tc	cell temperature [°C]
Ta	ambient temperature [°C]
G_T	total solar radiation striking the PV array [W/m2]
τ	solar transmittance of any cover over the PV array [%]
α	solar absorptance of the PV array [%]
τα	effective transmittance-absorptance product
η_{mp}	maximum power point efficiency [%]
α_P	temperature coefficient of power [%/°C]
Y_{PV}	rated capacity of the PV array [W]
f_{PV}	PV derating factor [%]
α_P	temperature coefficient of power [%/°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^{nd}, 3^{rd}, and 4^{th} 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^{th} order hyper-surface model at full tracking system increases by 24.2% more than the y 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