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Optimization of tilt angle for solar panel: Case study Tunisia

Hatem Tlijani*[1], Abir Aissaoui [2], Rached Ben Younes [3]
[1]Laboratory of Automatic Research/National Engineering school of Tunis
University Campus PO Box 37, the Blvdre 1002 Tunis
[2]Unit Research of physics mathematics and computer siences/ National Engineering school of Gabes
[3]Unit Research of physics mathematics and computer siences /Faculty of science of Gafsa
*Corresponding authors, e-mail: hatemtlijaniiissat@gmail.com[1], abiraissaouiingenieur@gmail.com[2], rachedbenyounes@fsgf.rnu.tn[3]

Abstract

This paper is a comparisation study between an experimental data and Matlab simulation of output PV characteristic affected by the orientation and the tilt angle of a photovoltaic solar module with inclined plane and by the dimension of the panel. The PV panel was rotated towards the east, south and west and positioned for the angles 0°, 30°, 45°, 60° and 90°. In this position, the values of current, voltage and power are measured. In the other side, using the mathematical model to calculate the solar radiation incident on an inclined surface as a function of the tilt angle was developed in MATLAB/SIMULINK model. The optimum angles were determined as positions in which maximum values of solar irradiation and maximum power were registered to characterize the P-V and V-I photovoltaic panel.

Keywords*: tilt angle, optimum angle, and photovoltaic panel.*

1. Introduction

Renewable energy sources in developing countries such as Tunisia offers a promising prospect for covering fundamental needs of electrical power. One of the most powerful solar energies is the photovoltaic power generators. For the optimum design of any photovoltaic systems, it is essential to determinate their performances, highly effected by the orientations and the tilt angles of the PV panel with the inclined plane.

This paper evaluates the performances of PV modules at different tilt angles and fixed orientations ,using actual measurement metrological data and three different dimensions of panels ,and examines the theoretical aspects that determine the optimal tilt angles for maximum output power. The comparison of the calculated values with the measurement results is an essential process to optimize the tilt angle and the perfect dimension of the PV panel. PV modules was rotated towards the East, South and West and positioned for the angles 0°, 30°, 45°, 60° and 90° in the site of Gafsa in Tunisia

MATLAB/ SIMULINK is used to simulate the mathematical method to determine the optimal tilt angle with the inclined surface and the optimal parameters design of the panel. The remainder of the paper is organized as follows: Section II analyses the experimental steps, the measurements are presented in section III. Section IV is devoted to the mathematical model and Section V summarizes the discussion of the results of this work and draws the optimal performances. The conclusion is reported in Section VI.

The literature on the optimization of the tilt angle of a PV module shows a variety of approaches: previous studies indicate that in the northern hemisphere the optimum tilt angle depends only on the latitude. Others articles approach the issue that there is a wide range of optimum tilt angle as recommended by different researchers and they are mostly for specific locations and climates. Several case studies have been devoted to this suggestion: For Serbia a method developed by [1] allows that PV module oriented towards the south gives the greatest value of electrical energy for the angle of 30°. For Turkey and Japan the researchers just estimated the tilt angle from the available data and measurements and fixed the yearly average of this angle [2] [3]. In fact, consideringthe effects of latitude in Chhattisgarh India [4] defends the idea that the tilt angle 23.5° is nearly corresponding to the latitude. [5] Also argue that with a fraction from 0° to 10° in the north and to 20° in the southern regions in Jordan. However [6]

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presents a quadratic regression model that allows the prediction of the annual optimal tilt angle, using 4 years data of daily global solar radiation on a horizontal surface in 35 sites in different countries of the Mediterranean region. [7] Have demonstrated three mathematical models: the isotropic, the Klucher and the Perez model for the point source with parameters optimized for a variety of climate conditions in Bangladesh. Although in Malaysia [8] the Liw and Jordan model was applied to found the monthly optimal tilt angle. The literature on Taiwan shows a variety of approaches: in [9] the PSO-NTVE method was adopted for fixed PV modules facing south and for [10] an ant direction differential evolution algorithm (ADHDEA) was proposed. [11] has also combined an artificial neural network and a genetic algorithm (ANNGA) to found the seasonal optimum angle.

2. Experimental outline

The experiment was conducted in the Higher Instituteof Applied Sciences and Technology of Gafsa situated at the N 34° 26’ 14.09’’ E8° 44’ for two days. The aim of this work was to determine the amount of electrical energy generated by two different solar panels towards the East, South and West and positioned for the angles 0°, 30°, 45°, 60° and 90°.In this positions the values of output voltage were measured. Two types of monocrystalline silicon panels with normal solar radiation intake intensity of 1000w/m² at temperature T = 25°c. The first panel was with dimensions 370x295x15 mm, with maximum power 10 W. The second one was with dimensions 215x225x18 mm, with maximum power 4 W. The solar modules were positioned in the predefined angles and orientations: On each ten minutes from 8.30 am until 1 pm for two days. The temperature was 29° in the first day and increase the second day to 32°.

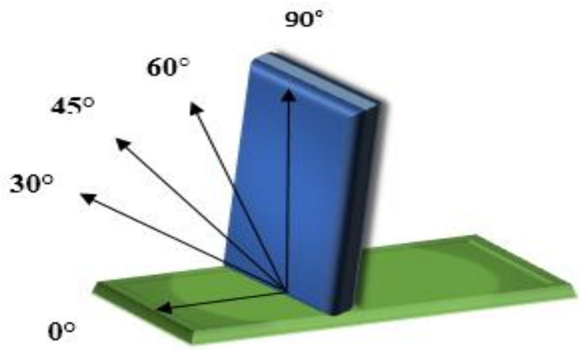

Figure. 1. Position of solar module for chosen angles

3. Theoretical analysis

The incident total radiation on tilted surface on an inclined angle from the horizontal is given by:

$$G_{inc} = B_{in} + D_i + R_i \quad (1)$$

The direct solar radiation received on an inclined surface can be expressed as:

$$B_{in} = R_b * (GH - DH) \quad (2)$$

Where GH and DH are the daily global and diffuse radiation on horizontal surface:

$$R_b = \frac{\cos\theta}{\sin h} \quad (3)$$

R_b is the ratio of the average daily incident radiation on a tilted surface to that on a horizontal surface.

The incidence angle θ is provided by Eq.(4), where parameters involved also include the panel tilt angle β the latitude of the location examined φ, the azimuth angle γ The solar hour angle ω and δ the solar declination

$$\cos\theta = (A - B) * \sin\delta + (C * \sin\omega + (D + E) * \cos\omega) * \cos\delta \quad (4)$$

With

$A = \sin\varphi * \cos\beta$
$B = \sin\beta * \cos\gamma * \cos\varphi$
$C = \sin\beta * \sin\gamma$
$D = \cos\varphi * \cos\beta$
$E = \sin\varphi * \sin\beta * \cos\gamma$

$$\gamma = 90 - \beta \quad (5)$$

Furthermore, solar hour angle ω is a function of solar time TS and is provided by the following equation:

$$T_S = T_0 - L_s + (\frac{E_t + 4\,L_c}{60}) \quad (6)$$

E_t corresponds to the time correction function

$$E_t = 229.2 * (0.000075 + 0.001868 * \cos\vartheta - 0.032077 * \sin\vartheta - 0.014615 * \cos 2\vartheta - 0.040089 * \sin 2\vartheta \quad (7)$$

With

$$\vartheta = \frac{360}{365} * (N - 1) \quad (8)$$

$$\sin h = \cos\varphi * \cos\omega + \sin\varphi * \sin\delta \quad (9)$$

The daily ground reflected radiation can be written as:

$$R_i = (B_{in} * \sin(\delta) + DH) * \rho * ((1 + \cos(\beta)) / 2) \quad (10)$$

Where ρ is the albedo (radiation reflection rate) of the ground. The diffused solar radiation of slope is calculated by the following expression:

$$D_i = DH * ((1 + \cos(\beta)) / 2) \quad (11)$$

The value of the monthly average daily diffuse radiation on a horizontal surface depends on three different ranges of clearness index. The resulting correlations are given in the Table.

4. Results and discussions

Experimental results of the panel I obtained appears in figure 2,3 and 4.In other side figure 5,6 and 7 show the results of the second panel. It is clear from the figures, representing the performance of the first panel, that the East and the South give the maximum output voltage. In order to decide the optimal tilt angle, the maximum output voltage generated was 38V, which corresponds to inclination angle of 90° East. It can therefore be concluded that 90° East is the experimental optimal angle of the panel I.

In fact, by observing the results obtained of the second panel, there is a minor difference in the produced electrical voltage between the three orientations even between the different proposed angles. However, it increases up to the point of 90° East. Acknowledging the experimental performance of the PV panels for the period of examination, it becomes evident that among the different dimensions, the angle that gives the maximum voltage is 90° East.
After the experimental investigation of the optimum tilt angle, it is necessary to interpret those results through the theoretical investigation. Theoretical determination of the optimum tilt angle is based on the equations proposed on section III.

The MATLAB results are illustrated in Figure 8,9,10,11,12 and 13. As follows from the figures shown above,let us first prove that there is not a big difference between the results of the two panels and the three orientations.But the inclination 90 _ East represents the optimal tilt angle that give the maximum output voltage. Then this theoretical method is an effective way to prove the experimental results. At this point, it is important to note that even there is a different in the dimensions of the two panel the optimized angle is nearly the same. It is then clear that the determination of the optimal tilt angle of a solar cell module depends on the solar radiation characteristics, season, and reflectivity in the local area.

5. Conclusion

Based on an experimental setup, installed at the Higher Institute of Applied Sciences and Technology of Gafsa, Tunisia (34° 26’ 14.09 ‘’ E8° 44’).Systematic series of measurements concerning the performance of two PV pairs were carried out during two days. Sets of measurements were taken for each different angle of the variable angles PV pair (0°, 30°, 45°, 60° and 90°) in different orientations.More precisely; measurements of PV voltage output were conducted throughout this period. A mathematical model for determining the optimal tilt angle for maximizing the total solar radiation incident on an inclined surface and the electrical characteristics of solar panels was suggested.

The expected optimum tilt angle was decided by considering the extent at which maximizing of the output voltage was obtained during the day. Through this theoretical investigation of the problem, experimental results obtained were validated.

The data obtained are broadly consistent with the major trends recommending that every location and climate have his specific tilt angle. However, a yearly average measurements data would be of interest. Based on the promising findings presented in this paper, the proposed method can be readily used in practice.

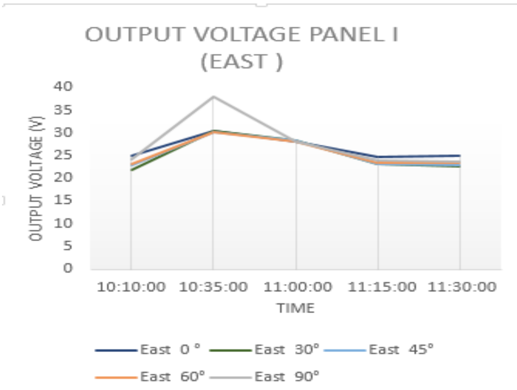

Figure. 2. Change in the obtained experimental electrical output voltage of panel I oriented toward the East

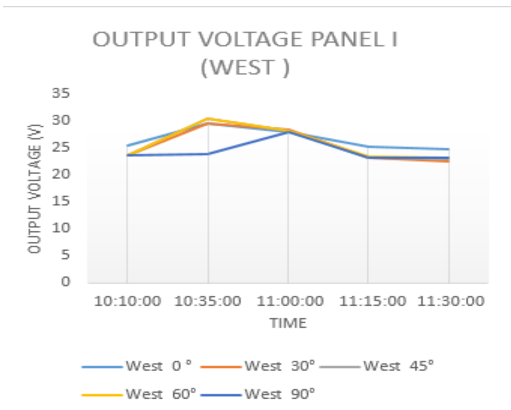

Figure. 3. Change in the obtained experimental electrical output voltage of panelI oriented toward the West

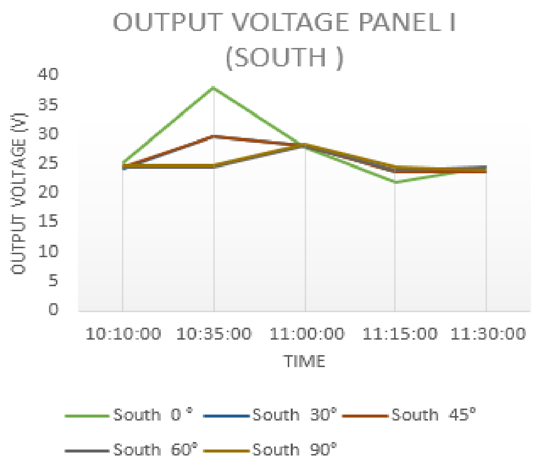

Figure. 4. Change in the obtained experimental electrical output voltage of panel I oriented toward the South

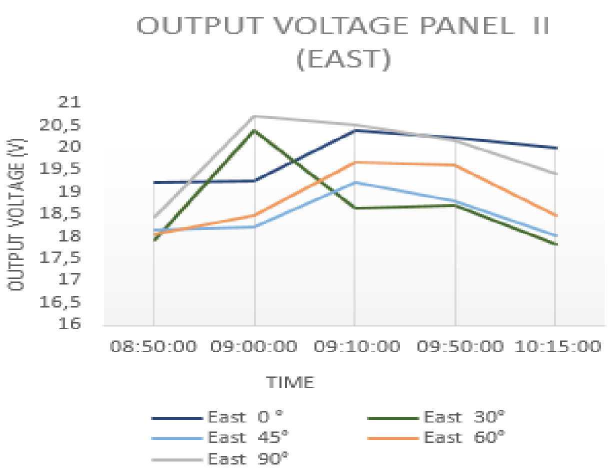

Figure. 5. Change in the obtained experimental electrical output voltage of panel II oriented toward the East

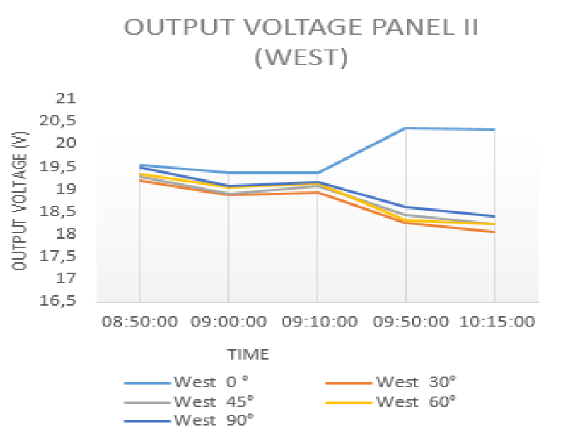

Figure. 6. Change in the obtained experimental electrical output voltage of panel II oriented toward the West

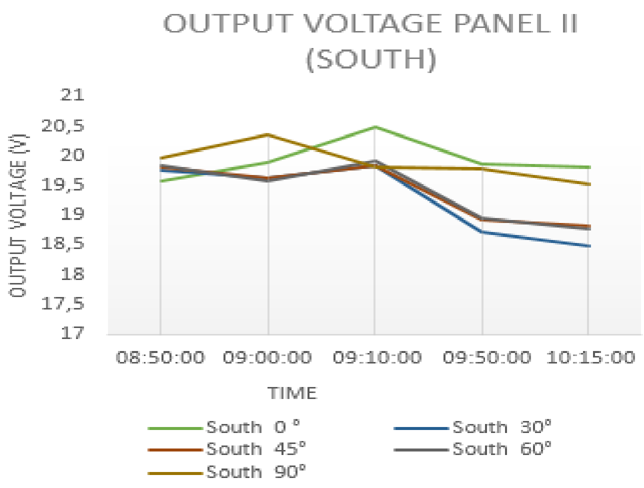

Figure. 7. Change in the obtained experimental electrical output voltage of panel II oriented toward the South

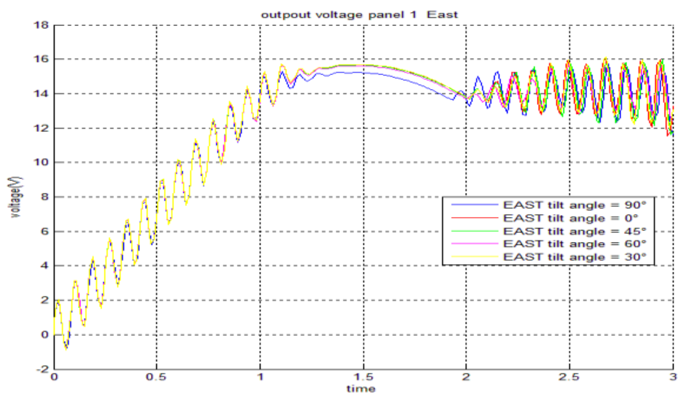

Figure. 8. Change in the simulated MATLAB output voltage of panel I oriented toward the East

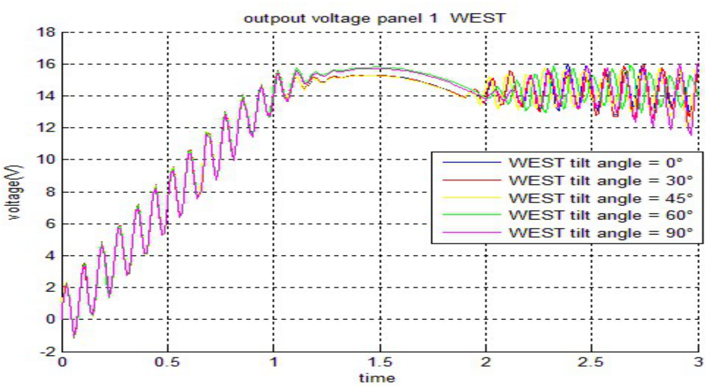

Figure. 9. Change in the simulated MATLAB output voltage of panel I oriented toward the West

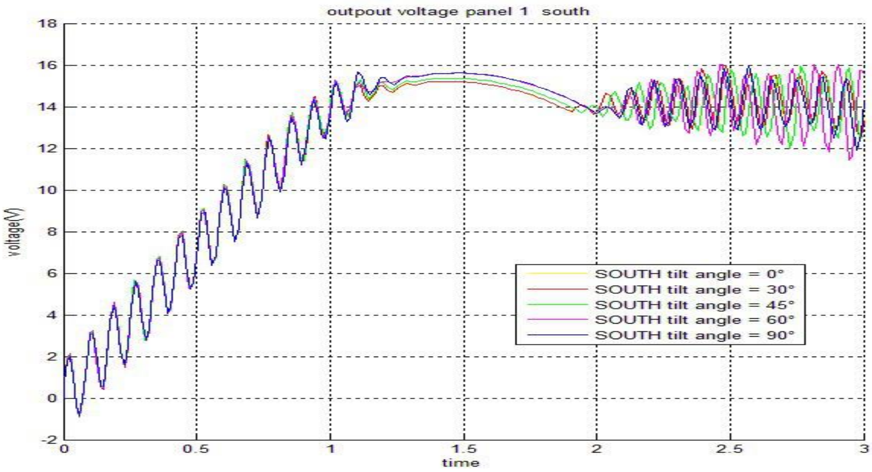

Figure. 10. Change in the simulated MATLAB output voltage of panel I oriented toward the South

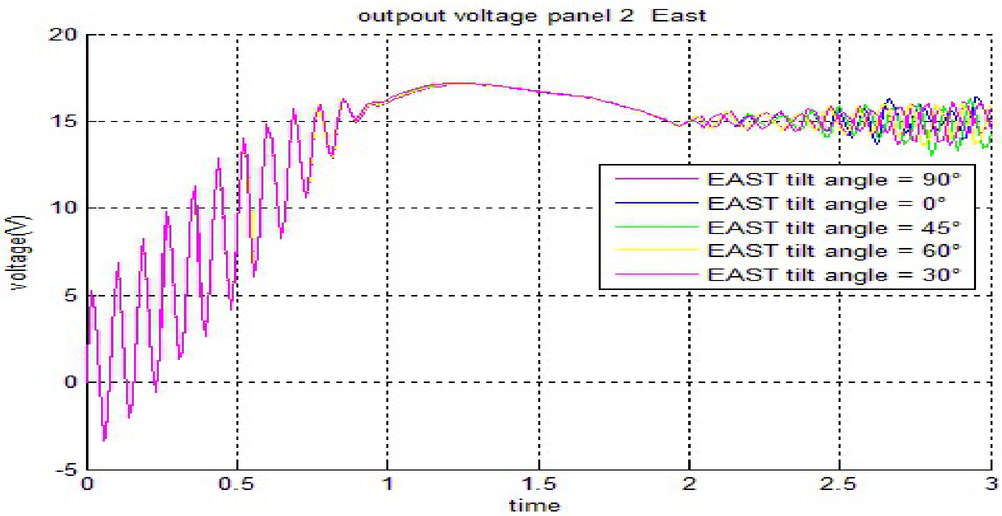

Figure. 11. Change in the simulated MATLAB output voltage of panel II oriented toward the East

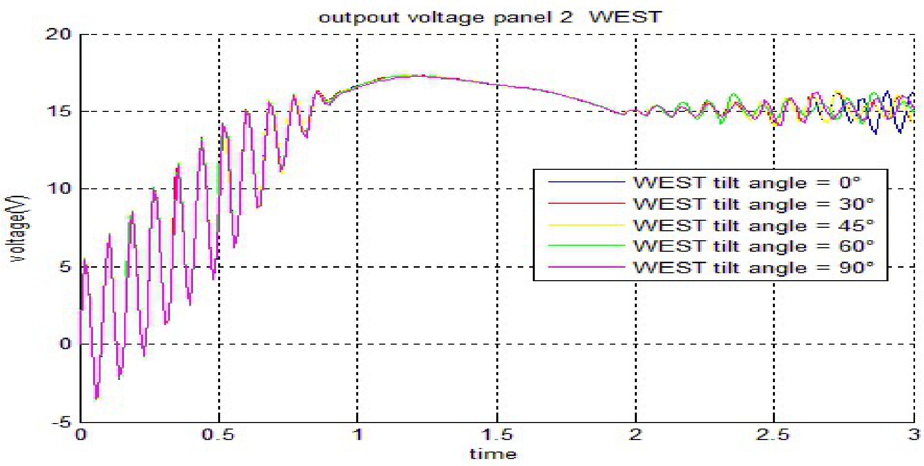

Figure. 12. Change in the simulated MATLAB output voltage of panel II oriented toward the West

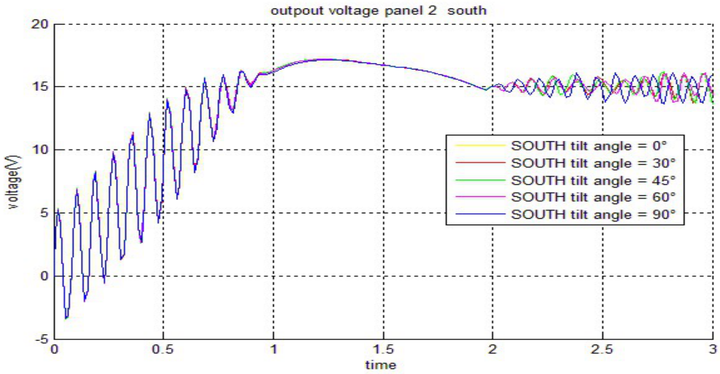

Figure. 13. Change in the simulated MATLAB output voltage of panel II oriented toward the South

RANGES	EXPRESSIONS
$K_T \leq 0.22$	$\frac{DH(t)}{GH(t)} = 1 - 0.09 \times K_T$
$0.22 \leq K_T \leq 0.80$	$\frac{DH(t)}{GH(t)} = 0.9511 - 0.164 \times K_T + 4.385 \times K_T^2 + 12.336 \times K_T^4$
$K_T \geq 0.80$	$\frac{DH(t)}{GH(t)} = 0.165$

Table 1

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