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Design of Photovoltaic Tracking Systems

by

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In Electrical Engineering at
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STATEMENT

This thesis is submitted as partial fulfilment of M.Sc. degree in Electrical Engineering (Electronics and Communication Engineering), Faculty of Engineering, Ain Shams University.The author carried out the work included in this thesis and no part of it has been submitted for a degree or qualification at any scientific entity.

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ABSTRACT

Automatic Solar Tracking is mainly utilized to maximize the efficiency of the output of the solar panel. Also, the main function of it is to follow the solar radiation at any time in any day taking into consideration that the panel is always perpendicular to the solar radiation.
Since the motion plane of the sun is varying everyday as the sun shines at a different angle each day and also all over the day because it goes from east direction to west direction, so a dual-axis tracker is used to track the sun in the vertical and horizontal motion .unlike the single axis tracking which follow only the sun's east-west motion.
However, the efficiency of the dual solar tracker is much higher than single tracker and fixed one, it is considered more complex and higher in cost than the other two designs; one needs a compromise between cost, complexity, and maximum collected power so a single axis tracker will be the applicable solution. And this thesis is to provide a solution of (dual and single axis) automatic tracking systems.

Keywords: Photovoltaic, Solar Tracking, Automatic tracking systems, Maximum effeciency ,Solar radiation.

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SUMMARY

This thesis discuss a vital product of Solar Electric technologies which is Solar panels and moreover the Solar tracker for enhancing the efficiency of the electrical output which is used in many applications in our lives as a clean source of energy instead of conventional sources of energy.

Chapter One: This chapter discusses short introduction about some types of renewable energy sources, use of solar energy to solve the energy problem, measuring the intensity of solar radiation on earth surface and their related angles. Also, discusses short introduction about solar cells, the different materials used in the manufacture of solar cells, PV systems and some of its applications.

Chapter Two: This chapter discusses types of solar PV systems such as: Fixed systems, Automatic Tracking systems (One Axis Automatic Tracking and Two Axis Automatic Tracking) and review about automatic tracking systems designed before.

Chapter Three: This chapter shows the implementation of a prototype of a Dual-axis tracker with wind sensor to overcome high wind speeds in order to save the panels and also, the implementation of a prototype of a single-axis tracker.

Chapter Four: This chapter shows results for this research point.

Chapter Five: This chapter shows conclusion and future work recommendations for this research point.

Last Part: it shows appendix and references for this thesis.

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Abbreviations

PV	Photovoltaic

ROW	Rest of world
N-type	Negative type
P-type	Positive type
UV	Ultraviolet
ST	Solar Time
Btu/ft^2	British thermal unit / feet square
J	Joule
W	Watt
KW	Kilo Watt
MW	Mega Watt
GW	Giga Watt
Wp	Watt Peak
KWh	Kilo Watt hour
PSAT	Polar Single axis tracker
HSAT	Horizontal One Axis Trackers
VSAT	Vertical One Axis Trackers
TSAT	Tilted Single Axis Trackers
AADAT	Azimuth- Altitude Dual Axis Trackers
TTDAT	Tip-Tilt Dual axis trackers
DC	Direct current
Cdte	Cadmium Telluride
Cuinse2	Copper-Indium Selenide
GaAs	Gallium Arsenide
DSSC	Dye-Sensitized Solar Cells
Si	Silicon
C-Si	Crystalline Silicon
MC-Si	Multi-Crystalline Silicon
CP	Concentration Polarization
LDR	Light detecting sensor
TFPV	Thin - Film Photovoltaic
CFC	Chlorofluorocarbon
MC	Mono- crystalline
PC	Poly-crystalline

Symbols

G_s	Solar constant
G	Irradiance
G_T	Instantaneous global radiation on tilted surface
G_T	Tracking Instantaneous radiation on tilted surface
H_B	Global solar radiation
H_D	Direct radiation on horizontal surface
$H_{D,t}$	Direct radiation on tilted surface
H_d	Diffuse solar radiation
H_T	Total radiation for any inclined
H_e	Extraterrestrial radiation
B	Tilt angle
Θ_Z	Zenith angle
γ_s	Solar azimuth angle
γ	Surface azimuth angle
Δ	Solar declination
Ø	Latitude angle
L_t	Longitude angle
Ω	Hour angle
Θi	Angle of incidence
$\propto$	Solar Altitude angle
D	Day of the year
T	Solar time
T_s	Sunset hour on surface horizontal
T_s ‟	Sunset hour on surface tilted
T_s	Sunrise hour on surface horizontal
T_s ‟	Sunrise hour on surface tilted
T_d	Daytime duration on surface horizontal
T_d ‟	Daytime duration on surface tilted
T_n	Night duration on surface horizontal
T_n ‟	Night duration on surface tilted
ω_s	Sunset hour angle on surface horizontal
ω_s ‟	Sunset hour angle on surface tilted
ρ	Reflectivity of ground
K_T	Clearness index
R_b	Ratio between direct radiations on tilted surface to on horizontal Surface
G_s	Solar constant
G	Irradiance
G_T	Instantaneous global radiation on tilted surface
G_T	Tracking Instantaneous radiation on tilted surface
H_B	Global solar radiation
H_D	Direct radiation on horizontal surface
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L_{τ}	Longitude angle
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Θi	Angle of incidence
∝	Solar Altitude angle
D	Day of the year
T	Solar time
T_s	Sunset hour on surface horizontal
T_s ‵	Sunset hour on surface tilted
T_s	Sunrise hour on surface horizontal
T_s ‵	Sunrise hour on surface tilted
T_d	Daytime duration on surface horizontal
T_d ‵	Daytime duration on surface tilted
T_n	Night duration on surface horizontal

CHAPTER 1: INTRODUCTION

1.1 Introduction

One of the main problems in our modern era is the conventional energy as it's resources is going to be vanished by the time because of the overuse and also it affects the environment badly. So the use of a clean renewable source of energy became an urgent solution to save our world and to prevent our conventional energy resources from vanishing. one of the cleanest and reliable renewable source of energy is solar power also it is used in several applications. PV panels are used to convert the solar radiation to electric energy that powers our homes, business and could be connected to the grid. PV panels use trackers inorder to increase the collected solar energy by decreasing the angle between the panel and the solar rays[1].

1.2 Solar energy

Solar energy means converting the power collected from the sun to another power whether electric, motion or any type of energy. Also, it is renewable cause it will exist as long as the sun exists and it is predicted to be another 4.5 billion years. In the old days, solar energy usage was only for drying anything and heating by direct contact. In modern days, solar energy wasn't used that much cause it was an expensive and irreliable source of energy. By modification and advancements, solar technology is moving forward and became an alternate solution to conventional energy nowadays. In these days, solar energy is produced primarily by using of photovoltaic solar cells.This is how it works, the rays of the sun strike the panel which is placed perpendicular to sun rays and when the sun hits the solar cell causes a chemical reaction that creates an electric current that turns into electricity but the efficiency of the cells is approximately 15 %.
There are two types of solar energy which are passive solar and active solar. They are discussed as below :

- The passive solar systems involves capturing the sun power by using windows, tanks and so on. It doesn't contain any tracking system also doesn't contain any mechanical system. Some examples of passive systems can be used in heating homes, water and things.
- The active solar systems are complex and expensive than passive systems cause they contain solar panels in their systems. Also, the panels are directed in order to increase the exposure to the sun, then the panels will perform its function and convert the sunrays into electricity ,then this electricity will be transformed from direct current to alternate current and stored in batteries to be used later or fid into the grid system of the local utility.

Solar energy has many pros over the other renewable energies. It is a clean source of energy and environmentally friendly, also it doesn't need a lot of maintenance. In a majority of places around the world, Solar energy can be sold to the local utilities per

a concept defined as net metering which will reduce the need to store the energy in batteries and also cuts utility bills.
Unluckily, Solar energy has some cons as well.The initial cost will be taken into consideration as the cost of purchasing and installation may be expensive according to the system and area used [2]. Second, There is a big issue here, as there are areas in which the daytime is a short period. Third, solar energy can't be collected at night time cause there is no light. In spite of all of these problems. Solar energy is widespread and booming renewable energy source.
Finally, figure (1.1) shows the largest producers of solar energy are China, Germany, Japan and the United States. the circular graph below shows Global Solar Market installation at 2017.

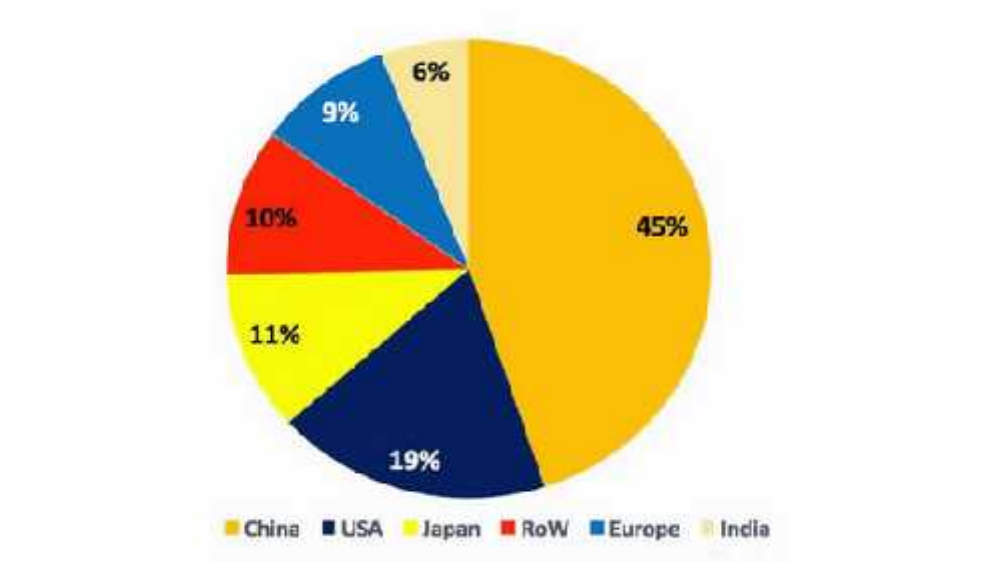

Figure 1.1 Global Solar Market installation at 2017 [2].

1.3 Solar radiation

The sun is the most important source of energy on the earth. Also, it determines the thermal conditions of any site in the world. It is very important to know the earth's relationship to the sun, estimation of solar radiation intensity and to know solar radiation equations. In order to design the tracking systems, thermal effects of solar radiation need to be known, so we can use and control them.

Figure (1.2) represents solar constant G_S (=1.35 KWh/ m^2) [3] is the energy from the sun, per unit time, received on a unit area of the surface perpendicular to the direction of propagation of the radiation, at a mean earth-sun distance, outside of the atmosphere.

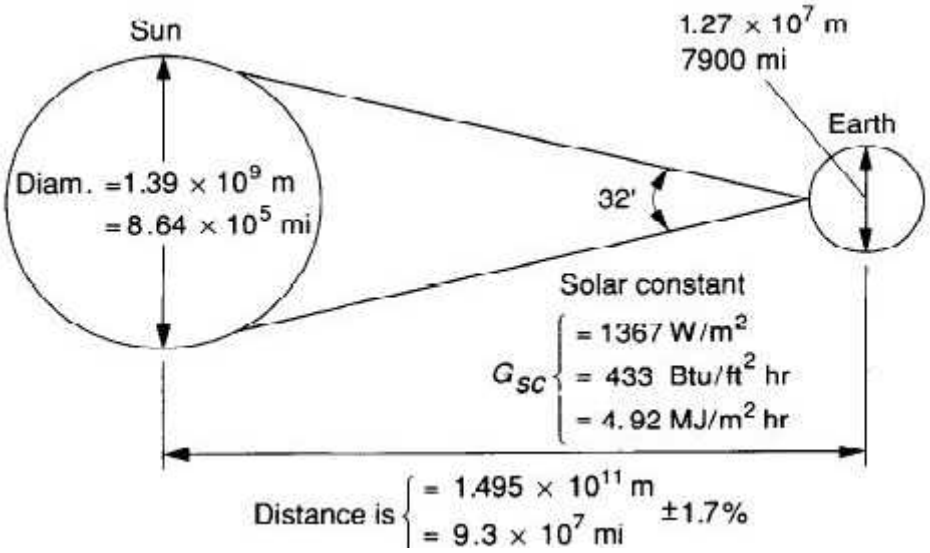

Figure 1.2. Sun-Earth Relationships [3].

Radiation: The radiation is the transferred energy by the mean of electromagnetic waves. The electromagnetic waves travel at the speed of light taking into consideration that the velocity of light in a vacuum is approximate equals to 3 x 10^8 m/s. The light takes about 8 minutes and 20 seconds to travel from the sun and reach earth. Heat can travel through empty space by mean of electromagnetic radiation. Also, it is important to know that even at temperature of absolute zero (-273.15° C) matter should radiate energy.

The wavelength of radiation can define the type of radiation. Also it the electromagnetic radiation can vary widely[4] as shown in figure (1.3).

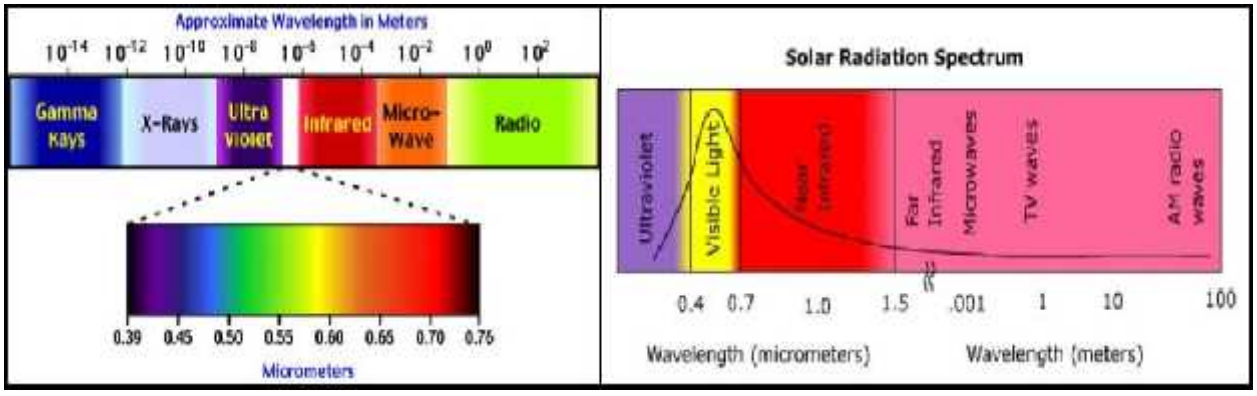

Figure1.3. Wavelength meters and solar radiation spectrum [4].

Irradiance: The measuring unit of irradiance is W/m^2, it is symbolized by G. We can define it by the average radiating energy that is incident on a surface per unit area.

Irradiation: The measuring unit of irradiation is J/m^2, it is calculated by the integration of irradiance over a particular time, maybe a day or an hour. Also, we can define it as the incident energy per unit area on a surface.